

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HONEYWELL INTERNATIONAL INC.

Petitioner,

v.

CREE, INC.

Patent Owner

Case IPR2015-_____

U.S. Patent No. 8,860,058

DECLARATION OF DR. E. FRED SCHUBERT

MAIL STOP PATENT BOARD

Patent Trial and Appeal Board

U.S. Patent and Trademark Office

P.O. Box 1450

Alexandria, VA 22313-1450

1. My name is Dr. E. Fred Schubert. I am over the age of 21 and am competent to make this declaration. I am a resident of the State of New York and declare as follows:

QUALIFICATIONS

2. I am currently a Distinguished Professor in the Department for Electrical, Computer, and Systems Engineering at the Rensselaer Polytechnic Institute located in Troy, New York.

3. In 1981, I received a Master's Degree in Electrical Engineering from the University of Stuttgart, Germany. In 1986, I received a Ph.D. degree in Electrical Engineering from the University of Stuttgart, Germany for research I performed at the Max Planck Institute in Stuttgart, Germany.

4. I have worked in the field of light-emitting diodes and semiconductor processing for over 30 years. From 1985 to 1987, I worked at AT&T Bell Labs in Holmdel, New Jersey, where I held the position of Post-doctoral Fellow. In 1988, I was promoted to Member of Technical Staff and Principal Investigator. I worked at AT&T Bell Labs in Murray Hill, New Jersey until 1995.

5. In 1995, I became a professor in the Department of Electrical and Computer Engineering at Boston University (Boston, MA). In 2002, I joined Rensselaer Polytechnic Institute as a distinguished professor, the Wellfleet Senior Constellation Professor, with appointments in the Department for Electrical,

Computer, and Systems Engineering and the Department for Physics, Applied Physics, and Astronomy. I am the founding Director of the Smart Lighting Engineering Research Center that is funded by the U.S. National Science Foundation at a volume of \$40 million over 10 years.

6. I am co-inventor of more than 30 U.S. patents and have co-authored more than 300 publications. I authored the books “Doping in III–V Semiconductors” (1993), “Delta Doping of Semiconductors” (1996), and the first and second editions of “Light-Emitting Diodes” (2003 and 2006); the latter book is known as a standard textbook in the field of LEDs and the book was translated into Russian, Japanese, and Korean. My publications have received more than 20,000 citations in the technical literature and thus are well recognized by the technical community.

7. I received several awards for my technical contributions. They include: Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) (1993); Literature Prize of Verein Deutscher Elektrotechniker for the book “Doping in III–V Semiconductors” (1994); Fellow of The International Society for Optics and Photonics (SPIE) (1999); Alexander von Humboldt Senior Research Award (1999); Fellow of the Institute of Electrical and Electronics Engineers (IEEE) (1999); Fellow of The Optical Society of America (OSA) (2000); Boston University Provost Innovation Award (2000); Discover Magazine Award for

Technological Innovation (2000); R&D 100 Award for Resonant Cavity Light Emitting Diodes (RCLED) (2001); Fellow of the American Physical Society (APS) (2001); RPI Trustees Award for Faculty Achievement (2002 and 2008); Honorary membership in Eta Kappa Nu (2004); 25 Most Innovative Micro- and Nano-Products of the Year Award of R&D Magazine (2007); and the Scientific American 50 Award (2007).

8. My work at Rensselaer Polytechnic Institute is focused on photonic semiconductor materials and devices, particularly on light-emitting diodes (LEDs). My work has included the design, fabrication, and testing of LEDs and associated electrical circuits as well as the employment of lighting devices in a variety of applications. I have made pioneering contributions to the following technical fields: Packaging of LEDs, phosphors for LEDs, LED lighting systems, solid-state lighting, and light-emitting diodes with remote phosphors. I have taught several courses related to the field of LEDs and microelectronics.

9. Additional details about my background and expertise, including publications, are further described in my professional curriculum vitae, which is attached as Attachment A to this report.

10. I have been retained by counsel for Petitioner Honeywell International Inc., (“Honeywell” or “Petitioner”) in the above-captioned matter as an independent technical expert. As part of this engagement, I have been retained to

provide opinions concerning the invalidity of United States Patent No. 8,860,058 (“the ’058 Patent”) (Ex. 1001). I expect to testify regarding the matters set forth in this declaration if asked to do so.

11. I am being compensated at my standard hourly rate of \$500 per hour for my work performed in connection with this matter. I have received no additional compensation for my work in this matter, and my compensation does not depend upon the contents of this report, any testimony I may provide, or the ultimate outcome of the matter.

12. In preparing this Declaration, I have considered the ’058 Patent’s claims and specification, the prosecution history for the ’058 Patent, the exhibits to this Petition for *inter partes* review of the ’058 Patent, materials cited within this declaration, and my own experience and expertise, including my knowledge of a person of ordinary skill in the art (“POSITA”) in the relevant timeframe.

13. Based on my expertise and knowledge, I believe that a POSITA would be someone having at least a bachelor’s degree in electrical engineering or physics (or equivalent) and at least five years of experience working on LED-related technologies; or someone with a Master’s Degree in electrical engineering or physics (or equivalent) and at least three years of experience working on LED-related technologies. I understand that the ’058 Patent claims priority back to an

earlier parent application. Therefore, a POSITA would have been someone prior to the time of the invention, particularly in 1994 or earlier.

14. Light is electromagnetic radiation. One type of electromagnetic radiation is visible light. Visible light is one range of frequencies on the electromagnetic spectrum, having associated wavelengths generally between 380 nanometers (“nm”) and 750nm. The boundaries between visible light and ultraviolet or infrared light are not precise. Within the visible light spectrum, violet and blue have the shortest wavelengths, with green and yellow wavelengths in the middle of the visible light spectrum, and orange and red having the longest wavelengths within the visible light spectrum. Of particular interest, blue light has wavelengths generally between 420nm and 490nm. *Gradiently Alloyed $Zn_xCd_{1-x}S$ Colloidal Photoluminescent Quantum Dots Synthesized via a Noninjection One-Pot Approach*, by Jianying Ouyang et al., published March 5, 2008 (“blue wavelength range of 420-490nm, according to the international standard for primary colors, namely CIE Chromaticity Diagram established in 1931 by the Commission Internationale d’Eclairage (CIE)”) (hereinafter “Ouyang”) (Ex. 1012) at p. 1. The visible light spectrum is continuous, so the boundaries between colors are not precise.

15. Visible light only constitutes one part of the electromagnetic spectrum. Electromagnetic radiation can be broadly classified into the following

categories from shortest wavelength to longest wavelength: a) gamma radiation; b) X-ray radiation; c) ultraviolet radiation; d) visible radiation (visible light); e) infrared radiation; f) terahertz radiation; g) microwave radiation; and h) radio waves.

16. Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light but longer than that of X-rays. Certain LEDs emit UV light. “Near UV light” refers to UV light closest to visible light. Near UV light has wavelengths generally between 320nm and 380nm.

17. An LED is a semiconductor light source. An LED consists of a p–n junction, i.e. the boundary or interface between two types of semiconductor material, p-type and n-type. The wavelength of the light emitted (and therefore the color emitted), depends on the semiconductor material of the p–n junction that releases energy in the form of light. For example, blue LEDs often use indium gallium nitride (InGaN) in the p-n junction. “In” refers to indium, “GaN” refers to gallium nitride. The p-n junction using InGaN semiconductor material can release energy in the form of blue light. Red LEDs, yellow LEDs, and certain other colored LEDs use different types of semiconductor material in the p-n junction to release a particular wavelength of colored light.

18. There are different ways to produce an LED that emits light that appears white. White light has practical uses, including for backlighting displays.

One way to form white light is to mix the light of different colored LEDs. This method can involve taking a separate red LED, green LED, and blue LED, and mixing their LED emissions to produce light that appears white. Another method involves using a blue LED (or UV LED) that emits blue (or UV) light that phosphors or fluorescers absorb, and in response, re-emit that light with shifted wavelengths that produce light that appears white.

19. In the '058 Patent, “down-converting” is a claim term. The patent specification indicates what “down-converting” refers to: “These inorganic phosphors are designed as such to offer white light emission by ‘down-converting’ (i.e., transforming a higher frequency, shorter wavelength form of energy to a lower frequency, longer wavelength form of energy)...” Ex. 1001, '058 Patent at 4:3-9. This comports with what a POSITA would understand down-converting to mean. Down-conversion of light is the process of taking a relatively shorter wavelength of light and converting it to a longer wavelength. The '058 Patent uses phosphors and/or fluorescers in a “luminophoric medium” to down-convert light to a longer wavelength.

20. In the '058 Patent, “luminophoric medium” is a claim term. The patent states that “the term ‘luminophoric medium’ refers to a material which in response to radiation emitted by the solid state device emits light in the white visible light spectrum by fluorescence and/or phosphorescence.” *Id.* at 8:9-13.

The specification provides that fluorescers and/or phosphors are materials for the “luminophoric medium”, which absorbs light from a light emitting device, and then in response, re-emits the light. *Id.* at Abstract, 7:40-52, 8:9-12.

21. The patent specification describes a phosphor as a substance that absorbs LED light and then in response, emits a longer wavelength form of light. Ex. 1001, '058 Patent at 7:44-48. For the past decades, a phosphor would generally be understood by a POSITA as a substance that gives off light when subject to electromagnetic radiation. *See Webster's New Twentieth Century Dictionary, Second Edition, 1997 (Ex. 1011), at p. 2.* Phosphors can be rare earth compounds of various types.

22. A fluorescer is a type of phosphor. A fluorescer or fluorescence material quickly re-emits light after it has absorbed light, due to its short radiative lifetime. Other phosphor or phosphorescent material may emit light more slowly after the original excitation by a light source. Like phosphor, a POSITA would understand a fluorescer to be a substance that gives off light when subject to electromagnetic radiation. Like phosphor, the patent specification describes a fluorescer as a substance that absorbs LED light and then in response, emits a longer wavelength form of light. Ex. 1001, '058 Patent at 7:44-48.

23. There are numerous types of phosphors and fluorescers. The intrinsic properties of certain phosphors and fluorescers allow them to absorb light and in

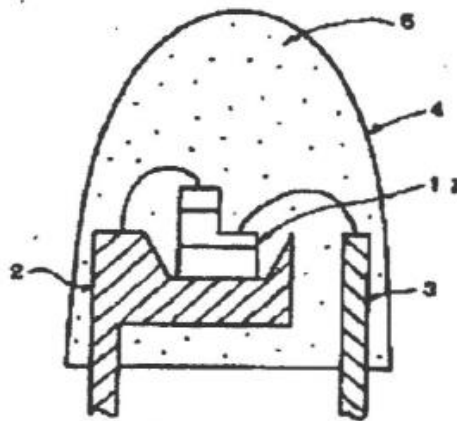
response, emit a secondary emission of light with a longer wavelength. That secondary emission would represent down-converted light. Some phosphors and fluorescers absorb blue light, while others absorb green light, or red light, or other colors. And different phosphors and fluorescers, when excited by light, emit at various, different wavelengths (and hence, colors). A phosphor blend is a mixture of two or more specific phosphors. A phosphor blend can emit at two or more colors, depending on the blend of the specific color emitting phosphors.

24. Down-conversion via phosphors or fluorescers had been well-known decades before 1994. In the specification, the patentee acknowledges that the “down-conversion” of light via fluorescers was “well known.” Ex. 1001, ’058 Patent at 3:64-4:9. Specifically, the patentee states that it was “well-known” to use “phosphors” to down-convert UV light to white light. *Id.* at 3:64-4:9. Further, the specification recognized that the invention used down-converting Lumogen® fluorescers that were “available commercially from Pacific Polytech.” *Id.* at 9:39-50.

25. I have reviewed JP 5-152609 A to Tadatsu, et al. (“Tadatsu”) (Ex. 1007). Tadatsu discloses an LED that includes a light emitting device packaged with fluorescent material. Ex. 1007, Tadatsu at [Constitution]. Tadatsu’s Figure 2 illustrates the structure. First, “numeral designator 11 represents a blue light emitting device”, which is a gallium nitride based semiconductor device. *Id.* at

[0008]. Second, the blue light emitting device at 11 is surrounded by the fluorescent material 5. *Id.* at [0008]. The fluorescent material “is mixed as a coloring agent.” *Id.* at [0003]. To a POSITA, the mixture of the fluorescent material in the resin should create a blended composition, homogeneous in nature. The dots in the Figure 2 further illustrate a uniform distribution of the fluorescent material.

[Figure 2]



The dots in Figure 2 represent the dispersal of the fluorescent material 5, including surrounding the top and sides of the blue light emitting device at 11. Tadatsu explains that this dispersal of fluorescent material is “surrounding” the light emitting device. *Id.* at [0009] (“fluorescent dye or pigment is added to a resin mold surrounding the light emitting device”). This is done so that “the fluorescent material can be most optimally excited.” *Id.* A POSITA reading Tadatsu would

understand that the fluorescent material touches and surrounds the light emitting device.

26. In Tadatsu, the fluorescent material is added in a resin, which is a type of polymer. Tadatsu discloses that the fluorescent material is found in a resin: the “inorganic or organic pigment is mixed as a coloring agent in the resin mold 4” and “fluorescent dye or pigment is added to a resin mold.” Ex. 1007, Tadatsu at [0003], [0009]. It is well-known that a resin is a type of polymer, and a POSITA in 1994 would understand that. *See* H. D. Stenzenberger, “Recent developments of thermosetting polymers”, 1993 at Abstract (“thermosetting polymers such as epoxy resins”) (“Stenzenberger”) (Ex. 1013) at p. 1. Tadatsu discloses a resin as an optimally transparent polymer that is light transmissive. The resin would form a film on the surface of the housing in Tadatsu. To a POSITA, the structure in Figure 2 would constitute an individual “light emitting diode lamp”, comprising the LED chip at 11, enclosed by the resin mold 4, and representing a functional unit that could be incorporated into various applications. Figure 2 and related discussion also discloses the inherent use of a power supply given the electrical connections for the n-type and p-type layers: “electrically connect an n-electrode on the GaAlN layer to the metal stem 2” and “electrically connected using a gold wire.” Ex. 1007, Tadatsu at [0008]. Further, “the other electrode is wire-bonded to the surface of the p-type layer using a gold wire coming from the metal post 3”.

Id.

27. Down-conversion of light is the process of taking a relatively shorter wavelength of light and converting it to a longer wavelength. The '058 Patent states: “‘down-converting’ (i.e., transforming a higher frequency, shorter wavelength form of energy to a lower frequency, longer wavelength form of energy)...” Ex. 1001, '058 Patent at 4:3-9. The '058 Patent uses phosphors and/or fluorescers in a “luminophoric medium” to down-convert the light to a longer wavelength. Tadatsu discloses that the light emitting device 11 will emit light exciting the fluorescent material, and in response, the fluorescent material will re-emit the light at a longer wavelength. Tadatsu states: “[Advantages of Invention] A fluorescent dye or pigment is generally excited with a short-wavelength light and emits light with a longer wavelength than that of the excitation light.” Ex. 1007, Tadatsu at [0009]. As discussed above, blue light has a shorter wavelength relative to other colors (e.g., green and red) in the visible light spectrum. Tadatsu discloses a gallium nitride based, blue light emitting device that emits a relatively shorter wavelength of light, and it can excite “different types of a fluorescent dye or pigment [that] can not only correct color of blue LED’s but also convert light into a variety of wavelengths.” *Id.* at [0009]. To a POSITA, Tadatsu discloses the down-conversion of light via a “luminophoric medium” of fluorescent material. That down-converted light comes from the fluorescer as a secondary emission,

where the primary emission comes from the light emitting device 11 in Tadatsu.

28. Tadatsu also discloses the down-conversion of light to produce a white light output. For example, Tadatsu discloses the output of white light by using a red fluorescent material to convert the wavelength from a single green LED: “For instance, when a red pigment is added to a resin mold around a green light emitting device having GaP semiconductor materials, its emission color turns into white.” *Id.* at [0003]. In this example, Tadatsu mixes the colors from the light emitting device and the fluorescent material to yield a white light output. Instead of using a green light emitting device, Tadatsu alternatively teaches that a blue light emitting device could be arranged with “different types” of fluorescent material. *Id.* at [0009]. To a POSITA, it would have been obvious to use a blue light emitting device so that the blue light mixes with light from the fluorescent material that together “turns into white”. *Id.* at [0003], [0009]. Tadatsu further teaches that the blue light emitting device works with “different types of a fluorescent” material to produce a “variety of wavelengths”. *Id.* at [0009] (“Therefore, different types of a fluorescent dye or pigment can not only correct color of blue LED’s but also convert light into a variety of wavelengths.”). A POSITA would understand a “variety of wavelengths” to mean a variety of colors, where the light is polychromatic, having multiple colors. It was well-known to a POSITA that a broad spectrum of colors will mix to appear white. Such a broad

spectrum of colors would have been an obvious “variety of wavelengths” because Tadatsu disclosed an example where the “emission color turns into white”.

Ex. 1007, Tadatsu at [0003], [0009].

29. On March 28, 1994, Shuji Nakamura (Yoshiaki Tadatsu’s colleague at Nichia Corporation) published his findings on a bright blue LED in “Candela-class high-brightness InGaN/AlGaN double-heterostructure blue-light-emitting diodes” (“Nakamura”) (Ex. 1006). Nakamura discloses a high-brightness InGaN/AlGaN blue LED. Ex. 1006, Nakamura at p. 1. “In” refers to indium. “GaN” refers to gallium nitride. “Al” refers to aluminum. Each of InGaN and AlGaN are gallium nitride alloys that mix metals (e.g. In and Ga). The bright blue LED in Nakamura measured a luminous intensity of 1000 millicandelas (or 1 candela). *Id.* This was luminous intensity about 100 times greater than certain existing devices made of Silicon Carbide (SiC). Nakamura discloses that “using these high-brightness blue LEDs, high-brightness full color indicators and flat panel displays will be developed in the near future.” *Id.* at p. 3. Because of the increased efficiency of the bright blue LED, the industry could now realize certain practical applications, including displays backlit with a white light LED.

30. In June 1993, Tadatsu disclosed the use of a “blue light emitting device.” Ex. 1007, Tadatsu at [0008]. That blue light emitting device was made of “gallium nitride related compound semiconductors.” *Id.* at [Claim 1]. But Tadatsu

also recognized that LEDs at “430nm” (a wavelength within blue light) had a poor “luminosity factor.” *Id.* at [0005]. So when Nakamura disclosed a “high brightness” blue LED in 1994, which was a gallium nitride based LED, adding indium, a POSITA at the time would have been motivated to combine Tadatsu and Nakamura. The authors of Tadatsu and Nakamura were also colleagues at Nichia Corporation, working on the same issues in LED technology. In sum, it would have been obvious for a POSITA in 1994 to combine the teachings Tadatsu and Nakamura.

31. The bright blue LED from Nakamura was also a watershed event for the industry. An IEEE publication recognized that the bright blue LED was a “long-sought Holy Grail of LED technology” that “may open the way for white LED light sources.” Werner, K., “Higher Visibility for LEDs”, IEEE Spectrum, July 1994 (hereinafter, “Werner”) (Ex. 1010), at pp. 1, 6. In 1994, a POSITA would have taken notice of this new discovery, particularly for potential uses in backlighting displays with white light. Tadatsu’s disclosures of a blue emitting device and the down-conversion to white light would have made for an obvious combination with Nakamura.

32. It was well-known to a POSITA that a broad spectrum of colors (e.g., red, green, and blue light) mixes to generate white light. Nakamura provides the blue light from the bright blue LED, and Tadatsu provides fluorescent light by

down-converting light to “variety of wavelengths” where the “emission color turns into white”. Ex. 1007, Tadatsu at [0003], [0009]. It would have been obvious and a POSITA would have been motivated to use “different types” of fluorescent material with the bright blue LED to make the “variety of wavelengths” where the “emission color turns into white”, as disclosed in Tadatsu. *Id.* The patentee also acknowledged that it had been known in 1991 that inorganic fluorescent materials were “capable of generating white light”, and identifies materials. Ex. 1001, ’058 Patent at 4:38-40. This is true whether the phosphor or fluorescer material is organic-based or inorganic-based.

33. With down-converting via phosphor in the prior art, and with the arrival of the bright blue LED, a POSITA in 1994 would have been able to and would have been motivated to consult a reference, such as GB 1305111 to Pinnow, et al. (hereinafter, “Pinnow”) (Ex. 1009), summarizing the types of phosphors/fluorescers and their characteristics. Pinnow provides a summary Table I of numerous down-converting materials. Table I provides the name of the phosphor or fluorescer, its absorption band, and its emission color. Ex. 1009, Pinnow at 5:1-3 (“Data on absorption and emission of selected dyes is given in Table I”); Table I. For each phosphor/fluorescer, Table I shows that the absorption band is of shorter wavelengths as compared to the “fluorescence band” (emission band) which has longer wavelengths. *Id.* at Table I. In addition to summarizing

the numerous phosphors and fluorescers, Pinnow focuses on getting a white light output. *Id.* at 3:121-122 (“the embodiment is primarily concerned with white or near-white”). And Pinnow focuses on down-conversion as the process to white light. *Id.* at 4:118-119 (“can be achieved by down-conversion of frequency”); Table I (listing down-converting phosphors). Accordingly, a POSITA would have been motivated to use Pinnow’s summary of phosphors/fluorescers in combination with Tadatsu and/or JP 50-79379 U to Tabuchi (hereinafter, “Tabuchi”) (Ex. 1008), each of which teach the down-conversion of light via phosphors/fluorescers. In addition, the introduction of the bright blue LED from Nakamura would serve as further motivation to consult a reference that summarizes the phosphors and/or fluorescers that absorb blue light (and down-converts blue light in advance of producing white light). A POSITA in 1994 would have consulted Pinnow in combination with Nakamura. Pinnow’s Table I provides numerous phosphors and/or fluorescers that absorb blue light, which falls in the range of 4200–4900 Å. *Id.* at Table I. And Pinnow’s disclosure focuses on the use of a blue light emitter. *Id.* at 4:110-121.

34. Table I uses Angstrom for measuring the wavelength. Throughout the disclosure, Pinnow uses various units of measurement for wavelengths of light, including Angstrom (Å), nanometer (nm), and micron (μ). 1 Angstrom equals 0.1 nanometer. 1 nanometer equals 0.001 micron. A POSITA would have known

these units of measurements.

35. Table I in Pinnow provides examples of fluorescers that have down-converted red emissions. These examples can absorb blue light, and emit down-converted red light. (For reference, blue light has wavelengths in the range of 4200–4900 Å). For example, “Rhodamine B extra” absorbs at the “4800-6000” Å band and emits at the “5500-7000” Å band having a “red strong” color. “Magdala red” absorbs at a “4000-6000” Å band and emits at the “5500-7000” Å band having a “red strong” color.

36. Table I provides examples of fluorescers that have down-converted green emissions. These examples can absorb blue light, and emit down-converted green light. (For reference, blue light has wavelengths in the range of 4200–4900 Å). For example, “Acridine yellow” absorbs at the “U.V.-5200” Å band and emits at the “4750-6400” Å band having a “green” color.

37. Table I provides examples of fluorescers that have down-converted blue emissions. These examples can absorb shorter-wavelength blue light, and emit down-converted, longer-wavelength blue light. (For reference, blue light has wavelengths in the range of 4200–4900 Å). For example, “Acridine” absorbs at the “3000-4500” Å band and emits at the “4000-4800” Å band.

38. As read by a POSITA, Pinnow discloses yellow emitting fluorescers that could be added to a fluorescer blend to offset or adjust slightly a combination

of wavelengths in the generation of white light. For example, Pinnow teaches the use of Xenylimide (peaking at 5300 Å wavelength; “yellow-green”) in combination with blue and red light to produce “a white appearance to the eye”. Ex. 1009, Pinnow at 4:29-46. Xenylimide absorbs blue light from a blue light emitting device, and re-emits down-converted “yellow-green” light. *Id.* at 4:29-46. Table I provides additional examples of fluorescers that have down-converted yellow emissions, absorbing blue light and re-emitting yellow, including “Rhodamine 6 G”, “Eosin”, “Euchrysine”, and “Acridine”.

39. Pinnow teaches the use of a blue light emitting device with phosphor to generate white light. Pinnow teaches that “a necessary condition for achieving true white” is using a light emitting device with a wavelength of no more than 4950 Å. As such, Pinnow teaches the use of a blue emitting device at a 4880 Å wavelength. *Id.* at 4:91, 4:119-120. Pinnow teaches using this blue emitting device with a fluorescer blend that absorbs the blue from the blue emitting device, and in response, re-emits a combination of down-converted light with wavelengths to generate the appearance of white light. *Id.* at 4:110-130; 4:29-46. Pinnow provides examples of red, blue, and green fluorescers for a blend, along with a reference to Table I for data on absorption and emission bands. *Id.* at 4:110-5:5; Table I. For example, Pinnow provides Rhodamine-B (red), Acridine yellow (green), and Acridine (blue) for a fluorescer blend that would absorb blue light,

and in response, emit down-converted light with wavelengths of red, green, and blue to generate the appearance of white light. *Id.* A POSITA in 1994 would know to mix red, green, and blue fluorsceners, as provided by Pinnow, to generate the appearance of white light. A POSITA in 1994 could apply this teaching by taking a bright blue LED and a fluorscener blend that emits down-converted red, green, and blue light that mixes to generate the appearance of white light.

40. To generate white light, Pinnow teaches the use of a blue emitting device in combination with two phosphors, red and green. *Id.* at 4:29-45. The blue emitting device emits blue light to excite a “50-50 phosphor blend” of Xenylimide (peaking at 5300 Å wavelength; yellow-green) and Rhodamine (peaking at 6050 Å wavelength; red). *Id.* at 4:29-33. To a POSITA, such a 50-50 phosphor blend would be a homogenous or uniform mixture. This 50-50 phosphor blend can absorb the blue emitted light at a 4880 Å wavelength. *Id.* at 4:35. In response, the 50-50 phosphor blend emits a secondary, down-converted emission of red and yellow-green -- such light is polychromatic in that it has multiple colors. That secondary emission mixes with primary blue emission from the laser to generate “a white appearance to the eye.” *Id.* at 4:35-46. This is another obvious way for a POSITA to mix red, green, and blue light to generate the appearance of white light. A POSITA in 1994 could apply this teaching by taking a bright blue LED and a 50-50 phosphor blend of red and yellow-green to generate white light.

41. Werner, entitled “Higher visibility for LEDs” (Ex. 1010), discloses LEDs for liquid crystal displays and in a backlighting array. This would have been an obvious extension to the prior art for a POSITA. A POSITA would have the ability to implement LEDs in an array for purposes of backlighting a liquid crystal display. Werner discloses an array having individual LED chips: “Rectangular LED light bars put two or more LED chips in an epoxy package and are used for backlighting stenciled messages. Long, thin, flexible packages containing dozens of LED chips are used as backlights for small liquid-crystal displays.” Ex. 1010, Werner at p. 6. And again, does so here: “LEDs are packaged as traditional lamps, as chips that are automatically mountable from tape, and as modules for numerical displays”. *Id.* Given the LEDs in Werner are “mountable from tape”, are “modules for numerical displays”, and “are used for backlighting stenciled messages”, the array would comprise a regular pattern. With Tadatsu disclosing an LED with down-conversion to white light and each of Nakamura and Pinnow disclosing displays, a POSITA in 1994 would have been motivated to combine their teachings with Werner’s disclosure of LEDs in an array for backlighting displays, including liquid crystal displays. Tadatsu discloses an LED with down-conversion to white light. And Nakamura already discloses “high brightness full-color indicators and flat panel displays will be developed in the near future.” Ex. 1006, Nakamura at p. 3. Further, Pinnow’s “invention relates to a visual display

apparatus.” Ex. 1009, Pinnow at 1:12-13. A POSITA in 1994 would have been motivated to combine this prior art with Werner. Werner was published by IEEE Spectrum in its “Advanced Technology/Displays” section. IEEE Spectrum has been a flagship publication for the IEEE. Werner is a publication that would have been typical for a POSITA’s review in 1994. Specifically, Werner is a timely July 1994 IEEE publication on the bright blue LED that would have been of particular interest, given Nakamura’s disclosure months earlier in March 1994. Werner refers to the Nakamura bright blue LED as the “long-sought Holy Grail of LED technology” and states that “even full-color outdoor video displays based on LEDs are now possible.” Ex. 1010, Werner at p. 1. Then, Werner discloses the use of LEDs in liquid crystal displays and in an array for backlighting displays. *Id.* at p. 6.

42. The bright blue LED from Nakamura was a breakthrough event for the LED industry, leading to the realization of the white light LED for backlighting displays in the marketplace. When Nakamura discloses the bright blue LED, the industry realized its potential, as evidenced by Werner exclaiming it as “long sought Holy Grail of LED technology” that “may open the way for white LED light sources that could be used as, for example, backlights for laptop computer screens.” *Id.* at pp. 1, 6. Given this practical and lucrative application, a POSITA in 1994 would have been motivated to use the bright blue LED from Nakamura for

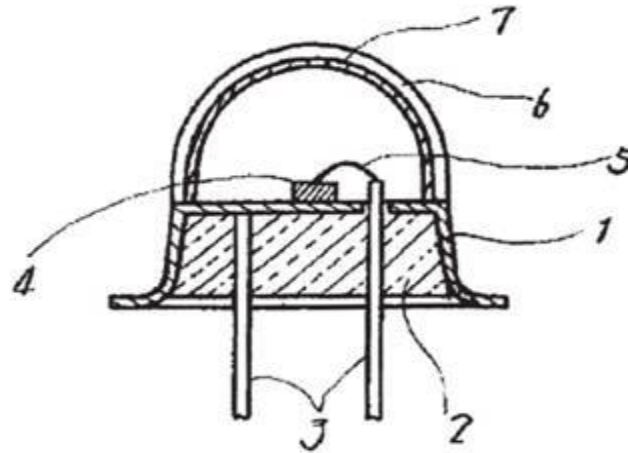
purposes of generating white light for backlighting devices.

43. I have reviewed Tabuchi, which is Ex. 1008. Tabuchi discloses a light emitting apparatus with an LED and a phosphor layer. Tabuchi discloses that the gallium nitride (GaN) based LED can emit ultraviolet (UV) light. Ex. 1008, Tabuchi at 5. UV light is electromagnetic radiation with a wavelength shorter than that of visible light but longer than that of X-rays. Like blue emitting LEDs, UV emitting LEDs are used in the industry with phosphor to produce a white light. Like blue LEDs, UV LEDs have a relatively short wavelength that excites phosphor. Blue light and violet light have the shortest wavelengths in the visible light spectrum, and are most similar to the wavelengths of “near” ultraviolet (near UV) light. Near UV light has wavelengths nearest to visible light. Tabuchi discloses a UV LED that emits “near UV light”, which would have a wavelength in the range of 320nm-380nm, as compared to blue light in the range of 420nm-490nm. In Tabuchi, the phosphor layer absorbs the shorter wavelength of UV light, and in response, re-emits the light with a longer wavelength of visible light. Tabuchi states: “a near UV light emitting devices with GaN can be employed and [] an ordinary UV-visible light conversion phosphor can be utilized.” *Id.* at 5. And again stating: “A phosphor layer 7 is provided ... in which a phosphor to convert the radiation from light emitting semiconductor device 4 to visible light.” *Id.* at 3. As discussed, down-conversion of light is the process of taking a

relatively shorter wavelength of light and converting it to a longer wavelength. The '058 Patent also states: “‘down-converting’ (i.e., transforming a higher frequency, shorter wavelength form of energy to a lower frequency, longer wavelength form of energy)...” Ex. 1001, '058 Patent at 4:3-9. The phosphor layer in Tabuchi is down-converting the UV light to visible light, transforming the relatively shorter wavelength of UV light into the longer wavelength of visible light. The down-converted light comes from the phosphor layer as a secondary emission, where the primary emission comes from the UV LED in Tabuchi.

44. Figure 1 illustrates an embodiment of the apparatus disclosed in Tabuchi. A semiconductor LED located at 4 is conductively connected to stem 1. Ex. 1008, Tabuchi at 3, Figure 1. A phosphor layer 7 is dispersed in a hemisphere facing the LED 4. *Id.* There is a gap in space between the LED and the phosphor layer. The phosphor layer (with the gap in space) form a hemisphere shape, running from the left side of the LED, over the top, and then to the right side of the LED. *Id.* The phosphor layer 7 “is provided by applying binding agent in which a phosphor” “is dispersed on the inner surface of a transparent cover 6” which “is made of a material such as glass or an epoxy resin.” *Id.* To a POSITA, the structure in Figure 1 would constitute an individual “light emitting diode lamp”, comprising the LED chip, enclosed by the transparent cover, and representing a functional unit that could be incorporated into various applications. Figure 1 also

discloses the inherent use of a power supply given “leads 3 in a TO-5 metal stem 1” and the “light emitting semiconductor device 4 is conductively connected to stem 1.”



45. A POSITA in 1994 would understand the “binding agent” in Tabuchi to be the disclosed epoxy resin, which is an adhesive material. Phosphor is a powder-like substance and needs a binding agent to absorb and hold it. The epoxy resin serves that function. *See*, for example, U.S. Patent No. 3,921,026 (Ex. 1014) at 2:9-10 (“transparent or translucent binding resin, for instance, epoxy resin”). The phosphor would be therefore mixed inside the epoxy resin binding agent in a hemisphere facing the LED 4, and on the inner surface of the transparent cover 7, which is also made of epoxy resin.

46. A resin is a type of polymer. *See* Ex. 1013, Stenzenberger at Abstract, p. 1 (“thermosetting polymers such as epoxy resins”). This was well-known to a POSITA in 1994. A POSITA would understand the disclosed resin to be optically

transparent and light transmissive.

47. Tabuchi discloses “an ordinary UV-visible light conversion phosphor.” Ex. 1008, Tabuchi. At the time of this disclosure in 1973, this refers to an “inorganic” phosphor. In 1973, “an ordinary UV-visible light conversion phosphor” was used in fluorescent lamps to provide white light. Fluorescent lamps used inorganic phosphor. The patentee acknowledges that it was “well-known” that “fluorescent lamps” used “inorganic phosphors” that would down-convert UV light to white light. Ex. 1001, '058 Patent at 3:64-4:9. A POSITA in 1994 would understand that Tabuchi is referring to an inorganic phosphor.

48. Pinnow discloses: “When the phosphor composition is at least in part organic due to the large variation of materials which are suitable for use . . .” Ex. 1009, Pinnow at 2:30-48. To a POSITA, the “at least in part organic” discloses a phosphor composition of, in part, inorganic.

49. Tabuchi discloses the use of “high brightness” LEDs to produce visible light. Ex. 1008, Tabuchi at 2. Tabuchi also discloses a gallium nitride based LED. *Id.* at 5. Tabuchi further discloses that LEDs can be used as “display devices with a long life.” *Id.* at 2. Accordingly, Tabuchi has the same focus on LED development as Nakamura. Nakamura discloses a “high brightness” blue LED, as well as a gallium nitride based LED, adding indium. Ex. 1006, Nakamura at p. 1. Nakamura further explains that “using these high-brightness

blue LEDs, high-brightness full color indicators and flat panel displays will be developed in the near future.” *Id.* at p. 3. In light of this similar focus on LED development, a POSITA in 1994 would have been motivated to use the teachings of Tabuchi with Nakamura. Further, the bright blue LED from Nakamura was a watershed event for the industry. An IEEE publication recognized that the bright blue LED was the “long-sought Holy Grail of LED technology” that “may open the way for white LED light sources.” Ex. 1010, Werner at pp. 1, 6. Accordingly, in 1994, a POSITA would have taken notice of this new discovery, and would have been motivated to use the bright blue LED as the “high-brightness”, gallium-nitride based LED disclosed in Tabuchi.

50. Werner discloses LEDs for liquid crystal displays and in a backlighting array. Ex. 1010, Werner. This would have been an obvious extension to the prior art for a POSITA in 1994. A POSITA at the time would have been able to incorporate an LED into a backlighting array, and also in incorporate it for use in a liquid crystal display. Tabuchi already discloses LEDs as “display devices with a long life.” Ex. 1008, Tabuchi at 2. And Nakamura discloses “high brightness full-color indicators and flat panel displays will be developed in the near future.” Ex. 1006, Nakamura at p. 3. Further, Pinnow’s “invention relates to a visual display apparatus.” Ex. 1009, Pinnow at 1:12-13. A POSITA would have been motivated to combine this prior art with Werner. Werner is entitled “Higher

visibility for LEDs” found in the “Advanced Technology/Displays” section of IEEE Spectrum. IEEE Spectrum has been a flagship publication for the IEEE. Werner is a publication that would have been typical for a POSITA’s review. Specifically, Werner is a timely July 1994 IEEE publication on the bright blue LED that would have been of particular interest, given Nakamura’s disclosure months earlier in March 1994. Werner refers to the Nakamura bright blue LED as the “long-sought Holy Grail of LED technology” and states that “even full-color outdoor video displays based on LEDs are now possible.” Ex. 1010, Werner at p. 1. Then, Werner discloses the use of LEDs in liquid crystal displays and in an array for backlighting displays. *Id.* at p. 6. With Tabuchi, Nakamura and Pinnow each disclosing light emitting devices for use in displays, a POSITA would have been motivated to combine their teachings with Werner’s disclosure of LEDs in an array for backlighting displays, including liquid crystal displays.

51. In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

52. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed this 26th day of May, 2015, in Troy NY.

Respectfully submitted.



E. Fred Schubert, Ph.D.

Attachment A

Curriculum Vitae: E. Fred Schubert

Contact information

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Marital status

Married to
Jutta M. Schubert

Education

<i>University of Stuttgart</i>	Electrical Engineering	Vordiplom	(U. S. equivalent BSEE)	1978
<i>University of Stuttgart</i>	Electrical Engineering	Diplom Ingenieur (Honors)	(U. S. equivalent MSEE)	1981
<i>Oregon State University</i>	Electrical Engineering	Exchange Student		1977–1978
<i>University of Stuttgart</i>	Electrical Engineering	Doktor Ingenieur (Honors)	(U. S. equivalent Ph. D.)	1986

Current appointment

2002 – present: Wellfleet Senior Constellation Chaired Professor, Future Chips; Head of Future Chips Constellation; Professor, Department of Electrical, Computer, and Systems Engineering; Rensselaer Polytechnic Institute

Previous appointments

2002 – 2012: Professor Department of Physics, Applied Physics, and Astronomy; Rensselaer Polytechnic Institute
2008 – 2009: Director, Founding Director, and Principal Investigator, NSF Engineering Center for Smart Lighting, *Rensselaer Polytechnic Institute*
2002 – 2003: Adjunct Professor, *Boston University*
1995 – 2002: Professor, *Boston University*, Department of Electrical and Computer Engineering; Director of the Semiconductor Devices Research Laboratory; Affiliated Faculty of the Photonics Center.
1988 – 1995: Member of Technical Staff; Principal Investigator; and Member of Management at *AT&T Bell Laboratories* in Murray Hill, New Jersey
1985 – 1987: Post-Doctoral Member of Technical Staff at *AT&T Bell Laboratories* in Holmdel, New Jersey.
1981 – 1985: Scientific Member of Staff at the *Max Planck Institute for Solid State Research* in Stuttgart, Germany. Ph. D. Thesis title: “Modern Schottky gate field-effect transistors based on III–V semiconductors”

Technical Achievements

- First study of hot electron effects in selectively doped $\text{Al}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ heterostructures (1983)
- Demonstration and elimination of parallel conduction in $\text{Al}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ heterostructures (1984)
- First analysis of semiconductors doped with simultaneously shallow and deep donors (1984).
- Proposal and demonstration of the δ -doped field-effect transistor. Short-channel effects in sub-micron field-effect transistors can be reduced to their theoretical minimum by using δ -doped structures (1985)
- Development of the theory of alloy broadening in luminescence spectra of alloy semiconductors such as $\text{Al}_x\text{Ga}_{1-x}\text{As}$. The current understanding of the low-temperature spectral linewidths of ternary and quaternary alloy semiconductors is based on this theoretical model. The publication analyzing the phenomenon of alloy broadening has been referenced far in excess of 100 times (1984)
- First demonstration of a light-emitting diode with a doping superlattice active region (1985).
- Application of δ -doping to selectively doped heterostructures. Demonstration of high-electron-mobility transistors with the highest free electron concentrations (1986).

- Demonstration of delta-doped non-alloyed ohmic contacts with very low contact resistance and subsequent demonstration of self-aligned field-effect transistor with delta-doped non-alloyed ohmic contacts (1986)
- Demonstration of the spatial localization of dopants within 20 Å for many doping elements in delta-doped semiconductors (1983-1988)
- Significant improvement of the optical properties of doping superlattices by employment of delta doping. Improvement is demonstrated by the first observation of quantized interband transitions in the absorption (1988) and in the emission spectra (1989)
- First demonstration of tunable doping superlattice laser (1989)
- First quantitative analysis of the capacitance-voltage (CV) profiling technique in semiconductors with quantum-confined carriers. Demonstration that resolution of CV profiles in quantum-confined semiconductors is not limited to the Debye screening length (1990)
- Invention and demonstration a new concept by which heterojunction band discontinuities occurring between two different semiconductors are eliminated. The *elimination of heterojunction barriers* is based on parabolic compositional grading of doped heterojunctions. This concept is widely used in the fabrication of vertical cavity surface emitting lasers and other heterojunction devices (1991)
- Invention and first demonstration of resonant cavity light-emitting diode (RCLED) which uses photon quantization in microcavities to enhance the spontaneous emission properties (1992)
- Demonstration of giant enhancement of luminescence intensity in Er-doped Si-SiO₂ microcavities (1992)
- First demonstration of a resonant-cavity detector which is useful for wavelength-selective detection (1993)
- Demonstration of resonant-cavity light-emitting diode (RCLED) with very high brightness. The experimental brightness of the RCLED is five times higher than that of conventional LEDs. Based on calculations, the brightness of RCLEDs is expected to exceed that of conventional LEDs by more than a factor of ten (1994)
- Invention of a new concept, *superlattice doping*, for enhanced p-type doping of GaN. All acceptors in GaN are deep, resulting in a low electrical acceptor activation of only 5 %. The new concept of superlattice doping is expected to increase the electrical activation of acceptors by more than a factor of ten (with post-doctoral associate Dr. W. Grieshaber, 1995)
- Investigation of yellow luminescence in GaN and the use of microcavity effects in Ag / GaN / sapphire structures to determine the refractive index of GaN (with post-doctoral associate Dr. W. Grieshaber, 1996)
- Demonstration of the first GaN / GaInN double heterostructure laser. The laser has cleaved facets and was optically pumped. Laser action was demonstrated by (i) a threshold in the light-versus-current characteristic, (ii) spectral narrowing below kT above threshold, (iii) a TE / TM polarization ratio greater than one hundred above threshold, and (iv) increased slope efficiency with increasing back-side facet reflectivity (with graduate student D. A. Stocker, 1997)
- Co-inventor of photonic-crystal light-emitting diode, PC-LED, jointly with group of Prof. John D. Joannopoulos at MIT (publication by Shanhui Fan *et al.* appeared in *Physical Review Letters* in 1997; US patent 5,955,749 was issued in 1999)
- First demonstration of crystallographic etching of GaN (with graduate student D. A. Stocker, 1998). The discovery, crystallographic etching, can be implemented by wet chemical etching, including photo-enhanced electrochemical (PEC) wet etching. The discovery is widely used in the LED industry to strongly enhance light extraction from LED chips and is found in LED light bulbs.
- Experimental demonstration of a ten-fold enhancement of p-type doping activation in Al_xGa_{1-x}N/GaN doped superlattices as compared to bulk GaN and Al_xGa_{1-x}N (with graduate students D. A. Stocker and I. D. Goepfert, 1999)
- Invention and demonstration of the photon-recycling semiconductor light-emitting diode (PRS-LED) which emits *white* light and many other colors with very high luminous performance of > 300 lm/W (with graduate students X. Guo and J. W. Graff, 1999). Invention of the monolithically integrated GaInN/GaN PRS-LED (with graduate students X. Guo and J. W. Graff, 2000)
- Invention and demonstration of polarization-enhanced ohmic contacts in p-type and n-type GaN (with graduate students Y.-L. Li and J. W. Graff 2000)
- Invention and demonstration of AlGaInP light-emitting diode with omni-directional reflector (ODR) for high light extraction efficiency (with post-doctoral associate Th. Gessmann and graduate student J. W. Graff, 2001)
- Developed novel model for high diodes ideality factors ($n \gg 2.0$) in UV LEDs based on multiple rectifying

elements (with graduate student J. M. Shah and Prof. Th. Gessmann, 2003)

- Developed theory for temperature coefficient of forward voltage in light-emitting diodes, particularly UV light-emitting diodes (with graduate student Yangang “Andrew” Xi, Dr. Jong Kyu Kim, and collaborators at Sandia National Laboratories, 2004, 2005)
- Invented highly efficient “remote phosphor configurations” in white light-emitting diodes (with Jong Kyu Kim, Hong Luo, and collaborators at SAIT-Samsung) (2004, 2005)
- Discovered whispering gallery modes in white LEDs with remote phosphors (with graduate student Hong Luo, Jong Kyu Kim, Yangang “Andrew” Xi, and collaborators at SAIT-Samsung, 2005)
- Developed new class of materials, low-refractive index materials, or low- n materials, with an unprecedented low refractive index of $n < 1.10$ (with Dr. Jong Kyu Kim, “JQ” Xi, Professors Joel Plawsky, Bill Gill, 2005)
- Developed graded-index antireflection coatings that, unlike conventional anti-reflection coatings, have broadband omni-directional characteristics; the graded-index antireflection coatings use novel low- n materials (with Jingqun “JQ” Xi, Jong Kyu Kim, 2007)
- Developed efficiency-droop reducing GaInN / GaInN and GaInN / AlGaInN LED active regions that were demonstrated to reduce the efficiency droop by as much as 40% (with Jong Kyu Kim, Martin Schubert, Di Zhu, Jiuru Xu, Mary Crawford, and Dan Koleske, 2009)
- Developed analytic model for efficiency droop based on drift-induced reduction of the carrier-injection efficiency (with Guan Bo Lin, Jaehee Cho, and others, 2012)

Honors and awards

- Google Scholar profile, including the Hirsch-index (h-index) can be found at < <http://scholar.google.com> > under profile “E. Fred Schubert”
- Elected to *Senior Member* of the *IEEE* “in recognition of professional standing” (1993)
- Recipient of the Literature Prize of the *Verein Deutscher Elektrotechniker (VDE)* for “Doping in III–V semiconductors” (Cambridge University Press, Cambridge, 1993). Citation: “The book concerns all aspects of doping in III–V semiconductors. Fundamental, practical, and technological issues of doping are addressed. The book covers the basic theory of shallow donors, shallow acceptors, deep levels, and their influence on the free carrier concentration. It also discusses doping during growth, epitaxy, diffusion, and ion implantation. In the field of semiconductor devices, the book emphasizes applications requiring highly controlled doping distributions. It is an excellent monograph equally suited for study, research, and industry” (1994)
- Elected as a member of the *Bohemian Physical Society* (Cornell University, Ithaca, New York). Citation: “For seminal contributions to the control of spontaneous emission by use of wavelength-size optical cavities, specifically the first demonstration in a glass host using rare earth implanted Si/SiO₂ resonant microcavities” (1994)
- Listed in “Who’s Who In Science And Engineering” and “Who’s Who in America” published by *Marquis Who’s Who*, publishers of the original *Who’s Who in America*. (*Marquis Who’s Who*, New Providence, NJ) ISBN 0-8379-5755-9 (1996 – present)
- Elected to *Fellow of the SPIE* “For pioneering research in semiconductor doping and sustained contributions to the development of high-efficiency light-emitting diodes and lasers”. According to the Society’s bylaws, a Fellow “shall be distinguished through his achievements and shall have made outstanding contributions in the field of optics, or optoelectronics, or in a related scientific, technical, or engineering field” (1999)
- Recipient of the *Alexander von Humboldt Senior Research Award* of the Alexander von Humboldt Foundation, a Bonn-based non-profit organization promoting the exchange of scientific knowledge between German and highly qualified foreign scholars. According to the Alexander von Humboldt Foundation, academic qualification is the only selection criterion for the award. The award resulted in two extended visits with the Microoptics Laboratory of Professor Jürgen Jahns at the University of Hagen, Germany (1999)
- Elected to *Fellow of the IEEE* “for contributions to semiconductor doping and resonant-cavity devices”. According to the IEEE definition “the grade of Fellow is one of unusual professional distinction conferred by the Board of Directors only upon a person of extraordinary qualifications and experience” (1999)
- Listed in the “Dictionary of International Biography, 29th Edition” published by the *International Biography Center*, Cambridge, United Kingdom (2000)
- Recipient of the 2000 *Discover Magazine Award for Technological Innovation* presented by the *Christopher*

Columbus Foundation in the category “Energy”. The prize was awarded “for the invention and demonstration of the photon recycling semiconductor light-emitting diode”, an all-semiconductor LED capable of emitting white light with very high efficiency, see < www.discover.com/awards > (2000)

- Recipient of the *RD100 Award* of the R&D Magazine that honors the “100 most technologically significant products of the year” (with Klaus Streubel of Osram-Sylvania Corp. and Rickard Marcks von Wurtemberg of Mitel Corp.). The prize was awarded for the “*Resonant-cavity light-emitting diode*” that uses enhanced spontaneous emission occurring in resonant cavities. The device is used in plastic optical fiber communication links, in telescopes for rifles, and many other applications (2000).
- Elected to *Fellow of the OSA* “for the invention and demonstration of the resonant-cavity LED and the photon-recycling semiconductor LED”. OSA Fellows are elected by the OSA Board of Directors (2001)
- Recipient of the Boston University Provost Innovation Fund Award (Provost Dennis D. Berkey) valued at \$ 25,000 for research and development of promising technologies (2001)
- Elected to *Fellow of the APS* “for pioneering contributions to the doping of semiconductors including delta doping, doping of compositionally graded structures resulting in the elimination of band discontinuities, and superlattice doping to enhance acceptor activation” (2001)
- Honored with RPI Medal as Senior Constellation Chair during Investiture Ceremony (2002)
- Received “2002 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award” (2002)
- Inducted as Wellfleet Senior Constellation Professor, Future Chips, Rensselaer Polytechnic Institute, November 21 (November 2003)
- Distinguished Lecturer of the IEEE Electron Devices Society (2003–2006)
- Elected member in Eta Kappa Nu (2004)
- “Best Oral Presentation Award” was won by Ph. D. student Hong Luo (who was the presenter), J. K. Kim, Y. A. Xi, J. M. Shah, Th. Gessmann and E. F. Schubert “Improvement of extraction efficiency of GaInN light-emitting diodes by employment diffuse omni-directional reflectors” *Connecticut Microelectronics & Optoelectronics Consortium (CMOC)*, 14th annual symposium, New Haven CT, March 17 (March 2005).
- “Best Student Poster Award” of the *International Semiconductor Device Research Symposium (ISDRS)* was won by Ph. D. student J.Q. Xi (who was the presenter), Jong Kyu Kim, Dexian Ye, Jasbir S. Juneja, T.-M. Lu, Shawn-Yu Lin, and E. Fred Schubert “Optical Thin Films with Very Low Refractive Index and Their Application in Photonic Devices”, *International Semiconductor Device Research Symposium (ISDRS)*, Dec. 7–9, Bethesda, MD (December 2005)
- “MRS Silver Award” of the Materials Research Society was won by Ph. D. student Yangang Andrew Xi (who was the presenter), K. X. Chen, F. Mont, J. K. Kim, C. Wetzel, E. F. Schubert, W. Liu, X. Li, J. A. Smart “Extremely high quality AlN grown on (0001) sapphire by using metal-organic vapor-phase epitaxy” *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (2006) Boston MA (December 2006)
- “25 Most Innovative Micro- and Nano-Products of 2007 Award” in July 2007 issue of *R&D Magazine* and *Micro/Nano Newsletter*. This recognition was given for the “Non-Reflective Coating” product that was published in *Nature Photonics* in 2007; full citation of publication: Xi, J.-Q., Martin F. Schubert, J. K. Kim, E. F. Schubert, Minfeng Chen, Shawn-Yu Lin, Wayne Liu, and Joe A. Smart “Optical thin-film materials with low refractive index for broadband elimination of Fresnel reflection” *Nature Photonics* **1**, 176, March 2007 (July 2007)
- “SCIENTIFIC AMERICAN 50 AWARD” of 2007, as published in the January 2008 issue of *Scientific American*. According to the *Scientific American Magazine*, this award “celebrates visionaries from the worlds of research, industry and politics whose recent accomplishments point toward a brighter technological future for everyone” (January 2008)
- “EDITORS’ CHOICE” of *Science Magazine*, *Science*, Volume **319**, page 1163, February 29 (February 2008). This distinction was awarded for the publication: Jong Kyu Kim et al., “Light-extraction enhancement of GaInN light-emitting diodes by graded-refractive-index indium tin oxide anti-reflection contact” that appeared in *Advanced Materials* **20**, 801, 2008 (February / March 2008)
- Received “2008 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award” (2008)
- “Best Oral Presentation Award” won by David J. Poxson (who was the presenter), Frank W. Mont, Jong Kyu Kim, and E. Fred Schubert “Multilayer nano-structured anti-reflection coating with broad-band omni-

directional characteristics" *Connecticut Microelectronics and Optoelectronics Conference (CMOC)*, University of Connecticut, Storrs, Connecticut, April 9 (April 2008)

- "Best Oral Presentation Award" for presentation: David Meynard, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Jong Kyu Kim, Daniel D. Koleske, and Mary H. Crawford "Temperature-dependent light-output characteristics of GaInN light-emitting diodes with different dislocation densities" *Connecticut Microelectronics and Optoelectronics Consortium (CMOC) Symposium*, New Haven CT, March 2 (March 2011)
- Identified as top 1% of patentees in the field of optoelectronics by study conducted by Professor Erica Fuchs of Carnegie Mellon University under a study supported by the US National Science Foundation (July 2011)
- Received "2012 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award" (November 2012)
- My "LinkedIn" profile was one of the top 10% most viewed "LinkedIn" profiles during 2012 (January 2013)
- My graduate student, Mr. Ming Ma, received the \$ 30,000.00 Lemelson-Rensselaer Student Prize for the invention entitled "Graded-refractive-index (GRIN) structures for brighter and smarter light-emitting diodes"; The Prize is awarded annually by the Lemelson Foundation (March 2013)

Service to the technical community

- Current or former member of the *American Physical Society* (Member of the *Division of Materials Physics*, Member of the *Division of Condensed Matter Physics*), *Institute of Electrical and Electronics Engineers*, *Materials Research Society*, *Optical Society of America*, *Society for Optical Engineering (SPIE)*, and the *Verein Deutscher Elektrotechniker*
- Co-author of hundreds of research articles, co-inventor of more than 30 United States patents, and numerous foreign patents (1981 – present)
- Gave many invited talks at scientific conferences organized by the *American Physical Society*, *Institute of Electrical and Electronic Engineers*, *Materials Research Society*, *SPIE (The International Society for Optical Engineering)*, *Electrochemical Society*, *American Vacuum Society*, *Engineering Foundation*, and other professional societies (1985 – present).
- Co-editor (with A. M. Glass) of a Special Issue of the *Journal of Optical and Quantum Electronics* (Vol. **22**, 1990) on "Charge-transport assisted optical non-linearities in semiconductors" (1990)
- Symposium chair of the *American Vacuum Society Greater New York and New Jersey Chapter* on "Epitaxially grown semiconductors with atomic level control" (1991).
- Moderator of an Internet discussion on "Doping and Dopants in GaN" of the *MRS Internet Journal* (1995 – 1997)
- Member of review panels of the National Science Foundation (1995 – present)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1997)
- Technical work has been featured in popular journals, magazines and newspapers including the *New Scientist*, *Discover Magazine*, *Wall Street Journal*, *Boston Globe*, *Focus*, and on National Public Radio (1996 – present)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1998)
- Program Committee Member: IEEE IEDM, International Electron Devices Meeting (1999 and 2000)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1999)
- Program Committee Member: ISBLLED, International Symposium on Blue Laser and Light-Emitting Diodes, Berlin, Germany, March 5 – 10 (2000)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (2000)
- Conference Chair and Co-Organizer of the TMS- and ONR-sponsored conference on "Doping, Dopants, and Low Field Carrier Dynamics in Wide Gap Semiconductors", Copper Mountain, Colorado, April 2 - 6 (2000)
- Chair, IEEE LEOS, Central New England Chapter. During my tenure as Chair, the Central New England Chapter won the IEEE LEOS Chapter award for the highest membership growth (1999 – 2000)
- Expert Witness involving compound semiconductor devices (1999 – 2010)
- Member of the Board of Governors, IEEE Laser and Electro-Optics Society (LEOS) (1999 – 2000)
- Member of the Optoelectronics Industry Development Association (OIDA) Roadmap Panel on Solid-State

Lighting, Albuquerque NM Oct. 26–28 (2000)

- Conference Chair of SPIE Photonics West conference on “Light-emitting diodes: Research, Manufacturing, and Applications” San Jose, CA (2001)
- Panel Member of National Research Council meeting on “Solid State Lighting:” held at NAS and NAE, Washington DC, March 26 (2001)
- Program Committee Member of SPIE Photonics West conference on “Laser and LED Applications” chaired by Dr. Kurt Linden, San Jose CA Jan (2002)
- Conference Chair of SPIE Photonics West conference on “Light-emitting diodes: Research, Manufacturing, and Applications” San Jose, CA (2002)
- Program Committee Member: ISBLLED, International Symposium on Blue Laser and Light-Emitting Diodes, Cordoba, Spain, March 11–15 (2002)
- Program Committee Member for subcommittee on “Semiconductor lasers and LEDs” for OSA Conference on Lasers and Electro-Optics and Quantum Electronics and Laser Science Conference (CLEO / QELS) (2002 – 2003) Baltimore MD June 1–6 (2003)
- Reviewer for National Research Council of report entitled “Partnerships for Solid-State Lighting: Report of a Workshop” authored by the Board on Science, Technology, and Economic Policy. This report is forwarded to the US Congress for the initiation of a national Solid-State Lighting Initiative. (2002)
- Program Committee Member “Lester Eastman conference on high performance devices” University of Delaware, Newark, Delaware, August 6 – 8 (2002)
- Conference Chair of SPIE Photonics West conference on “Light-emitting diodes: Research, Manufacturing, and Applications” San Jose CA (2003)
- OIDA Next Generation Lighting (NGL) Consortium. Member of “Light-Emitting Diode” Committee (2003)
- Program Committee Member, International Semiconductor Device Research Symposium (ISDRS) Washington DC, Dec. 8 – 12 (2003)
- Program Committee Member of “Display and Solid-State Lighting Devices” conference for OSA/IEEE Conference on Lasers and Electro-Optics (CLEO) (2003 – 2004)
- Elected Member of the IEEE Electron Device Society Administration Committee (IEEE AdCom) (2003–2008)
- Conference Chair of SPIE Photonics West conference on “Light-emitting diodes: Research, Manufacturing, and Applications” San Jose CA (2004)
- Program Committee Member “Fourth International Conference on Solid State Lighting” August 2 – 6 Denver, CO (2004)
- Program Committee Member for the “Blue 2004: Advanced LEDs and Lasers Conference” Hsinchu, Taiwan, May 10–12 (2004)
- Conference Chair of SPIE Photonics West conference on “Light-emitting diodes: Research, Manufacturing, and Applications” San Jose CA (2005)
- Program Committee Member “International Semiconductor Device Research Symposium” December 7 – 9 Washington, DC (2005)
- Chair of “Display and Solid-State Lighting Devices” conference of OSA/IEEE Conference on Lasers and Electro-Optics (CLEO) (2005)
- Best Oral Presentation Award (Presenter: Hong Luo) at *Connecticut Microelectronics & Optoelectronics Consortium* (CMOC), 14th annual symposium, New Haven CT, March 17 (March 2005)
- Conference Chair of MRS Spring meeting “Symposium DD: Solid-State Lighting Materials and Devices” San Francisco, April 17–21 (April 2006)
- Member on the International Advisory Committee of *First International Conference on Display LEDs* (ICDL 2007), Seoul, Korea, January 31 to February 2 (2007)
- Member, Program Committee of *SPIE Photonics West* conference “Light-Emitting Diodes: Research, Manufacturing, and Applications XI” San Jose, CA, January 20 – 25 (2007)
- Program Chair of *SPIE Photonics West* conference “Semiconductor Lasers and LEDs” San Jose, CA, January 20 – 25 (2007)
- Member, Executive Organizing Committee *SPIE Photonics West* conference “LASE 2007” San Jose, CA, January 20–25 (2007)

- Opto Track Chair of *SPIE Photonics West* conference “Semiconductor Lasers and LEDs” San Jose, CA, January 21–24 (January 2008)
- Member, Program Committee, Light-emitting diodes: Research, Manufacturing, and Applications, SPIE Photonics West 2008, San Jose, California, January 19 – 24 (January 2008)
- Program Committee Member of the 7th International Symposium on Semiconductor Light Emitting Devices (ISSLED-2008) held in Phoenix, Arizona (USA), April 27 – May 2 (April 2008)
- Member, Program Committee, China SSL 2008, Shenzhen Convention & Exhibition Center, China, July 24 – 26 (July 2008)
- Member, Program Committee, International Workshop on Nitride Semiconductors, IWN 2008, Montreux, Switzerland, October 6 – 10 (October 2008)
- Opto Track Chair of *SPIE Photonics West* conference “Semiconductor Lasers and LEDs” San Jose, CA, January 25 – 29 (January 2009)
- Guest Editor of Special Issue on *Solid-State Lighting* published in the *IEEE Journal of Selected Topic in Quantum Electronics*, July / August edition (August 2009)
- Honorable Conference Chair, 6th China International Forum on Solid State Lighting (China SSL), Shenzhen Convention & Exhibition Center, China, October 14 – 16 (October 2009)
- Program Committee Member, International Conference on Nitride Semiconductors (ICNS), Jeju, South Korea, October 18 – 23 (October 2009)
- Program Committee Member, The Second International Conference on White LEDs and Solid State Lighting, Taipei, Taiwan, December 13 – 16 (December 2009)
- Editor, *Compound Semiconductors and Energy Applications and Environmental Sustainability*, Materials Research Society (MRS) Symposium Proceedings Volume 1167 (MRS, Warrendale PA, 2009)
- Conference Chair, OPTO, *SPIE Photonics West 2010*, San Francisco, California, January 23 – 27 (January 2010)
- Guest Editor of Special Issue on *Light-Emitting Diodes* published in the *IEEE Transactions on Electron Devices* (January 2010)
- Program Committee Member, *8th International Symposium on Semiconductor Light Emitting Devices* (ISSLED), Beijing, China, May 16 – 21 (May 2010)
- International Advisory Committee Member of the 16th *Microoptics Conference* (MOC’10) held in Hsinchu, Taiwan, sponsored and endorsed by OSA and IEEE/Photonics Society and organized by National Chiao Tung University, Oct. 31 to Nov. 3 (October 2010)
- Member of Academic Committee of *China Solid-State Lighting Conference* (CHINA SSL 2010) Shenzhen, China, October 14 – 16 (October 2010)
- Conference Co-Chair, OPTO, *SPIE Photonics West 2011*, San Francisco, California, January 22–27 (January 2011)
- Executive Organizing Committee OPTO, *SPIE Photonics West 2011*, San Francisco, California, January 22–27 (January 2011)
- Program Committee Member of conference entitled: “Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XV *SPIE Photonics West 2011*, San Francisco, California, January 22–27 (January 2011)
- Member of CLEO Subcommittee 15, entitled “LEDs, Photovoltaics and Energy-Efficient (“Green”) Photonics” for the 2011 Conference on Lasers and Electro-Optics (CLEO), Baltimore, Maryland May 1– 6 (May 2011)
- Member of the Academic Committee of the 8th China International Forum on Solid State Lighting (CHINA-SSL-2011) Guangzhou November 8–10 (November 2011)
- Program Committee Member of conference entitled: “Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XV *SPIE Photonics West 2012*, San Francisco, California, January 21–26 (January 2012)
- Member of CLEO Subcommittee 15, entitled “LEDs, Photovoltaics and Energy-Efficient (“Green”) Photonics” for the 2012 Conference on Lasers and Electro-Optics (CLEO), San Jose, California, May 6–11 (May 2012)
- Member of Academic Committee of the 9th China International Forum on Solid State Lighting (CHINA SSL 2012), Guangzhou, China, November 5–7, 2012 (November 2012)

- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XVI" *SPIE Photonics West 2013*, San Francisco, California, 2–7 February 2013 (February 2013)
- Member of CLEO Subcommittee in the topic area: "Science & Innovation 15: LEDs, Photovoltaics and Energy-Efficient ("Green") Photonics" for the CLEO 2013 conference, April 28–May 3, 2013 in Baltimore, Maryland (May 2013)
- Member, International Advisory Committee of the International Conference on Advanced Electromaterials (ICAE 2013) held on Jeju Island, Korea, from November 12–15, 2013 (November 2013)
- Program Committee Member, *Solid State and Organic Lighting (SOLED)*, OSA Topical Meeting, 3–7 November 2013, Marriott Tucson Star Pass, Tucson, Arizona, USA (November 2013)
- Co-Chair, OPTIC International Conference, Chung Li, Taiwan, National Central University, December 5–7, 2013 (December 2013)
- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XVII" *SPIE Photonics West 2013*, San Francisco, California, 1–8 February (2014)
- Publication Committee Member, *5th International Conference on White LEDs and Solid State Lighting* (White LEDs), Jeju Island, Korea, May 25–28, 2014 (May 2014)
- Sub-Committee Chair of Track 6: Displays, Solid-State Lighting, Photovoltaics, and Energy-Efficient Photonics of *Asia Communications and Photonics Conference 2014* (ACP 2014). ACP is the largest and the most influential conference in Asia and Pacific Rim for communications and photonics technologies. ACP 2014, Shanghai International Convention Center, Shanghai, China, November 11–14 (2014)
- International Consultant of technical seminar of the 11th China International Forum on Solid State Lighting (SSL-China 2014) Guangzhou, China, November 6–8 (2014)

Books

- ***Doping in III-V semiconductors*** (author) Hardback and paperback, 628 pages (Cambridge University Press, Cambridge, UK, 1993). The following excerpt is from a book review by D. L. Miller, *University of Pennsylvania*, University Park PA, which appeared in *Physics Today*, Oct. 1994, p. 71: "[...] Fred Schubert has written a book that very nicely fills two roles: It serves as a reference volume for those of us who use III-V materials, and it provides enlightening explanations of interesting and important problems in semiconductor physics. [...] Schubert, who is employed by AT&T Bell Laboratories, brings his extensive research involvement with III-V materials physics straight to this book. His lucid explanations of some of the important physics of doped semiconductors is a major strength. For example, the chapter on deep centers provides the clearest treatment of the DX center I can remember reading, and it uses the large lattice distortion model and configurational coordinates introduced for the DX center to describe the EL2 deep level. This book can also serve as an excellent reference volume, because it briefly describes epitaxial growth techniques and the doping methods used with them, catalogs dopant-related phenomena, describes characterization techniques and provides 45 pages of citations to published articles and books. [...] I will use it to help my graduate students in the physics of semiconductors. [...] It will certainly be available on my bookshelf, in part to remind me what the Burstein-Moss shift is and in part for the literally hundreds of references that it provides on nearly every topic related to III-V semiconductor doping. Because of its clarity in treating some interesting phenomena of modern semiconductor physics, you too might want to get a copy of this book, even if you believe that Ga and As are just poor alternatives for doping silicon"
- ***Delta doping in semiconductors*** (editor) Hardback and paperback, 616 pages (Cambridge University Press, Cambridge, U. K., 1996)
- ***Light-emitting diodes*** (author) Hardback and paperback, 328 pages (Cambridge University Press, Cambridge, UK, 2003). The following excerpt is from a book review by David Bour, *Agilent Laboratories*, Palo Alto CA, which appeared in *Physics Today*, Nov. 2004, p. 66: "[...] In *"Light-emitting diodes"*, E. Fred Schubert provides an excellent review of the physics and technology of semiconductor LEDs. [...] Interesting anecdotes like [the first demonstration of electroluminescence], clearly written by someone with a broad perspective and expertise, appear throughout the book, making it enjoyable to read. [...] Schubert provides an excellent description of the undesirable [non-radiative] recombination pathway. [...] Schubert has made pioneering

contributions to those devices, and this variety of LEDs may become more widely used in the future. [...] Overall, *"Light-emitting diodes"* is an excellent examination of the physics and technology of semiconductor LEDs. The narration is simple and direct, and the book is well referenced for those seeking a deeper understanding of the topic. Written for the graduate level, the text will appeal to a broad audience; and for specialists who make semiconductor LEDs and laser diodes, it will serve as a useful connection to the scientific literature."

- ***Light-emitting diodes, second edition*** (author) Hardback, 422 pages (Cambridge University Press, Cambridge, UK, 2006)

Courses and laboratories developed at Boston University

- Developed first laboratory for "Physics of semiconductor devices" (SC-471) Fall (1998)
- Developed course "Quantum mechanics applied to semiconductor devices" (SC-574) Fall (1999)
- Developed course "Semiconductor light emitters" (SC-760) Fall (2000)
- Developed distance-learning course and NTU course on "Light-emitting diodes – Device physics and applications" Fall (2000)

Courses taught at Boston University

- Undergraduate Course "Physics of semiconductor devices" (SC-471)
- Graduate course "Fiber optic communication systems" (SC-563)
- Graduate course "Quantum mechanics applied to semiconductor devices" (SC-574)
- Graduate course "Introduction to solid state physics of devices" (SC-577)
- Graduate course "Quantum electronics" (SC-700)
- Graduate course "Integrated optoelectronics" (SC-770)
- Graduate course "Compound semiconductor devices" (SC-771)
- Graduate course "Light-emitting diodes" (SC-760)
- Graduate course "Research seminar" (SC-860, SC-892)
- Other courses "Research", "Guided Study", "Master Thesis", and "Dissertation" (SC-900)

Courses taught at Rensselaer Polytechnic Institute

- Graduate Course "Semiconductor devices and models II" (ECSE-6290)
- Undergraduate course "Microelectronics technology" (ECSE-2210)
- Graduate course "Quantum mechanics applied to semiconductor devices" (ECSE-6968)
- Graduate course "Physical foundations of solid-state devices" (SC-6960)
- Graduate course "Light-emitting diodes and solid-state lighting" (SC-6961)
- Other courses "Research", "Guided Study", "Master Thesis", and "Dissertation"

Teaching evaluations and students' comments

(1997) Students have made the following comments: Clear ... organized ... excellent explanations ... I've never had a professor like him – I wish all are like him ... very clear and concise presentation ... strong response to students questions and concerns ... Professor provided excellent notes ... laid out lectures in a clear and precise manner which worked out wonderfully ... well organized and confident ... responsive to students' concerns ... excellent for students going into semiconductor industry ... excellent hand-outs and course materials ... well prepared ... clear lectures ... I was strongly encouraged ... materials is very interesting ... hand-outs were excellent ... material is very important ... presentation of materials was very clear ... hand-outs were excellent support to the class ... efforts made by Prof. Schubert in keeping everyone at the same pace was remarkable ...

(1998) Professor was always well prepared ... excellent content ... very relevant for the field of solid state devices ... excellent preparation for the class ... handouts were very good ... very well organized teacher ... excellent knowledge of material ... provided complete background of all material ... easy to talk to ... excellent overall teaching skills ... really enjoyed coming to class ... his choice of topics and homework helped me a lot ... enthusiastic in teaching and helpful during the office hours ... one of the best professors I have had at BU ... course gave a very good overview of the different solid state physics principles ... course was very well organized ... relevant examples and homework were given ... good explanations were given ... presented clearly ... presentation

was clear ... communicated effectively ... very knowledgeable ... good demonstrations in class ... gives clear descriptions ... asks questions of class ... grades homework fairly ... good at answering questions ... no weak points ... excellent instructor and scientist ... inspiring professor ... thorough ... instructor is very precise and well prepared ... his knowledge of the material is exact ... very responsive to feedback ... encourages student questions, class participation and discussion ... instructor cared about whether students understood material ... instructor used applications immediately after showing theory ... handouts were excellent ... guest lecture and lab tour excellent idea ... excellent class notes ... presented topics neatly ... well prepared ... review of ongoing research topics was great ... Professor Schubert is undoubtedly an expert in his area ...

(1999) He enjoyed teaching the material and was very clear ... presentation of the material in class was excellent ... he helped me to understand a lot about semiconductors ... Prof. Schubert always tried to make sure that we would all have a clear understanding of the material ... manuscripts were very helpful ... encouraged lots of class participation and was always readily available for help ... presentation was excellent ... instructor was always willing to help me ... very helpful ... clearly, Prof. Schubert is more than just extremely knowledgeable about this material ... very thorough and exact communication of points ... excellent course packet written by instructor ... he was very well prepared for class ... He is extremely fair and encourages participation ... he is also very accessible ... excellent instructor ... very approachable and easy to ask questions of ... handouts were very effective and helpful ... Prof. Schubert is very prepared and concepts are well explained ... [materials] will be very useful for my future ... very open to questions ...

(2000) He did a lot of experiments which really helped ... material is very interesting and cutting edge ... clear presentations ... good in-class demonstrations ... very clear lectures ... the material really does challenge you ... takes the time to answer your questions ... very interesting material ... relevant to today's world of communication ... field trip was fun ... in-class demonstrations really added to class ... good understanding of course material ... excellent details, willing to help, good explanations ... in-depth details on quantum mechanics ... instructor was extremely accessible to students ... he encouraged participation in class ... he gave intuitive arguments and explained concepts in a very physical way ... I very much enjoyed Professor Schubert and would like to take more classes with him ... material was very beautiful ... I very much enjoyed the papers that were discussed ... everything is well organized ... hand-out material is very complete and clear ... lectures are clear ... professor prepared an excellent manuscript ... explained things very clearly ... he has strong enthusiasm to solve students' questions ... it's a very important course ... Professor follows the course notes exactly, so one can concentrate on material without having to focus on details ... clearly presented material ... course is great preparation for future courses in solid state ... I greatly admire Professor Schubert ...

(2001) He has thorough understanding of subject ... I like the fact that he shows us examples in class demonstrations ... manuscript was good ... instructor provides good notes ... materials are presented clearly ... in this course you learn a lot ... very illustrative and in depth ... very interesting course ... Professor presented material well ... Professor seemed to have strong grasp on what he was teaching ... the basics were presented correctly ... smooth transition into more complex materials ... presented basics well ... Professor's strong points are knowledge, organization and class materials ... clear conception ... very important and useful class ... Professor knew what was going on ... manuscript and his notes were very helpful ... responded to suggestions ... notes were comprehensive ... just fine ... manuscript was good ... knows the material very well ... notes handed out are good ... expert knowledge of material ... developed lectures logically and straightforward ... lecture notes were prepared for us - very nice touch ... Professor has deep knowledge of the materials ... Professor is always prepared for lectures ... he emphasizes principles and the concepts ... good preparation ... good stuff and clear presentation ... good research and industry experience ... excellent handout notes and materials ... excellent teaching skills ... inspires the interest of students ... great knowledge of material ... well organized course notes ... Professor Schubert gave very clear instructions ... listening to his presentation is a true enjoyment of an excellent art of lecture style ... manuscript has quality of excellent book ... manuscript was excellent reference source book ... instructor was very clear and well organized and encouraged participation ... text [written by Schubert] was extremely good ... expert knowledge of materials ... class demonstrations were very beneficial ... can clearly relate complex ideas - very good ... has a high amount of patience ... excellent understanding of material ... very enthusiastic in teaching ... always available for discussion ... very knowledgeable ... I don't see any weak points ... he explains the theory very clearly ...

(2002) Always prepared ... presented difficult material in a manner that was easy to understand ... presented everything neatly ... very helpful and organized ... presents subject in an very easy and friendly format ... very well

qualified ... great experience ... very detailed notes ... well organized ... very useful ... very good diagrams and explanations ... he knows the material extremely well ... notes given to us are extremely helpful ... professor was very knowledgeable ... was able to answer any of our questions ... very informative course ... very knowledgeable and a great teacher ... instructor is enthusiastic to teach students ... instructor can explain theory very clearly ...

(2003) Great overall knowledge ... good organization skills ... demonstrations were very interesting and useful ... effective instructor ... handouts were extremely useful and organized ... good course for completely understanding many points of fiber optics ...

(2004) SPIE short course: ... encouraged questions and handled them well ... excellent short course ... I really appreciated and enjoyed this course ... good course – covered very broad matter ... the instructor was very knowledgeable on the topic ... excellent! ... RPI Semiconductor devices and models II (ECSE 6290): Overall excellence of teacher: 4.8 (average 4.2). Overall excellence of course: 4.6 (average 3.9). Comments: ... course was very well prepared ... [course] was very organized ... this is an excellent course ... I learned a lot from this course ... course was very good ... thanks Prof. Schubert for a wonderful course ... it's been a great course ... thank you ... RPI Microelectronics Technology (ECSE 2210): Overall excellence of teacher: 4.7 (average 4.2). Overall excellence of course: 4.3 (average 3.9). Comments: ... understandable presentation ... great job [of] Prof. Schubert ... very nicely done class ... very helpful throughout the entire course ... provided timely explanations to complicated material ... very informative ... course was fun and interesting ... very interesting lecturer ... very down to earth and easy to ask for help ... [instructor] did a good job in presenting [material] ... good course ... fun course ... excellent instructor ... he is a great guy and very knowledgeable (RateMyProfessor.com) ... I would definitely take a class from him again (RateMyProfessor.com) **Book review** by Neal Oldham (San Jose, CA, USA) on "Doping in III–V semiconductors" (E. F. Schubert, Cambridge University Press, Cambridge UK, 1993) on amazon.com (May 17, 2002): [This is the] best book I've encountered in the semiconductor field. This is, no question, the best book that I've encountered in the entire field of semiconductor physics. It is expertly organized and indexed, easy to follow, complete in its treatment of electrical and materials-science aspects of III-V semiconductor production and measurement, well-written ... worth every penny if you even have the most remote interest in the subject. **Book review** by Debdeep Jena (Santa Barbara, CA, United States) on "Doping in III–V semiconductors" (E. F. Schubert, Cambridge University Press, Cambridge UK, 1993) on amazon.com (July 6, 2001): Very useful text for semiconductor crystal growers. Doping is a big, big issue in semiconductors; this text does appreciable justice in its treatment of the issue. In addition, Schubert treats heterostructure physics appreciably well (in fact better than many textbooks on semiconductor physics!). Perusal of this book has proved very rewarding for me, and I expect it will do the same wonder for you too.

(2005) SPIE Photonics West short course: ... very good instructor! ... very knowledgeable ... clear on complex subjects ... good job fielding questions ... (numerical score 4.3 out of 5.0). Educational materials on the web: ... I have greatly enjoyed your LED slide show. CLEO short course: ... very good and well organized course! ECSE 6968: ... class presentations were very helpful in learning ... very useful in learning the details of fundamental concepts ... course is very good ... course is excellent for engineers ... your [...] treatment brought about a much better understanding ... examples were great and helpful ... [discussion of] history and photons [...] helped increase interest ... after your course now, I can actually approach a quantum mechanics text book without fear ... overall, I just wanted to say – thank you ... excellent course ... instructor made it interesting and taught very effectively ... manuscript provided was also very well written ... class was excellently structured ... will benefit my studies in the future ... especially liked the term paper requirement ... Prof. Schubert is an excellent instructor, who is well prepared (improved student attitude: 4.6 out of 5.0; overall excellence of teacher: 4.8 out of 5.0; overall excellence of course: 4.8 out of 5.0). SPIE Photonics North short course: ... very good and clear in presentation ... (numerical score 4.4 out of 5.0). ECSE 6960 mid-course and final feedback: ... Professor has provided all course materials ... really appreciate it ... well presented ... technical support was great ... my learning experience has been good ... responses to my homework questions have been very timely ... I have enjoyed the course and found it interesting and useful ... homework assignments has been extremely beneficial ... set of notes is very comprehensive ... good class structure ... (improved student attitude: 4.4 out of 5.0; overall excellence of teacher: 5.0 out of 5.0; overall excellence of course: 4.6 out of 5.0). Comment on web educational materials: ... notes look very thorough and clear ...

(2006) SPIE Photonics West short course: ... excellent, knowledgeable ... excellent presentation ... (numerical score 3.91 out of 5.0). ECSE 6961 (Light-emitting diodes and solid-state lighting) mid-course and final feedback: ... excellent: informative, comprehensive and interesting ... the best part of this course, in terms of my learning

experience, has been the course materials ... just an outstanding class ... so much is newly discovered and so much is current on-going research and commercially relevant ... Dr. Schubert is obviously a leading researcher and did a great job of conveying his experience and understanding to the class ... a highly technical topic that still makes a good general conversational topic ... I liked the course material ... I liked the fact that Prof. Schubert lectured directly from the textbook ... I liked the structure of the course ... I learned a lot about lasers and LEDs and other optical devices ... it is a basic and fundamental class ... instructor gives ideas, concepts, and samples very clearly ... very good course ... students interested in LEDs and solid-state lighting are strongly recommended to take it ... liked the overall coverage ... teaching pace was good ... he covered a lot of material that is important for the subject, but it was clearly always related to the topic ... the manuscript that he let us use was excellent in my opinion ... the most important thing I liked about the course was the course material and the structure of the course ... right amount of homework and the two exams and the term paper presentation ... it was great to learn this course from someone who is a world leader in this field ... well-organized material ... liked the course format ... organization was good ... allowed me to know exactly what we were covering so I could look through the material prior to the lecture ... course content was good, starting with LED basics and covering materials through modern technologies, and then a look at solid-state lighting and sort of an intro to communication devices ... good fundamentals in LEDs ... GREAT Professor ... awesome course ... informative course ... ability to view course online was helpful ... very fruitful course ... covering a lot of materials ... very good and very important for graduate students to take this one ... for people in industry it's also useful ... for the instructor, this course is thought through very clearly ... the text book is also very good ... great course ... excellent instructor ... cute instructor ... course is very good ... I benefited a lot from it ... (numerical scores: excellence of teacher 4.7 out of 5.0; excellence of course 4.4 out of 5.0; overall average of ratings 4.6 out of 5.0). ECSE 2210 (Microelectronics Technology) ... excellent teaching method ... I like that the Professor asks random questions at the end of class – it helped me understand the subject better ... I thought Prof. Schubert was fabulous ... his organization of the class encouraged learning ... I highly recommend this class to everyone ... a devoted and involved teacher ... displayed more enthusiasm in teaching than other Professors I had ... he also seemed to have a philosophy about teaching that was beyond helping students get good grades ... he emphasized real-world applications of material and had general advice about working in the real world after leaving academia ... helpful ... though he was harder in grading and exams, Prof. Schubert challenged us more and made the course more interesting ... the many class activities provide lots of practice of materials just learned ... provided good back-up information ... made sure students understood concepts ... thank you for asking students questions during class to reinforce concepts ... thank you for allowing open book exams ... (numerical scores: excellence of teacher 4.4 out of 5.0; excellence of course 4.3 out of 5.0; overall average of ratings 4.4 out of 5.0)

(2007) Book review by Steven J. Wojtczuk (Lexington, MA, USA) on “Light-Emitting Diodes” (E. F. Schubert, Cambridge University Press, Cambridge UK, 2003) on amazon.com (March 14, 2006): ... Schubert (RPI) has written an excellent book on LEDs that manages to explain and derive simple quantitative models for many phenomena of current interest ... many monographs are a compendium of results in the field with hundreds of references ... in contrast, Schubert, while giving copious references, is the sole author, leading to a coherent presentation well suited to learning ... there are plentiful and good figures and drawings, as well as many exercises and solutions integrated into the text ... SPIE photonics West Short Course: ... excellent talk ... ECSE 2210 (Microelectronics Technology) ... thank you ... great course ... excellent instructor ... interesting course ... appreciated that you did not lecture completely from the slides and that you probed the class to ensure that we were understanding the key points ... course is fine ... good professor ... Professor Schubert is one of the best lecturers I had ... the pace at which he moves the topic, the way he explains things, and the manner in which he asks students questions all came together to help me learn much more from his lectures than I could on my own ... instructors are absolutely very intelligent ... Professor Schubert was a good professor ... I actually learned things when Professor Schubert taught ... ECSE 6968 (Physical Foundations of Solid-State Devices) ... the instructor explained every concept in a very simple and effective manner ... I really enjoyed taking this course ... (numerical scores: excellence of teacher 4.5 out of 5.0; excellence of course 4.5 out of 5.0; overall average of ratings 4.5 out of 5.0)

(2008) SPIE Photonics West short course feedback: ... very good ... clear ... very nice ... answered questions readily ... (numerical score 4.25 out of 5.0) ... ECSE 6961 (Light-emitting diodes and solid-state lighting) feedback: ... It was great for me to have the opportunities to take two consecutive classes, *Physical Foundation* and *LEDs*, from you ... both these classes have taught me a lot ... they were very well organized ... thank you for all the help ... I have really enjoyed your classes ... relevant material ... very good professor ... (numerical scores: excellence of

teacher 4.3 out of 5.0; excellence of course 4.3 out of 5.0; overall average of ratings 4.3 out of 5.0) ... Internet educational materials feedback: ... I recently came across your course notes while trying to get a basic understanding about semiconductors and I wanted to thank you. Your notes for course "ECSE-2210 Microelectronics Technology" are the most useful and informative thing I have found on semiconductors on the Internet. I'm a chemist by trade and this is a great introduction for me ... 2007 Chautauqua Short Course and High School Teacher Summer Course, held at RPI June 26 and July 12, 2007 (numerical average of scores: 9 out of 10) ... ECSE 6968 (Physical Foundations of Solid-State Devices) feedback: ... Prof. Schubert is one of the best professors I've ever had ... his ability to explain difficult and complex materials in a clear and concise manner is unmatched ... the presentations, although time consuming, I felt were a great idea ... thanks for your efforts professor! ... I have really enjoyed taking this course ... By email: ... thank you professor ... it has been a pleasure taking this course with you ... (numerical scores: excellence of teacher 4.4 out of 5.0; excellence of course 4.4 out of 5.0)

(2009) SPIE Photonics West short course feedback: ... one of the best short courses I have taken ... it was very nice to hear about the history of LEDs ... very interesting but also very theoretical ... (numerical score 4.10 out of 5.0). ECSE 2210 (Microelectronics Technology) ... great course ... instructors were excellent ... encourages students to stay up to date with the subject matter ... thanks for this well-organized class ... [the instructor] tries to get students come out with the best grade possible ... this was a good class ... ECSE 6968 (Physical Foundations of Solid-State Devices) feedback: ... it is really an excellent course ... clear hand script ... great professor! ... (numerical scores: excellence of teacher 4.6 out of 5.0; excellence of course 4.7 out of 5.0)

(2010) SPIE Photonics West short course feedback: ... good to get the latest data and charts ... very good ... very broad course and well organized ... it was great ... (numerical score 4.04 out of 5.0) ... ECSE 6961 (Light-emitting diodes and solid-state lighting) feedback: ... a good course ... this was a wonderful course ... it has given me a lot of understanding ... the course has inspired me to take up LED research ... useful ... straight forward ... very good advisor ... good course ... (numerical scores: excellence of teacher 4.3 out of 5.0; excellence of course 4.2 out of 5.0) ... ECSE 6220 (Physical Foundations of Solid-State Devices) feedback: ... overall excellent course ... Professor Schubert is a good teacher ... he can explain every discipline very clearly and relate them to practical applications ... I like his teaching style very much ... overall, it was a nice course ... material explained in a clear organized manner ... (numerical scores: excellence of teacher 4.7 out of 5.0; excellence of course 4.3 out of 5.0)

(2011) SPIE Photonics West short course feedback: "... very nice overview ... instructor was excellent! ... very good instructor ... I would recommend lengthening to 6 hours ... excellent presentation, materials and text ... thanks ... very clear and easy to follow ... to be recommended ... excellent presentation ... good compromise for a person with a busy schedule ..." (numerical score 4.45 out of 5.0); ... ECSE 2210 (Microelectronics Technology) "... this was a great course ... I enjoyed Professor Schubert's views ... I was successful ... this course was taught very well ... this subject I now find quite interesting and am no longer intimidated by it ... I liked the material of this course ... thank you ..." (numerical scores: excellence of teacher 3.3 out of 5.0; excellence of course 3.2 out of 5.0); Feedback on book *Light-Emitting Diodes*: I am a graduate student from National Chiao Tung University, Taiwan ... your wonderful book *Light-Emitting Diodes*, both first- and second- edition, gave me a lot of information and help ... I would like to ask when can the third of the masterpiece be published? I wish I can get it as soon as possible and study more about the lighting devices; Feedback on Internet pages: I found your website and information [...] quite enlightening and provides a great start ... I simply wish to quickly express my thanks and gratitude. Feedback on book *Physical Foundations of Solid-State Devices*: Dear Prof. Schubert, I have read your book *Physical Foundations of Solid-State Devices* and I must say it is amazing the explanations are really good and I am most thankful that you have decided to put the book online thank you. Itamar Jade Balla, The Israel Institute Of Technology. Feedback on book *Light-Emitting Diodes* by Trung Nguyen (San Jose, California): It is a good book about Light Emitting Diodes (LEDs). It provides very good info and it is a good reference for engineers who work in LED field; ... ECSE 6220 (Physical Foundations of Solid-State Devices) feedback: "... amazing course ... great instructor ... very good course ... the text and lectures were very useful and informative ... I definitely learned a lot from taking this course ... I liked the course materials! ..." (numerical scores: excellence of teacher 4.6 out of 5.0; excellence of course 4.5 out of 5.0)

(2012) Feedback on Internet-based materials: "I'm Cheng Liu [Wuhan National Laboratory for Optoelectronics, China], currently a graduate student major in Physical Electronics ... I deeply admire your profound knowledge on this field and your unselfish sharing of it ..." ; ... SPIE Photonics West short course feedback: ... Dr. Schubert was very clear and very patient with people who had questions ... the materials were

comprehensive ... ; Feedback on Internet-based materials: "... supremely-rich course contents posted on your website. Thank you very much for showing such awesome materials for the world to see ..." (Prof. Natee Tangtrakarn, Thailand) ... ECSE 6962 (Light-Emitting Diodes and Solid-State Lighting) feedback: "... very interesting course ... Professor Schubert did a great job explaining the material ... his textbook is very clear and understandable ... nice course ... I learned a lot of new things by taking it ..." (numerical scores: excellence of teacher 4.7 out of 5.0; excellence of course 4.7 out of 5.0)

(2013) SPIE Photonics West short course feedback (SC-052, Light-Emitting Diodes): "... Great instructor with admirable combination of knowledge in academic and commercial knowledge ... I appreciated the depth of his knowledge and experience ... length of the course was good ... Overall this was an excellent course ... Thank you ... course is very easy and I understand easily ... Excellent course! ... Instructor was fantastic -- clear, explicit, took questions as we went and answered well ... One of the best SPIE courses I've taken (and I've taken lots)! ... Great course -- thanks! ... I was happy that the slides were updated with 2012 data". RPI course numerical scores (ECSE-6962, Light-Emitting Diodes and Solid-State Lighting): The instructor's presentation is clear and understandable: 4.67 out of 5.0; The instructor is aware of students' understanding or difficulties: 4.5 out of 5.0; The pace of the class is appropriate: 4.33 out of 5.0; The instructor adequately covers ways of applying discussed theories or methods to actual, real-world engineering systems: 4.50 out of 5.0; Verbatim comments: "... The course is pretty good ... needs no improvement ... I can appreciate the more wide-angle approach from the course ... These areas are very important and previously I had no knowledge of them ... It was a pleasure attending your class ..." RPI course numerical scores (ECSE-6968, Physical Foundations of Solid-State Devices): Excellence of course: 4.83 out of 5.0; Excellence of instructor: 4.83 out of 5.0; Verbatim comments: "It has been an awesome experience of learning for me in this course ... Thanks you for everything ... Thank you for the great semester ... Have a good break ... Thank you for the great semester ... Have a good break ... Professor, thank you for an engaging and interesting class this semester ... I enjoyed the subject of my paper and learned quite a bit particularly about GaN, which I had not had a chance to really do any research into before ... Very good and interactive class ... I liked the style of the class ... I thought the topics covered were very interesting ... I think I got much more out of the class this way than if we would have followed the manuscript chapter by chapter."

(2014) SPIE Photonics West short verbatim course feedback (SC-052, Light-Emitting Diodes): "Very knowledgeable instructor ... course was packed with information ... handouts are excellent ... Excellent presentation and contents ... the color rendering section which was interesting and fun ..." Numerical score: 4.36 out of 5.0; RPI Course ECSE-2210 Microelectronics Technology; Verbatim comments: "Instructor is clearly very knowledgeable about the topics ... Very clear and comprehensive ... This is the best class ever ... I'm quite enjoying this course ... I don't really have any recommendations on things to change ... The homeworks and lectures being sent out at the beginning was very helpful ... Both the TA and the professor were able to explain things very well ... I think he is a good lecturer ... I think the homeworks each were very very good at teaching me the material and the exam was fairly graded and easy to understand ... I like the professor definitely and I would have him again ... A good class ... I enjoyed Prof. Schubert's style of teaching ... I would still recommend Prof. Schubert as a professor ... Microelectronics is a good class ... Prof. Schubert keeps it interesting though ... he's a great professor ... The two TAs are also great ..." Numerical score of students' evaluation of instructor: 4.25 out of 5.0 (RPI median). RPI Course ECSE-6220 Physical Foundations of Solid-State Devices; Verbatim comments: "The book and lectures seem to be entirely in sync with one another ... it really enforces the material covered in the book ... the material is covered thoroughly and improves students' understanding of quantum physics ... The class was interesting with excellent learning materials ... I loved how the course was so well organized ... The lectures were very well put together ..." Numerical score of students' evaluation of instructor: 4.75 out of 5.0 (average).

(2015) RPI Course ECSE-6960 Light-Emitting Diodes; Verbatim comments: "the class has been excellent! ... I've learned a good amount about LEDs ..."

Post-doctoral fellows and visiting personnel for which I served as Major Research Advisor

Dr. Li-Wei Tu	Post-Doctoral Fellow	1988–1990
Dr. Neil Hunt	Post-Doctoral Fellow	1991–1993
Dr. Matthias Passlack	Post-Doctoral Fellow	1993–1995
Dr. Wolf Grieshaber	Post-Doctoral Fellow	1995–1997
Dr. Thomas Gessmann	Post-Doctoral Fellow	2000–2002
Dr. Jong Kyu Kim	Post-Doctoral Fellow	2003–2005

Dr. Min Ho Kim, SEMCo	Visiting Engineer	2007–2008
Prof. Ji-Myon Lee, Sunchon University	Visiting Professor	2007–2008
Dr. Jaehee Cho	Post-Doctoral Fellow	2008–2009
Dr. Yongjo Park, Samsung LED	Visiting Vice President	2010–2012
Dr. Yangang Andrew Xi	Visiting Scientist	2013–2014
Dr. Guan-Bo Lin	Post-Doctoral Fellow	2014–2015

Graduate students for which I served as Major Research Advisor

Dr. Dean A. Stocker	Ph.D. Dissertation	Ph. D. completed in 1999
Xiaoyun (Jane) Guo	Master Thesis	M.S.E.E. completed in 1999
John W. Graff	Master Thesis	M.S.E.E. completed in 1999
Dr. Ian D. Goepfert	Ph.D. Dissertation	Ph. D. completed in 2000
Yun-Li Li	Master Thesis	M.S.E.E. completed in 2000
Dr. Xiaoyun (Jane) Guo	Ph.D. Dissertation	Ph. D. completed in 2001
Dr. John W. Graff	Ph.D. Dissertation	Ph. D. completed in 2002
Dr. Erik L. Waldron	Ph.D. Dissertation	Ph. D. completed in 2002
Jay M. Shah	Master Thesis	M.S.E.E. completed in 2002
Dr. Yun-Li Li	Ph.D. Dissertation	Ph. D. completed in 2003
Jingqun (“JQ”) Xi	Master Thesis	M.S. completed in 2003
Yangang Andrew Xi	Master Thesis	M.S. completed in 2003
Ronald Jackson	Master Thesis	M.S. completed in 2004
Sameer Chhajed	Master Thesis	M.S. completed in 2004
Hong Luo	Master Thesis	M.S. completed in 2005
Xiaolu Li	Master Thesis	M.S. completed in 2005
Kaixuan Chen	Master Thesis	M.S. completed in 2005
Dr. Jay M. Shah	Ph.D. Dissertation	Ph. D. completed in 2006
Frank Mont	Master Thesis	M.S.E.E. completed in 2006
Dr. Hong Luo	Ph.D. Dissertation	Ph. D. completed in 2006
Dr. Jingqun (“JQ”) Xi	Ph.D. Dissertation	Ph. D. completed in 2006
Dr. Yangang Andrew Xi	Ph.D. Dissertation	Ph. D. completed in 2006
Won Seok Lee	Master Thesis	M.S. completed in 2007
Qi Dai	Master Thesis	M.S. completed in 2007
Di Zhu	Master Thesis	M.S. completed in 2007
Jiuru Xu	Master Thesis	M.S. completed in 2007
Ahmed Noemaun	Master Thesis	M.S. completed in 2007
Roya Mirhosseini	Master Thesis	M.S. completed in 2008
David Poxson	Master Thesis	M.S. completed in 2008
Qifeng Shan	Master Thesis	M.S. completed in 2009
Ming Ma	Master Thesis	M.S. completed in 2010
Xing Yan	Master Thesis	M.S. completed in 2010
Dr. Roya Mirhosseini	Ph.D. Dissertation	Ph. D. completed in 2010
Dr. Sameer Chhajed	Ph.D. Dissertation	Ph. D. completed in 2010
Dr. Jiuru Xu	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Frank Mont	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Wonseok Lee	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Di Zhu	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Qi Dai	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Ahmed Noemaun	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. David Poxson	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Qifeng Shan	Ph.D. Dissertation	Ph. D. completed in 2012
Dr. Ann Mao	Ph.D. Dissertation	Ph. D. completed in 2013
Dr. Xing Yan	Ph.D. Dissertation	Ph. D. completed in 2013

Dr. Ming Ma
Dr. David Meyaard
Dr. Guan-Bo Lin

Ph.D. Dissertation
Ph.D. Dissertation
Ph.D. Dissertation

Ph. D. completed in 2013
Ph. D. completed in 2013
Ph. D. completed in 2013

Publications

1982

1. H. Künzel, H. Jung, E. F. Schubert, and K. Ploog "Influence of growth conditions and of alloy composition on electrical and optical properties of MBE AlGaAs" *Journal Physique Colloque C5*, **C5/175**, 42 (1982)

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2. E. F. Schubert, K. Ploog, H. Dämbkes, and K. Heime "Selectively doped n-AlGaAs/ GaAs heterostructures with high-mobility two-dimensional electron gas for field-effect transistors. Part I: Effect of parallel conductance" *Applied Physics* **A33**, 63 (1984)
3. E. F. Schubert, K. Ploog, H. Dämbkes., and K. Heime "Selectively doped n-AlGaAs/ GaAs heterostructures with high-mobility two-dimensional electron gas for field-effect transistors. Part II: Hot electron effects" *Applied Physics* **A33**, 183 (1984)
4. E. F. Schubert and K. Ploog "Transient photoconductivity in selectively doped n-type AlGaAs/GaAs heterostructures" *Physical Review* **B29**, 4562 (1984)
5. E. F. Schubert, E. O. Göbel, Y. Horikoshi, K. Ploog, and H. J. Queisser "Alloy broadening in photoluminescence spectra of AlGaAs" *Physical Review* **B30**, 813 (1984)
6. E. F. Schubert and K. Ploog "Shallow and deep donors in direct-gap n-AlGaAs:Si grown by molecular-beam epitaxy" *Physical Review* **B30**, 7021 (1984)

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7. E. F. Schubert, J. Knecht, and K. Ploog "Transient and persistent photoconductivity in n-AlGaAs and selectively doped n-AlGaAs/GaAs heterostructures" *Journal of Physics C: Solid State Physics* **18**, L215 (1985)
8. E. F. Schubert, A. Fischer, and K. Ploog "GaAs sawtooth superlattice light-emitting diode operating monochromatically at $\lambda > 0.9 \mu\text{m}$ " *Electronics Letters* **21**, 411 (1985)
9. E. F. Schubert, A. Fischer, Y. Horikoshi, and K. Ploog "GaAs sawtooth superlattice laser emitting at wavelengths $\lambda > 0.9 \mu\text{m}$ " *Applied Physics Letters* **47**, 219 (1985)
10. E. F. Schubert, A. Fischer, and K. Ploog "Electron-impurity tunneling in selectively doped n-type AlGaAs/GaAs heterostructures" *Physical Review* **B31**, 7937 (1985)
11. E. F. Schubert, Y. Horikoshi, and K. Ploog "Radiative electron-hole recombination in a new sawtooth semiconductor superlattice grown by molecular-beam epitaxy" *Physical Review* **B32**, 1085 (1985)
12. E. F. Schubert and K. Ploog "The delta-doped field-effect transistor" *Japanese Journal Applied Physics Letters* **24**, L608 (1985)
13. K. Ploog, A. Fischer, E. F. Schubert "Preparation and properties of a new GaAs sawtooth doping superlattice" *Proceedings of the Second International Conference (Yamada Conference) on Modulated Semiconductor Structures*; September 9-13 (1985), Kyoto, Japan
14. E. F. Schubert and K. Ploog "Electron subband structure in selectively doped n-AlGaAs/ GaAs heterostructures" *IEEE Transactions on Electron Devices*, **ED-32**, 1868 (1985)
15. E. F. Schubert and K. Ploog "Optical properties of a new sawtooth superlattice grown by molecular beam epitaxy" *Journal de Physique (Paris)*, **46**, 147 (1985)

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16. E. F. Schubert, A. Fischer, and K. Ploog "The delta-doped field-effect transistor" *IEEE Transactions on Electron Devices*, **ED-33**, 625 (1986)
17. E. F. Schubert and K. Ploog "Interpretation of capacitance-voltage profiles from delta-doped GaAs grown by molecular-beam epitaxy" *Japanese Journal of Applied Physics* **25**, 966 (1986)
18. E. F. Schubert and W. T. Tsang "Photoluminescence line shape of excitons in alloy semiconductors" *Physical Review B, Rapid Communications*, **B34**, 2991 (1986)
19. E. F. Schubert, J. E. Cunningham, W. T. Tsang, and T. H. Chiu "Delta-doped ohmic contacts to n-GaAs" *Applied Physics Letters* **49**, 292 (1986) and *Applied Physics Letters* **49**, 984 (1986)
20. K. Ploog, A. Fischer, and E. F. Schubert "Preparation and properties of a new GaAs sawtooth doping superlattice" *Surface Science* **174**, 120 (1986)

21. B. I. Miller, E. F. Schubert, U. Koren, A. Ourmazd, A. H. Dayem, and R. J. Capik "High quality narrow GaInAs/InP quantum wells grown by atmospheric organometallic vapor phase epitaxy" *Applied Physics Letters* **49**, 1384 (1986)
22. E. F. Schubert, Cunningham J. E., and Tsang W. T. "Self-aligned enhancement and depletion-mode GaAs field-effect transistors employing the delta-doping technique" *Applied Physics Letters* **49**, 1729 (1986)
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32. J. E. Cunningham, W. T. Tsang, T. H. Chiu, and E. F. Schubert "Molecular beam epitaxial growth of high purity AlGaAs" *Applied Physics Letters* **50**, 769 (1987)
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38. B. Ullrich, E. F. Schubert, J. Stark, and J. E. Cunningham "Localization of impurities in delta-doped n-type GaAs" *Applied Physics* **A47**, 123 (1988)
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42. T. H. Chiu, E. F. Schubert, J. E. Cunningham, and B. Tell "Diffusion studies of the Si delta-doped GaAs by capacitance-voltage measurements" *Journal of Applied Physics, Rapid Communication* **64**, 1578 (1988)
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44. E. F. Schubert, B. Ullrich, T. D. Harris, and J. E. Cunningham "Quantum-confined interband absorption in GaAs sawtooth doping superlattices" *Physical Review* **B38**, 8305 (1988)
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50. T. Y. Kuo, J. E. Cunningham, E. F. Schubert, W. T. Tsang, T. H. Chiu, and C. G. Fonstad "Experimental and theoretical characterization of the delta-doped quantum well transistor grown by gas source molecular beam epitaxy" *IEEE Transactions on Electron Devices* **35**, 2449 (1988).

1989

51. E. F. Schubert, J. E. Cunningham, T. H. Chiu, J. B. Stark, B. Tell, and C. W. Tu "Spatial localization and diffusion of Si in delta-doped GaAs and AlGaAs and its application to electron-mobility optimization in selectively doped heterostructures" *GaAs and Related Compounds* Ed. J. S. Harris. (1989)
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53. J. E. Cunningham, G. Timp, A. M. Chang, T. H. Chiu, W. Jan, E. F. Schubert, and W. T. Tsang "Spatial localization of Si in selectively delta-doped AlGaAs/GaAs heterostructures for high mobility and density realization" *Journal Crystal Growth* **95**, 253 (1989)
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55. E. F. Schubert, J. E. Cunningham, T. H. Chiu, J. B. Stark, B. Tell, and C. W. Tu. "Spatial localization and diffusion of Si in delta-doped GaAs and AlGaAs and its application to electron-mobility optimization in selectively doped heterostructures" *GaAs and Related Compounds 1988* (Institute Physics Conference Series **96**, Bristol, 1989) p. 33
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5629 (1989)

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1990

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66. (Invited) E. F. Schubert "Optical properties of delta-doped doping superlattices" *Surface Science*, **228**, 240 (1990)
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71. (Invited) E. F. Schubert "Optical and electronic properties of delta-doped doping superlattices" *Journal of Optical and Quantum Electronics*, **22**, S141 (1990)
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Patent Licensing

Patents invented or co-invented by E. Fred Schubert have been licensed to several companies.

Presentations

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3. A. M. Vredenberg, E. F. Schubert, P. C. Becker, L. C. Feldman, N. E. J. Hunt, D. C. Jacobson, J. M. Poate, Y. H. Wong, and G. J. Zydzik "Spontaneous emission from Er implanted in a resonant Si/SiO₂ optical cavity" *8th Int. Conference on Ion Beam Modification on Materials (IBMM)* Heidelberg, Germany, Sept. 7 – 11 (1992)
4. A. M. Vredenberg, D. C. Jacobson, J. M. Poate, P. C. Becker, L. C. Feldman, R. C. Kistler, and E. F. Schubert "High energy Er implantation doping of optical devices" *IX International Conference on Ion Implantation Technology* University of Florida, Gainesville, FL Sept. 21 – 24 (1992)
5. R. F. Kopf, E. F. Schubert, T. D. Harris, and R. S. Becker "Modification of GaAs/AlGaAs growth-interrupted interfaces through changes in ambient conditions during growth" *North American Conf. on Molecular Beam Epitaxy* Ottawa, Canada, October 12 – 14 (1992)
6. A. M. Vredenberg, E. F. Schubert, N. E. J. Hunt, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Control of spontaneous emission from MeV-implanted Er in a resonant Si/SiO₂ optical cavity" *Materials Research Society Fall Meeting, Symposium A* Boston, MA, November 30 – December 4 (1992)
7. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Alcatel/SEL Research Laboratories* Stuttgart, August 31 (1992)
8. E. F. Schubert and R. F. Kopf "Selective n- and p-type C-doping in Ga_{0.47}In_{0.53}As ordered superlattices" *International Conference on Molecular Beam Epitaxy* Schwäbisch Gmünd, Germany, August 24 – 28 (1992)
9. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Max-Planck-Institut für Festkörperforschung* Stuttgart, Sept. 1 (1992)
10. N. E. J. Hunt, E. F. Schubert, R. A. Logan, and G. J. Zydzik "Extremely narrow spectral widths from resonant cavity light-emitting diodes (RCLEDs) suitable for wavelength-division multiplexing at 1.3 μm and 1.5 μm" *1992 International Electron Devices Meeting (IEDM)* San Francisco, CA, December 13 – 16 (1992)

1993

1. A. M. Vredenberg, N. E. J. Hunt, E. F. Schubert, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Controlled atomic-like spontaneous emission from implanted erbium in a Si/SiO₂ microcavity" *Quantum Optoelectronics Topical Meeting* Palm Springs, CA, March 17 – 19 (1993)
2. N. E. J. Hunt, E. F. Schubert, D. L. Sivco, A. Y. Cho, R. F. Kopf, and G. J. Zydzik "Narrow spectral emission and high output efficiencies from resonant cavity light-emitting diodes at 0.94 μm wavelength" *Conference of Lasers and Electro-Optics (CLEO '93)* Baltimore, MD, May 2 – 7 (1993)
3. **(Invited talk)** N. E. J. Hunt, E. F. Schubert, D. L. Sivco, A. Y. Cho, R. F. Kopf, and G. J. Zydzik "High-intensity resonant-cavity light-emitting diodes" *March Meeting of the American Physical Society* Seattle WA, March 22 – 26 (1993)

4. H. Yao, E. F. Schubert, and R. F. Kopf "Optical characterizations of delta-doped GaAs" *March Meeting of the American Physical Society* Seattle WA, March 22 – 26 (1993)
5. R. S. Becker, E. F. Schubert, and R. Kopf "Surface/interface morphology of As-capped III–V heterostructure materials" *March Meeting of the American Physical Society* Seattle WA, March 22 – 26 (1993)
6. **(Invited colloquium)** E. F. Schubert and N. E. J. Hunt "Resonant-cavity light-emitting diodes" *Seminar Series on Quantum Devices* Northwestern University, Evanston IL, March 26 (1993)
7. **(Invited talk)** E. F. Schubert and N. E. J. Hunt "Resonant cavity devices" *Brazilian School on Semiconductor Physics* Sao Carlos, Brazil, July 11 – 16 (1993)
8. **(Invited talk)** N. E. J. Hunt, E. F. Schubert, D. L. Sivco, A. Y. Cho, R. F. Kopf, R. A. Logan, and G. J. Zydzik "High efficiency, narrow spectrum resonant cavity light emitting diodes" *A NATO Advanced Study Institute on Confined Electrons and Photons: New Physics and Applications* Erice, Italy, July 13 – 26 (1993)
9. **(Invited talk)** N. E. J. Hunt, A. M. Vredenberg, E. F. Schubert, P. C. Becker, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Spontaneous emission control of Er^{3+} in Si/SiO₂ microcavities" *A NATO Advanced Study Institute on Confined Electrons and Photons: New Physics and Applications* Erice, Italy, July 13 – 26 (1993)
10. **(Invited colloquium)** E. F. Schubert "Integration of information and communication – A technology vision of AT&T" *Hessische Zentrale für Datenverarbeitung (HZD) and Landesautomationsausschuß Hessen (LAA)* Wiesbaden, Germany, November 5 (1993)
11. W. Tsang, E. F. Schubert, and J. E. Cunningham "Doping in semiconductor layered structures and their applications" *1993 Fall Meeting of the Materials Research Society* Boston, MA November 29 – December 3 (1993)

1994

1. N. E. J. Hunt, E. F. Schubert, R. J. Malik and G. J. Zydzik "Resonant cavity light-emitting diodes for optical interconnections" *1994 March Meeting of the American Physical Society* Pittsburgh PA, March 21 – 25 (1994)
2. M. Passlack, N. E. J. Hunt, E. F. Schubert and G. J. Zydzik "High quality dielectric Ga₂O₃ films for electronic and optoelectronic applications" *1994 March Meeting of the American Physical Society* Pittsburgh, PA, March 21 – 25 (1994)
3. H. Yao, E. F. Schubert, R. F. Kopf and Y. C. Chang "Optical studies of doped GaAs/AlGaAs quantum wells and delta-doped GaAs – a 2D electron system" *1994 March Meeting of the American Physical Society* Pittsburgh PA, March 21 – 25 (1994)
4. **(Invited talk)** E. F. Schubert "Doping in III–V semiconductors" *Spring Meeting of the Materials Research Society* San Francisco, CA, April 4 – 8 (1994)
5. M. Passlack, E. F. Schubert, M. Hong, G. J. Zydzik, W. S. Hobson, J. P. Mannaerts and N. E. J. Hunt "Ga₂O₃ films for electronic and optoelectronic applications" *21st International Symposium on Compound Semiconductors* San Diego CA, Sept. 18 – 22 (1994)
6. **(Invited talk)** E. F. Schubert "Resonant cavity light-emitting diodes" *21st International Symposium on Compound Semiconductors* San Diego CA, Sept. 18 – 22 (1994)
7. **(Invited colloquium)** E. F. Schubert "Optoelectronic Devices with Optical Cavities" *Walter Schottky Institute* Garching, Munich, Germany, October 19 (1994)
8. **(Invited talk)** E. F. Schubert "Resonant cavity light-emitting diodes" *International Symposium on guided-Wave Optoelectronics: Device Characterization, Analysis and Design* Polytechnic University, Brooklyn NY, October 26 – 28 (1994)

1995

1. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Yale University* New Haven CT, January 20 (1995)
2. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Stanford University*, Edward L. Ginzton Laboratory, Stanford CA, February 6 (1995)
3. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Hewlett-Packard Research Laboratories* Palo Alto CA, February 7 (1995)
4. **(Invited talk)** E. F. Schubert "Resonant cavity devices" *International Symposium on Opto-electronic, Microphotonic, and Laser Technologies* San Jose CA, February 4 – 10 (1995)
5. **(Invited colloquium)** E. F. Schubert "Resonant cavity devices" *Colorado State University* Fort Collins CO, February 10 (1995)

6. Y. C. Chang, H. Yao, E. F. Schubert, and R. F. Kopf "Raman studies of heavily doped GaAs/Al_xGa_{1-x}As multiple quantum wells" *1995 March Meeting of the American Phys. Soc.* San Jose CA, March 20 – 24 (1995)
7. M. Passlack, M. Hong, E. F. Schubert, J. Kwo, J. P. Mannaerts, and G. J. Zydzik "In-situ fabricated Ga₂O₃-GaAs structures with low interface recombination velocity" *1995 March Meeting of the American Physical Society* San Jose CA, March 20 – 24 (1995)
8. **(Invited colloquium)** E. F. Schubert "Semiconductor LEDs and lasers" *University of Nebraska* Lincoln NE, April 6 (1995)
9. **(Invited colloquium)** E. F. Schubert "Die Zukunft der Computertechnik und Kommunikationstechnik" *Informationsveranstaltung der AT&T Global Information Solutions und der BB-Data*, Kiel, Germany, June 22 (1995)
10. **(Invited colloquium)** E. F. Schubert "Directions in semiconductor laser and LED research" *Lasertron*, Burlington MA, October 5 (1995)
11. E. F. Schubert "Future Research Directions in the Semiconductor Devices Research Laboratory" Graduate Seminar of the Electrical and Computer Engineering Department, Boston University, Boston MA, November (1995)

1996

1. Y. C. Chang, H. Yao, M. Mohiuddin, E. F. Schubert, and L. Pfeiffer "Raman spectra of delta-doped GaAs and heavily doped GaAs/Al_xGa_{1-x}As multiple quantum wells" *1996 March Meeting of the American Physical Society* Saint Louis MO, March 18 – 22 (1996)
2. **(Invited colloquium)** Schubert E. F. "Resonant Cavity Devices" EECS/RLE Seminar Series on "Optics and Quantum Electronics" Massachusetts Institute of Technology, Cambridge MA, March 6 (1996)
3. **(Invited colloquium)** Schubert E. F. "Improvement of Light Emitting Diodes with Resonant Cavities" Rome Laboratories, Hanscom Air Force Base, Lexington MA, May 23 (1996)
4. **(Invited colloquium)** Schubert E. F. "Improvement of Light Emitting Diodes with Resonant Cavities" *Quantum Energy*, Cambridge MA, June, 6 (1996)
5. Grieshaber W., Schubert E. F., Goepfert I. D., Karlicek R. F. Jr., Schurman M. J., and Tran C. "Nature of ultraviolet and yellow luminescence in GaN" *Fall Meeting of the Materials Research Society*, Boston MA, November (1996)
6. W. Grieshaber, E. F. Schubert, R. F. Karlicek Jr., M. J. Schurman, and C. Tran "Yellow luminescence under spontaneous and stimulated emission conditions in GaN homostructures and heterostructures" *LEOS 1996 Annual Meeting*, Boston MA, October (1996)
7. **(Invited colloquium)** E. F. Schubert "Novel designs for high-efficiency optoelectronic semiconductor devices" Colloquium of the Boston Section of IEEE/LEOS, Lexington MA, December 19 (1996)

1997

1. Grieshaber W., Schubert E. F., Karlicek Jr. R. F., Schurman M. J., and Tran C. "Relevance of the GaN yellow luminescence for light-emitting diodes" *SPIE Photonics West Conf. on Light-emitting diodes: Research and Manufacturing*, San Jose CA February 10 – 14 (1997)
2. **(Invited colloquium)** Schubert E. F. "Optical Properties of GaN" Emcore Corp., Somerset NJ, March 11 (1997)
3. Tu L.-W., Schubert E. F., Hong M., and Zydzik G. J. "In-situ cleaving and coating of semiconductor laser facets" *March Meeting of the American Physical Society*, Kansas City MO, March 17 – 21 (1997)
4. **(Invited colloquium)** Schubert E. F. "Optical Properties of GaN" *Spire Corporation*, Bedford MA, April 8, (1997)
5. **(Invited colloquium)** Schubert E. F. "Microoptoelectromechanical research at Boston University" *Physical Sciences Inc.*, Andover MA, June. 13 (1997)
6. **(Invited colloquium)** Schubert E. F. "Optical Properties of GaN" *Cree Research Corp.*, Durham NC, June 16 (1997)
7. **(Invited colloquium)** Schubert E. F. "GaN and MEMS research at Boston University" *US Army Research Office*, Research Triangle Park NC, June 17 (1997)
8. **(Invited colloquium)** Schubert E. F. "Demonstration of optically pumped GaInN/GaN double heterostructure lasers" *Dept. of Electrical Engineering*, University of Connecticut, Storrs CT, November 14 (1997)
9. **(Invited colloquium)** Schubert E. F. "Demonstration of optically pumped GaInN/GaN double heterostructure lasers" *Dept. of Electrical Engineering*, University of Connecticut, Storrs CT, November 14 (1997)

10. Stocker D., Schubert E. F., Grieshaber W., Redwing J. M., Boutros K. S., Flynn J. S., and Vaudo R. P., "Fabrication and optical pumping of laser cavities made by cleaving and wet chemical etching" *Mater. Res. Soc. Symp.*, Boston MA, December 1 – 5 (1997)
11. Goepfert I. D. Schubert E. F. and Redwing J. M. "Luminescence properties of Si-doped GaN and evidence of compensating defects as the origin of the yellow luminescence" *Materials Research Society Symposium*, Boston MA, December 1 – 5 (1997)

1998

1. Schubert E. F., Grieshaber W., Boutros K. S., and Redwing J. M. "Yellow luminescence in MOCVD-grown n-type GaN" *SPIE Photonics West*, San Jose CA, January 28 – 29 (1998)
2. Stocker D. A., Schubert E. F., Boutros K. S., Flynn J. S., Vaudo R. P., Phanse V. M., and Redwing J. M. "Optically pumped InGaN/GaN double heterostructure lasers with cleaved facets" *SPIE Photonics West*, San Jose CA, January 28 – 29 (1998)
3. Schubert E. F. "Demonstration of the first GaInN/GaN double heterostructure laser" *Graduate Student Seminar, Dept. of Elec. and Comp. Eng.*, Boston Univ., Boston MA, April 18, (1998)
4. Stocker D. A., Schubert E. F., Boutros K. S. and Redwing J. M. "Fabrication of smooth GaN-based laser facets" *Fifth Wide Bandgap Nitride Semiconductor Workshop*, St. Louis MO, August 5 – 7 (1998)
5. Toussaint K., Goepfert I. D., and Schubert E. F. "Differential Hall-effect measurement technique on lightly doped p-type GaN" *Fifth Wide Bandgap Nitride Semiconductor Workshop*, St. Louis MO, August 5 – 7, (1998)

1999

1. **(Invited talk)** Boutros K., Smith G. M., Vaudo R. P., Redwing J. M., and Schubert E. F., "InGaN/GaN LED development on GaN-on-sapphire substrates" *SPIE Photonics West*, San Jose CA, January 26 – 28 (1999)
2. **(Invited colloquium)** Schubert E. F. "Demonstration optically pumped GaInN/GaN lasers with smooth facets" *Hewlett Packard Optoelectronics Division*, San Jose CA, January 25 (1999)
3. **(Invited colloquium)** Schubert E. F. "Demonstration optically pumped GaInN/GaN lasers with smooth facets" *Xerox Palo Alto Research Center*, Palo Alto, CA, January 29 (1999)
4. **(Invited colloquium)** Schubert E. F. "P-type doping in GaN and demonstration optically pumped GaInN/GaN lasers with smooth facets" *Army Research Laboratory*, Adelphi MD, February 24 (1999)
5. **(Invited colloquium)** Schubert E. F. "P-type doping in GaN and" *University of Maryland*, College Park MD, February 24 (1999)
6. (The following paper won the Best Student Presentation Award) Stocker D. A., Schubert E. F. and Redwing J. M. "Optically pumped InGaN/GaN lasers with photo-electrochemically and crystallographically wet-etched facets" *Connecticut Symposium on Microelectronics and Optoelectronics* held at Yale University, New Haven CT, March 16 (1999)
7. Goepfert I. D. and Schubert E. F. "Superlattice doping p-type GaN to efficiently activate the deep acceptor magnesium" *Connecticut Symposium on Microelectronics and Optoelectronics* held at Yale University, New Haven CT, March 16 (1999)
8. Schubert E. F. "GaN-based white-light-emitting diodes with high luminous performance" *Optical Physics Seminar Series*, Boston University, Boston MA, October 7 (1999)
9. Schubert E. F. "GaN-based white-light-emitting diodes with high luminous performance", *Optics and Quantum Electronics Seminar Series*, Massachusetts Institute of Technology (MIT), Cambridge MA, November 10 (1999)
10. Guo X. Y., Graff J., and Schubert E. F. "Photon-recycling semiconductor white light emitting diodes" *International Electron Devices Meeting (IEDM)*, Washington DC, December 7 (1999)
11. Goepfert I. D., Schubert E. F., Osinski A. and Norris P. E. "Superlattice doping p-type GaN to efficiently activate the deep acceptor magnesium" *Fall meeting of the Materials Research Society (MRS)* Boston MA, November 29 (1999)

2000

1. Guo X. Y., Graff J., and Schubert E. F. "Photon-recycling semiconductor white light emitting diodes" *SPIE Photonics West*, San Jose CA, January 25 – 27 (2000)
2. Schubert E. F. "Light-emitting diodes: Device physics and applications" Short course given at the *SPIE Photonics West*, San Jose CA, January 25 – 27 (2000)

3. Waldron E. L., Graff J. W., Schubert E. F., Osinsky A., Schaff W. J., and Eastman L. F. "P-doped AlGa_N / Ga_N superlattices: Physical properties and device applications" *6th Annual Wide Bandgap III-Nitride Workshop*, Richmond VA, March 12 – 15 (2000)
4. Osinsky A., Chernyak L., Zhou L., Adesida I., Graff J. W., and Schubert E. F. "Characterization of Diodes Based on AlGa_N/Ga_N Heterostructures and Superlattices for Bipolar Transistor Applications" *6th Annual Wide Bandgap III-Nitride Workshop*, Richmond VA, March 12 – 15 (2000)
5. Waldron E. L., Schubert E. F., Graff J. W., and Schaff W. J. "Polarization effects in AlGa_N/Ga_N superlattices" *Connecticut Microelectronics and Optoelectronics Symposium*, Hartford CT, March 14 (2000)
6. **(Invited talk)** Schubert E. F., Waldron E. L., Graff J. W., Osinsky A., Schaff W. J., and Eastman L. F. "Current results and future potential of doped AlGa_N/Ga_N superlattices", *ONR / TMS Workshop on Doping and Dopants in Ga_N*, Copper Mountain CO, April 2 – 6 (2000)
7. Osinsky A., Chernyak L., Fuflyigin V., Graff J. W., and Schubert E. F. "P-type superlattice doping: Material characteristics pertaining to bipolar devices" *ONR / TMS Workshop on Doping and Dopants in Ga_N*, Copper Mountain CO April 2 – 6 (2000)
8. Schubert E. F. "Light-emitting diodes: Device physics and applications" Short course given at the *University of Hagen*, Germany, July 19 (2000)
9. **(Invited colloquium)** Schubert E. F. "Photon-recycling semiconductor light-emitting diodes" the *University of Hagen*, Germany, July 11 (2000)
10. Graff J. W., Schubert E. F., and Osinsky A. "Reduction of base access resistance in npn AlGa_N/Ga_N heterobipolar transistors with p-type AlGa_N / Ga_N superlattice base layers" *Cornell Workshop on High-Speed Semiconductor Devices*, Ithaca NY, August 6 – 9 (2000)
11. **(Invited talk)** Schubert E. F. Interview on National Public Radio (NPR) in "Here and Now" with Robin Young on the "Photon-recycling semiconductor light-emitting diode". Interviewed on August 22 (2000). Interview transmitted on NPR on August 29 (2000)
12. **(Invited talk)** Schubert E. F., Graff J. W., Li Y.-L., Waldron E. L. and Osinsky A. "Polarization effects, acceptor activation, and ohmic contacts in p-type Ga_N and AlGa_N / Ga_N superlattices" *ONR Workshop on Polarization Effects in III-Nitrides*, Kalispell MO, August 27 – 31 (2000)
13. Schubert E. F. "Light-emitting diodes: Device physics and applications" Short course given at the *OSA Annual Meeting*, Providence RI, October 22 (2000)
14. **(Invited colloquium)** Schubert E. F. "Novel concepts for high-efficiency white-light LEDs" *Sandia National Laboratories*, Albuquerque NM, October 24 (2000)
15. **(Invited talk)** Schubert E. F. "Novel concepts for high-efficiency white-light LEDs" *OIDA Workshop and Roadmap Panel on "LED and VCSEL Solid State Lighting"* Albuquerque NM, October 25 – 26 (2000)
16. Schubert E. F. "Light-emitting diodes: Device physics and applications" Short course given at the *Photonics East Meeting*, Boston MA, November 8 (2000)
17. Schubert E. F. "Light-emitting diodes: Device physics and applications" Short course given at the *IEEE LEOS Central New England Chapter*, Boston MA, November 18 (2000)
18. **(Invited colloquium)** Schubert E. F. "Ga_N materials for high-efficiency light emitters" *National Central University*, Chung-Li, Taiwan, R.O.C., December 4 (2000)
19. **(Invited colloquium)** Schubert E. F. "Novel concepts for high-efficiency white-light LEDs" *National Chiao Tung University*, Hsin Chu, Taiwan, R.O.C., December 5 (2000)
20. **(Invited colloquium)** Schubert E. F. "Novel concepts for high-efficiency white-light LEDs" *National Taiwan University*, Taipei, Taiwan R.O.C., December 6 (2000)
21. **(Invited colloquium)** Schubert E. F. "Light emitting diodes" *National Sun Yat-Sen University*, Kaohsiung, Taiwan, R.O.C., December 8 (2000)
22. **(Invited colloquium)** Schubert E. F. "Novel concepts for high-efficiency white-light LEDs" *National Cheng Kung University*, Tainan, Taiwan, R.O.C., December 11 (2000)
23. **(Television Interview)** Schubert E. F. "Light emitting diodes for illumination applications" interview broadcast on the 11 PM News of WB56 Boston Television Station. Also shown on many other stations December 15 (2000)
24. Waldron E. L., Schubert E. F., Graff J. W., Osinsky A., Murphy M. J., and Schaff W. F. "Polarization effects in Al_xGa_{1-x}N / Ga_N superlattices" *Fall Meeting of the Materials Research Society (MRS)*, Boston MA, November 27 – December 1 (2000)

2001

1. Guo X. and Schubert E. F. "Current crowding in GaInN / GaN LEDs grown on insulation substrates" *SPIE Photonics West*, San Jose CA, January 24 – 25 (2001)
2. **(Invited colloquium)** Schubert E. F. "GaN materials for high-efficiency light emitters" University of Central Florida, Orlando, Florida, February 22 (2001)
3. **(Invited colloquium)** Schubert E. F. "GaN materials and device issues for high-efficiency light emitting diodes" National Research Council, Ottawa, Canada, March 5 (2001)
4. Li Y.-L., Schubert E. F., Graff J. W., Guo X. Y., and Waldron E. "Low-resistance ohmic contacts to p-type GaN" Connecticut Microelectronics and Optoelectronics Symposium, Storrs CT, April 3 (2001)
5. Guo X. and Schubert E. F. "Current crowding and efficiency improvement in GaInN / GaN LEDs" Connecticut Microelectronics and Optoelectronics Symposium, Storrs CT, April 3 (2001)
6. **(Invited colloquium)** Schubert E. F. "GaN materials and device issues for high-efficiency light emitting diodes" Yale University, New Haven, CT, May 2 (2001)
7. Waldron E. L., Graff J. W., and Schubert E. F. "Improved mobilities and resistivities in modulation doped p-type AlGaIn/GaN superlattices" Fourth International Conference on Nitride Semiconductors, Denver CO, July 16 – 20 (2001)
8. Li Y.-L., Graff J. W., Waldron E. L., Guo X., Shah J., and Schubert E. F. "Novel polarization enhanced ohmic contacts to GaN" Fourth International Conference on Nitride Semiconductors, Denver CO, July 16 – 20 (2001)
9. Schubert E. F. "Low-resistance ohmic contacts to p-type GaN using thin InGaIn cap layers" ONR workshop on "Sub-surface and near-surface effects in GaN and GaN substrate materials" Kodiak, Alaska, August 6 – 10 (2000)
10. **(Invited talk)** Schubert E. F. "Future light emitting diodes" Symposium on "Future Chips" held at Rensselaer Polytechnic Institute, Troy NY, November 2 (2001)
11. **(Invited talk)** Schubert E. F. "White LEDs based on semiconductors" *Fall meeting of the Materials Research Society (MRS)* Boston MA, November 26 – 30 (2001)
12. Gessmann Th., Li Y.-L., Graff J. W., and Schubert E. F. "Low-resistance ohmic contacts to p-type GaN by using InGaIn cap layers" *Fall meeting of the Materials Research Society (MRS)* Boston MA, November 26 – 30 (2001)
13. (The following paper won a Best Student Presentation Silver Award) Waldron E. L., Graff J. W., and Schubert E. F. "Improved mobilities in modulation doped p-type AlGaIn / GaN superlattices" *Fall meeting of the Materials Research Society (MRS)* Boston MA, November 26 – 30 (2001)

2002

1. Gessmann Th., Li Y.-L., Waldron E. L., Graff J. W., and Schubert E. F. "Novel type of ohmic contacts to p-type GaN utilizing polarization fields in thin InGaIn capping layers" *Connecticut Symposium on Microelectronics and Optoelectronics*, New Haven, CT, March 13 (Mar 2002)
2. Schubert E. F., Graff J. W., Waldron E. L., Li Y.-L., Gessmann Th., and Sheu J. K. "Recent progresses on superlattice doping of ternary III-nitrides" *Seventh Wide Bandgap III-Nitride Workshop*, Richmond, VA, March 10 – 14 (Mar 2002)
3. Schubert E. F. "The bright future of light-emitting diodes" Brown Bag Lunch Seminar Series at Boston University, Boston, MA, May 22 (May 2002)
4. **(Invited short course)** Schubert E. F. "Light-emitting diodes" *SPIE Photonics Boston*, Boston MA, July 29 – August 2 (Aug 2002)
5. Gessmann Th., Graff J. W., Li Y.-L., Waldron E. L., and Schubert E. F. "Novel ohmic contact technology in III-nitrides using polarization effects in cap layers" *Lester Eastman conference on high-speed devices*, University of Delaware, Newark, DE, August 6 – 8 (Aug 2002)
6. **(Invited talk)** Schubert E. F. "White LEDs based on semiconductors" *Department of Physics, Applied Physics, and Astronomy*, Rensselaer Polytechnic Institute, Troy NY, October 9 (Oct 2002)
7. **(Invited talk)** Schubert E. F. "White LEDs based on an all-semiconductor approach" *Intertech conference entitled Light-emitting diodes 2002*, San Diego CA, October 21 – 23 (Oct 2002)
8. (Short-course) Schubert E. F. "Fundamentals of white LEDs" *Intertech conference entitled Light-emitting diodes 2002*, San Diego CA, October 21 – 23 (Oct 2002)

2003

1. (Short course) Schubert E. F. "Light-emitting diodes" *SPIE Photonics West*, San Jose CA, January 27 (January 2003)
2. Gessmann Th., Li Y.-L., Schubert E. F., Graff J. W., and Sheu J. K. "GaInN light-emitting diodes with omni-directional reflectors" *SPIE Photonics West: Integrated Optoelectronic Devices*, San Jose CA, January 25 – 31 (January 2003)
3. Gessmann Th., Schubert E. F., Graff J. W., and Streubel K. "AlGaInP light-emitting diodes with omni-directionally reflecting submount" *SPIE Photonics West: Integrated Optoelectronic Devices*, San Jose CA, January 25 – 31 (January 2003)
4. Schubert E. F. "Ultraviolet-spectrum light-emitting diodes with omni-directional reflectors for high extraction efficiency" *DARPA SUVOS Program Review*, Dana Point CA, February 4 – 6 (February 2003)
5. Li Y.-L., Gessmann Th., Shah J. M., and Schubert E. F. "GaInN-based light-emitting diodes with two active regions for white light emission" *Fifth International Conference on Nitride Semiconductor Research*, Nara, Japan, May 25 – 30 (May 2003)
6. (Short course) Schubert E. F. "Light-emitting diodes" *Conference on Lasers and Electrooptics (CLEO)*, Baltimore MD, June 2 – 6 (June 2003)
7. Schubert E. F., Gessmann Th., Graff J. W., Li Y.-L., Sheu J. K., and Streubel K. "Light-emitting diodes with omni-directional reflectors" *Conference on Lasers and Electrooptics (CLEO)*, Baltimore MD, June 2 – 6 (June 2003)
8. (Short course) Schubert E. F. "Nanostructures in Optoelectronics" NSF Chautauqua Short Course at RPI, Troy NY, June 23 (June 2003)
9. Schubert E. F. "Research in the Future Chips Constellation on GaN materials and devices" *IBM-RPI Broadband Center Meeting*, Yorktown Heights NY, July 8 (July 2003)
10. Li Y.-L., Shah J. M., Gessmann Th., and Schubert E. F. "Performance characteristics of white light sources consisting of multiple light-emitting diodes" *SPIE Annual Meeting*, San Diego CA, August 4 – 8 (August 2003)
11. Shah J. M., Li Y.-L., Gessmann Th., and Schubert E. F. "Experimental analysis and theoretical model for anomalously high ideality factors in AlGaIn/GaN p-n junction diodes" *8th Wide Band Gap III-V Nitride Workshop*, Richmond VA, Sept. 29 – October 1 (October 2003)
12. **(Invited Colloquium)** Schubert E. F. "Semiconductor light emitting diodes for illumination and information technology applications" University at Albany SUNY, School of Nano-sciences, Albany NY, October 16 (October 2003)
13. **(Invited Colloquium)** Schubert E. F. "Semiconductor light emitting diodes for illumination and information technology applications" University at Buffalo SUNY, Department of Electrical Engineering, Buffalo NY October 22 (October 2003)
14. Schubert E. F. "Light-emitting diodes and color perception" undergraduate lecture series entitled *A Passion for Physics*, Rensselaer Polytechnic Institute November 6 (November 2003)
15. Schubert E. F. "Perpendicular transport in AlGaIn superlattices and UV-LED diode ideality factors" *DARPA SUVOS Program Review*, Austin TX, November 18 – 20 (November 2003)
16. Shah J. M., Li Y.-L., Gessmann Th., and Schubert E. F. "Experimental analysis and a new theoretical model for anomalously high ideality factors ($n \gg 2.0$) in GaN-based p-n junction diodes" *2003 MRS Fall Meeting*, Boston MA, December 1 – 5, (December 2003)
17. Kim J. K., Gessmann Th., Li Y.-L., and Schubert E. F. "GaInN Light-emitting diodes with omni-directional reflectors using rare-earth metal oxides", *2003 MRS Fall Meeting*, Boston MA, December 1 – 5 (December 2003)
18. Li Y.-L., Shah J. M., Gessmann Th., Schubert E. F., and Sheu J. K. "Carrier dynamics of monolithic InGaIn/GaN light-emitting pn-junction structures with two active regions" *2003 MRS Fall Meeting*, Boston MA, December 1 – 5 (December 2003)
19. Shah J. M., Li Y.-L., Gessmann Th., and Schubert E. F. "Experimental analysis and a new model for the high ideality factors in GaN-based diodes" *2003 International Semiconductor Device Research Symposium (ISDRS)*, Washington D.C., December 10 – 12 (December 2003)

2004

1. Gessmann T., Luo H., Xi J.-Q., Streubel K. P., and Schubert E. F. "Light-emitting diodes with integrated

- omnidirectionally reflective contacts" *Photonics West*, San Jose, CA, January 27 – 28 (2004)
2. Shah J., Li Y., Gessmann T., and Schubert E. F. "Experimental analysis and new theoretical model for anomalously high ideality factors ($n \gg 2$) in GaN-based p-n junction diodes" *SPIE Photonics West – Light Emitting Diodes: Research, Manufacturing, and Applications*, San Jose CA, January 27 – 28 (2004)
 3. (Short course) Schubert E. F. "Light-emitting diodes" *SPIE Photonics West*, San Jose CA, January 29 (January 2004)
 4. **(Invited)** Schubert E. F. "Semiconductor light emitting diodes for illumination and information technology applications" *Samsung Research Center (SAIT)*, Seoul, Korea, March 15 (March 2004)
 5. **(Invited)** Schubert E. F. "Smart lighting" *International Symposium on the Physics of Semiconductors and Applications (ISPSA)*, Gyeongju, Korea, March 16 (March 2004)
 6. **(Invited)** Schubert E. F. "Semiconductor light emitting diodes for illumination and information technology applications" *Pohang University for Science and Technology (POSTECH)*, Pohang, Korea, March 17 (March 2004)
 7. Kim J. K., Waldron E. L., Lee Y.-L., Gessmann T., Jang H. W., Lee J.-L., and Schubert E. F. "P-type conductivity in bulk $\text{Al}_x\text{Ga}_{1-x}\text{N}$ and $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{Al}_y\text{Ga}_{1-y}\text{N}$ superlattices with average Al mole fraction $\geq 20\%$ for LED confinement layers" *The 5th International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED-2004)* p. 275, Gyeongju, Korea, March 15 – 19 (2004)
 8. Kim J. K., Gessmann T., Luo H., and Schubert E. F. "GaInN light emitting diodes with omni-directional reflectors" *Connecticut Microelectronics and Optoelectronics Symposium*, Univ. of Connecticut, Storrs CT, April 7 (2004)
 9. Li Y.-L., J. Shah M., Jackson R., Xi Y., Chhajed S., Kim J. K., Gessmann Th., and Schubert E. F. "Illumination sources based on multiple light-emitting diodes" *Conference on Lasers and Electro-Optics (CLEO)*, San Francisco CA, May 16 – 20 (2004)
 10. (Short course) Schubert E. F. "Light Emitting Diodes and Solid-State Lighting" *Conference on Lasers and Electrooptics (CLEO)*, San Francisco CA, May 16 – 20 (2004)
 11. (Short course) Schubert E. F. "Nanostructures in Optoelectronics" NSF Chautauqua Short Course at RPI, Troy NY, June 28 – 29 (2004)
 12. Schubert E. F. "Smart Lighting" *University of Rochester*, Rochester NY, July 12 (2004)
 13. Furis M., Cartwright A. N., Waldron E. L., and Schubert E. F. "Spectral and temporal resolution of recombination dynamics from multiple states in modulation-doped AlGaIn/GaN multiple quantum well heterostructures" *International Workshop on Nitride Semiconductors (IWNS)*, Pittsburgh PA, July 19 – 23 (2004)
 14. Kim J. K., Gessmann T., Luo H., and Schubert E. F. "GaInN light-emitting diodes with omni-directional reflectors" *2004 IEEE Lester Eastman Conference on High Performance Devices*, Rensselaer Polytechnic Institute, USA, August 4 – 6 (2004)
 15. Xi Y. and Schubert E. F. "Junction-temperature measurements in GaN UV light-emitting diodes using the diode forward voltage" *IEEE Lester Eastman Conference on High Performance Devices*, Troy NY, August 4 – 6 (2004)
 16. Xi J.-Q., Ojha M., Cho W., Gessmann T., Schubert E. F., Plawsky J. L., and Gill W. N. "Omni-directional reflector using a low-refractive-index material" *IEEE Lester Eastman Conference on High-Performance Devices*, Rensselaer Polytechnic Institute, Troy NY August 4 – 6 (2004)
 17. Luo H., Gessmann Th., and Schubert E. F. "Ray tracing simulation of extraction efficiency of truncated-inverted pyramid AlGaInP light emitting diodes with omni-directional reflector" *IEEE Lester Eastman Conference on High-Performance Devices*, Rensselaer Polytechnic Institute, Troy NY August 4 – 6 (2004)
 18. Chhajed S., Xi Y., Li Y.-L., Gessmann T., and Schubert E. F. "Influence of junction temperature on luminous efficacy and color rendering properties of a trichromatic LED-based white light source" *IEEE Lester Eastman Conference on High Performance Devices*, Troy NY, August 4 – 6 (2004)
 19. (Short course) Schubert E. F. "Light Emitting Diodes and Solid-State Lighting" *SPIE Photonics North*, Ottawa, Canada, September 27 – 29 (2004)
 20. **(Invited)** Schubert E. F. "Novel Concepts for the Advancement of Solid-State Light Emitters" Seminar at Department of Physics, Applied Physics, and Astronomy, RPI, October 4 (2004)
 21. **(Invited)** Schubert E. F., Kim J. K., Gessmann T., Chhajed S., Li Y.-L., Luo H., Mont F. W., Shah C., Shah J., Xi J.Q., Xi Y., Lin S. Wetzels C. Plawsky J., Gill W., and Siegel R. "Research in the Future Chips Constellation" *General Electric Corporation*, Schenectady NY, October 26 (2004)

22. **(Invited)** Schubert E. F. "Light-emitting diodes and solid-state lighting" featured as module in the web-based IEEE Xplore-Enabled Learning Library (IEEE XELL). The module was delivered to IEEE in October (2004)
23. **(Invited)** Schubert E. F. "Efficiency limitations of solid-state sources used in general illumination applications" *28th Annual EDS/CAS Activities in Western New York Conference*, Rochester, NY, November 3 (2004)
24. **(Invited)** Schubert E. F. "Nano-Materials in Optoelectronics" Nanotechnology – Innovation, Opportunity, and Commercialization RPI, Troy NY, Nov 15 – 16 (2004)
25. **(Invited)** Schubert E. F. "Efficiency limitations in inorganic solid-state sources for lighting applications" *Annual Meeting of the American Vacuum Society*, Anaheim CA, November 15 – 19 (2004)
26. **(Invited)** Schubert E. F. "Novel omnidirectional reflectors with unprecedented performance characteristics" *2004 OIDA Annual Forum*, Washington, D.C. November 18 – 19 (2004)
27. Xi Y., Xi J.-Q., Gessmann Th., Shah J. M., Kim J. K., Schubert E. F., Fischer A. J., Crawford M. H., Bogart K. H. A., and Allerman A. A. "Junction temperature measurements in deep-UV light-emitting diodes" *MRS Fall meeting*, Boston MA, November 29 – December 3 (2004)
28. Kim J. K., Luo H., Xi Y., Shah J. M., Gessmann Th., and Schubert E. F. "Enhancement of light extraction efficiency of GaInN LEDs by omni-directional diffuse reflectors" *MRS Fall Meeting*, Boston MA, November 29 – December 3 (2004)
29. Xia Y., Williams E., Park Y., Yilmaz I., Shah J., Schubert E. F., and Wetzel C. "Discrete steps in the capacitance-voltage characteristics of GaInN/GaN light emitting diode structures" *MRS Fall Meeting*, Boston MA, November 29 – December 3 (2004)
30. **(Invited)** Schubert E. F. "High-reflectivity omni-directional reflectors for light-emitting diodes" *International Electron Devices and Materials Symposium (IEDMS)*, National Chiao Tung Univ., Hsin Chu, Taiwan, December 20 – 23 (2004)

2005

1. Yangang Xi, Sameer Chhajed, J.-Q. Xi, Thomas Gessmann, Jay M. Shah, Jong Kyu Kim and E. F. Schubert "Junction and carrier temperature measurements in light-emitting diodes using three different methods" *SPIE Photonic West*, San Jose CA, January 22 – 27 (Jan 2005)
2. J.-Q. Xi, M. Ojha, W. Chow, C. Wetzel, Th. Gessmann, E. F. Schubert, J. L. Plawsky, and W. N. Gill "Omni-directional reflector using a low-refractive-index material" *SPIE Photonics West – Light-Emitting Diodes: Research, Manufacturing, and Applications*, San Jose CA, January 22 – 27 (Jan 2005)
3. **(Invited short course)** E. F. Schubert "Light-emitting diodes and solid-state lighting" *SPIE Photonics West – Light-Emitting Diodes: Research, Manufacturing, and Applications*, San Jose CA, January 22 – 27 (Jan 2005)
4. **(Invited keynote address)** E. F. Schubert, Jong Kyu Kim, Hong Luo, Yangang Xi, Jay M. Shah, and Thomas Gessmann "Enhancement of light extraction in GaInN light-emitting diodes by diffuse omni-directional reflectors" *Second Asia-Pacific Workshop on Widegap Semiconductors (APWS-2005)* Hsinchu, Lakeshore Hotel, Hsinchu, Taiwan, March 7 – 9 (March 2005)
5. **(Invited colloquium)** E. F. Schubert "Innovations in Light-Emitting Diodes" University of Florida, Department of Electrical and Computer Engineering, Gainesville FL, March 15 (March 2005)
6. **(Best Oral Presentation Award. Speaker Hong Luo)** Hong Luo, Jong Kyu Kim, Yangang Xi, Jay M. Shah, Thomas Gessmann and E. Fred Schubert "Improvement of extraction efficiency of GaInN light-emitting diodes by employment diffuse omni-directional reflectors" *Connecticut Microelectronics & Optoelectronics Consortium (CMOC)*, 14th annual symposium, New Haven CT, March 17 (March 2005)
7. Yangang Xi, J.-Q. Xi, Thomas Gessmann, Jay M. Shah., Jong Kyu Kim, E. F. Schubert, A. J. Fischer, M. H. Crawford, K. H. A. Bogart and A. A. Allerman "Junction temperature and thermal resistance measurement in deep-UV light-emitting diodes" *Connecticut Microelectronics & Optoelectronics Consortium*, 14th annual symposium, New Haven CT, March 17 (March 2005)
8. J.-Q. Xi, M. Ojha, W. Cho, Th. Gessmann, E. F. Schubert, J. L. Plawsky, and W. N. Gill "Omni-directional reflector using a low refractive index material" *Connecticut Microelectronics & Optoelectronics Consortium*, 14th annual symposium, New Haven CT, March 17 (March 2005)
9. J.-Q. Xi, M. Ojha, W. Chow, C. Wetzel, T. Gessmann, E. F. Schubert, J. L. Plawsky, and W. N. Gill "Omni-Directional Reflector Using a Low Refractive Index Material" *Conference on Lasers and Electrooptics (CLEO)*, Baltimore MD, May 22 – 27 (May 2005)
10. **(Invited short course)** E. F. Schubert "Light-emitting diodes and solid-state lighting" *Conference on Lasers and*

Electrooptics (CLEO), Baltimore MD, May 22 – 27 (May 2005)

11. **(Invited)** E. F. Schubert “Solid-state light sources getting smart” Radio interview with BBC Worldwide Service, May 26 (May 2005)
12. **(Invited)** E. F. Schubert “Solid-state light sources getting smart” Radio interview with German SWR Service, May 26 (May 2005)
13. **(Invited short course)** E. F. Schubert “Light-emitting diodes and solid-state lighting” *Chautauqua Short Course* at RPI, Troy NY, June 13 (June 2005)
14. **(Invited)** E. F. Schubert and Jong Kyu Kim “Solid-state light sources getting smart” Television interview with Jim Kambrich, Albany NBC Affiliate, Channel 13, June 15 (June 2005)
15. **(Invited)** E. F. Schubert and Jong Kyu Kim “Innovations in light-emitting devices” Samsung Advanced Institute of Technology, Suwan City, Korea, June 27 (June 2005)
16. **(Invited)** E. F. Schubert “Short course on light-emitting diodes” Samsung Mechatronics Corporation, Suwan City, Korea, June 28 (June 2005)
17. **(Invited)** E. F. Schubert and Jong Kyu Kim “Innovations in light-emitting devices” Seoul National University, Seoul Korea, June 29 (June 2005)
18. E. F. Schubert “AlGa_N UV light-emitting diodes grown by MOVPE” Crystal IS Corporation, Green Island NY, July 22 (July 2005)
19. Jong Kyu Kim, J.-Q. Xi, Hong Luo, and E. Fred Schubert “Enhancement of light extraction in GaN ultraviolet light-emitting diodes by omni-directional reflectors with nanoporous low-index layer” *SPIE Annual Meeting, Illumination Engineering, Fifth International Conference on Solid State Lighting*, San Diego, CA, August 1 – 4, (August 2005)
20. **(Invited)** E. F. Schubert “Innovations in light-emitting devices” University of Delaware, Department of Electrical and Computer Engineering, September 7 (September 2005)
21. Thomas Gessmann, Yangang Xi, Hong Luo, Jong Kyu Kim, J.-Q. Xi, Kaixuan Chen, Jay M. Shah and E. Fred Schubert “Polarization-enhanced ohmic contacts to GaInN-based blue light-emitting diodes” *AVS 52nd International Symposium & Exhibition*, October 30 – November 4, Boston MA (October 2005)
22. Hong Luo, Jong Kyu Kim, Yangang Xi, E. Fred Schubert, Jaehee Cho, Cheolsoo Sone, and Yongjo Park “Trapped whispering-gallery optical modes in white light-emitting diodes lamps with remote phosphor” *AVS 52nd International Symposium & Exhibition*, October 30 – November 4, Boston MA (October 2005)
23. Yangang Xi, Xiaolu Li, Jong Kyu Kim, Frank W. Mont, Thomas Gessmann, Hong Luo, Alyssa Pasquale, and E. Fred Schubert “Quantitative assessment of diffusivity and specularity of textured surfaces for light extraction in light-emitting diodes”, *AVS 52nd International Symposium & Exhibition*, October 30 – November 1, Boston MA (October 2005)
24. Hong Luo, Jong Kyu Kim, Yangang Xi, E. F. Schubert, Jaehee Cho, Cheolsoo Sone, and Yongjo Park “Analysis of high-power packages for white-light-emitting diode lamps with remote phosphor” *MRS Fall Meeting*, November 28 – December 2, Boston MA (November 2005)
25. Jong Kyu Kim, J.-Q. Xi, Hong Luo, Jay M. Shah, Thomas Gessmann, Jaehee Cho, Cheolsoo Sone, Yongjo Park, and E. Fred Schubert “Enhancement of light extraction in GaInN light-emitting diodes by omni-directional reflectors with ITO nanorod low-index layer” *2005 Materials Research Society (MRS) Fall Meeting* November 28 – December 2, Boston MA (November 2005)
26. Jay M. Shah, Jong Kyu Kim, Hong Luo, Yangang Xi, Thomas Gessmann, and E. Fred Schubert “Reduction of base access resistance in AlGa_N/Ga_N heterojunction bipolar transistors using GaInN base cap layer and selective epitaxial growth” *2005 Materials Research Society (MRS) Fall Meeting* November 28 – December 2, Boston MA (November 2005)
27. J.-Q. Xi, Jong Kyu Kim, Dexian Ye, Jasbir S. Juneja, T.-M. Lu, Shawn-Yu Lin and E. F. Schubert “Optical thin films with very low refractive index and their application in photonics” *2005 Materials Research Society (MRS) Fall Meeting* November 28 – December 2, Boston MA (November 2005)
28. Hong Luo, Jong Kyu Kim, Yangang Xi, Jaehee Cho, Cheolsoo Sone, Yongjo Park, and E. Fred Schubert, “High power packages for phosphor-based white-light-emitting diode lamps” *International Semiconductor Device Research Symposium (ISDRS)*, December 7 – 9, Bethesda MD (December 2005)
29. **(Best Poster Award)** J.-Q. Xi, Jong Kyu Kim, Dexian Ye, Jasbir S. Juneja, T.-M. Lu, Shawn-Yu Lin, and E. Fred Schubert “Optical Thin Films with Very Low Refractive Index and Their Application in Photonic Devices”, *International Semiconductor Device Research Symposium (ISDRS)*, December 7 – 9, Bethesda, MD (December 2005)

2005)

30. **(Key Note Address)** E. F. Schubert and Jong Kyu Kim “Innovations in Light-Emitting Devices” Thirteenth International Workshop on The Physics of Semiconductor Devices, New Delhi, India, December 13–17 (December 2005)

2006

1. **(Invited short course)** E. F. Schubert “Light-emitting diodes and solid-state lighting” Centro de Investigacion Y De Estudios Avanzados del I.P.N. (Center for Research and Advanced Studies) Mexico City, Mexico, January 12–13 (January 2006)
2. **(Invited colloquium, IEEE Distinguished Lecture Program)** E. F. Schubert and Jong Kyu Kim “Innovations in light-emitting diodes” Centro de Investigacion Y De Estudios Avanzados del I.P.N. (Center for Research and Advanced Studies) Mexico City, Mexico, January 12–13 (January 2006)
3. **(Invited colloquium)** E. F. Schubert and Jong Kyu Kim “Innovations in light-emitting diodes” Optical Science Center, University of Arizona, Tucson, January 19 (January 2006)
4. **(Invited colloquium)** E. F. Schubert “Innovations in light-emitting diodes” Nanotechnology Seminar, Wayne State University, Detroit MI, February 7 (February 2006)
5. **(Invited colloquium)** E. F. Schubert “Material challenges for solid-state lighting” Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy NY, February 23 (February 2006)
6. **(Invited)** E. F. Schubert “Material challenges for solid-state lighting” March Meeting of the American Physical Society (APS), Baltimore MD, March 13 (March 2006)
7. **(Invited press conference presentation)** E. F. Schubert “Material challenges for solid-state lighting” March Meeting of the American Physical Society (APS), Baltimore MD, March 13 (March 2006)
8. **(Invited colloquium)** E. F. Schubert “Innovations in light-emitting diodes for solid-state lighting applications” New Jersey Institute of Technology together with the IEEE NJ Section Electron Devices, Circuits and Systems; New Jersey Institute of Technology (NJIT), Newark NJ, March 22 (March 2006)
9. **(Invited plenary short course)** E. F. Schubert “Light-emitting diodes for solid-state lighting” *Spring Meeting of Materials Research Society*, MRS, San Francisco CA, April 17 – 21 (April 2006)
10. Y. A. Xi, Th. Gessmann, K. X. Chen, X. Li, J. K. Kim, E. F. Schubert, W. Liu, J. A. Smart, and L. J. Schowalter “AlGaIn UV LEDs emitting at 340 nm grown on AlN bulk substrates” *Spring Meeting of Materials Research Society*, MRS, San Francisco CA, April 17 – 21 (April 2006)
11. **(Invited colloquium)** E. F. Schubert “Innovations in light-emitting diodes for solid-state and smart lighting applications” *The Ohio State University, IEEE Distinguished Lecture Series*, Columbus OH, April 27 (April 2006)
12. **(Plenary presentation)** E. F. Schubert “Solid-state lighting – Opportunities for fundamental innovation” U.S. Department of Energy (DOE), *Solid State Lighting Workshop*, Bethesda MD, May 21 – 24 (May 2006)
13. **(Invited tutorial)** E. F. Schubert “Solid-state lighting – Opportunities for fundamental innovation” *Conference on Lasers and Electrooptics (CLEO)*, Long Beach CA, May 22 – 26 (May 2006)
14. **(Invited short course)** E. F. Schubert “Light-emitting diodes and solid-state lighting” *Conference on Lasers and Electrooptics (CLEO)*, Long Beach CA, May 22 – 26 (May 2006)
15. Jong Kyu Kim, J.-Q. Xi, Hong Luo, E. Fred Schubert, Jaehee Cho, Cheolsoo Sone, and Yongjo Park “Enhancement of light-extraction in GaN light-emitting diodes by conductive omni-directional reflectors” *Conference on Lasers and Electrooptics (CLEO)*, Long Beach CA, May 22 – 26 (May 2006)
16. **(Invited short course)** E. F. Schubert “Solid-state lighting” Summer Short Course under “2006 Summer @ Rensselaer” program organized by the *RPI Outreach Programs Office*, Troy NY, June 7 – 8 (June 2006)
17. **(Invited short course)** E. F. Schubert “Light-emitting diodes and solid-state lighting” Short Course under “Chautauqua Program of the National Science Foundation and the RPI Center for Directed Assembly of Nanostructures” Troy NY, June 12 (June 2006)
18. Y. A. Xi, Th. Gessmann, K. X. Chen, X. Li, J. K. Kim, E. F. Schubert, W. Liu, J. A. Smart, L. J. Schowalter “AlGaIn UV light-emitting diodes emitting at 340 nm grown on AlN bulk substrates” *IEEE Lester Eastman Conference on High Performance Devices*, Ithaca NY, August 2 – 4 (August 2006)
19. K. X. Chen, Y. A. Xi, F. Mont, J. K. Kim, E. F. Schubert, C. Wetzel, W. Liu, X. Li, J. A. Smart, and L. J. Schowalter “Very high quality AlN grown on (0001) sapphire by using metal-organic vapor-phase epitaxy” *IEEE Lester Eastman Conference on High Performance Devices*, Ithaca NY, August 2 – 4 (August 2006)
20. Hong Luo, Jong Kyu Kim, E. Fred Schubert, Jaehee Cho, Cheolsoo Sone, and Yongjo Park “Highly efficient

- package configurations for white-light-emitting diode lamps" *IEEE Lester Eastman Conference on High Performance Devices*, Ithaca NY, August 2 – 4 (August 2006)
21. **(Plenary presentation)** E. Fred Schubert and Jong Kyu Kim "Solid-state lighting – Opportunities for fundamental innovation" *International Symposium on Compound Semiconductors (ISCS)*, Vancouver, Canada, August 14 – 17 (August 2006)
 22. **(Plenary presentation)** E. Fred Schubert and Jong Kyu Kim "Solid-state lighting – Opportunities for fundamental innovation" *Asia-Pacific Optical Communications Conference (APOC)*, Gwangju, Korea, September 3 – 7 (September 2006)
 23. **(Invited)** E. F. Schubert and Jong Kyu Kim "Smart lighting" Seminar at *Samsung Advanced Institute of Technology (SAIT)*, Suwon, Korea, September 18 (September 2006)
 24. **(Plenary presentation)** E. Fred Schubert and Jong Kyu Kim "Solid-state lighting – Opportunities for fundamental innovation" *13th International Workshop on Inorganic and Organic Electroluminescence and 2006 International Conference on the Science and Technology of Emissive Displays and Lighting (EL2006)*, Jeju Island, Korea, September 18 – 22 (September 2006)
 25. Jong Kyu Kim, J.-Q. Xi, Hong Luo, E. F. Schubert, Jaehye Cho, Cheolsoo Sone, and Yongjo Park "Improvements in light-extraction efficiency of light-emitting diodes with omnidirectional reflectors" *13th International Workshop on Inorganic and Organic Electroluminescence and 2006 International Conference on the Science and Technology of Emissive Displays and Lighting (EL2006)*, Jeju Island, Korea, September 18 – 22 (September 2006)
 26. Y. Li, W. Zhao, Y. Xia, M. Zhu, J. Senawiratne, T. Detchprohm, E. F. Schubert, and C. Wetzel "Temperature dependence of the quantum efficiency in green light-emitting diode dies" *International Workshop on Nitride Semiconductors (IWN 2006)* Kyoto, Japan, October 22 – 27 (October 2006)
 27. **(Invited colloquium)** E. F. Schubert "Solid-State Lighting – Opportunities for Fundamental Innovation" *OSA Colloquium Rochester*, University of Rochester, Institute of Optics, October 24 (October 2006)
 28. **(Invited colloquium)** E. F. Schubert, S. Y. Lin, and C. Wetzel "Solid-state lighting research at RPI" *Sandia National Laboratories*, Albuquerque NM, November 3, (November 2006)
 29. **(Invited short course)** E. F. Schubert "Light-emitting diodes and LED-based Imaging Systems" *Thirteenth Color Imaging Conference*, Scottsdale AZ, November 7 – 11 (November 2006)
 30. J. Das, J. K. Kim, Y. A. Xi, E. F. Schubert, and P. M. Mensz "Recombination dynamics at dislocations in GaInN-based light-emitting diodes" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 31. Y. A. Xi, K. X. Chen, F. Mont, J. K. Kim, C. Wetzel, E. F. Schubert, W. Liu, X. Li, J. A. Smart "Extremely high quality AlN grown on (0001) sapphire by using metal-organic vapor-phase epitaxy" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 32. Y. A. Xi, K. X. Chen, F. Mont, J. K. Kim, E. F. Schubert, W. Liu, J. A. Smart, X. Li, L. J. Schowalter "AlGaIn UV light-emitting diodes (< 345 nm) grown on AlN bulk substrates" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 33. Roya Mirhosseini, Jong Kyu Kim, Hong Luo, J. Cho, C. Sone, Y. Park, and E. F. Schubert "Omni-directional reflectors for GaInN vertical-structure light-emitting diodes" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 34. Frank Mont, Hong Luo, Jong Kyu Kim, E. F. Schubert, and R. W. Siegel "Enhancement of light-extraction efficiency in light-emitting diodes by optimized scattering properties of nanoparticle-loaded encapsulants" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 35. J.-Q. Xi, Jong Kyu Kim, and E. F. Schubert "Low-refractive-index materials: A new class of material for optoelectronic and photonic applications" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 36. J.-Q. Xi, Hong Luo, Jong Kyu Kim, and E. F. Schubert "High light-extraction efficiency in GaInN light-emitting diode with pyramid reflector" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)
 37. Kaixuan Chen, Yangang A. Xi, Frank Mont, Jong Kyu Kim, E. F. Schubert, Xiaolu Li, Wayne Liu, Joseph A. Smart "Effect of Si modulation doping in multiple quantum well active region on characteristics of AlGaIn ultraviolet light-emitting diodes" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)

38. Hong Luo, Jong Kyu Kim, E. Fred Schubert, Jaehee Cho, Cheolsoo Sone, and Yongjo Park "Whispering-gallery modes in GaN-based white-light-emitting diode lamps with remote phosphor" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (December 2006)

2007

1. Frank W. Mont, Jong Kyu Kim, Martin F. Schubert, Hong Luo, E. Fred Schubert, and Richard W. Siegel "High refractive index nanoparticle-loaded encapsulants for light-emitting diodes" *SPIE Photonic West*, San Jose CA, January 22 – 26 (January 2007)
2. J.-Q. Xi, Hong Luo, Jong Kyu Kim, and E. F. Schubert "High light-extraction efficiency in GaInN light-emitting diode with pyramid reflector" *SPIE Photonic West*, San Jose CA, January 22 – 26 (January 2007)
3. Frank W. Mont, Jong Kyu Kim, Martin F. Schubert, Hong Luo, E. Fred Schubert, and Richard W. Siegel "High refractive index nanoparticle-loaded encapsulants for light-emitting diodes" *Connecticut Microelectronics & Optoelectronics Consortium*, 16th annual symposium, New Haven CT, March 21 (March 2007)
4. **(Invited short course)** E. Fred Schubert "Light-emitting diodes and solid-state lighting" *SPIE Photonic West*, San Jose CA, January 22 – 26 (January 2007)
5. **(Invited colloquium)** E. Fred Schubert "Solid-state lighting – Opportunities for fundamental innovation" Department of Physics Colloquium, Queen's University, Kingston, Ontario, Canada, March 28 (March 2007)
6. Arthur J. Fischer, Frank Mont, Jong Kyu Kim, E. Fred Schubert, Daniel Koleske, and Mary Crawford "Enhanced light extraction from InGaN quantum wells using refractive-index-matched TiO₂" *Conference on Lasers and Electro-optics (CLEO)*, Baltimore MD, May 6 – 11 (May 2007)
7. Jong Kyu Kim, Martin F. Schubert, J. Q. Xi, Frank W. Mont, and E. Fred Schubert "Enhancement of light extraction in GaInN light-emitting diodes with graded-index indium tin oxide layer" *Conference on Lasers and Electro-optics (CLEO)*, Baltimore MD, May 6 – 11 (May 2007)
8. **(Invited colloquium)** E. Fred Schubert "Solid-state lighting – Opportunities for fundamental innovation" General Electric (GE) Global Research Laboratories with live simulcast to GE Research Laboratories in Munich, Germany and Bangalore, India; Niskayuna NY, May 25 (May 2007)
9. E. Fred Schubert "Nanotechnology – Opportunities for Innovations in Solid-State Lighting" *National Institute for Nano-Engineering (NINE) Workshop*, Sandia National Laboratories, Albuquerque NM, June 11 – 13 (June 2007)
10. E. Fred Schubert "Solid-state lighting – Opportunities for fundamental innovation" *RPI NSEC Center Seminar for Graduate Students*, RPI, Troy NY, June 26 (June 2007)
11. E. Fred Schubert "Solid-state lighting – Opportunities for fundamental innovation" *RPI NSEC Nanoscale Science and Engineering: A Short Course for High School Teachers*, RPI, Troy NY, July 12 (July 2007)
12. **(Invited keynote address)** E. Fred Schubert and Jong Kyu Kim "Light-Emitting Diodes – Looking back 100 years and looking forward to the next 10 years" 2007 China International Solid State Lighting Forum and Exhibition (CHINA SSL 2007), Shanghai, China, August 22 – 24 (August 2007)
13. Y. A. Xi, K. X. Chen, F. W. Mont, J. K. Kim, W. Lee, and E. F. Schubert "Kinetic study of Al-mole fraction in Al_xGa_{1-x}N grown on c-plane sapphire and AlN bulk substrates by metal-organic vapor-phase epitaxy" *7th International Conference on Nitrides Semiconductors (ICNS-7)* Las Vegas, NV, September 16 – 21 (September 2007)
14. M. H. Crawford, D. D. Koleske, N. A. Missert, S. R. Lee, M. A. Banas, D. M. Follstaedt, K. H. A. Bogart, G. Thaler, and K. C. Cross, Y. Xia, C. Wetzels, and E. F. Schubert "Mechanisms for enhanced quantum efficiency of InGaN quantum wells grown on InGaN underlayers" *7th International Conference on Nitrides Semiconductors (ICNS-7)* Las Vegas, NV, September 16 – 21 (September 2007)
15. Min-Ho Kim, Martin F. Schubert, Qi Dai, Jong Kyu Kim, Joachim Piprek, Yongjo Park, and E. Fred Schubert "Cause and solution of efficiency droop in GaN-based light-emitting diodes" *7th International Conference on Nitrides Semiconductors (ICNS-7)* Las Vegas, NV, September 16 – 21 (September 2007)
16. K. X. Chen, W. Lee, Q. Dai, F. W. Mont, J. K. Kim, E. F. Schubert, W. Liu, S. Wu, and J. A. Smart "Effect of ammonia and silane flow rate on the structural, electrical and optical properties of n-type AlGaIn for UV emitter applications" *7th International Conference on Nitrides Semiconductors (ICNS-7)* Las Vegas, NV, September 16 – 21 (September 2007)
17. Jong Kyu Kim, Sameer Chhajed, Martin F. Schubert, Jaehee Cho, Cheolsoo Sone, and E. Fred Schubert "Enhancement in light-extraction of GaInN light-emitting diodes by using indium-tin-oxide graded-refractive-

index antireflection contacts” *7th International Conference on Nitrides Semiconductors (ICNS-7)* Las Vegas, NV, September 16 – 21 (September 2007)

18. **(Invited keynote address)** E. Fred Schubert and Jong Kyu Kim “Low-refractive-index materials: A new class of optical thin-film materials for solid-state lighting” *7th International Conference on the Numerical Simulation of Optoelectronic Devices (NUSOD 2007)*, Newark DE, September 24 – 27 (September 2007)
19. Min-Ho Kim, Martin F. Schubert, Qi Dai, Jong Kyu Kim, Joachim Piprek, Yongjo Park, and E. Fred Schubert “Cause and solution of efficiency droop in GaN-based light-emitting diodes” *31st Annual EDS/CAS Activities in Western New York Conference, Electron Devices Society – Western New York*, Rochester NY, November 7 (November 2007)
20. K. X. Chen, Q. Dai, W. Lee, Jong Kyu Kim, E. Fred Schubert, W. Liu, S. Wu, X. Li, and J. A. Smart “Parasitic sub-band-gap emission originating from compensating native defects in Si doped AlGaIn” *31st Annual EDS/CAS Activities in Western New York Conference, Electron Devices Society – Western New York*, Rochester NY, November 7 (November 2007)
21. **(Invited keynote address)** E. Fred Schubert and Jong Kyu Kim “Light-emitting diodes – Looking back 100 years and looking forward to the next 10 years” *S&T/SID’s 15th Color Imaging Conference (CIC)*, Albuquerque NM, November 5 – 9 (November 2007)
22. Min-Ho Kim, Martin F. Schubert, Jong Kyu Kim, and E. Fred Schubert, Hee Seok Park, Yong Jo Park, and Joachim Piprek “Investigation on origin of efficiency droops in InGaIn-based high-power blue light emitting diodes” *Materials Research Society (MRS) Fall Meeting*, Boston, MA, November 26 – 30 (November 2007)
23. Wonseok Lee, Kaixuan Chen, Qi Dai, Min-Ho Kim, Jong Kyu Kim, and E. Fred Schubert, W. Liu, S. Wu, X. Li, and J. A. Smart “Effect of structural properties of AlN templates on the optical and electrical properties of n-type AlGaIn” *Materials Research Society (MRS) Fall Meeting*, Boston, MA, November 26 – 30 (November 2007)
24. Martin. F. Schubert, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, and Jaehee Cho “Polarization anisotropy in the light emission of blue GaInN/GaN light-emitting diodes grown on (0001) oriented sapphire substrates” *Materials Research Society (MRS) Fall Meeting*, Boston, MA, November 26 – 30 (November 2007)
25. Frank Wilhelm Mont, David J. Poxson, Jong Kyu Kim, E. Fred Schubert, Arthur J. Fischer and Mary H. Crawford “Enhancement of light extraction efficiency in GaInN blue light-emitting diodes by graded-refractive-index antireflection coating of co-sputtered titanium dioxide and silicon dioxide” *Materials Research Society (MRS) Fall Meeting*, Boston, MA, November 26 – 30 (November 2007)

2008

1. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Innovation in optical materials for the advancement of solid-state lighting technologies” *Workshop on Nano Optoelectronics*, Korea Institute of Science and Technology (KAIST), Daedeok Science Town, Daejeon, South Korea, January 6 – 8 (January 2008)
2. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Progress on light-emitting diode research” Samsung Electro-Mechanics Company, Suwon-City, South Korea, January 9 (January 2008)
3. **(Invited short course)** E. Fred Schubert “Light-emitting diodes and solid-state lighting” *SPIE Photonic West*, San Jose CA, January 21 – 24 (January 2008)
4. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Low-refractive index materials – A new class of materials for photonic applications” *SPIE Photonic West*, San Jose CA, January 21 – 24 (January 2008)
5. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Innovation in optical materials for the advancement of solid-state lighting technologies” *Colloquium*, Rochester Institute of Technology, Rochester, New York, March 13 (March 2008)
6. Q. Dai, M. F. Schubert, M. H. Kim, J. K. Kim, E. F. Schubert, D. D. Koleske, M. H. Crawford, S. R. Lee, A. J. Fischer, G. Thaler, and M. A. Banas “Effect of dislocation density on internal quantum efficiency in GaInN/GaN multiple quantum wells” *Connecticut Microelectronics and Optoelectronics Conference (CMOC)*, University of Connecticut, Storrs, Connecticut April 9 (April 2008)
7. **(Best Oral Presentation Award)** David J. Poxson, Frank W. Mont, Jong Kyu Kim, and E. Fred Schubert “Multilayer nano-structured anti-reflection coating with broad-band omni-directional characteristics” *Connecticut Microelectronics and Optoelectronics Conference (CMOC)*, University of Connecticut, Storrs, Connecticut April 9 (April 2008)
8. Frank W. Mont, David J. Poxson, Martin F. Schubert, Ahmed Noemaun, Jong Kyu Kim, E. Fred Schubert, Arthur J. Fischer and Mary H. Crawford “Micro-patterned graded-refractive-index coatings of co-sputtered TiO₂ and

- SiO₂ for enhanced light-extraction from GaInN light-emitting diodes" *International Symposium on Semiconductor Light Emitting Devices, ISSLED*, Phoenix, Arizona, April 27 – May 2 (April 2008)
9. M. F. Schubert, S. Chhajed, J. K. Kim, E. F. Schubert, M. H. Kim, D. D. Koleske, M. H. Crawford, S. R. Lee, A. J. Fischer, G. Thaler, M. A. Banas, and J. Piprek "Efficiency droop in GaInN/GaN LEDs: the effect of dislocation density, physical origin, and possible solution" *International Symposium on Semiconductor Light Emitting Devices, ISSLED*, Phoenix, Arizona, April 27 – May 2 (April 2008)
 10. J. R. Grandusky, J. A. Smart, M. C. Mendrick, L. J. Schowalter, K. X. Chen, and E. F. Schubert, "Pseudomorphic growth of thick n-Al_xGa_{1-x}N layers on low defect density bulk AlN substrates for UV LED applications", *International Symposium on Semiconductor Light Emitting Devices*, Phoenix, AZ, April 27 – May 2 (April 2008)
 11. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Innovation in optical materials for the advancement of solid-state lighting technologies" *Colloquium*, State University of New York Stony Brook, Stony Brook, New York, May 6 (May 2008)
 12. **(Invited)** Jong Kyu Kim, Min-Ho Kim, Martin F. Schubert, Qi Dai, Sagong Tan, Sukho Yoon, Cheolsoo Sone, Yongjo Park, Joachim Piprek, and E. Fred Schubert "The origin of efficiency droop in GaN-based light-emitting diodes and its solution" *Conference on Lasers and Electro-Optics, CLEO*, San Jose, California May 4 – 9 (May 2008)
 13. K. X. Chen, Q. Dai, W. Lee, J. K. Kim and E. F. Schubert, W. Liu, S. Wu, X. Li, and J. A. Smart "Parasitic sub-band-gap emission originating from compensating native defects in Si- doped AlGaIn" *2008 Electronic Materials Conference, EMC*, Santa Barbara, California, June 25 – 27 (June 2008)
 14. J. R. Grandusky, J. A. Smart, M. C. Mendrick, L. J. Schowalter, K. X. Chen, and E. F. Schubert "Pseudomorphic growth of thick n-type Al_xGa_{1-x}N layers on low defect density bulk AlN substrates for UV LED applications" *2nd International Symposium on Growth of III-Nitrides*, Laforet Shuzenji, Izu, Japan, July 6 – 9 (July 2008)
 15. Frank W. Mont, Arthur J. Fischer, Mary H. Crawford, David J. Poxson, Sameer Chhajed, Ahmed Noemaun, Jong Kyu Kim and E. Fred Schubert "Enhanced light extraction from GaInN light-emitting diodes using micro-patterned graded-refractive-index coatings" *Sandia NINE Community Week Conference*, Sandia National Laboratories, Albuquerque NM, July 31, 2008
 16. Roya Mirhosseini, Jong Kyu Kim, C. Sone, Y. Park, and E. F. Schubert "Light-extraction efficiency enhancement in vertically structured GaInN-based light-emitting diode on bulk GaN substrate" *2008 Lester Eastman Biennial Conference on High-Performance Devices*, University of Delaware, Newark, Delaware, August 5 – 7 (August 2008)
 17. Jiuru Xu, Martin F. Schubert, Jong Kyu Kim, and E. Fred Schubert, "The effect of hole-injection efficiency on efficiency droop of GaN-based light emitters investigated by light-emitting triodes" *2008 Lester Eastman Biennial Conference on High-Performance Devices*, University of Delaware, Newark, Delaware, August 5 – 7 (August 2008)
 18. Ahmed Noemaun Frank W. Mont, David J. Poxson, Di Zhu, Jong Kyu Kim, and E. Fred Schubert "Design of graded refractive index micro-patterns to enhance light-extraction efficiency in GaInN blue light-emitting diodes" *2008 Lester Eastman Biennial Conference on High-Performance Devices*, University of Delaware, Newark, Delaware, August 5 – 7 (August 2008)
 19. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Relevance of light-emitting diodes and photonics for energy" *US-Korea Conference on Science, Technology, and Entrepreneurship*, UKC 2008, San Diego, California, August 14 – 17 (August 2008)
 20. M. F. Schubert, S. Chhajed, Jong Kyu Kim, J. Cho, and E. F. Schubert "Polarized c-plane GaInN/GaN light-emitting diodes" *International Workshop on Nitride Semiconductors, IWN 2008*, Montreux, Switzerland, October 6 – 10 (October 2008)
 21. Jong Kyu Kim, M. H. Kim, M. F. Schubert, Q. Dai, J. Piprek, S.-M. Lee, S. Yoon, C. Sone, Y. Park, D. D. Koleske, M. H. Crawford, S. R. Lee, E. Fred Schubert "Efficiency droop in GaN-based light-emitting diodes" *International Workshop on Nitride Semiconductors, IWN 2008*, Montreux, Switzerland, October 6 – 10 (October 2008)
 22. David J. Poxson, F. W. Mont, M. F. Schubert, J. K. Kim, E. F. Schubert "Quantification of porosity and deposition rate of nano-porous films grown by oblique angle deposition" *55th International Symposium of the American Vacuum Society*, Boston, Massachusetts, October 19 – 24 (October 2008)
 23. **(Invited short course)** E. Fred Schubert "Light emitting diodes and solid-state lighting" *OSA Frontiers in Optics 2008*, University of Rochester, Rochester, New York, October 24 – 26 (October 2008)

24. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Energy implications of solid-state lighting technology" *OSA Frontiers in Optics 2008*, University of Rochester, Rochester, New York, October 24 – 26 (October 2008)
25. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Smart Lighting" *BASF Corporation*, Ossining, New York, December 1 (December 2008)
26. **(Invited)** Jong Kyu Kim and E. Fred Schubert "Low-refractive index materials" *BASF Corporation*, Ossining, New York, December 1 (December 2008)
27. **(Invited)** E. Fred Schubert "Smart Lighting" *ERC 2008 Annual Meeting*, Bethesda Maryland, December 3 – 5 (December 2008)
28. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Light-Emitting Diodes – Looking back 100 years and looking forward to the next 10 years" *Interlight Show*, Moscow, Russia, December 8 – 12 (December 2008)
29. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Light-Emitting Diodes – Looking back 100 years and looking forward to the next 10 years" *Moscow University*, Moscow, Russia, December 11 (December 2008)

2009

1. **(Invited short course)** E. Fred Schubert "Light-emitting diodes and solid-state lighting" *SPIE Photonic West*, San Jose CA, January 26 – 30 (January 2009)
2. **(Invited)** E. Fred Schubert, Jong Kyu Kim, Min Ho Kim, Martin F. Schubert "Polarization-matching in GaInN light-emitting diodes: a new concept for reducing efficiency droop and enhancing performance" *SPIE Photonic West*, San Jose CA, January 26 – 30 (January 2009)
3. **(Invited)** Min-Ho Kim, Wonseok Lee, Zhu Di, Martin F. Schubert, Jong Kyu Kim, E. Fred Schubert, Cheolsoo Sone, Yongjo Park, and Joachim Piprek "Origin of Efficiency Droop in GaInN/GaN MQW LEDs and its Possible Solution" *SPIE Photonic West*, San Jose CA, January 26 – 30 (January 2009)
4. Jiuru Xu, Martin F. Schubert, Ahmed N. Noemaun, Di Zhu, Jong Kyu Kim, E. Fred Schubert, Min Ho Kim, Sukho Yoon, Hun-Jae Chung, Cheolsoo Sone, and Yongjo Park "Reduction of Efficiency Droop, Forward Voltage, Electroluminescence Peak Shift and Ideality Factor in Polarization-matched GaInN/GaN Multi-quantum-well Light-emitting Diodes" *MRS Spring Meeting*, San Francisco, California, April 13 – 17 (April 2009)
5. **(Invited)** M. F. Schubert, J. Xu, Q. Dai, F. Mont, M. H. Kim, J. K. Kim, E. F. Schubert, H. Chung, S. Yoon, C. Sone and Y. Park "Study of Efficiency Droop in GaInN/GaN and Polarization-matched GaInN/AlGaInN and GaInN/GaN Light-emitting Diodes" *215th Electrochemical Society Meeting*, San Francisco CA, May 24 – 29 (2009)
6. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Low-refractive index materials – A new class of optical thin-film materials for photonics applications" *Workshop on Metamaterials*, University of North Carolina, Charlotte, North Carolina, May 27 – 29 (May 2009)
7. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Low-refractive index materials – A new class of optical thin-film materials for photonics applications" *Conference on Lasers and Electro-optics (CLEO / IQEC)* Baltimore, Maryland, May 31 – June 5 (June 2009)
8. Q. Dai, M. F. Schubert, M. H. Kim, J. K. Kim, E. F. Schubert, D. D. Koleske, M. H. Crawford, S. R. Lee, A. J. Fischer, G. Thaler, and M. A. Banas "Internal quantum efficiency and non-radiative recombination coefficient of GaInN/GaN multiple quantum wells with different dislocation densities" *Conference on Lasers and Electro-optics (CLEO / IQEC)* Baltimore, Maryland, May 31 – June 5 (June 2009)
9. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Energy implications of solid-state lighting technology" *OSA 2009 Topical Meeting, Optics and Photonics for Advanced Energy Technology*, Massachusetts Institute of Technology (MIT), Cambridge MA, June 24 and 25 (June 2009)
10. Wonseok Lee, Min-Ho Kim, Di Zhu, Ahmed N. Noemaun, E. Fred Schubert, and Jong Kyu Kim "Growth and characteristics of GaInN/GaN light-emitting diodes: 2009 *Electronic Materials Conference (EMC)* University Park, Pennsylvania, June 24 – 26 (June 2009)
11. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Energy implications of solid-state lighting technology" *Colloquium at the University of Hagen*, Hagen, Germany, July 14 (July 2009)
12. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Energy implications of solid-state lighting technology" *Colloquium at Everlight Europe*, Karlsruhe, Germany, July 15 (July 2009)
13. **(Invited)** E. Fred Schubert and Jong Kyu Kim "Energy implications of solid-state lighting technology" *Osram Opto Semiconductors*, Regensburg, Germany, July 17 (July 2009)

14. **(Invited)** Jong Kyu Kim and E. Fred Schubert “Energy implications of solid-state lighting technology” *US-Korea Conference on Science, Technology and Entrepreneurship*, Raleigh, North Carolina, July 16 – 19 (July 2009)
15. Roya Mirhosseini, Martin F. Schubert, Sameer Chhajed, Jaehee Cho, Jong. K. Kim, and E. Fred Schubert “Enhancements in color rendering and luminous efficacy of phosphor-converted white light-emitting diodes with dual-blue emitting active regions” *SPIE Annual Meeting, Ninth International Conference on Solid-State Lighting*, San Diego, California, August 2 – 6 (August 2009)
16. Martin F. Schubert, Jong Kyu Kim and E. Fred Schubert “Novel low-refractive-index materials and their applications” *SPIE Annual Meeting, Ninth International Conference on Solid-State Lighting*, San Diego, CA, August 2 – 6 (August 2009)
17. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Light-emitting diode designs for high power applications – overcoming high-power loss mechanisms” *International Conference on Nitride Semiconductors (ICNS)* Jeju, South Korea, October 18 – 23 (October 2009)
18. Jong Kyu Kim, F. W. Mont, A. Noemaun, D. Meyaard, and E. Fred Schubert “Enhanced light extraction and controllability of far-field emission pattern of GaInN light-emitting diodes by graded-refractive-index micro-pillars” *International Conference on Nitride Semiconductors (ICNS)* Jeju, South Korea, October 18 – 23 (October 2009)
19. **(Invited)** E. Fred Schubert “Light-emitting diode designs for high power applications – overcoming high-power loss mechanisms” Samsung LED Company, Suwon, South Korea October 21 (October 2009)
20. **(Invited)** E. Fred Schubert and Jong Kyu Kim “Challenges and opportunities in solid-state lighting” *Materials Research Society Fall Symposium (MRS)*, Boston, Massachusetts, November 30 – December 4 (December 2009)
21. Di Zhu, Jiuru Xu, Ahmed N. Noemaun, Jong-Kyu Kim, E. Fred Schubert, Mary H. Crawford, and Daniel D. Koleske “The origin of the high diode-ideality factors in GaInN/GaN multiple quantum well light-emitting diodes” *Materials Research Society Fall Symposium (MRS)*, Boston, Massachusetts, November 30 – December 4 (December 2009)
22. Ahmed N. Noemaun, Frank Mont, David J. Poxson, Jong-Kyu Kim, E. Fred Schubert “Graded-refractive-index micro-patterns on GaInN light-emitting diodes for enhanced light extraction and control over the far field emission pattern” *Materials Research Society Fall Symposium (MRS)*, Boston, Massachusetts, November 30 – December 4 (December 2009)
23. David Meyaard, Jaehee Cho, Martin F. Schubert, Sameer Chhajed, Jong Kyu Kim, and E. Fred Schubert “Nitride based light emitting diodes embedded with a wire-grid polarizer” *Materials Research Society Fall Symposium (MRS)*, Boston, Massachusetts, November 30 – December 4 (December 2009)
24. **(Keynote address)** E. Fred Schubert and Jong Kyu Kim “Material and Device Innovations in Light-Emitting Diodes for High Efficiency at High Currents” *International Conference on White LEDs and Solid State Lighting*, Taipei, Taiwan, December 13 – 16 (December 2009)

2010

1. **(Invited short course)** E. Fred Schubert “Light-emitting diodes and solid-state lighting” *SPIE Photonic West*, San Francisco CA, January 24 – 28 (January 2010)
2. **(Invited)** E. Fred Schubert “Promises and challenges in solid-state lighting” *March Meeting of the American Physical Society*, Portland, Oregon, March 15 – 19 (March 2010)
3. **(Keynote presentation)** E. Fred Schubert “Tailored refractive index structures for photonic devices” *Workshop on Black Materials organized by the Defense Advanced Research Projects Agency (DARPA)*, Arlington, Virginia, March 31 – April 1 (March 2010)
4. **(Invited)** E. Fred Schubert “Promises and challenges in solid-state lighting” *Connecticut Symposium on Microelectronics and Optoelectronics (CMOC)*, Storrs, Connecticut, April 7 (April 2010)
5. **(Invited)** E. Fred Schubert and Martin F. Schubert “Efficiency droop in GaInN solid-state-lighting devices” *Conference on Lasers and Electro-optics (CLEO)*, San Jose, California, May 16 – 21 (May 2010)
6. **(Invited)** E. Fred Schubert “Promises and challenges in solid-state lighting” *AVS-MI Spring Symposium*, University of Michigan, Ann Arbor, Michigan, May 26 (May 2010)
7. Qi Dai, Qifeng Shan, Jing Wang, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, and Daniel D. Koleske “Carrier-loss mechanisms behind efficiency droop in GaInN/GaN light-emitting diodes” *IEEE Lester*

Eastman Conference on High Performance Devices, Rensselaer Polytechnic Institute, Troy NY, August 3 – 5 (August, 2010)

8. An Mao, Qi Dai, Jaehee Cho, and E. Fred Schubert “Characteristics of dot-shaped green emission in GaInN blue light-emitting diode” *IEEE Lester Eastman Conference on High Performance Devices*, Rensselaer Polytechnic Institute, Troy NY, August 3 – 5 (August, 2010)
9. Jiuru Xu, Martin. F. Schubert, Ahmed. N. Noemaun, Jaehee Cho, E. Fred Schubert, Min-Ho Kim, and Yongjo Park “Reducing efficiency droop in GaInN based light-emitting diodes by matching material polarization” *IEEE Lester Eastman Conference on High Performance Devices*, Rensselaer Polytechnic Institute, Troy NY, August 3 – 5 (August, 2010)
10. Xing Yan, Frank W. Mont, David J. Poxson, Martin F. Schubert, Jaehee Cho, and E. Fred Schubert “Anti-reflection coating made of indium-tin-oxide (ITO) electrode for liquid crystal display panel” *IEEE Lester Eastman Conference on High Performance Devices*, Rensselaer Polytechnic Institute, Troy NY, August 3 – 5 (August, 2010)
11. Di Zhu, Ahmed N. Noemaun, Martin F. Schubert Jaehee Cho, E Fred Schubert, Mary H. Crawford, Daniel D. Koleske “Enhanced electron capture and symmetrized carrier distribution in GaInN LEDs having tailored barrier doping” *International Workshop on Nitride Semiconductors (IWN2010)* Tampa, Florida, September 19 – 24 (September 2010)
12. Jaehee Cho, Di Zhu, An Mao, Jong Kyu Kim, Joong Kon Son, Yongjo Park, and E. Fred Schubert “Characteristics of reverse current in GaInN light-emitting diodes” *International Workshop on Nitride Semiconductors (IWN2010)* Tampa, Florida, September 19 – 24 (September 2010)

2011

1. **(Invited short course)** E. Fred Schubert “Light-emitting diodes and solid-state lighting” *SPIE Photonic West*, San Francisco CA, January 22 – 27 (January 2011)
2. **(Invited)** E. Fred Schubert and Jaehee Cho “The efficiency droop in GaInN light-emitting diodes” *SPIE Photonic West*, San Francisco CA, January 22 – 27 (January 2011)
3. Ashok K. Sood, Roger E. Welsch, Adam W. Sood, E. James Egerton and Yash R. Puri, David Poxson, Jaehee Cho, E. Fred Schubert, Dennis L. Polla, Nibir K. Dhar, and Martin B. Soprano “Nanosdtructure-based antireflection coatings for EO/IR sensor applications” *SPIE Photonic West*, San Francisco CA, January 22 – 27 (January 2011)
4. Qi Dai, Qifeng Shan, Jing Wang, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, Daniel D. Koleske, Min-Ho Kim, and Yongjo Park “Carrier recombination mechanisms and efficiency droop in GaInN/GaN light-emitting diodes” *SPIE Photonic West*, San Francisco CA, January 22 – 27 (January 2011)
5. **(Best Oral Paper Award)** David Meyaard, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Jong Kyu Kim, Daniel D. Koleske, and Mary H. Crawford “Temperature-dependent light-output characteristics of GaInN light-emitting diodes with different dislocation densities” *Connecticut Microelectronics and Optoelectronics Consortium (CMOC) Symposium*, New Haven CT, March 2 (March 2011)
6. **(Invited)** E. Fred Schubert and Jaehee Cho “Promises and challenges in light-emitting diodes for lighting applications” 2011 IEEE Workshop on Microelectronics and Electron Devices, WMED-2011, Boise State University, April 22, (2011)
7. Qi Dai, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, Daniel D. Koleske, Min-Ho Kim, and Yongjo Park “On the symmetry of efficiency-versus-carrier-concentration curves in GaInN/GaN light-emitting diodes and relation to droop-causing mechanisms” *Conference on Lasers and Electro Optics, CLEO*, Baltimore, Maryland, May 1 – 6 (2011)
8. **(Invited)** E. Fred Schubert and Jaehee Cho “Tunable-refractive-index materials – A new class of optical thin-film materials” *Workshop on Meta-materials and Plasmonics: Novel Materials, Designs, and Applications*, University of Buffalo, Buffalo NY, May 16 and 17 (2011)
9. Qi Dai, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, and Daniel D. Koleske “On the symmetry of efficiency-versus-carrier-concentration curves in GaInN/GaN light-emitting diodes and relation to droop-causing mechanisms” *Energy Frontiers Research Center (EFRC) Meeting*, US Department of Energy, Washington DC May 25 – 27 (2011)
10. **(Invited)** Jong Kyu Kim, Jaehee Cho, and E. Fred Schubert “Promises and challenges in light-emitting diodes for lighting applications” 15th International Symposium on the Physics of Semiconductors and Applications (ISPSA-XV), Jeju, Korea, July 5 – 8 (2011)

11. Jaehee Cho, An Mao, Qifeng Shan, Jong Kyu Kim, Joong Kon Son, and E. Fred Schubert "Leakage current analysis in GaInN blue light-emitting diodes" *International Conference on Nitride Semiconductors ICNS*, Glasgow, UK, July 10 – 15 (2011)
12. Ahmed N. Noemaun, Frank W. Mont, Gi Bum Kim, Cheolsoo Sone, Jaehee Cho, and E. Fred Schubert "Study of patterned graded-refractive-index layers to enhance light-extraction efficiency and control of far-field emission pattern of GaInN LEDs" *International Conference on Nitride Semiconductors ICNS*, Glasgow, UK, July 10 – 15 (2011)
13. E. Fred Schubert, Jaehee Cho, Mary Crawford, and Dan Koleske "Efficiency droop in GaInN LEDs" Sandia National Laboratories, Albuquerque NM, July 27 (2011)
14. David J. Poxson, Richard Siegel and E. Fred Schubert "Tailored refractive index nanoporous thin films on flexible substrates" *Rensselaer Nanotechnology Center Symposium*, Troy NY (Oct 2011)
15. Sameer Chhajed, Jong Kyu Kim, Wonseok Lee, Jaehee Cho, E. Fred Schubert "Light-Extraction Enhancement in GaInN LEDs by Self-Organized Nanoscale Patterning of p-Type GaN using Oblique-Angle Deposition" *International Conference on Applied Electromaterials, ICAE 2011*, Jeju, Korea, November 7 – 10 (2011)
16. **(Invited Plenary Presentation)** Jaehee Cho, E. Fred Schubert "Promises and challenges in light-emitting diodes for lighting applications" *International Conference on Applied Electromaterials, ICAE 2011*, Jeju, Korea, November 7 – 10 (Nov 2011)
17. David J. Poxson, Xing Yan, Frank W. Mont, Jaehee Cho, E. Fred Schubert "Broadband Omnidirectional Antireflection Coatings: Enhanced Solar Cell Device Performance" *Center for Future Energy Systems Symposia*, RPI Troy NY (Nov 2011)
18. **(Invited Plenary Presentation)** E. Fred Schubert "Promises and challenges in light-emitting diodes for lighting applications" *State and Organic Lighting (SOLED) Meeting of the OSA*, Austin Texas, November 2 – 3 (Nov 2011)
19. Qifeng Shan, David S. Meynard, Qi Dai, Jaehee Cho, E. Fred Schubert, Joong Kon Son and Cheolsoo Sone, "On the reverse leakage current in GaInN light-emitting diodes" *MRS Fall Meeting*, Boston, Massachusetts, Nov. 28 – Dec. 2 (2011)
20. David J. Poxson, Frank W. Mont, Jaehee Cho, E. Fred Schubert, and Richard W. Siegel "Optical Coatings Utilizing Nanoporous Thin Films Fabricated on Flexible Polymer Substrates" *MRS 2011 Fall Meeting*, Boston, Massachusetts, Nov. 28 – Dec. 2 (Dec 2011)

2012

1. **(Invited short course)** E. Fred Schubert "Light-emitting diodes and solid-state lighting" *SPIE Photonic West*, San Francisco CA, January 21 – 26 (January 2012)
2. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "The Efficiency Droop in GaInN Light-Emitting Diodes" *SPIE Photonic West*, San Francisco CA, January 21 – 26 (January 2012)
3. Jiuru Xu, Martin F. Schubert, Di Zhu, Jaehee Cho, and E. Fred Schubert, Hyunwook Shim and Cheolsoo Sone "Effects of polarization-field tuning in GaInN light-emitting diodes" *SPIE Photonic West*, San Francisco CA, January 21 – 26 (January 2012)
4. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "The seed of a revolution in lighting: Light-emitting diodes" *Institute of Optical Sciences, University of Toronto*, Toronto, Canada, March 15 (March 2012)
5. **(The Boris P. Stoicheff Lecture; Invited keynote presentation)** E. Fred Schubert "The Seed of a Revolution in Lighting: Light-Emitting Diodes" *University of Toronto*, Toronto, Canada, March 16 (March 2012)
6. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "High-injection phenomena in GaN-based LEDs" *Coffee / Desert Hour of the Energy Frontiers Research Center on Solid-State Lighting Sciences*; Sandia National Laboratories, Albuquerque NM, March 29, (March 2012)
7. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "The seed of a revolution in lighting: Light-emitting diodes" *Conference on Opto and Microelectronics (CMOC)*, Storrs, CT, April 11 (April 2012)
8. **(Keynote presentation)** E. Fred Schubert and Jaehee Cho "The seed of a revolution in lighting: Light-emitting diodes" *Compound Semiconductor Manufacturing Technologies (CSMantech)*, Boston, MA, April 23-26 (April 2012)
9. Guan-Bo Lin, Q. Shan, A. J. Birkel, J. Cho, and E. F. Schubert, D. D. Koleske and M. H. Crawford "Internal quantum efficiency in light-emitting diodes based on the width of efficiency-versus-carrier-concentration curve" *Conference on Lasers and Electro-optics (CLEO)*, San Jose, California, May 6 – 11 (May 2012)

10. David S. Meyaard, Guan-Bo Lin, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Hyun Wook Shim, Min-Ho Kim, Cheolsoo Sone, Hyun Wook Shim, Min-Ho Kim, and Cheolsoo Sone "Asymmetry of carrier transport leading to efficiency droop in GaInN based light-emitting diodes" *Conference on Lasers and Electro-optics (CLEO)*, San Jose, California, May 6 – 11 (May 2012)
11. J. Kim, S. Hwang, J. Park, D. Kim, J. Cho, and E. F. Schubert "Efficiency Droop in GaN-based Light-Emitting Diodes: Mechanisms and Solutions" PRIME 2012, State-of-the-Art Program on Compound Semiconductors 54 (SOTAPOCS 54), Honolulu, Hawaii, October 7 – 12, 2012 (October 2012)
12. Yong Suk Cho, M. Evans, S. Chowdhury, D. Meyaard, M. Ma, X. Yan, J. Cho, and E. Fred Schubert "GaN growth on ion-implanted patterned sapphire substrates" *International Workshop on Nitride Semiconductors, IWN 2012*, Sapporo, Japan, October 14 – 19, 2012 (October 2012)
13. Sunyong Hwang, Junhyuk Park, Dong-Yeong Kim, Woo Jin Ha, Jong Kyu Kim, Jiuru Xu, Jaehee Cho, and E. Fred Schubert "Promotion of hole injection enabled by GaInN/GaN light-emitting triodes and its effect on the efficiency droop" *International Workshop on Nitride Semiconductors, IWN 2012*, Sapporo, Japan, October 14 – 19, 2012 (October 2012)
14. Jaehee Cho, David S. Meyaard, Sang-Heon Han, Min-Ho Kim, Cheolsoo Sone, and E. Fred Schubert "Temperature dependence of the efficiency droop in GaInN light-emitting diodes" *International Workshop on Nitride Semiconductors, IWN 2012*, Sapporo, Japan, October 14 – 19, 2012 (October 2012)
15. **(Invited presentation)** E. Fred Schubert "Unraveling the mystery of the efficiency droop in GaInN LEDs" *International Workshop on Nitride Semiconductors, IWN 2012*, Sapporo, Japan, October 14 – 19, 2012 (October 2012)
16. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "Tunable-refractive-index materials – A new class of optical thin-film materials with applications in solid-state lighting and solar photovoltaics" *AVS 59th International Symposium and Exhibition, AVS 2012*, Tampa, Florida, October 28 – November 2 (October 2012)
17. **(Invited presentation)** "Light-emitting diodes for lighting applications" E. Fred Schubert, *Lutron Company*, Coopersburg, Pennsylvania, November 5 and 6 (November 2012)
18. Roger E. Welsner, Adam W. Sood, Jaehee Cho, E. Fred Schubert, Jennifer L. Harvey, Nibir K. Dhar, and Ashok K. Sood "Nanostructured Transparent Conductive Oxides for Photovoltaic Applications" *MRS 2012 Fall Meeting*, Boston, Massachusetts, November 26 – 30 (November 2012)

2013

1. **(Plenary presentation)** E. Fred Schubert "A revolution in lighting: Light-emitting diodes" *Workshop on "Phosphor-free white LEDs for solid-state lighting"* McGill University, Montreal, Canada, January 11 (January 2013)
2. **(Invited short course)** E. Fred Schubert "Light-emitting diodes" *SPIE Photonic West*, San Francisco CA, February 2 – 7 (February 2013)
3. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "Analytic model for the efficiency droop, in light-emitting diodes made of semiconductors with asymmetric carrier-transport properties, based on drift-induced reduction of injection efficiency" *SPIE Photonic West*, San Francisco CA, February 2 – 7 (February 2013)
4. **(Invited presentation)** Jaehee Cho, David S. Meyaard, Jong Kyu Kim, Cheolsoo Sone, and E. Fred Schubert "Temperature-dependent efficiency droop in GaInN light-emitting diodes" *SPIE Photonic West*, San Francisco CA, February 2 – 7 (February 2013)
5. **(Invited presentation)** Jaehee Cho and E. Fred Schubert "Temperature dependence of the efficiency droop in GaInN light-emitting diodes" Connecticut Microelectronics and Optoelectronics Consortium (CMOC), Yale University, New Haven, Connecticut, March 13 (March 2013)
6. **(Invited presentation, Shell Graduate Seminar)** E. Fred Schubert "Enabling a Revolution in Lighting: Light-Emitting Diodes" Shell Graduate Seminar, University of Houston, Houston, Texas, April 11 (April 2013)
7. **(Invited presentation)** E. Fred Schubert "Band-edge discontinuities in semiconductor heterostructures – The fundamental building blocks of modern devices" Superlattice Workshop: Development of Man Made Electronic Materials and Devices – Past and Future; University of North Carolina – Charlotte; Symposium in honor of Distinguished Professor Raphael (Ray) Tsu; Charlotte, North Carolina, May 6 (May 2013)
8. **(Plenary presentation)** E. Fred Schubert "Enabling a revolution in lighting: Light-emitting diodes" *Photonics North*, Ottawa, Canada, June 3 – 5 (June 2013)

9. David S. Meyaard, Guan-Bo Lin, Jaehee Cho, E. Fred Schubert, Hyunwook Shirn, Sang-Heon Han, Min-Ho Kim, Young Sun Kim, and Cheolsoo Sone "Correlation between the onset of high injection and the onset of efficiency droop in GaInN light-emitting diodes" *International Conference on Nitride Semiconductors* (ICNS), Washington DC, August 25–30 (August 2014)
10. **(Invited rump-session presentation)** E. Fred Schubert "What causes droop and what are potential solutions?" *Rump Session, International Conference on Nitride Semiconductors* (ICNS), Washington DC, August 25–30 (August 2014)
11. **(Invited presentation)** E. Fred Schubert "Challenges in solid-state lighting associated with materials research" *246th American Chemical Society National Meeting*, September 8–12 (September 2013)
12. **(Invited presentation)** E. Fred Schubert and Jaehee Cho "Unraveling mystery of efficiency droop in III-V LEDs" *Second International Conference on Advanced Electromaterials* (ICAE 2013), ICC Jeju, Jeju, South Korea, November 12–15 (November 2013)

2014

1. Ming Ma, Jaehee Cho, E. Fred Schubert, Gi Bum Kim, and Cheolsoo Sone "Optically functional structures on GaN-based light-emitting diodes for emission pattern control and light-extraction efficiency enhancement" *SPIE Photonic West*, San Francisco CA, February 1–6 (February 2014)
2. David S. Meyaard, Guan-Bo Lin, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, Sang-Heon Han, Min-Ho Kim, Cheolsoo Sone, and Young Sun Kim "Identifying the cause of the efficiency droop in GaInN light-emitting diodes by correlating the onset of high injection with the onset of the efficiency droop" *SPIE Photonic West*, San Francisco CA, February 1–6 (February 2014)
3. **(Invited short course)** E. Fred Schubert "Light-emitting diodes" *SPIE Photonic West*, San Francisco CA, February 1–6 (February 2014)
4. **(Invited presentation)** E. Fred Schubert "The efficiency droop in III-V semiconductor light-emitting diodes" *SPIE Photonic West*, San Francisco CA, February 1–6 (February 2014)
5. **(Invited presentation)** Guan-Bo Lin, David S. Meyaard, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, Min-Ho Kim, and Cheolsoo Sone "Correlation between high injection and efficiency droop in GaInN light-emitting diodes" *Connecticut Symposium on Microelectronics and Optoelectronics* (CMOC), University of Connecticut, Storrs CT, April 9 (April 2014)
6. **(Invited presentation)** E. Fred Schubert and Guan-Bo Lin "The efficiency droop in III-V semiconductor light-emitting diodes" Luminus Company, Billerica MA, July 9 (July 2014)
7. **(Invited short course)** E. Fred Schubert and Guan-Bo Lin "Light-emitting diodes" Hualei Optoelectronics Company, Chenzhou, Hunan Province, PR China, August 11 and 12 (August 2014)
8. **(Invited presentation)** E. Fred Schubert and Guan-Bo Lin "The efficiency droop in III-V semiconductor light-emitting diodes" Hualei Optoelectronics Company, Chenzhou, Hunan Province, PR China, August 11 and 12 (August 2014)
9. **(Plenary presentation)** E. Fred Schubert "Progress in understanding and overcoming the efficiency droop in III-V light-emitting diodes" *International Symposium on Semiconductor Light-Emitting Diodes* (ISSLED), Kaohsiung, Republic of China (Taiwan), December 15–19 (December 2014)

2015

1. Jaehee Cho, E. Fred Schubert, et al. "Temperature dependence of efficiency in GaInN/GaN light-emitting diodes with a strain-control layer" *SPIE Photonic West*, San Francisco CA, February 7–12 (February 2014)
2. **(Invited short course)** E. Fred Schubert "Light-emitting diodes" *SPIE Photonic West*, San Francisco CA, February 7–12 (February 2014)
3. Guan-Bo Lin and E. Fred Schubert "Efficiency re-climbing in high-current droop regime for GaN-based light-emitting diodes" *Connecticut Symposium on Microelectronics and Optoelectronics* (CMOC), University of Bridgeport, Bridgeport, CT, April 1 (2015)
4. Jaehee Cho, Jong Kyu Kim, E. Fred Schubert "On the temperature dependence of efficiency in III-Nitride light-emitting diodes" *International Conference on Materials for Advanced Technologies*, ICMAT-2015, Suntec, Singapore, June 28 – July 3 (2015)