

DOCKET NO: 0107131.00271US1  
'142 PATENT

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

PATENT: 6,853,142

CLAIMS 1, 3-10, 12, 15, 17-20 AND  
42

INVENTOR: ROMAN CHISTYAKOV

FILED: NOV. 4, 2002

ISSUED: FEB. 8, 2005

TITLE: METHODS AND APPARATUS FOR GENERATING HIGH-  
DENSITY PLASMA

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U.S. Patent & Trademark Office  
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**DECLARATION OF UWE KORTSHAGEN, PH.D., REGARDING  
CLAIMS 1, 3-10, 12, 15, 17-20 AND 42 U.S. PATENT NO. 6,853,142**

I, Uwe Kortshagen, declare as follows:

1. My name is Uwe Kortshagen.
2. I received my Diploma in Physics from the University of Bochum in Germany in 1988. I received my Ph.D. in Physics from University of Bochum in 1991 and my Habilitation in Experimental Physics from University of Bochum in 1995.

3. I am a Distinguished McKnight University Professor at the University of Minnesota. I have been the Head of the Mechanical Engineering Department at the University of Minnesota since July 2008. I have been a Professor at the Mechanical Engineering Department at the University of Minnesota since August 2003. Between August 1999 and August 2003, I was an Associate Professor at the Mechanical Engineering Department at the University of Minnesota. Between July 1996 and August 1999, I was an Assistant Professor at the Mechanical Engineering Department at the University of Minnesota. Between April 1996 and July 1996, I was a Lecturer at the Department of Physics and Astronomy at the University of Bochum, Germany. Between August 2006 and June 2008, I was the Director of Graduate Studies at the Mechanical Engineering Department at the University of Minnesota.

4. I have taught courses on Introduction to Plasma Technology and Advanced Plasma Technology. These courses include significant amounts of material on plasma technology. In addition, I have taught a Special Topics class on Plasma Nanotechnology.

5. Plasma processes for advanced technological applications has been the primary area of my professional research for over 30 years. Most of my Ph.D. students go on to work on plasmas either in academia or the semiconductor industry.

6. A copy of my latest *curriculum vitae* (CV) is attached as Appendix A.

7. I have reviewed the specification, claims, and file history of U.S. Patent No. 6,853,142 (the "'142 patent") (Ex. 1001). I understand that the '142 patent was filed on November 4, 2002. I understand that, for purposes determining whether a publication will qualify as prior art, the earliest date that the '142 patent could be entitled to is November 4, 2002.

8. I have reviewed the following publications:

- D.V. Mozgrin, et al, High-Current Low-Pressure Quasi-Stationary Discharge in a Magnetic Field: Experimental Research, Plasma Physics Reports, Vol. 21, No. 5, pp. 400-409, 1995 ("Mozgrin" (Ex. 1003)).
- U.S. Pat. No. 6,190,512 ("Lantsman" (Ex. 1004)).
- U.S. Pat. No. 6,413,382 ("Wang" (Ex. 1005)).

9. I have read and understood each of the above publications. The disclosure of each of these publications provides sufficient information for someone to make and use the plasma generation and sputtering processes that are described in the above publications.

10. I have considered certain issues from the perspective of a person of ordinary skill in the art at the time the '142 patent application was filed. In my opinion, a person of ordinary skill in the art for the '142 patent would have found the '142 patent invalid.

11. I have been retained by Intel Corporation (“Intel” or “Petitioner”) as an expert in the field of plasma technology. I am being compensated at my normal consulting rate of \$350/hour for my time. My compensation is not dependent on and in no way affects the substance of my statements in this Declaration.

12. I have no financial interest in the Petitioner. I similarly have no financial interest in the '142 patent, and have had no contact with the named inventor of the '142 patent.

## **I. RELEVANT LAW**

13. I am not an attorney. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the law is as follows:

### **A. Claim Construction**

14. I have been informed that claim construction is a matter of law and that the final claim construction will ultimately be determined by the Board. For the purposes of my invalidity analysis in this proceeding and with respect to the prior art, I have applied the broadest reasonable construction of the claim terms as they would be understood by one skilled in the relevant art.

15. I have been informed and understand that a claim in *inter partes* review is given the “broadest reasonable construction in light of the specification.” 37 C.F.R. § 42.100(b). I have also been informed and understand that any claim

term that lacks a definition in the specification is therefore also given a broad interpretation.

**B. Obviousness**

16. I have been informed and understand that a patent claim can be considered to have been obvious to a person of ordinary skill in the art at the time the application was filed. This means that, even if all of the requirements of a claim are not found in a single prior art reference, the claim is not patentable if the differences between the subject matter in the prior art and the subject matter in the claim would have been obvious to a person of ordinary skill in the art at the time the application was filed.

17. I have been informed and understand that a determination of whether a claim would have been obvious should be based upon several factors, including, among others:

- the level of ordinary skill in the art at the time the application was filed;
- the scope and content of the prior art;
- what differences, if any, existed between the claimed invention and the prior art.

18. I have been informed and understand that the teachings of two or more references may be combined in the same way as disclosed in the claims, if such a combination would have been obvious to one having ordinary skill in the

art. In determining whether a combination based on either a single reference or multiple references would have been obvious, it is appropriate to consider, among other factors:

- whether the teachings of the prior art references disclose known concepts combined in familiar ways, and when combined, would yield predictable results;
- whether a person of ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- whether the claimed elements represent one of a limited number of known design choices, and would have a reasonable expectation of success by those skilled in the art;
- whether a person of ordinary skill would have recognized a reason to combine known elements in the manner described in the claim;
- whether there is some teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and
- whether the innovation applies a known technique that had been used to improve a similar device or method in a similar way.

19. I understand that one of ordinary skill in the art has ordinary creativity, and is not an automaton.

20. I understand that in considering obviousness, it is important not to determine obviousness using the benefit of hindsight derived from the patent being considered.

## **II. BRIEF DESCRIPTION OF TECHNOLOGY**

### **A. Plasma**

21. A plasma is a collection of ions, free electrons, and neutral atoms. The negatively charged free electrons and positively charged ions are present in roughly equal numbers such that the plasma as a whole has no overall electrical charge. The “density” of a plasma refers to the number of ions or electrons that are present in a unit volume.<sup>1</sup>

22. Plasma had been used in research and industrial applications for decades before the '142 patent was filed. For example, sputtering is an industrial process that uses plasmas to deposit a thin film of a target material onto a surface called a substrate (e.g., silicon wafer during a semiconductor manufacturing operation). Ions in the plasma strike a target surface causing ejection of a small

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<sup>1</sup> The terms “plasma density” and “electron density” are often used interchangeably because the negatively charged free electrons and positively charged ions are present in roughly equal numbers in plasmas that do not contain negatively charged ions or clusters.

amount of target material. The ejected target material then forms a film on the substrate.

23. Under certain conditions, electrical arcing can occur during sputtering. Arcing is undesirable because it causes explosive release of droplets from the target that can splatter on the substrate. The need to avoid arcing while sputtering was known long before the '142 Patent was filed.

**B. Ions and excited atoms**

24. Atoms have equal numbers of protons and electrons. Each electron has an associated energy state. If all of an atom's electrons are at their lowest possible energy state, the atom is said to be in the "ground state."

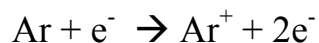
25. On the other hand, if one or more of an atom's electrons is in a state that is higher than its lowest possible state, then the atom is said to be an "excited atom." Excited atoms are electrically neutral— they have equal numbers of electrons and protons. A collision with a free electron ( $e^-$ ) can convert a ground state atom to an excited atom. For example, the '142 Patent uses the following equation to describe production of an excited argon atom,  $Ar^*$ , from a ground state argon atom,  $Ar$ . See '142 Patent at 10:12 (Ex. 1001).



26. An ion is an atom that has become disassociated from one or more of its electrons. A collision between a free, high energy, electron and a ground state



or excited atom can create an ion. For example, the '142 Patent uses the following equations to describe production of an argon ion,  $\text{Ar}^+$ , from a ground state argon atom,  $\text{Ar}$ , or an excited argon atom,  $\text{Ar}^*$ . See '142 Patent at 3:1 and 9:14 (Ex. 1001).



27. The production of excited atoms and ions was well understood long before the '142 patent was filed.

### **III. OVERVIEW OF THE '142 PATENT**

#### **A. Summary of Alleged Invention of the '142 Patent**

28. The '142 Patent describes generating a plasma by applying an electrical pulse in a manner that allegedly reduces the probability of arcing. More specifically, the claims of the '142 Patent are generally directed to generating a, so called, “weakly-ionized plasma” and then applying an electrical pulse to increase the density of that plasma so as to form a “strongly-ionized plasma.” The weakly-ionized plasma is claimed to reduce the probability of forming an electrical breakdown condition.

29. Specific claims are directed to further operational details such as supplying a feed gas to the plasma, characteristics of the electrical pulse, generating a magnetic field and the type of power supply used.

**B. Prosecution History**

30. I understand that the first substantive office action rejected all independent claims as anticipated. *See* 10/07/03 Office Action at 3 (Ex. 1007). I understand that the applicant then amended every independent claim to require “the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber” or similar limitations. *See* 03/08/04 Resp. (Ex. 1008).

31. I understand that following that amendment, the claims were allowed. I understand that the Notice of Allowance explicitly recites these limitations as the examiner’s reasons for allowance. 03/29/04 Allowance at 2 (“The prior art neither discloses nor suggests ... the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber such as required by claims 1, 22, 43, 44...10 and 33.”) (Ex. 1009). However, as explained in detail below, and contrary to the Examiner’s reasons for allowance, the prior art addressed herein teaches those and all other limitations of the challenged claims.

**IV. OVERVIEW OF THE PRIMARY PRIOR ART REFERENCES**

**A. Summary of the prior art**

32. As explained in detail below, limitation-by-limitation, there is nothing new or non-obvious in the challenged claims of the ‘142 Patent.

## B. Overview of Mozgrin<sup>2</sup>

33. Mozgrin teaches forming a plasma “without forming an arc discharge.”

34. Fig. 7 of Mozgrin, copied below, shows the current-voltage characteristic (“CVC”) of a plasma discharge.

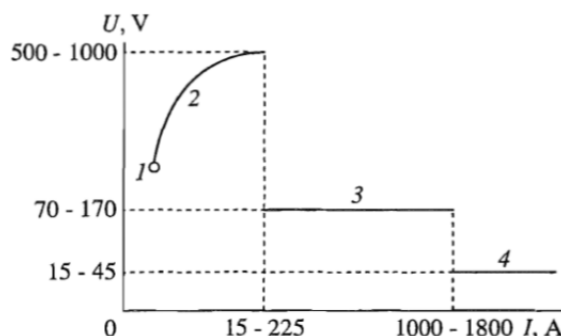


Fig. 7. Generalized ampere-voltaic characteristic CVC of quasi-stationary discharge.

35. As shown, Mozgrin divides this CVC into four distinct regions.

36. Mozgrin calls region 1 “pre-ionization.” Mozgrin at 402, right col, ¶ 2 (“Part 1 in the voltage oscillogram represents the voltage of the stationary discharge (pre-ionization stage).” (Ex. 1003).

37. Mozgrin calls region 2 “high current magnetron discharge.” Mozgrin at 409, left col, ¶ 4 (“The implementation of the high-current magnetron discharge (regime 2)...” (Ex. 1003). Application of a high voltage to the pre-ionized plasma

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<sup>2</sup> I understand that Mozgrin was art of record, but was not applied substantively during prosecution.

causes the transition from region 1 to 2. Mozgrin teaches that region 2 is useful for sputtering. Mozgrin at 403, right col, ¶ 4 (“Regime 2 was characterized by an intense cathode sputtering...”) (Ex. 1003).

38. Mozgrin calls region 3 “high current diffuse discharge.” Mozgrin at 409, left col, ¶ 5, (“The high-current diffuse discharge (regime 3)...”) (Ex. 1003). Increasing the current applied to the “high-current magnetron discharge” (region 2) causes the plasma to transition to region 3. Mozgrin also teaches that region 3 is useful for etching, i.e., removing material from a surface. Mozgrin at 409, left col, ¶ 5 (“The high-current diffuse discharge (regime 3) is useful ... Hence, it can enhance the efficiency of ionic etching...”) (Ex. 1003).

39. Mozgrin calls region 4 “arc discharge.” Mozgrin at 402, right col, ¶ 3 (“...part 4 corresponds to the high-current low-voltage arc discharge...” (Ex.

1003). Further increasing the applied current causes the plasma to transition from region 3 to the “arc discharge” region 4.<sup>3</sup>

40. Within its broad disclosure of a range of issues related to sputtering and etching, Mozgrin describes arcing and how to avoid it.

### **C. Overview of Wang<sup>4</sup>**

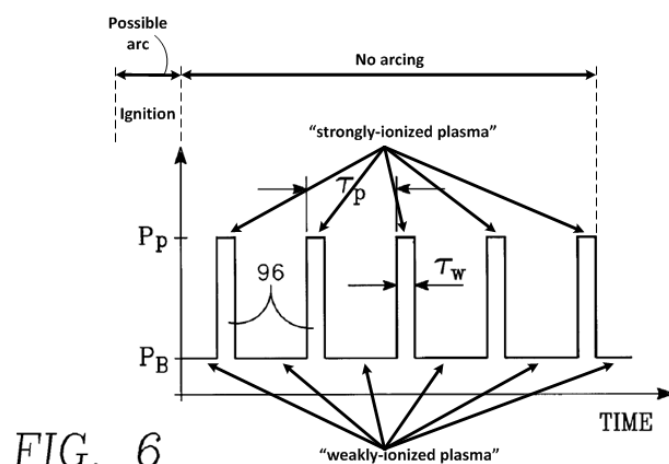
41. Wang discloses a pulsed magnetron sputtering device having an anode (24), a cathode (14), a magnet assembly (40), a DC power supply (100) (shown in Fig. 7), and a pulsed DC power supply (80). *See* Wang at Figs. 1, 7, 3:57-4:55; 7:56-8:12 (Ex. 1005). Fig. 6 (annotated and reproduced below) shows a graph of the power Wang applies to the plasma. The lower power level,  $P_B$ , is generated by

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<sup>3</sup> As one of ordinary skill would understand, the oscillogram shown in Mozgrin's Fig. 3 when taken as a whole corresponds to region 3 on Mozgrin's Figs. 4 and 7, i.e., Fig. 3 represents currents and voltages used to reach stable operation in region 3. Further, as one of ordinary skill would understand, an oscillogram corresponding to region 2 on Mozgrin's Figs. 4 and 7 (i.e., stable operation in region 2) would have a different shape, e.g., the voltage would not drop as low as shown in Fig. 3b and the current would be lower than what is shown in Fig. 3a.

<sup>4</sup> I understand that Wang was art of record, but was not substantively applied during prosecution.

the DC power supply 100 (shown in Fig. 7) and the higher power level,  $P_P$ , is generated by the pulsed power supply 80. *See* Wang 7:56-64 (Ex. 1005). Wang's lower power level,  $P_B$ , maintains the plasma after ignition and application of the higher power level,  $P_P$ , raises the density of the plasma. Wang at 7:17-31 ("The background power level,  $P_B$ , is chosen to exceed the minimum power necessary to support a plasma... [T]he application of the high peak power,  $P_P$ , quickly causes the already existing plasma to spread and increases the density of the plasma.") (Ex. 1005). Wang applies the teachings of Mozgrin in a commercial, industrial plasma sputtering device.



#### D. Overview of Lantsman

42. Like Mozgrin and Wang, Lantsman relates to plasma sputtering systems. Lantsman at Title ("Soft Plasma Ignition in Plasma Processing Chambers") (Ex. 1004); 1:6-8 ("This invention relates to reduction of device damage in plasma processes, including DC (magnetron or non-magnetron)

sputtering, and RF sputtering.”) (Ex. 1004). Also like Mozgrin and Wang, Lantsman is concerned with generating a plasma while avoiding arcing. Lantsman at 1:51-59 (“Furthermore, arcing which can be produced by overvoltages can cause local overheating of the target, leading to evaporation or flaking of target material into the processing chamber and causing substrate particle contamination and device damage.... Thus, it is advantageous to avoid voltage spikes during processing whenever possible.”) (Ex. 1004).

43. Lantsman also teaches supplying the feed gas during the entirety of the plasma processing. Lantsman at 3:9-13 (“[A]t the beginning of processing, this switch is closed and gas is introduced into the chamber. When the plasma process is completed, the gas flow is stopped....”) (Ex. 1004); 4:36-38 (“To end processing, primary supply 10 is disabled, reducing the plasma current and deposition on the wafer. Then, gas flow is terminated....”) (Ex. 1004).

44. I understand that Lantsman was not of record during the prosecution of the '142 Patent.

## **V. CLAIM CONSTRUCTION**

45. I have been informed and understand that a claim in *inter partes* review is given the “broadest reasonable construction in light of the specification.” 37 C.F.R. § 42.100(b). I have also been informed and understand that any claim term that lacks a definition in the specification is therefore also given a broad

interpretation. The following discussion proposes constructions of and support therefore of those terms. I have been informed and understand that any claim terms not included in the following discussion are to be given their broadest reasonable interpretation in light of the specification as commonly understood by those of ordinary skill in the art. Moreover, should the Patent Owner, in order to avoid the prior art, contend that the claim has a construction different from its broadest reasonable interpretation, I have been informed and understand that the appropriate course is for the Patent Owner to seek to amend the claim to expressly correspond to its contentions in this proceeding.

**A. “weakly-ionized plasma” and “strongly-ionized plasma”**

46. The challenged claims recite “weakly-ionized plasma” and “strongly-ionized plasma.” These terms relate to the density of the plasma, i.e., a weakly-ionized plasma has a lower density than a strongly-ionized plasma. With reference to Fig. 3, the '142 Patent describes forming a weakly-ionized plasma between times  $t_1$  and  $t_2$  by application of the low power 302 and then goes on to describe forming a strongly-ionized plasma by application of higher power 304. '142 Patent at 11:32-38; 12:9-16 (Ex. 1001). The '142 Patent also provides exemplary densities for the weakly-ionized and strongly-ionized plasmas. See '142 Patent at claim 17 (“wherein the peak plasma density of the weakly-ionized plasma is less



than about  $10^{12} \text{ cm}^{-3}$ "); claim 18 ("wherein the peak plasma density of the strongly-ionized plasma is greater than about  $10^{12} \text{ cm}^{-3}$ ") (Ex. 1001).

47. Therefore, I have used the following constructions:

- "weakly-ionized plasma" means "a lower density plasma" and
- "strongly-ionized plasma" means "a higher density plasma."

48. The constructions proposed above are consistent with the position the Patent Owner has taken in other jurisdictions. For example, I understand that the Patent Owner, when faced with a clarity objection during prosecution of a related European patent application, argued that "it is [sic] would be entirely clear to the skilled man, not just in view of the description, that a reference to a 'weakly-ionised plasma' in the claims indicates a plasma having an ionisation level lower than that of a 'strongly-ionized plasma' and there can be no lack of clarity."

04/21/08 Response in EP 1560943 (Ex. 1014).

## **VI. SPECIFIC GROUNDS FOR REJECTION**

49. The below sections demonstrate in detail how the prior art discloses each and every limitation of claims 1, 3-10, 12, 15, 17-20 and 42 of the '142 patent, and how those claims are rendered obvious by the prior art.

50. I have further reviewed and understand the claim charts submitted by Petitioner in the above-captioned *inter partes* review (Exs. 1015-1017), showing that each limitation in the foregoing claims is taught in the art. I understand these

claim charts were submitted in an ongoing litigation involving the Petitioner and the Patent Owner. Those charts present in summary form the analysis below and I agree with them.

**A. Ground I: Claims 1, 3-10, 12, 15, 17-20 and 42 are obvious in view of the combination of Mozgrin and Lantsman**

51. I have further reviewed and understand the claim charts submitted by Petitioner in the above-captioned *inter partes* review (Ex. 1015), showing that claims 1, 3-10, 12, 15, 17-20 and 42 are obvious in view of the combination of Mozgrin and Lantsman. I understand these claim charts were submitted in an ongoing litigation involving the Petitioner and the Patent Owner. Those charts present in summary form the analysis below and I agree with them.

1. Independent claim 1 is obvious in view of the combination of Mozgrin and Lantsman

*a) The preamble*

52. Claim 1 begins, “[a]n apparatus for generating a strongly-ionized plasma in a chamber.” As shown in Fig. 1, Mozgrin teaches generating plasma in “two types of devices: a planar magnetron and a system with specifically shaped hollow electrodes.” Mozgrin at Fig. 1; 400, right col, ¶ 4. (Ex. 1003). The densities in Mozgrin’s regions 1-3 are summarized below.

- Region 1:  $10^9 - 10^{11} \text{ cm}^{-3}$ .<sup>5</sup>
- Region 2: exceeding  $2 \times 10^{13} \text{ cm}^{-3}$ .<sup>6</sup>
- Region 3:  $1.5 \times 10^{15} \text{ cm}^{-3}$ .<sup>7</sup>

53. Mozgrin generates a strongly-ionized plasma in both regions 2 and 3. The density in those regions matches the exemplary density given for a strongly-ionized plasma in the '142 Patent. '142 Patent at claim 18 (“wherein the peak plasma density of the strongly-ionized plasma is greater than about  $10^{12} \text{ cm}^{-3}$ ”) (Ex. 1001).

54. Finally, Mozgrin generates a strongly-ionized plasma in a chamber. For example, Mozgrin states “[t]he gas from the discharge volume was pumped out; minimal residual gas pressure was about  $8 \times 10^{-6}$  torr.” Mozgrin at 401, left

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<sup>5</sup> Mozgrin at 401, right col, ¶2 (“For pre-ionization ... the initial plasma density in the  $10^9 - 10^{11} \text{ cm}^{-3}$  range.”) (Ex. 1003).

<sup>6</sup> Mozgrin at 409, left col, ¶ 4 (“The implementation of the high-current magnetron discharge (regime 2) in sputtering ... plasma density (exceeding  $2 \times 10^{13} \text{ cm}^{-3}$ ).”) (Ex. 1003).

<sup>7</sup> Mozgrin at 409, left col, ¶5 (“The high-current diffuse discharge (regime 3) is useful for producing large-volume uniform dense plasmas  $n_i \cong 1.5 \times 10^{15} \text{ cm}^{-3}$  ...”). (Ex. 1003).

col, ¶ 3 (Ex. 1003). That is, Mozgrin pumped the gas out to achieve a desired base pressure within the chamber. *See also* Mozgrin at Figs. 1 and 6 (Ex. 1003).

***b) Limitation (a)***

(1) “an ionization source that generates a weakly-ionized plasma from a feed gas”

55. The '142 Patent uses the terms “weakly-ionized plasma” and “pre-ionized plasma” synonymously. '142 Patent at 5:18-19 (“The weakly-ionized plasma is also referred to as a pre-ionized plasma.”) (Ex. 1001). Mozgrin’s power supply (shown in Fig. 2) generates a pre-ionized plasma in Mozgrin’s region 1. Mozgrin at 402, right col, ¶2 (“Figure 3 shows typical voltage and current oscillograms.... Part I in the voltage oscillogram represents the voltage of the stationary discharge (pre-ionization stage).”) (Ex. 1003).

56. Moreover, the density of Mozgrin’s pre-ionized plasma matches the exemplary density for weakly-ionized plasma given in the '142 Patent. '142 Patent at claim 17 (“wherein the peak plasma density of the weakly-ionized plasma is less than about  $10^{12} \text{ cm}^{-3}$ ”) (Ex. 1001); Mozgrin at 401, right col, ¶2 (“[f]or pre-ionization, we used a stationary magnetron discharge; ... provided the initial plasma density in the  $10^9 - 10^{11} \text{ cm}^{-3}$  range.”) (Ex. 1003).

57. Mozgrin also teaches generating its plasma from feed gasses such as Argon and Nitrogen. Mozgrin at 400, right col, ¶ 3 (“We investigated the

discharge regimes in various gas mixtures at  $10^{-3} - 10$  torr..."); 402, ¶ spanning left and right cols ("We studied the high-current discharge in wide ranges of discharge current...and operating pressure...using various gases (Ar, N<sub>2</sub>, SF<sub>6</sub>, and H<sub>2</sub>) or their mixtures of various composition...") (Ex. 1003).

(2) "the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber"

58. Mozgrin states "pre-ionization was not necessary; however, in this case, the probability of discharge transferring to arc mode increased." Mozgrin at 406, right col, ¶3 (Ex. 1003). Thus, Mozgrin teaches that failing to make the weakly-ionized plasma increases the probability of arcing and that creation of the weakly-ionized plasma (Mozgrin's region 1) reduces "the probability of developing an electrical breakdown condition in the chamber."

(a) The Patent Owner mischaracterized Mozgrin during prosecution of the related U.S. Pat. No. 7,147,759

59. The '142 Patent (Ex. 1001) and the '759 Patent (Ex. 1010) name the same inventor and are owned by a common assignee. Both patents are asserted in related litigation (Ex. 1018). I understand that during prosecution of the '759 Patent, the Patent Owner argued that Mozgrin does not teach "without forming an arc." See 05/02/06 Resp. of '759 Patent file history at 2, 5, 7 and 13-16 (Ex. 1011). However, the Patent Owner was wrong. Mozgrin does teach "without forming an

arc” as required by the ‘759 patent as well as “reducing the probability of developing an electrical breakdown condition” as required by the ‘142 patent.

60. As shown in Mozgrin’s Fig. 7, if voltage is steadily applied, and current is allowed to grow, the plasma will eventually transition to the arc discharge region (Mozgrin’s region 4). However, if the current is limited, the plasma will remain in the arc-free regions 2 (sputtering) or 3 (etching).

61. Mozgrin is an academic paper and it explores all regions, including the arc discharge region, so as to fully characterize the plasma. But Mozgrin’s discussion of arcing does not mean that arcing is inevitable. Rather, Mozgrin’s explanation of the conditions under which arcing occurs provides a recipe for avoiding arcs. Mozgrin explicitly notes that arcs can be avoided. *See* Mozgrin at 400, left col, ¶ 3 (“Some experiments on magnetron systems of various geometry showed that discharge regimes which do not transit to arcs can be obtained even at high currents.”) (Ex. 1003).

62. One of ordinary skill would understand that the arc discharge region should be avoided during plasma generation that is used for applications such as sputtering or etching. For example, *Plasma Etching: An Introduction*, by Manos and Flamm (“Manos”), a well-known textbook on plasma processing, which was published in 1989, over a decade before the ‘142 Patent was filed, states that “arcs...are a problem...” Manos at 231 (Ex. 1006).

63. One of ordinary skill would further understand that Mozgrin's arc region can be avoided, such as by generating a weakly-ionized plasma as explained above. Mozgrin's determination of conditions that cause transition to the arc regime is useful because it teaches one of ordinary skill how to avoid arcs.

64. Specifically, one of ordinary skill reading Mozgrin would understand that controlling discharge parameters, such as by generating the weakly-ionized plasma, causes the plasma to remain in the arc-free regions 2 (sputtering) or 3 (etching). *See* Mozgrin at 406, right col, ¶3 (Ex. 1003).

***c) Limitation (b)***

(1) “a power supply that supplies power to the weakly-ionized plasma though [sic] an electrical pulse applied across the weakly-ionized plasma”

65. Mozgrin's Fig. 3(b) shows a voltage pulse, which is an “electrical pulse,” generated by the “high-voltage supply unit” of Mozgrin's power supply (shown in Mozgrin's Fig. 2 (Ex. 1003)). Region 1 of Mozgrin's Fig. 3(b) represents the voltage used for pre-ionization, corresponding to generation of the weakly-ionized plasma. Mozgrin at 402, right col, ¶ 2 (“Part 1 in the voltage oscillogram represents the voltage of the stationary discharge (pre-ionization stage).”) (Ex. 1003). Region 2a of Mozgrin's Fig. 3(b) represents a voltage pulse that is applied across, and supplies power to, the weakly-ionized plasma. Mozgrin

at 401, left col, ¶ 4 (“[A]pplying a square voltage pulse to the discharge gap which was filled up with either neutral or pre-ionized gas.”) (Ex. 1003).

(2) “the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma”

66. Mozgrin’s voltage pulse has both a magnitude and a rise time. Table 1 of Mozgrin shows the parameters, including voltage, used in Mozgrin’s region 2. Mozgrin at 406, right col, ¶ 2 (“Table 1 presents parameter ranges corresponding to regime 2.”) (Ex. 1003). As shown in Mozgrin’s Table 1, the voltage in region 2 was controlled in a series of experiments to be in sub-ranges of 260-1100 Volts (e.g., in one experiment being controlled to 260-990 Volts). Mozgrin at 406, Table 1 (Ex. 1003). Mozgrin’s voltage pulse therefore has a magnitude. Mozgrin’s voltage pulse also has a rise time. Mozgrin at 401, right col, ¶ 1 (“[t]he power supply was able to deliver square voltage and current pulses with [rise] times (leading edge) of 5 – 60  $\mu$ s ....”) (Ex. 1003).

67. Mozgrin’s applied voltage pulse increases the plasma density from  $10^9 - 10^{11} \text{ cm}^{-3}$  in region 1 to greater than  $10^{13} \text{ cm}^{-3}$  in regions 2 and 3. Mozgrin therefore teaches generating a strongly-ionized plasma.

68. Because Mozgrin’s pulse created a strongly-ionized plasma, its magnitude and rise time were sufficient to generate a strongly-ionized plasma.



**d) Limitation (c)**

**(1) “a gas line that supplies feed gas”**

69. Use of gas feed lines in sputtering chambers was notoriously well known before the '142 Patent. To illustrate examples of gas feed lines in typical sputtering systems, Fig. 3-13 of Ohring (Ex. 1012) and Fig. 3-1 of Smith (Ex. 1013) are copied below. Ohring and Smith are both well-known text books and represent background knowledge that one of ordinary skill would have in mind while reading Mozgrin.

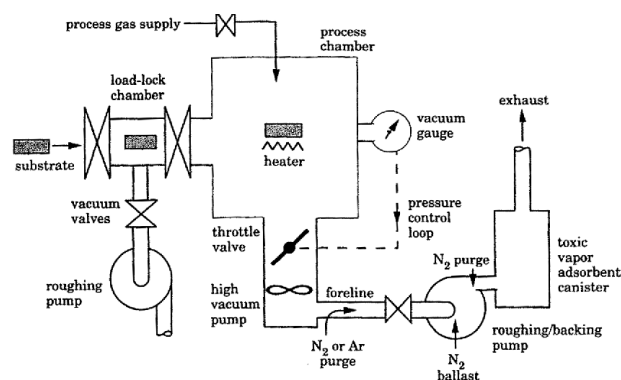


Figure 3.1 Typical vacuum-system components for thin-film deposition.

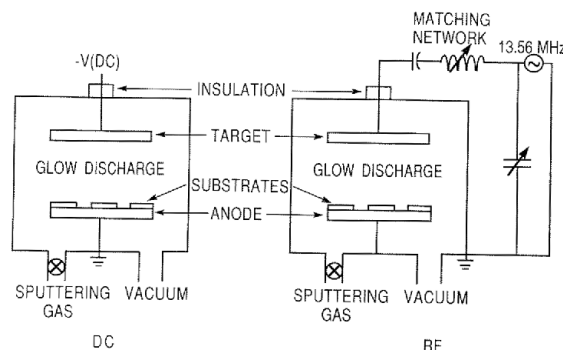


Figure 3-13. Schematics of simplified sputtering systems: (a) dc, (b) RF.

70. Both Figs. show a chamber that is connected to both (a) a source of sputtering (or “process”) gas via a gas line and (b) a vacuum pump. Further, both Figs. show a valve in the gas line for controlling the flow of gas into the chamber. Smith describes the valve as follows, “Process gasses and vapors are metered into the chamber through mass flow-controlled supply lines....” Smith at 35, ¶2 (Ex. 1013). Use of gas feed lines, gas control valves, and vacuum pumps are so notoriously well known, they are often omitted from references related to plasma

and sputtering. They need not be discussed in references because those of ordinary skill know that they are there.

71. Also, the Patent Owner admitted that use of gas feed lines was known in the art. '142 Patent at 2:21-34 (“FIG. 1 illustrates a cross-sectional view of a known plasma generating apparatus 100.... A feed gas from feed gas source 109, such as an argon gas source, is introduced into the vacuum chamber 104 through a gas inlet 110. The gas flow is controlled by a valve 112.”) (Ex. 1001); Fig. 1 (Ex. 1001).

72. Mozgrin discloses “[A]pplying a square voltage pulse to the discharge gap which was filled up with either neutral or pre-ionized gas.” Mozgrin at 401, left col, ¶ 4 (Ex. 1003). Lantsman also discloses providing a gas during processing. Lantsman at 5:39-42 (“Sometime thereafter, gas flow is initiated and the gas flow and pressure (trace 48) begin to ramp upwards toward normal processing levels.”); Fig. 6 (Ex. 1006). One of ordinary skill would have understood that Mozgrin and Lantsman used a gas line and valve, such as those illustrated in Ohring and Smith, for controlling the exchange of gas into and out of the plasma chamber.

(2) “to the strongly-ionized plasma, the feed gas diffusing the strongly-ionized plasma, thereby allowing additional power from the pulsed power supply to be absorbed by the strongly-ionized plasma”

73. It would have been obvious to one of ordinary skill to continue to add and remove (i.e., exchange) the feed gas in Mozgrin during production of the strongly-ionized plasma (i.e., during either of regions 2 or 3). Such exchange of the feed gas into and out of Mozgrin's chamber would have both diffused the strongly-ionized plasma and allowed additional power from Mozgrin's repeating voltage pulses to be absorbed by the strongly-ionized plasma as required by claim 1.<sup>8</sup> See Mozgrin at ¶ spanning pp. 403-404 ("The ... repetition frequency was 10 Hz....") (Ex. 1003). One of ordinary skill would have further understood that there is nothing inventive about this portion of claim 1 – it merely recites the natural

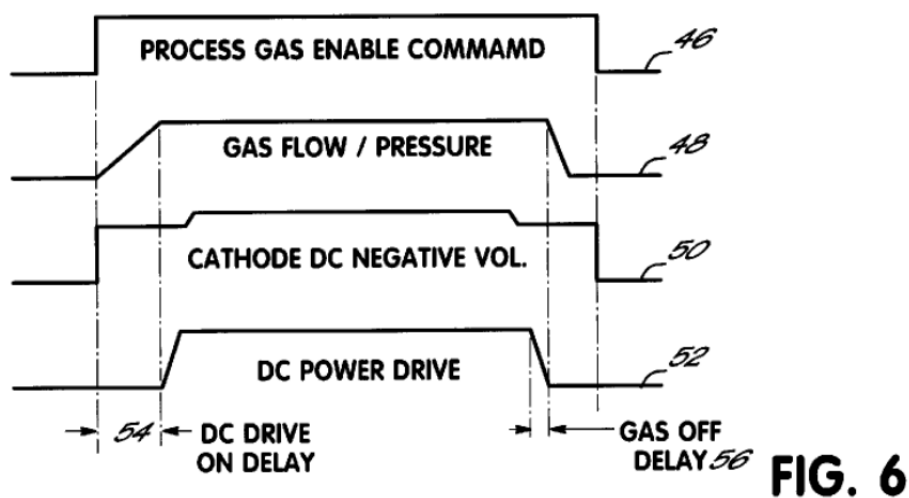
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<sup>8</sup> The continuous exchange of gas into and out of the magnetron sputtering chamber diffuses the plasma due to the gas flow, leading to more plasma being created. Moreover, the exchange of gas in the plasma volume with the feed gas reduces the gas temperature in the plasma compared to when there is no gas exchange. This lower gas temperature results in a higher density of the neutral gas. Furthermore, in magnetron sputtering chambers, the rate coefficients for ionization are mainly determined by the cathode layer voltage. Hence, a gas exchange that causes lower gas temperature and higher neutral gas density also results in higher rate of plasma generation through ionization and higher power absorption, compared to discharges without gas exchange.

consequence of exchanging gas during processing, e.g., by adding gas to balance gas withdrawn by the vacuum system.

74. Lantsman explicitly discloses supplying the feed gas during the entirety of the plasma processing. Lantsman at 3:9-13 (“[A]t the beginning of processing, this switch is closed and gas is introduced into the chamber. When the plasma process is completed, the gas flow is stopped....”) (Ex. 1004); 4:36-38 (“To end processing, primary supply 10 is disabled, reducing the plasma current and deposition on the wafer. Then, gas flow is terminated....”) (Ex. 1004).

75. Fig. 6 of Lantsman further clarifies that gas flows into the chamber throughout the plasma processing. In Figure 6, trace 48 indicates when gas is flowing into the chamber. Lantsman at 5:39-42 (“Sometime thereafter, gas flow is initiated and the gas flow and pressure (trace 48) begin to ramp upwards toward normal processing levels.”) (Ex. 1002). As shown in Fig. 6 by trace 48 and reference characters 54 and 56, gas flow ramps up at the beginning of processing and ramps down at the conclusion of processing. *See* Lantsman at 5:42-45 (Ex. 1004).



76. Lantsman discloses both pre-ionization and deposition phases as part of its processing, and teaches that gas flows into the chamber during the entirety of that processing. *See* Lantsman at 2:48-51 (“This secondary power supply ‘pre-ignites’ the plasma so that when the primary power supply is applied, the system smoothly transitions to final plasma development and deposition.”) (Ex. 1004).

77. Lantsman's pre-ionization corresponds to Mozgrin's region 1<sup>9</sup> and Lantsman's deposition corresponds to Mozgrin's region 2.<sup>10</sup> It would have been obvious to one of ordinary skill to continue to apply the feed gas during Mozgrin's regions 1 and 2 as taught by Lantsman. Such a continuous introduction of feed gas

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<sup>9</sup> Lantsman teaches that "the output voltage of secondary DC supply 32 was set at - 300 Volts." Lantsman at 4:17-18 (Ex. 1004). Similarly, Mozgrin teaches that "part 1 corresponds to the magnetron discharge with current up to 0.2 A and voltage range from 260 to 280 V." Mozgrin at 402, right col., ¶ 3. (Ex. 1003). Mozgrin's cathode was also negatively biased but reports the voltage in absolute values. *See* Mozgrin at 408, left col, ¶ 5 ("Because the negative potential of the cathode is..."). (Ex. 1003)

<sup>10</sup> Lantsman teaches that the "DC power supply 10 was set to output 6-10 kW of power." Lantsman at 4:11-12 (Ex. 1004). Similarly, Mozgrin teaches that "[i]f the discharge current ranged from 0.2 to 15A, a high-current magnetron discharge having initial discharge characteristics was observed (part 2 of the oscillogram). In this case the discharge voltage was rather high, approximately 350-500 V." Mozgrin at 402, right col., ¶ 3 – 403, left col., ¶ 1. (Ex. 1003). Taking the exemplary values of 500 V and 15A, Mozgrin applied 7.5 kW (=500 V x 15A) of power, which is between 6 - 10 kW utilized by Lantsman.

balances gas withdrawn by the vacuum system (e.g., as shown above in the drawings from Ohring and Smith) so as to maintain a desired pressure.

78. One of ordinary skill would have been motivated to combine Mozgrin and Lantsman. Both Mozgrin and Lantsman are directed to sputtering using plasma. *See* Mozgrin at 409, left col, ¶ 4 (“The implementation of the high-current magnetron discharge (regime 2) in sputtering or layer-deposition technologies provides an enhancement in the flux of deposited materials and plasma density....”) (Ex. 1003); *see also* Lantsman at 1:6-8 (“This invention relates to reduction of device damage in plasma processes, including DC (magnetron or non-magnetron) sputtering, and RF sputtering.”) (Ex. 1004). Both references also relate to sputtering systems that use two power supplies, one for pre-ionization and one for deposition. *See* Lantsman at 4:45-47 (“[T]he secondary [power] supply 32 is used to pre-ignite the plasma, whereas the primary [power] supply 10 is used to generate deposition.”) (Ex. 1004); *See* Mozgrin at Fig. 2. (showing the “high-voltage supply unit” and the “stationary discharge supply unit”) (Ex. 1003).

79. Moreover, both Mozgrin and Lantsman are concerned with generating plasma while avoiding arcing. *See* Mozgrin at 400, right col, ¶ 3 (“The main purpose of this work was to study experimentally a high-power noncontracted<sup>11</sup>

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<sup>11</sup> “Noncontracted” discharge means formation of plasma without arcing.

quasi-stationary discharge in crossed fields of various geometry and to determine their parameter ranges.”) (Ex. 1003); *see also* Lantsman at 1:51-59 (“Furthermore, arcing which can be produced by overvoltages can cause local overheating of the target, leading to evaporation or flaking of target material into the processing chamber and causing substrate particle contamination and device damage.... Thus, it is advantageous to avoid voltage spikes during processing whenever possible.”) (Ex. 1004).

80. Summarizing, Mozgrin and Lantsman relate to the same application. Further, one of ordinary skill would have been motivated to use Lantsman’s continuous gas flow in Mozgrin so as to maintain a desired pressure in the chamber. Finally, use of Lantsman’s continuous gas flow in Mozgrin would have been a combination of old elements in which each element behaved as expected.

81. Accordingly, the combination of Mozgrin and Lantsman teach the claimed “gas line...,” performing the function of “diffusing the strongly-ionized plasma with additional feed gas thereby allowing the strongly-ionized plasma to absorb additional energy from the power supply.”

82. In summary, the chart below identifies how claim 1 of the ‘142 Patent is rendered unpatentable by the combination of Mozgrin and Lantsman.

1. An apparatus for generating a strongly-ionized plasma in a chamber, the apparatus comprising:	<i>See, e.g.,</i> Mozgrin at 406 at Table 1; 407 at Table 2; 409, left col, ¶¶ 4-5 (Ex. 1003)
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an ionization source that generates a weakly-ionized plasma from a feed gas, the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber;	<i>See, e.g., Mozgrin at 400, right col, ¶ 3; 401, right col, ¶2; 402, right col, ¶ 2; 402, ¶ spanning left and right cols; 406, right col, ¶3 (Ex. 1003)</i>  <i>See, e.g., Mozgrin at Fig. 7; 400, left col, ¶ 3; 400, right col, ¶ 1; 403, left col, ¶ 2; 404, left col, ¶ 4; 406, right col, ¶ 3 (Ex. 1003).</i>
a power supply that supplies power to the weakly-ionized plasma though an electrical pulse applied across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma; and	<i>See, e.g., Mozgrin at Figs. 2, 3; 401, left col, ¶ 4; 401, right col, ¶ 1; 402, right col, ¶ 2; 403, right col, ¶4; 406, right col, ¶ 2; Table 1; 409, left col, ¶ 4 (Ex. 1003)</i>
a gas line that supplies feed gas to the strongly-ionized plasma, the feed gas diffusing the strongly-ionized plasma, thereby allowing additional power from the pulsed power supply to be absorbed by the strongly-ionized plasma.	<i>See, e.g., Lantsman at Fig. 6; 1:6-8; 1:51-59; 2:48-51; 3:9-13; 4:36-38; 4:45-47; 5:39-45 (Ex. 1004).</i>  <i>See, e.g., Mozgrin at Fig. 2; 400, right col, ¶ 3; 409, left col, ¶ 4 (Ex. 1003).</i>

2. Independent claim 10 is obvious in view of the combination of Mozgrin and Lantsman

*a) The preamble*

83. The preamble of claim 10 reads “[a] method for generating a strongly-ionized plasma in a chamber.” The preamble of claim 10 is taught by Mozgrin as explained above with respect to the preamble of claim 1.

*b) Limitation (a)*

84. Limitation (a) of claim 10 reads “ionizing a feed gas to form a weakly-ionized plasma that reduces the probability of developing an electrical breakdown condition in the chamber” and is taught by Mozgrin as explained above with respect to limitation (a) claim 1.

***c) Limitation (b)***

85. Limitation (b) of claim 10 reads “supplying power to the weakly-ionized plasma by applying an electrical pulse across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma” and is taught by Mozgrin as explained above with respect to limitation (b) of claim 1.

***d) Limitation (c)***

86. Limitation (c) of claim 10 reads “diffusing the strongly-ionized plasma with additional feed gas thereby allowing the strongly-ionized plasma to absorb additional energy from the power supply” and is taught by the combination of Mozgrin and Lantsman as explained above with respect to limitation (c) of claim 1.

87. In summary, the chart below identifies how claim 10 of the '142 Patent is rendered unpatentable by the combination of Mozgrin and Lantsman.

10. A method for generating a	<i>See, e.g., Mozgrin at 406 at Table 1;</i>
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strongly-ionized plasma in a chamber, the method comprising:	407 at Table 2; 409, left col, ¶¶ 4-5 (Ex. 1003)
ionizing a feed gas to form a weakly-ionized plasma that reduces the probability of developing an electrical breakdown condition in the chamber;	<p><i>See, e.g., Mozgrin at 400, right col, ¶ 3; 401, right col, ¶2; 402, right col, ¶ 2; 402, ¶ spanning left and right cols; 406, right col, ¶3 (Ex. 1003)</i></p> <p><i>See, e.g., Mozgrin at Fig. 7; 400, left col, ¶ 3; 400, right col, ¶ 1; 403, left col, ¶ 2; 404, left col, ¶ 4; 406, right col, ¶ 3 (Ex. 1003).</i></p>
supplying power to the weakly-ionized plasma by applying an electrical pulse across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma; and	<i>See, e.g., Mozgrin at Figs. 2, 3; 401, left col, ¶ 4; 401, right col, ¶ 1; 402, right col, ¶ 2; 403, right col, ¶4; 406, right col, ¶ 2; Table 1; 409, left col, ¶ 4 (Ex. 1003)</i>
diffusing the strongly-ionized plasma with additional feed gas thereby allowing the strongly-ionized plasma to absorb additional energy from the power supply.	<p><i>See, e.g., Lantsman at Fig. 6; 1:6-8; 1:51-59; 2:48-51; 3:9-13; 4:36-38; 4:45-47; 5:39-45 (Ex. 1004).</i></p> <p><i>See, e.g., Mozgrin at Fig. 2; 400, right col, ¶ 3; 409, left col, ¶ 4 (Ex. 1003).</i></p>

3. Dependent claims 3-9, 12, 15, 17-20 and 42 are obvious in view of the combination of Mozgrin and Lantsman

88. **Claims 3 and 12** depend from claims 1 and 10, respectively. Claim 3 recites “wherein the gas line supplies additional feed gas that exchanges the weakly-ionized plasma while applying the electrical pulse across.” Claim 12

recites “further comprising exchanging the weakly-ionized plasma with additional feed gas.”

89. As explained above with respect to limitation (c) of claim 1, Lantsman teaches supplying feed gas during the entirety of plasma processing. For the same reason that one of ordinary skill would have added feed gas to the plasma in Mozgrin’s region 2 (as explained above with respect to claim 1), one of ordinary skill would have also added feed gas to the plasma in Mozgrin’s region 1. Mozgrin’s region 1 has a weakly-ionized plasma and corresponds to Lantsman’s pre-ionization phase. One of ordinary skill would have added feed gas to the plasma in Mozgrin’s region 1 so as to maintain a desired pressure in the chamber. Such addition of gas would have exchanged the weakly-ionized plasma with additional feed gas. One of ordinary skill would have further understood that there is nothing inventive about claims 3 and 12 – they merely recite the natural consequence of exchanging gas during processing, e.g., by adding gas to balance gas withdrawn by the vacuum system. The combination of Mozgrin and Lantsman therefore teaches the limitations added by claims 3 and 12.

90. **Claim 4** depends from claim 1 and recites “wherein the power supply generates a constant power.”

91. Fig. 4 of the ‘142 Patent shows voltage, current and power generated by the power supply and applied to the plasma. *See, e.g.*, ‘142 Patent, 12:47-51

(Ex. 1001). The lower portion of Fig.4 (which shows power on the Y-axis) shows a constant power segment between  $t_1$  and  $t_2$ . '142 Patent, 12:66-67 (“Between time  $t_1$  and time  $t_2$ , the voltage 326, the current 328, and the power 330 remain constant....”). Fig. 4 shows two other constant power segments between (a)  $t_5$  and  $t_6$  and (b)  $t_6$  and  $t_7$ .

92. Figs. 3(b) and 3(a) of Mozgrin shows the voltage and current, respectively (both of which are nearly identical to that of Fig. 4 of the '142 Patent), generated by the power supply and applied to the plasma (Mozgrin's power supply is shown in Fig. 2). Mozgrin's Fig. 3 does not have a separate graph for power, but because power equals voltage times current, Mozgrin's Fig. 3 discloses the power generated by the supply<sup>12</sup>. As shown, the power applied to the plasma in Mozgrin's region 3 is constant (i.e., the voltage and current are both constant in that region). Therefore, Mozgrin teaches the limitation of claim 4, “wherein the power supply generates a constant power.”

93. Moreover, Lantsman teaches that power supplies that generate constant power were well known. Lantsman at 1:22-24 (“A typical DC power

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<sup>12</sup> Mozgrin's Fig. 3 represents measured data from an actual experiment, so the traces are not perfectly horizontal, as shown in the idealized Fig. 4 of the '142 Patent.

supply 10 includes a relatively sophisticated control system, designed to permit operation in constant power, constant voltage, or constant current modes.”) (Ex. 1004). The combination of Mozgrin and Lantsman therefore also teaches the limitation of claim 4.

94. **Claim 5** depends from claim 1 and recites “wherein the power supply generates a constant voltage.”

95. As noted above with respect to claim 4, Mozgrin discloses a power supply that generates a constant voltage, as illustrated in region 3 of Mozgrin’s Fig. 3(b). Moreover, Lantsman teaches that power supplies that generate constant voltage were well known. Lantsman at 1:22-24 (“A typical DC power supply 10 includes a relatively sophisticated control system, designed to permit operation in constant power, constant voltage, or constant current modes.”) (Ex. 1004). The combination of Mozgrin and Lantsman therefore also teaches the limitation of claim 5.

96. **Claim 6** depends from claim 1 and recites “wherein the ionization source is chosen from the group comprising an electrode coupled to a DC power supply...”

97. Mozgrin explains that the stationary discharge supply unit of the power supply unit shown in Fig. 2 is a DC power supply. Mozgrin at 401, left col, ¶ 5 (“...The pre-ionization system provided direct current up to 0.3A and voltage

up to 3 kV.”) (Ex. 1003). Moreover, either of the anode or cathode shown in Mozgrin’s Fig. 1 satisfy the “electrode” limitation of claim 6.

98. **Claims 7 and 20** depend from claims 1 and 10, respectively. Claim 7 recites “further comprising a magnet that is positioned to generate a magnetic field proximate to the weakly-ionized plasma, the magnetic field trapping electrons in the weakly-ionized plasma.” Claim 20 recites “further comprising generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field trapping electrons in the weakly-ionized plasma.

99. In Fig. 1 of Mozgrin, the magnets are labeled “3.” The field generated by those magnets extends through the cathode “2,” anode “1,” and the space between them. Mozgrin at 401, left col, ¶ 1 (“The electrodes were immersed in a magnetic field of annular permanent magnets.”) (Ex. 1003). Further, Mozgrin’s magnetic field is proximate to the weakly-ionized plasma, because the weakly-ionized plasma is generated between the electrodes that were immersed in the magnetic field. See Mozgrin at 401, left col, ¶ 1 (“The [plasma] discharge had an annular shape and was adjacent to the cathode.”) (Ex. 1003); 401, right col, ¶2 (“We found out that only the regimes with magnetic field strength not lower than 400 G provided the initial plasma density in the  $10^9$ - $10^{11}$  cm<sup>-3</sup> range.”) (Ex. 1003).

100. The ‘142 Patent admits that prior art magnetrons trap electrons. ‘142 Patent at 1:41-43 [*in the Background of the Invention*] (“Magnetron sputtering

systems use magnetic fields that are shaped to trap and concentrate secondary electrons...” (Ex. 1001). Like the prior art acknowledged by the '142 Patent, Mozgrin's magnetic field traps electrons thereby enhancing collisions between electrons and gas particles. Mozgrin at 407, left col, ¶ 3 (“The action of the magnetic field serves only to limit the electron thermal conductivity and to provide collisions sufficient for efficient energy transfer from electrons to heavy particles.”) (Ex. 1003). Therefore, Mozgrin teaches the limitations of claims 7 and 20.

101. **Claim 8** depends from claim 7 and recites “wherein the magnet comprises an electro-magnet.” Fig. 1b of Mozgrin shows a shaped-electrode magnetron. Mozgrin at 401, right col, Fig. 1 caption, (“Fig. 1. Discharge device configurations: (a) planar magnetron; (b) shaped-electrode configuration...”) (Ex. 1003). In Mozgrin's shaped-electrode magnetron, magnet 3 is an electro-magnet. Mozgrin at 401, left col, ¶ 2 (“The system with shaped electrodes involved two axisymmetrical electrodes 120 mm in diameter separated by about 10 mm, and immersed in a cusp-shaped magnetic field produced by oppositely directed multilayer coils. The values of  $B_{\max}$  were controlled by coil current variation to range from 0 to 1000 G.”) (Ex. 1003).

102. **Claim 9** depends from claim 7 and recites “wherein the magnet is movable.” Mozgrin discloses that “[t]o control the magnetic field strength at the



cathode surface, we displaced the magnetic system along the axis z (Fig. 1)...”

Mozgrin at 401, left col, ¶ 1 (Ex. 1003). Hence, Mozgrin discloses a movable magnet.

103. **Claim 15** depends from claim 10 and recites “further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse in order to cause the strongly-ionized plasma to be substantially uniform.”

104. As discussed above with respect to claim 1, Mozgrin teaches using a pulse amplitude (or “magnitude”) of the electrical pulse that is sufficient to generate the strongly-ionized plasma, such as in region 2.

105. Mozgrin further teaches generation of a strongly-ionized plasma that is uniform in region 2 near the cathode. Mozgrin, at 403, left col, last ¶ (“...being transferred to the high-current regime, the discharge expands over a considerably larger area of the cathode surface than it occupied in the stationary pre-ionization regime.”) (Ex. 1003). One of ordinary skill would understand that such an expanded plasma discharge is substantially uniform. Mozgrin’s voltage pulse also has a width, shown in region 2a of Fig. 3(b). Mozgrin at Fig. 3(b).

106. Mozgrin’s pulse, which was characterized by a particular amplitude and pulse width, produces a substantially uniform plasma. Mozgrin therefore teaches the limitation of claim 15.

107. **Claim 17** depends from claim 10 and recites “wherein the peak plasma density of the weakly-ionized plasma is less than about  $10^{12} \text{ cm}^{-3}$ .”

108. Mozgrin’s region 1, pre-ionized, plasma is the claimed “weakly-ionized plasma.” Mozgrin’s pre-ionized plasma has a density of  $10^9 - 10^{11} \text{ cm}^{-3}$ , which satisfies the requirement of claim 17. Mozgrin at 401, right col. ¶ 2 (“For pre-ionization, ... the initial plasma density [is] in the  $10^9 - 10^{11} \text{ cm}^{-3}$  range....”) (Ex. 1003) .

109. **Claim 18** depends from claim 10 and recites “wherein the peak plasma density of the strongly-ionized plasma is greater than about  $10^{12} \text{ cm}^{-3}$ .”

110. As explained above with respect to claim 1, the plasma in either of Mozgrin’s region 2 or 3 corresponds to the claimed “strongly-ionized plasma.” Mozgrin measured the density of the plasma in region 2 as exceeding  $2 \times 10^{13} \text{ cm}^{-3}$ . Mozgrin at 409, left col, ¶ 4. Mozgrin also measured the density of the plasma in region 3 as being as high as  $1.5 \times 10^{15} \text{ cm}^{-3}$ . Mozgrin at 409, left col, last ¶. (Ex. 1003). Both of those measured densities satisfy the limitation of claim 18.

111. **Claim 19** depends from claim 10 and recites “wherein the ionizing the feed gas comprises exposing the feed gas to...an pulsed electric field....”

112. Fig. 1a of Mozgrin illustrates the electric field (labeled “E”) for a planar magnetron. Mozgrin, at 401, Fig. 1 caption, (“Fig. 1. Discharge device configurations: (a) planar magnetron;”). The voltage applied between the anode

and cathode of that planar magnetron determines the electric field. The voltage pulse shown in region 2 of Mozgrin's Fig. 3 causes Mozgrin's electric field to be "pulsed" as required by claim 19. Moreover, Mozgrin teaches repeating its voltage pulse at a frequency of 10 Hertz. Mozgrin, at 403-404, right col, last paragraph of 403, left col, first paragraph of 404 ("The current pulse ... repetition frequency was 10 Hz...") (Ex. 1003). Each repetition of Mozgrin's voltage pulse generates another pulse of Mozgrin's electric field and Mozgrin therefore teaches the "pulsed electric field" limitation of claim 19.

113. **Claim 42** depends from claim 1 and recites "wherein the power supply comprises the ionization source."

114. In claim 1, the "ionization source" generates the weakly-ionized plasma and the "power supply" generates the strongly-ionized plasma. As shown in Fig. 2, Mozgrin's power supply contains two distinct units: a stationary discharge supply unit for making the pre-ionized plasma and a high-voltage supply unit for applying pulses. Mozgrin at 401, left col, ¶5 ("Figure 2 presents a simplified scheme of the discharge supply system. The supply unit involved a pulsed discharge supply unit and a system for pre-ionization.") (Ex. 1003). Both of Mozgrin's units belong to a common power supply that supplies power to the cathode from a common point as shown in Fig. 2. Mozgrin therefore teaches the limitation of claim 42.

**B. Ground II: Claims 1, 3-7, 9, 10, 12, 15, 19, 20 and 42 are obvious in view of the combination of Wang and Lantsman**

115. I have further reviewed and understand the claim chart submitted by Petitioner in the above-captioned inter partes review (Ex. 1016), showing that claims 1, 3-7, 9, 10, 12, 15, 19, 20 and 42 are obvious in view of the combination of Wang and Lantsman. I understand this claim chart was submitted in an ongoing litigation involving the Petitioner and the Patent Owner. This chart presents in summary form the analysis below and I agree with it.

116. The technology described in Mozgrin has been implemented in a commercial grade sputtering system, such as is described in Wang, which is assigned to Applied Materials, Inc., one of the world's leading suppliers of sputtering tools.

1. Independent claim 1 is obvious in view of the combination of Wang and Lantsman

*a) The preamble*

117. Claim 1 begins, “[a]n apparatus for generating a strongly-ionized plasma in a chamber.”

118. Wang generates a low density plasma during application of the background power,  $P_B$ , and a high density plasma during application of the peak power  $P_P$ . Wang at 7:17-31 (“The background power level,  $P_B$ , is chosen to exceed the minimum power necessary to support a plasma... [T]he application of the high

peak power,  $P_P$ , quickly causes the already existing plasma to spread and increases the density of the plasma.”) (Ex. 1005). The high density plasma that Wang generates with the peak power,  $P_P$ , is a strongly-ionized plasma. Wang discloses that the background power,  $P_B$ , can be 1 kW and the peak power,  $P_P$ , can be 1000 times greater, i.e., 1 MW. Wang at 7:19-25; 7:28-30 (Ex. 1005). Wang also discloses that “highly ionized sputtering” occurs during application of the peak power  $P_P$ . Wang at 7:31-39 (Ex. 1005).

119. Finally, Wang’s plasma is generated with a chamber, i.e., chamber 12 as shown in Fig. 1. (Ex. 1005).

(1) “an ionization source that generates a weakly-ionized plasma from a feed gas”

120. Wang teaches using feed gasses such as Argon and Nitrogen for forming its plasmas. *See, e.g.*, Wang at 4:5-6 (“A sputter working gas such as argon is supplied from a gas source 32....”); and 4:20-21 (“... a reactive gas, for example nitrogen is supplied to the processing space 22....”) (Ex. 1005).

121. Wang generates a low density plasma with the background power,  $P_B$ , and a high density plasma with the peak power,  $P_P$ . Wang at 7:17-31 (“The background power level  $P_B$  is chosen to exceed the minimum power necessary to support a plasma... [T]he application of the high peak power  $P_P$  quickly causes the already existing plasma to spread and increases the density of the plasma.”) (Ex.

1005). Wang's low density plasma is generated using DC power supply 100, shown in Fig. 7. *See* Wang 7:56-64 (Ex. 1005). Wang's low density plasma causes little if any sputtering and the background power,  $P_B$ , used to generate it is 1000 times lower than the peak power,  $P_P$ . Wang at 7:19-25 ("Preferably, the peak power  $P_P$  is at least 10 times the background power  $P_B$  ... and most preferably 1000 times to achieve the greatest effect of the invention. A background power  $P_B$  of 1 kW [causes] little if any actual sputter deposition." (Ex. 1005).

122. The low density plasma that Wang generates with the background power,  $P_B$  (which is 1000 times lower than the peak power), which causes little if any sputtering, is a weakly-ionized plasma.

(2) "the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber"

123. Wang teaches that maintaining the weakly-ionized plasma between the pulses reduces arcing, or breakdown conditions. Wang at 7:3-49 ("Plasma ignition, particularly in plasma sputter reactors, has a tendency to generate particles during the initial arcing, which may dislodge large particles from the target or chamber... The initial plasma ignition needs be performed only once and at much lower power levels so that particulates produced by arcing are much reduced.") (Ex. 1005).

124. As shown in the annotated version of Fig. 6 above in Section IV.C, Wang teaches that arcing may occur during ignition, i.e., prior to the first pulse shown in Fig. 6, and that since the plasma need not be reignited thereafter, arcing will not occur during subsequent applications of the background and peak power levels,  $P_B$  and  $P_P$ . See Wang at 7:25-28 (“As a result, once the plasma has been ignited at the beginning of sputtering prior to the illustrated waveform, no more plasma ignition occurs.”). Wang therefore teaches that the weakly-ionized plasma reduces “the probability of developing an electrical breakdown condition.”

***b) Limitation (b)***

(1) “a power supply that supplies power to the weakly-ionized plasma though [sic] an electrical pulse applied across the weakly-ionized plasma”

125. Fig. 7 of Wang shows a pulsed DC supply 80 that generates a train of voltage pulses. Wang at Fig. 7; 7:61-62 (“The pulsed DC power supply 80 produces a train of negative voltage pulses.”) (Ex. 1005). Application of those voltage pulses to Wang’s cathode 14 and anode 24 produces Wang’s peak power pulses,  $P_P$ , which are applied to Wang’s weakly-ionized plasma, i.e., the plasma generated by the background power,  $P_B$ . Wang’s power pulses, shown in Fig. 6, are “electrical pulses.”

(2) “the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the

weakly-ionized plasma to generate a strongly-ionized plasma”

126. As explained above with respect to the preamble, the high density plasma that Wang generates with the peak power pulses,  $P_P$ , is a strongly-ionized plasma.

127. The voltage pulses disclosed in Wang have a magnitude and a rise time. Wang at 5:23-27 (“[The pulse’s] exact shape depends on the design of the pulsed DC power supply 80, and significant rise times and fall times are expected.”) (Ex. 1005).

128. Wang specifies that the background power  $P_B$  can be 1 kW and that the peak power  $P_P$  can be 1,000 times greater than the background power, i.e., 1 MW. Wang at 7:19-25 (“Preferably, the peak power  $P_P$  is at least 10 times the background power  $P_B$  ... and most preferably 1000 times.... A background power  $P_B$  of one kW will typically be sufficient....”) (Ex. 1005). Wang’s electrical pulses therefore have a magnitude of 1 MW.

129. Wang’s pulse also has a rise time. Wang at 5:23-26 (“The illustrated pulse form is idealized. Its exact shape depends on the design of the pulsed DC power supply 80, and significant rise times and fall times are expected.”) (Ex. 1005).



130. Because Wang's pulse produce a strongly-ionized plasma, the magnitude and rise time of the pulse "is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma" as required by claim 1.

*c) Limitation (c)*

(1) "a gas line that supplies feed gas"

131. Fig. 1 of Wang shows a gas source 32 that supplies gas, such as argon, through a gas flow controller 34. As shown in Fig. 1, the gas is supplied by a "gas line."

(2) "to the strongly-ionized plasma, the feed gas diffusing the strongly-ionized plasma, thereby allowing additional power from the pulsed power supply to be absorbed by the strongly-ionized plasma"

132. As shown in Fig. 1, Wang's feed gas is supplied into the chamber with the strongly-ionized plasma. Wang at 4:5-6 ("A sputter working gas such as argon is supplied from a gas source 32 through a mass flow controller 34 to a region in back of the grounded shield 24.") (Ex. 1005); 4:8-10 ("The gas flows into the processing region 22 through a gap formed between the pedestal 18, the grounded shield 24, and a clamp ring or plasma focus ring 36 surrounding the periphery of the wafer 20.") (Ex. 1005).

133. One of ordinary skill would understand that Wang supplies the feed gas during the entirety of its processing. Fig. 1 of Wang shows a mass flow

controller 34 for metering gas into the chamber. Wang at 4:51-55 (“A computerized controller 58 controls the ... mass flow controller 34, as illustrated....”) (Ex. 1005). As one of ordinary skill would understand, mass flow controllers are used in sputtering chambers like Wang’s when it is desired to exchange gas into and out of a plasma chamber continuously throughout the process. This is because mass flow controllers are inaccurate during start up and ramp down – but they are accurate for maintaining a stable inflow that is balanced by the outflow of a vacuum system such as shown in Wang at 38. Wang at 4:11-12 (“A vacuum system 38 pumps the chamber....”) (Ex. 1005). If Wang wanted to shut off the flow of gas during processing, one of ordinary skill would understand that Wang would have used a valve instead of a mass flow controller.

134. Further, it would have been obvious to one of ordinary skill to continue to exchange the feed gas into and out of Wang’s chamber during production of the strongly-ionized plasma (i.e., during the application of the high peak power  $P_p$  pulses). Such exchange of the feed gas into and out of Wang’s chamber would have both diffused the strongly-ionized plasma and allowed additional power from Wang’s repeating voltage pulses to be absorbed by the

strongly-ionized plasma as required by claim 10<sup>13</sup>. *See* Wang at 5:66-67 (“It is anticipated that the pulse repetition frequency is best maintained around 50 to 500 Hz.”) (Ex. 1005). One of ordinary skill would have further understood that there is nothing inventive about this portion of claim 10 - it merely recites the natural consequence of exchanging gas during processing, e.g., by adding gas to balance gas withdrawn by the vacuum system. As explained above with respect to Ground I, Lantsman explicitly discloses supplying the feed gas during the entirety of the plasma processing.

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<sup>13</sup> The continuous exchange of gas into and out of the magnetron sputtering chamber diffuses the plasma due to the gas flow, leading to more plasma being created. Moreover, the exchange of gas in the plasma volume with the feed gas reduces the gas temperature in the plasma compared to when there is no gas exchange. This lower gas temperature results in a higher density of the neutral gas. Furthermore, in magnetron sputtering chambers, the rate coefficients for ionization are mainly determined by the cathode layer voltage. Hence, a gas exchange that causes lower gas temperature and higher neutral gas density also results in higher rate of plasma generation through ionization and higher power absorption, compared to discharges without gas exchange.

135. As was also explained above with respect to Ground I, Lantsman discloses both pre-ionization and deposition phases as part of its processing and gas flows into the chamber during the entirety of that processing. *See* Lantsman at 2:48-51 (“This secondary power supply ‘pre-ignites’ the plasma so that when the primary power supply is applied, the system smoothly transitions to final plasma development and deposition.”) (Ex. 1005).

136. Lantsman’s pre-ionization corresponds to Wang’s application of background power,  $P_B$ <sup>14</sup>, and Lantsman’s deposition corresponds to Wang’s

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<sup>14</sup> Lantsman teaches that “the output voltage of secondary DC supply 32 was set at -300 Volts.” Lantsman at 4:17-18 (Ex. 1004). Lantsman further notes that “[t]his confirms that secondary power supply 32 is holding cathode 14 at a voltage of approximately -300 Volts DC, thereby maintaining ignition of plasma within chamber 14 before and after deposition. Lantsman at 6:7-11 (Ex. 1004).

Similarly, Wang teaches a “background power  $P_B$  of 1kW will typically be sufficient to support a plasma...” Wang at 7:22-24 (Ex. 1005). Moreover, the “background level  $P_B$  is chosen to exceed the minimum power necessary to support a plasma in the chamber at the operational pressure.” Wang at 7:17-19 (Ex. 1005)

application of high peak power,  $P_p$ <sup>15</sup>. It would have been obvious to one of ordinary skill to continue to exchange the feed gas during Wang's application of background power and high peak power, as taught by Lantsman. Such a continuous introduction of feed gas balances gas withdrawn by Wang's vacuum system 38 so as to maintain a desired pressure.

137. One of ordinary skill would have been motivated to combine Wang and Lantsman. Both Wang and Lantsman are directed to sputtering using plasma. *See* Wang at Title (Ex. 1005); 3:20-21 (Ex. 1005); *see also* Lantsman at 1:6-8 (Ex. 1004). Also, both references relate to sputtering systems that use two power supplies, one for pre-ionization and one for deposition. *See* Wang at Fig. 7 [showing pulsed supply 80 and constant supply 100] (Ex. 1005); *see also* Lantsman at 4:45-47 ("...the secondary [power] supply 32 is used to pre-ignite the plasma, whereas the primary [power] supply 10 is used to generate deposition.") (Ex. 1004). Moreover, as explained above with respect to Ground I, Lantsman is

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<sup>15</sup> Lantsman teaches that the "DC power supply 10 was set to output 6-10 kW of power." Lantsman at 4:11-12 (Ex. 1004). Similarly, Wang teaches that "the peak power  $P_p$  is at least 10 times the background power  $P_B$ ...A background power  $P_B$  of 1 kW will typically be sufficient..." Wang at 7:19-23 (Ex. 1005).

concerned with generating plasma while avoiding arcing. So is Wang. Wang at 7:3-49 (Ex. 1005).

138. Summarizing, Wang and Lantsman relate to the same application. Further, one of ordinary skill would have been motivated to use Lantsman's continuous gas flow in Wang so as to maintain a desired pressure in the chamber. Also, use of Lantsman's continuous gas flow in Wang would have worked well with Wang's mass flow controller 34 and would have been a combination of old elements in which each element behaved as expected. Finally, such a continuous flow of gas in Wang would diffuse the strongly-ionized plasma and allow additional power to be absorbed by the plasma as required by claim 1.

139. In summary, the chart below identifies how claim 1 of the '142 Patent is rendered unpatentable by the combination of Wang and Lantsman.

1. An apparatus for generating a strongly-ionized plasma in a chamber, the apparatus comprising:	<i>See, e.g.,</i> Wang at Fig. 1; 4:29-31; 7:19-22; 7:28-30 (Ex. 1005)
an ionization source that generates a weakly-ionized plasma from a feed gas, the weakly-ionized plasma reducing the probability of developing an electrical breakdown condition in the chamber;	<i>See, e.g.,</i> Wang at Figs. 1, 6; 4:5-8; 4:20-21; 7:3-6; 7:13-30; 7:47-49 (Ex. 1005)
a power supply that supplies power to the weakly-ionized plasma through an electrical pulse applied across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma	<i>See, e.g.,</i> Wang at Figs. 6, 7; 5:23-26; 7:19-25; 7:28-30; 7:61-62 (Ex. 1005)

to generate a strongly-ionized plasma; and	
a gas line that supplies feed gas to the strongly-ionized plasma, the feed gas diffusing the strongly-ionized plasma, thereby allowing additional power from the pulsed power supply to be absorbed by the strongly-ionized plasma.	<p><i>See, e.g., Wang at Title; Figs. 1, 7; 4:5-6; 4:8-12; 4:51-55; 7:3-49 (Ex. 1005)</i></p> <p><i>See, e.g., Lantsman at 1:6-8; 1:51-59 2:48-51; 4:45-47 (Ex. 1004)</i></p>

2. Independent claim 10 is obvious in view of the combination of Wang and Lantsman

***a) The preamble***

140. The preamble of claim 10 reads “[a] method for generating a strongly-ionized plasma in a chamber” and is taught by Wang as explained above with respect to the preamble of claim 1.

***b) Limitation (a)***

141. Limitation (a) of claim 10 reads “ionizing a feed gas to form a weakly-ionized plasma that reduces the probability of developing an electrical breakdown condition in the chamber” and is taught by Wang as explained above with respect to limitation (a) of claim 1.

***c) Limitation (b)***

142. Limitation (b) of claim 10 reads “supplying power to the weakly-ionized plasma by applying an electrical pulse across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase

the density of the weakly-ionized plasma to generate a strongly-ionized plasma”

and is taught by Wang as explained above with respect to limitation (b) of claim 1.

***d) Limitation (c)***

143. Limitation (c) of claim 10 reads “diffusing the strongly-ionized plasma with additional feed gas thereby allowing the strongly-ionized plasma to absorb additional energy from the power supply” and is taught by the combination of Wang and Lantsman as explained above with respect to limitation (c) of claim 1.

144. In summary, the chart below identifies how claim 10 of the ‘142 Patent is rendered unpatentable by the combination of Wang and Lantsman.

10. A method for generating a strongly-ionized plasma in a chamber, the method comprising:	<i>See, e.g.,</i> Wang at Fig. 1; 4:29-31; 7:19-22; 7:28-30 (Ex. 1005)
ionizing a feed gas to form a weakly-ionized plasma that reduces the probability of developing an electrical breakdown condition in the chamber;	<i>See, e.g.,</i> Wang at Figs. 1, 6; 4:5-8; 4:20-21; 7:3-6; 7:13-30; 7:47-49 (Ex. 1005)
supplying power to the weakly-ionized plasma by applying an electrical pulse across the weakly-ionized plasma, the electrical pulse having a magnitude and a rise-time that is sufficient to increase the density of the weakly-ionized plasma to generate a strongly-ionized plasma; and	<i>See, e.g.,</i> Wang at Figs. 6, 7; 5:23-26; 7:19-25; 7:28-30; 7:61-62 (Ex. 1005)
diffusing the strongly-ionized plasma with additional feed gas thereby allowing the strongly-ionized plasma to absorb additional energy from the power supply.	<i>See, e.g.,</i> Wang at Title; Figs. 1, 7; 4:5-6; 4:8-12; 4:51-55; 7:3-49 (Ex. 1005)  <i>See, e.g.,</i> Lantsman at 1:6-8; 1:51-59



	2:48-51; 4:45-47 (Ex. 1004)
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3. Dependent claims 3-7, 9, 12, 14, 15, 19, 20 and 42 are obvious in view of the combination of Wang and Lantsman

145. **Claims 3 and 12** depend from claims 1 and 10, respectively. Claim 3 recites “wherein the gas line supplies additional feed gas that exchanges the weakly-ionized plasma while applying the electrical pulse across.” Claim 12 recites “further comprising exchanging the weakly-ionized plasma with additional feed gas.”

146. As explained above with respect to limitation (c) of claim 1, Lantsman teaches supplying feed gas during the entirety of plasma processing. Wang teaches supplying feed gas into Wang’s processing region 22. In Wang, during application of the background power,  $P_B$ , processing region 22 has a weakly-ionized plasma that corresponds to Lantsman’s pre-ionization phase. One of ordinary skill would have added feed gas during application of Wang’s background power,  $P_B$ , as taught by Lantsman, so as to maintain a desired pressure in the chamber. Such an addition of gas would have exchanged the weakly-ionized plasma as required by claims 3 and 12. One of ordinary skill would have further understood that there is nothing inventive about claims 3 and 12 – they merely recite the natural consequence of exchanging gas during processing, e.g., by adding gas to balance

gas withdrawn by the vacuum system. The combination of Wang and Lantsman therefore teaches the limitations of claims 3 and 12.

147. **Claim 4** depends from claim 1 and recites “wherein the power supply generates a constant power.”

148. As explained above with respect to claim 4 in Ground I, Fig. 4 of the '142 patent shows constant power segments between (a)  $t_1$  and  $t_2$  (b)  $t_5$  and  $t_6$  and (c)  $t_6$  and  $t_7$ . Wang's pulsed DC power supply 80 (shown in Wang's Figs. 1 and 7) generates a peak level power,  $P_P$ , which is constant for the duration of the pulse  $\tau_w$ , as shown in Fig. 6.

149. Moreover, Lantsman teaches that power supplies that generate constant power were well known. Lantsman at 1:22-24 (“A typical DC power supply 10 includes a relatively sophisticated control system, designed to permit operation in constant power, constant voltage, or constant current modes.”) (Ex. 1004). The combination of Wang and Lantsman therefore also teaches the limitation of claim 4.

150. **Claim 5** depends from claim 1 and recites “wherein the power supply generates a constant voltage.”

151. Wang's “pulsed DC power supply 80 produces a train of negative voltage pulses.” Wang at 7:61-62 (Ex. 1005). Application of those voltage pulses to Wang's cathode 14 and anode 24 produces Wang's peak power pulses,  $P_P$ . One

of ordinary skill would have understood that Wang's voltage would be constant for at least a portion of the duration of the pulse  $\tau_w$  so as to produce pulse  $P_p$  of constant power.

152. Moreover, Lantsman teaches that power supplies that generate constant voltage were well known. Lantsman at 1:22-24 ("A typical DC power supply 10 includes a relatively sophisticated control system, designed to permit operation in constant power, constant voltage, or constant current modes.") (Ex. 1004). The combination of Wang and Lantsman therefore teaches the limitation of claim 5.

153. **Claim 6** depends from claim 1 and recites "wherein the ionization source is chosen from the group comprising an electrode coupled to a DC power supply..."

154. Wang explains that the power supply 100 connected to the cathode 14 is a DC power supply. Wang at 7:58 ("... DC power supply 100 is connected to the target 14.") (Ex. 1005); *see also* Fig. 7 (Ex. 1005). Moreover, the cathode 14 shown in Wang's Fig. 1 satisfies the "electrode" limitation of claim 6. Wang therefore teaches the limitation of claim 6.

155. **Claims 7 and 20** depend from claims 1 and 10, respectively. Claim 7 recites "further comprising a magnet that is positioned to generate a magnetic field proximate to the weakly-ionized plasma, the magnetic field trapping electrons in

the weakly-ionized plasma.” Claim 20 recites “further comprising generating a magnetic field proximate to the weakly-ionized plasma, the magnetic field trapping electrons in the weakly-ionized plasma.

156. As explained above with respect to claims 7 and 20 in Ground I, the '142 Patent admits that trapping electrons using magnetic fields was well known. '142 Patent at 1:41-43 [*in the Background of the Invention*] (“Magnetron sputtering systems use magnetic fields that are shaped to trap and concentrate secondary electrons....”) (Ex. 1001).

157. Similarly, Wang discloses that “[a] small rotatable magnetron 40 is disposed in the back of the target 14 to create a magnetic field near the face of the target 14 which traps electrons from the plasma to increase the electron density.” Wang at 4:23-27. (Ex. 1005). Wang’s rotating magnet assembly forms a region of high density plasma, shown in Wang’s Fig. 1 at 42.<sup>16</sup> Wang at 4:23-31 (“A small rotatable magnetron 40 ... traps electrons from the plasma to increase the electron density. For charge neutrality, the ion density also increases, thus creating a region

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<sup>16</sup> Wang calls the region 42, which is proximate to the sputtering target, a “high density plasma” (HDP) because the magnets trap the electrons and increase the plasma density in that region. For the same reason, the plasma generated by background power,  $P_B$ , is also trapped in the same region.

42 of a high-density plasma (HDP)...”) (Ex. 1005). Because it is created by the magnetron 40, Wang’s HDP region 42 is proximate to the magnetic field. During application of Wang’s background power level,  $P_B$ , the weakly-ionized plasma in region 42 is proximate to the magnetic field as required by claims 7 and 20.

158. **Claim 9** depends from claim 7 and recites “wherein the magnet is movable.”

159. Wang discloses a rotating magnetron assembly. Wang at 4:23-24 (“A small rotatable magnetron 40 is disposed in the back of the target 14”) (Ex. 1005).

160. **Claim 15** depends from claim 10 and recites “further comprising selecting at least one of a pulse amplitude and a pulse width of the electrical pulse in order to cause the strongly-ionized plasma to be substantially uniform.”

161. As explained above with respect to claim 1, Wang teaches using a magnitude/amplitude of the electrical pulse that generates a strongly-ionized plasma. Wang’s pulses also have a pulse width,  $\tau_w$ , as shown in Fig. 6, and that pulse width again results in generation of Wang’s strongly-ionized plasma.

162. Also, Wang teaches eroding the target “evenly” so as to provide a “uniform” sputter coating. Wang at 4:49-51 (“The rotation scans the HDP region 42 about the face of the target 14 to more evenly erode the target 14 and to produce a more uniform sputter coating on the wafer 20.”) (Ex. 1005). Wang’s even target

erosion occurs because Wang's strongly-ionized plasma is substantially uniform, at least within the HDP region.

163. The amplitude and width taught in Wang results in a substantially uniform strongly-ionized plasma. Wang therefore teaches the limitation of claim 15.

164. **Claim 19** depends from claim 10 and recites "wherein the ionizing the feed gas comprises exposing the feed gas to ... an pulsed electric field...."

165. As shown in Wang's Fig. 7, Wang uses a low magnitude voltage to produce the background power  $P_B$  and a higher magnitude voltage to produce the peak power  $P_P$ . Wang at 7:61-63 ("The pulsed DC power supply 80 produces a train of negative voltage pulses...."). Each of those voltages generates a different electric field between Wang's cathode 14 and its anode 24. Successive application of those voltage pulses produces a pulsed electric field. Moreover, as explained above with respect to claim 1, the application of those voltage pulses generates Wang's high-density sputtering plasma. Wang therefore teaches the "pulsed electric field" limitation of claim 19.

166. **Claim 42** depends from claim 1 and recites "wherein the power supply comprises the ionization source."

167. In claim 1, the "ionization source" generates the weakly-ionized plasma and the "power supply" generates the strongly-ionized plasma. In Wang,

the supply 100 (shown in Fig. 7) generates the weakly-ionized plasma and the pulsed supply 80 generates the strongly-ionized plasma. Wang at 7:57-63 (“A variable DC power supply 100 is connected to the target 14 ... and supplies an essentially constant negative voltage to the target 14 corresponding to the background power  $P_B$ . The pulsed DC power supply 80 produces a train of negative voltage pulses....”) (Ex. 1005). Both supplies 80 and 100 are part of a common power supply that supplies power to the cathode 14 from a common point as shown in Fig. 7. Therefore, Wang teaches the limitation of claim 42.

**C. Ground III: Claims 8, 17 and 18 are obvious in view of the combination of Wang, Lantsman and Mozgrin**

168. I have further reviewed and understand the claim chart submitted by Petitioner in the above-captioned inter partes review (Ex. 1017), showing that claims 8, 17 and 18 are obvious in view of the combination of Wang, Lantsman and Mozgrin. I understand this claim chart was submitted in an ongoing litigation involving the Petitioner and the Patent Owner. This chart presents in summary form the analysis below and I agree with it.

169. **Claim 8** depends from claim 7 and recites “wherein the magnet comprises an electro-magnet.”

170. Wang does not explicitly disclose that its magnets, e.g., as shown in Fig. 1, can be electro-magnets. However, electro-magnets were well known and it

would have been obvious to use them in Wang. For example, as explained above with respect to claim 8 in Ground I, Mozgrin discloses electro-magnets.

171. Mozgrin and Wang both related to pulsed magnetron sputtering and it would have been obvious to use Mozgrin's electron magnet in Wang. Further, using Mozgrin's electro-magnet in Wang would have been a combination of old elements in which each element performed as expected.

172. **Claim 17** depends from claim 10 and recites "wherein the peak plasma density of the weakly-ionized plasma is less than about  $10^{12} \text{ cm}^{-3}$ ."

173. One of ordinary skill would recognize that Wang's plasma, made with the background power,  $P_B$ , has the density specified by claim 17. Further, one of ordinary skill would expect Wang's pre-pulse plasma (generated with  $P_B$ ) to have a density similar to that of Mozgrin's pre-pulse plasma. Mozgrin's pre-pulse plasma, in Mozgrin's region 1, has a density that is below  $10^{12} \text{ cm}^{-3}$ . Mozgrin at 401, right col, ¶2. ("We found out that only the regimes with magnetic field strength not lower than 400 G provided the initial plasma density in the  $10^9$ - $10^{11} \text{ cm}^{-3}$  range. This initial density was sufficient for the plasma density to grow when the square voltage pulse was applied to the gap.") (Ex. 1003). Further, as noted in Mozgrin, having a density in the  $10^9$ - $10^{11} \text{ cm}^{-3}$  range permitted the density to grow upon application of the pulse. *Id.* (Ex. 1003). One of ordinary skill reading Wang



would be motivated to use a density in the  $10^9$ - $10^{11}$   $\text{cm}^{-3}$  range so that its plasma density would grow suitably upon application of Wang's pulse.

174. **Claim 18** depends from claim 10 and recites "wherein the peak plasma density of the strongly-ionized plasma is greater than about  $10^{12}$   $\text{cm}^{-3}$ ."

175. One of ordinary skill would recognize that Wang's plasma, made with the peak power,  $P_p$ , has the density specified by claim 18. Further, as explained above with respect to claim 17, it would have been obvious to use the densities described in Mozgrin in Wang, e.g., so as to achieve desired sputtering.

## **VII. CONCLUSION**

176. Based on the foregoing, it is my opinion that claims 1, 3-10, 12, 15, 17-20 and 42 of the '142 Patent recite subject matter that is unpatentable.

## **VIII. AVAILABILITY FOR CROSS-EXAMINATION**

177. 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.

## **IX. RIGHT TO SUPPLEMENT**

178. I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner raises and to take into account new information as it becomes available to me.

**Jurat**

179. I 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 1101 of Title 18 of the United States Code.

Dated: *March 12, 2014*



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Uwe Kortshagen  
Minneapolis, MN

## **APPENDIX A**

**Uwe R. Kortshagen, Ph.D.**

Distinguished McKnight University Professor  
Professor and Head of Mechanical Engineering  
University of Minnesota, 111 Church Street S.E., Minneapolis, MN 55455

**Education:**

Nov. 1995            Habilitation in experimental physics, University of Bochum, Germany.  
Jan. 1991            Ph.D. in physics, University of Bochum, Germany.  
June 1988            Diploma degree in physics, University of Bochum, Germany.

**Academic Employment and Appointments:**

7/2008 – present: Head, Department of Mechanical Engineering, U. of Minnesota  
7/2007- present: Distinguished McKnight University Professor  
8/2006- 6/2008: Director of Graduate Studies, Dept. of Mechanical Eng., U. of Minnesota  
8/2003- present: Professor, Mechanical Engineering, U. of Minnesota  
8/1999 – 8/2003: Associate Professor, Mechanical Engineering and Physics, U. of Minnesota  
7/1996 – 8/1999: Assistant Professor, Mechanical Engineering, University of Minnesota.  
4/1996 - 7/1996: Lecturer, Dept. of Physics and Astronomy, University of Bochum, Germany.  
3/1995 – 3/1996: Visiting scholar, University of Wisconsin - Madison, Dept. of Physics.  
1/1991 – 3/1995: Research Associate, Dept. of Physics and Astronomy, University of Bochum.  
  
2/2008-present: Graduate Faculty of Chemical Engineering  
2/2008-present: Graduate Faculty of Materials Science  
9/2003-present: Graduate Faculty, Free-standing Minor in Nanoparticle Science and Eng.  
9/1999-present: Graduate Faculty of Physics

**Research Interests:** Nonthermal plasma physics, plasma modeling and diagnostics, electron kinetics in nonthermal plasmas, atmospheric pressure discharges, nanoparticles in plasma environments, plasma synthesis of materials, nanoparticle materials for photovoltaics and luminescent devices.

**Publications and presentations** (ISI Science Citation Index: ~4,100 citations, H-index: 36)

> 130 publications in peer-review journals  
> 250 conference contributions (partly reviewed)  
1 book (co-editor)  
4 book chapters  
2 patents  
> 100 invited lectures

**Awards and Honors:**

2013 Fellow, International Plasma Chemistry Society  
2009 Fellow, American Society of Mechanical Engineers

2008 President, International Plasma Chemistry Society  
2007 Distinguished McKnight University Professor  
2005 U. Minnesota Institute of Technology-George Taylor Award for Distinguished Research  
2004 Fellow, Institute of Physics (U.K.)  
1999 NSF Career Award  
1997 Director, NATO Advanced Research Workshop  
1997 Mayhugh Assistant Professor  
1994 Lynen Award of Alexander von Humboldt Foundation  
1991 "Preis an Studenten," best dissertation award of the Ruhr-Universität Bochum

### **Significant Activities:**

- Editorial Boards:
  - Plasma Sources Science and Technology (IOP) (2002-present)
  - Contributions to Plasma Physics (Wiley) (2007-2011)
- Chair, Gordon Research Conference on Plasma Processing Science, July 11-16, 2010, Colby Sawyer College, NH.
- Organized "Tips for Promotion and Tenure" Workshop at ASME annual fall meeting (IMECE), Nov. 2011, Vancouver, BC.
- Organized Iprime Renewable Energy Materials Meeting, May 28, 2009.
- Track Chair, ASME 3rd Energy Nanotechnology International Conference, Aug. 2008, Jacksonville, FL.
- Group Leader for "Interaction of plasmas with, and production of, nanostructures," tasked with writing part of DOE Workshop on Low Temperature Plasma Science (LTPS) report to initiate new DOE funding initiative for LTPS, March 2008.
- President, International Plasma Chemistry Society, 2008-2009.
- Board of Directors, International Plasma Chemistry Society, 2003-2011.
- Vice Chair, Gordon Research Conference on Plasma Processing Science, 2008.
- Member, Executive Committee, UMN Cntr. for Nanostructure Applications, 2007-present.
- Program Committee, ASME 2nd Energy Nanotechnology International Conference, Sept. 2007, San Jose, CA.
- Advisory (Editorial) Board, Contributions to Plasma Physics (Wiley), 2007-present.
- Vice President, Board of Directors, International Plasma Chemistry Society, 2006-2007.
- Scientific Advisor, Innovalight, Inc., Santa Clara, CA, 2005-2007.
- Group Leader, UMN Nanoparticle Initiative, 2005-2008.
- Member, UMN MRSEC Executive Committee, 2005-present.
- Leader, IPRIME Nanoparticle Technology program, 2004-2009. Co-Leader, IPRIME Renewable Energy Materials Program, 2010-2013.
- Director of Graduate Studies, Mechanical Engineering, 2006-2008.
- Director of Graduate Studies, freestanding minor in Nanoparticle Science and Engineering. 2002-present.
- Tutorial Speaker:
  - 2006 ASME Nano Bootcamp

- 2007 Spring Course, Graduiertenkolleg, University Duisburg-Essen
- 2008 ASME Nano Training Summer School
- 2008 American Association for Aerosol Research
- Lead-author, proposal for free-standing Minor in Nanoparticle Science and Engineering, 2001.
- Director, NSF-IGERT project for Nanoparticle Science and Engineering, 2001-2008.
- Editorial Board, Plasma Sources Science and Technology (Institute of Physics), 2002-present.
- Secretary and local organizer of the 55<sup>th</sup> Gaseous Electronics Conference held in Minneapolis in Oct. 2002.
- Member of the Executive Committee of the Gaseous Electronics Conference, 2000-2003.
- Member of the International Organizing Committee, 15<sup>th</sup> International Symposium on Plasma Chemistry, Orleans, France, 2001.
- Member of the Scientific Advisory Board of the Institute of Low-Temperature Plasma Physics in Greifswald, Germany, (Federal Institute with 100+ employees) 2001-2008.
- Program Committee, Gordon Research Conference on Plasma Processing Science, Tilton, NH, July 2000.
- Director and Organizer of the NATO Advanced Research Workshop on “Electron Kinetics and Applications of Glow Discharges,” held May 19-23, 1997, in St. Petersburg, Russia.
- Editor of the NATO ASI Series volume “Electron Kinetics and Applications of Glow Discharges,” Plenum Publishing Corp., New York, 1998.

**Memberships to Professional Organizations:**

American Association for the Advancement of Science (AAAS)  
American Chemical Society (ACS)  
American Physical Society (APS)  
American Society of Mechanical Engineers (ASME)  
Alexander von Humboldt Association of America  
Deutsche Physikalische Gesellschaft (DPG, German Physical Society)  
Materials Research Society  
Sigma Xi

**Reviewer for Funding Agencies:**

National Science Foundation  
US Department of Agriculture  
US Department of Energy  
California Micro Program  
Irish Science Foundation  
FOM, Netherlands Foundation for Fundamental Research on Matter

**Reviewer for Professional Journals:**

ACS Nano  
Advanced Materials  
Advanced Functional Materials  
Aerosol Science and Technology

AIAA Journal  
Applied Physics Letters  
Chemistry of Materials  
Contributions to Plasma Physics  
European Journal of Applied Physics  
Europhysics Letters  
IEEE Transactions on Plasma Science  
International Journal of Heat and Mass Transfer  
Journal de Physique III  
Journal of Applied Physics  
Journal of Nanoparticle Research  
Journal of Luminescence  
Journal of Physics D: Applied Physics  
Journal of Physical Chemistry  
Journal of Plasma Physics  
Journal of Vacuum Science and Technology A  
Plasma Sources Science and Technology  
Plasma Chemistry and Plasma Processing  
Physics of Plasmas  
Physical Review E  
Physical Review Letters  
Progress in Energy and Combustion Science



### **Administrative Activities**

#### **Head, Mechanical Engineering, July 2008-present**

- Led 2008-09 ME department strategic planning process.
- Leading implementation of ME strategic plan 2009-14.
- Provided leadership for planned ME building projects: Renovation of ME building (~\$46M project), move of ME Engine Lab to new location (~\$5M+ project).
- Appointed new team of ME department academic officers.
- Led restructuring of ME administrative and academic units.
- From 2008-2012, grew number of ME faculty from 33 to 38. Growth of ME faculty continuing.
- Initiated ME Alumni Network, now with more than 1,000 registered members.
- Initiated events to engage all stakeholders: ME public lectures, homecoming open house, research symposium, informal faculty lunches for staff members, welcome event for new undergraduate students, etc.
- Initiated reviews of graduate and undergraduate curriculum.
- Representing ME department at national meetings of the American Society of Mechanical Engineers.
- Elected member of ASME Department Head Executive Committee. Elected to officer position: Secretary, 2011-12; Vice Chair, 2012-13; Chair, 2013-14.
- Organizer, "Tips for Promotion and Tenure" Workshop at ASME annual fall meeting (IMECE), Nov. 2011, Vancouver, BC.
- Organizer, Professional Development Workshop for ME Department Heads, ASME annual fall meeting (IMECE), Nov. 2012, Houston, TX.
- Organizer and facilitator for annual meeting of Big Ten Plus ME department heads. 2009-present
- Successfully defended against several attempts by other universities to hire some of the ME department's top faculty.

#### **Director of Graduate Studies, Mechanical Engineering, 2006-2008**

- Responsible for admission decisions for the mechanical engineering Ph.D. and M.S. program.
- Responsible for graduate student recruiting: Organized annual recruiting weekend; developed new recruiting materials; presented mechanical engineering graduate program at UMN and local and regional four-year colleges.
- Implemented new Ph.D. oral qualifying exam procedure: Responsible for forming qualifying exam committees and organizing qualifying exam procedure administered every semester.
- Responsible for departmental fellowship decisions: selected departmental fellowship committees; made fellowship decisions based on committee recommendations. Increased number of departmental fellowship offers from 42 (2006) to 74 (2008).
- Represented graduate program at the graduate school and the Mathematics, Physical Sciences and Engineering Policy and Review Council.

- Represented mechanical engineering graduate program at the Network for Interdisciplinary Initiatives.
- Increased block grant funding from graduate school from \$120k/yr with one-year commitment to \$160k/yr with three-year commitment.
- Coordinated decadal National Research Council ranking of graduate programs for the mechanical engineering program in 2007.

**Director, NSF-IGERT program for Nanoparticle Science and Engineering, 2001-2009**

- Administration of grant involving more than 30 faculty and 35 students from six departments within the Institute of Technology.
- Managed budget of ~\$3.3M over seven years.
- Organized annual meetings and reviews by External Advisory Board.
- Organized international collaboration, including three joint workshops, with international partner (University of Duisburg-Essen, Germany).
- Represented IGERT grant at NSF and within the University.
- Responsible for data collection and annual reporting to NSF.
- Responsible for undergraduate summer program in collaboration with Florida A&M University.
- Organized bi-weekly IGERT seminar since Fall 2002.

**Director of Graduate Studies, Freestanding Minor for Nanoparticle Science and Engineering,  
2002-present**

- Developed proposal to the graduate school for free-standing minor.
- Managed implementation of minor program. Represented minor program at graduate school.
- Oversaw and participated in the development of two new core courses.
- Responsible for staffing courses, which are largely taught through voluntary faculty teaching overload.

**Other administrative activities:**

- Group Leader, Nanoparticle-Materials Initiative at UMN:  
Proposed initiative to Institute of Technology Dean in 2004; group of 7 faculty was established in 2005 as seed cluster (proto-IRG) within the Materials Research Science and Engineering Center (MRSEC); proto-IRG was successfully reviewed by NSF in Fall 2006; proto-IRG emerged as full IRG in the MRSEC renewal proposal and was funded as IRG-IV "Nanoparticle-based Materials".
- Member of the MRSEC executive committee, 2004-present.
- Member of the UMN Center for Nanostructure Applications Executive Committee, 2007-present.
- Group Leader, Nanoparticle-Technology (NPT) Program with Iprime (Industrial Partnership for Research in Interfacial and Materials Engineering, a consortium at UMN

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involving more than 40 companies): Assembled NPT faculty team, represented NPT program at member companies, recruited companies to join NPT program.

### Advising Activities

Student	Field	Co-Advisor	Year
<b>Ph. D.</b>			
Gianluca Gregori	plasma diagnostics	J. Heberlein	2001
Upendra Bhandarkar	nanoparticles (NP)	n/a	2003
Peng Zheng	plasma modeling	J. Heberlein	2005
Lorenzo Mangolini	NP luminescence	n/a	2006
Ameya Bapat	nanoparticles	n/a	2007
Curtis Anderson	photovoltaics	n/a	2008
Chin-Yi Liu	photovoltaics	n/a	2009
Jason Holm	NP surface chem.	J. Roberts	2009
Richard Liptak	NP luminescence	S. Campbell	2009
Federico Galli	nanoparticles	n/a	2010
Zak Holman	photovoltaics	n/a	2010
Rebekah Anthony	NP luminescence	n/a	2011
David Rowe	photovoltaics	n/a	2013
Song Guo	plasma actuators	n/a	2013
Lin Cui	photovoltaics	n/a	2013
Jason Trask	Si films	n/a	2013
Meenakshi Manunuru	plasma modeling	n/a	exp. 2013
Andrew Wagner	Si films	A. Mkhoyan	exp. 2013
Lance Wheeler	NP films	n/a	exp. 2014
Nic Kramer	NP films	n/a	exp. 2015
Ting Chen	NP luminescence	n/a	exp. 2015
Jeslin Wu	NP luminescence	n/a	exp. 2015
Narula Bilik	plasma science	n/a	exp. 2016
Elliot Combs	Plasma Science	E. Aydil	exp. 2017
Ben Greenberg	NP plasmonics	n/a	exp. 2017
<b>M.S. Plan A</b>			
Paul Schwendinger	plasma diagnostics	E. Pfender	1997
Gurprit Singh Chandhoke	nanoparticles	n/a	1998
Brian G. Heil	plasma kinetics	n/a	1999
Upendra Bhandarkar	nanoparticles	n/a	2000
Zhe Shen	nanoparticles	n/a	2000
Antonio Maresca	plasma kinetics	n/a	2001
Giovanni Visentin	plasma diagnostics	J. Heberlein	2001
Svetoslav Stoykov	plasma modeling	n/a	2001
Lorenzo Mangolini	plasma modeling	n/a	2002
Siri Thompson	nanoparticles	n/a	2003
Ameya Bapat	nanoparticles	n/a	2003
Michael Hebert	plasma kinetics	n/a	2004
Patrizio Cerneti	nanoparticles	n/a	2006
Marco Gatti	nanoparticles	n/a	2007

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Ross Cram	nanoparticles	n/a	2008
Ryan Gresback	nanoparticle	n/a	2010
Dart-Ken Poon	plasma actuators	Doug Ernie	2011
Brian Merrit	Plasma Science	E. Aydil	2013
Katelyn Schramke	NP plasmonics	n/a	2014

**M.S. Plan B**

Tony Borders	plasma diagnostics	n/a	2002
Ghidewon Arefi	nanoparticles	Allison Hubel	2008
Ariel Chatman	Thermoelectrics	n/a	2010
David Bruce	Thermoelectrics	n/a	2011
Daniel Rave	Plasma science	n/a	2011

**Undergraduate Advisees**

Ben Speakman	plasma kinetics	n/a	1996-1997
Kelly Pogatchnik	plasma kinetics	n/a	1997-1998
Zakir Hussain	plasma modeling	n/a	1998-1999
Jason Janish	plasma kinetics	n/a	1999
Matt Kuzma	plasma diagnostics	n/a	2000
Kristin Sittig	carbon nanotubes	n/a	2002-2003
Elijah Thimsen	nanoparticles	n/a	2002-2005
Josh Phillips	nanoparticles	n/a	2004
Jarred Fisher	nanoparticles	n/a	2004
Ryan Gresback	nanoparticles	n/a	2004-2009
Brandon Jalbert	Si nanowires	n/a	2005
Ben Sigrin	nanoparticles	n/a	2005
Shantelle Hughes	nanoparticles	n/a	2006
Michael Risch-Janson	nanoparticles	n/a	2007
John Tritsch	nanoparticles	n/a	2007
Christina Jones	nanoparticles	n/a	2007, 2008
Thomas Brieze	nanoparticles	n/a	2009
Lauren Cantely	nanoparticles	n/a	2010
Mark Dunham	plasma science	n/a	2010
Angelo Fabroni	nanoparticle	n/a	2009-11
David Barton	nanoparticle	n/a	2010-13
Jessica Malone	nanoparticle	n/a	2012
Reid Herd	nanoparticle	n/a	2013
Alex Behr	nanoparticle	n/a	2013
Ben Pearce	nanoparticle	n/a	2013

**High School Students (Roseville Area High School)**

Ryan Gresback	nanoparticles	n/a	2003-2004
Tissana Kijsanajotin	plasma diagnostics	n/a	2004
Robin Olson	plasma diagnostics	n/a	2006

**High School Science Teachers (Roseville Area High School)**

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Peter Sullivan	nanoparticles	n/a	2001
<b>Post-doctoral Associates</b>			
Christoph Eggs	plasma modeling	n/a	1998
Eli Stoykova	plasma modeling	n/a	1999-2000
Vitaly Schweigert	plasma modeling	n/a	2000-2001
Konstantin Orlov	plasma diagnostics	n/a	2000-2001
Min Hur	plasma diagnostics	n/a	2002-2003
Upendra Bhandarkar	plasma modeling	n/a	2003
Dirk Uhrlandt	plasma modeling	n/a	2003
Tomohiro Nozaki	carbon nanotubes	Joachim Heberlein	2003-2004
Feng Liao	nanoparticles	n/a	2005
Xiaodong Pi	nanoparticles	Steve Campbell	2005-2008
Jason Schmidt	nanoparticles	Eray Aydil	2005-2006
Sonya Caston-Pierre	nanoparticles	n/a	2006
Guang Yang	plasma actuators	Terry Simon	2007
Jihua Yang	Nanoparticles	n/a	2009-
Elijah Thimsen	Nanoparticles	Eray Aydil	2012-
Woo Jin An	Nanoparticles	n/a	2013-
Shreyashi Ganguli	Nanoparticles	n/a	2013-

### Courses Taught

Course	Term	# of stu.	teaching eval. (averages)		
			Q1	Q2	Q3
ME 3020 "Mechanical Engineering Computation"	Sp 97	72	5.9	6.3	6.1
	F 98	27	5.4	6.1	5.2
X. ME 3301 "Engineering Thermodynamics"	F 96	57	5.6	6.1	5.9
	F 97	46	6.2	6.5	6.2
	Sp 98	58	6.2	6.4	6.2
	F 98	61	5.8	6.4	6.0
ME 3331 "Engineering Thermodynamics"	F 07	58	6.1	6.5	6.1
ME 4331 "Thermal Engineering Laboratory"	Sp 00	19	5.6	6.0	6.1
	F 00	14	5.8	6.4	6.3
	Sp 03	25	5.8	6.3	5.9
ME 4054 "Design Projects"	F 01	8	group advisor		
ME 5254 "Design Morphology"	W 97	6	group advisor		
ME 5342 "Introduction to Heat Transfer"	W 97	30	6.2	6.7	6.4
ME 8337 "Experimental Methods in Thermal Science"	F 02	17	5.7	6.6	5.8
ME 8361 "Introduction to Plasma Technology"	F 01	17	6.5	6.7	6.1
ME 8361 "Molecular Gas Dynamics"	F 02	23	6.1	6.4	6.1
	F 04	10	5.7	6.4	6.0
	F 05	16	5.4	6.0	6.0
ME 8362 "Advanced Plasma Technology"	Sp 02	16	6.3	6.8	6.2
ME 8372 "Optical Diagnostics of Flow Systems"	Sp 99	12	6.3	6.3	5.8
ME 8390 "Special Topics: Plasma Nanotechnology"	Sp 05	8	6.0	6.4	6.3
ME 8641 "Statistical and Nonequilibrium Thermodynamics"	F 00	8	6.4	5.9	5.9

Teaching evaluations are scored on a scale from 1 (poor) to 7 (exceptional). Scores reported here are averages, the medians are usually slightly higher. Scores are reported for the following questions:

Q1: How would you rate the instructor's overall teaching ability?

Q2: How would you rate the instructor's knowledge of the subject matter?

Q3: How would you rate the instructor's respect and concern for students?

New Student Rating of Teaching (Scale 1-6)

Course	Term	# of stu.	teaching eval. (averages)			
			Q1	Q2	Q3	Q4
ME3324 "Intro to Thermal Sciences"	Sp 09	81	5.73	5.02	5.39	5.36
ME 3331 "Engineering Thermodynamics"	Sp 08	68	5.67	5.56	5.27	5.62
	F11	110	5.18	4.92	4.89	5.46
ME 4131 "Thermal Environmental Engineering Laboratory"	F 12	22	5.25	5.19	4.56	5.38

Teaching evaluations are scored on a scale from 1 (strongly disagree) to 6 (strongly agree). Scores reported here are averages, the medians are usually slightly higher. Scores are reported for the following questions:

- Q1: The instructor is well prepared for class
- Q2: The instructor presented the subject matter clearly
- Q3: The instructor provided feedback to improve my performance
- Q4: The instructor treated me with respect



### Funding History

<i>Agency</i>	<i>Role</i>	<i>Title</i>	<i>Dates</i>	<i>Amount</i>
<b><i>Past Support</i></b>				
DOE	Faculty Assoc.	Thermal Plasma Chemical Vapor Deposition of Advanced Materials	9/97-8/00	\$520,000
NATO	PI	NATO-ARW Workshop: Electron Kinetics and Applications of Glow Discharges	9/96	\$47,800
NSF	PI	Advanced Kinetic Methods for the Modeling of Low Pressure Glow Discharges	8/97-7/01	\$250,000
Gen. Electric	PI	Unrestricted Research Gift	12/98	\$50,000
Hewlett Packard	PI	Equipment Donation	12/97	\$50,000
NSF	PI	Contaminant Particle Formation in Radio Frequency Silane Plasmas	7/98-6/02	\$169,148
NSF	Co-PI	GOALI: Studies of Particle Nucleation, Growth and Transport in Advanced Semiconductor Processing Tools	9/99-8/03	\$440,000
NSF	PI	CAREER: Photodetachment from Nanometer-Sized Particles	9/99-8/03	\$287,351
DOE	PI	Kinetics of Electron Fluxes in Low-Pressure Nonthermal Plasmas	8/99-8/04	\$420,000
DOE	Co-PI	Plasma Processing of Advanced Materials	9/00-12/03	\$510,000
DOE	PI	Study of the Transition between Filamentary Dielectric Barrier Discharges and Uniform Atmospheric Pressure Glows	8/00-8/05	\$480,000
Innova-Light	PI	Luminescent Silicon Nanocrystals from a Nonthermal Plasma Process	4/04-8/05	\$55,000
DOE	PI	Nucleation and Dynamics of Nanometer-sized Particles in Silane Plasmas	6/03-6/07	\$405,000
NSF	Co-PI	NER: Plasma Process for Co-Deposition of Nanoparticles for a New Class of Mixed-Phase Materials	7/04-7/07	\$100,000
NSF	PI	IGERT: Nanoparticle Science and Engineering	10/01-9/08	\$3,317,000
NSF	Co-PI	NIRT: Single Nanoparticle Devices, A New Technique for Bottom-Up Manufacturing	8/03-7/08	\$1,100,000
IREE	Co-PI	Solar Cells Based on Semiconductor Nanoparticles and Nanowires	6/05-6/08	\$300,000
NSF	PI	Collaborative Research: GOALI: Nanocrystal Formation and Morphology in	8/05-8/09	\$360,000

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		Nonthermal Plasmas		
NSF	Co-PI	NIRT: Designing photovoltaic from semiconductor nano-particles	8/05-8/09	\$1,000,000
NSF	PI	Scaleable High-Yield Plasma Production of Functionalized Semiconductor Nanocrystals	4/06-3/10	\$330,000
NASA	Co-PI	Separation control using plasma actuators on low pressure turbine airfoils with passing wakes: experiments and modeling	01/07-12/09	\$750,000
Xcel Energy	PI	Embedded Nanocrystal Silicon Thin Films: A new paradigm of improving the stability of thin-film silicon	07/08-06/11	\$732,032
Dow Corning	PI	Silicon Nanocrystal Photostability PI: U. Kortshagen co-PI: S.A. Campbell	01/11-06/11	\$ 97,380
NSF	Co-PI	Dual-Plasma Co-Deposition of Mixed Phase Thin Film Materials	06/07-05/12	\$419,769
NSF	PI	Solar Cells from Silicon and Germanium Nanocrystals Inks	04/08-04/12	\$285,000
<b><i>Current Support</i></b>				
NSF	IRG-Leader	IRG-4: Nanoparticle Based Materials of UMN Materials Research Science and Engineering Center	08/08-07/14	~\$2,800,000
DOE	Co-PI	Energy Frontier Research Center: Center for Advanced Photophysics PI: V. Klimov , co-PI: U. Kortshagen and ~20 others	09/09-08/14	\$425,000
DOE	Co-PI	DOE Center for Low Temperature Plasma Science PI: M. Kushner , co-PI: U. Kortshagen and ~20 others	09/09-08/14	\$1,630,000
NSF/DOE	PI	Charging and Heating Dynamics of Nanoparticles in Nonthermal Plasmas	09/09-09/14	\$300,000
NSF	CO-PI	Hybrid Organic-Inorganic Infrared Light-Emitting Devices using Group IV Semiconductor Nanoparticles PI: R. Holmes co-PI: U. Kortshagen	09/09-08/14	\$ 459,636
AOR	CO-PI	MURI: Coherent effects in hybrid nanostructures for lineshape engineering of electromagnetic media (PI: N. Halas, Rice University, total \$6.25M, UMN share: \$1.73M)	07/12-06/17	\$1,726,241
NSF	Co-PI	Manufacture and Characterization of	08/13-08/16	\$550,000

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		Nanocrystalline/Amorphous Silicon for Particle Detection		
BASF	PI	Aerosol based coating technology	06/13-06/14	\$353,292
Dow Corning	PI	Air and UV stability of photoluminescent Si nanoparticles	06/12-06/14	\$320,000

Total current or past funding: \$ 20,039,633

of that as PI: \$  
12,838,864

### List of publications and presentations

#### Publications in refereed scientific journals:

Statistics according to ISI Web of Science (Jan. 2014)

Sum of the Times Cited: 4265

Sum of Times Cited without self-citations: 3792

Citing Articles: 2837

Citing Articles without self-citations: 2730

Average Citations per Item: 30.9

h-index: 37

136. "Transient Photoluminescence Dynamics in Quantum-Confined Silicon Nanocrystals: Crystalline vs. Amorphous Particles," Daniel C. Hannah, Jihua Yang, George C. Schatz, Uwe Kortshagen, Richard D. Schaller, Nat. Commun., submitted.
135. "Controlled Doping of Silicon Nanocrystals Investigated by Solution-Processed Field Effect Transistors," Ryan Gresback, Nicolaas J. Kramer, Yi Ding, Ting Chen, Uwe R. Kortshagen, Tomohiro Nozaki, ACS Nano, submitted.
134. "Boron- and phosphorus-doped silicon germanium alloy nanocrystals–Nonthermal plasma synthesis and gas-phase thin film deposition," David J. Rowe and Uwe R. Kortshagen, Applied Physics Letters Materials, submitted.
133. "Hopping conduction in assemblies of hydrosilylated silicon nanocrystals," Ting Chen, Brian Skinner, Wei Xie, B. I. Shklovskii, and Uwe R. Kortshagen, Physical Review B, submitted.
132. "High quantum yield dual-emission from gas phase grown crystalline Si nanoparticles", Alexandre M. P. Botas, Rute A. S. Ferreira, Rui N. Pereira, Rebecca J. Anthony, Teresa Moura, David J. Rowe, and Uwe Kortshagen, J. Phys. Chem. C, submitted.
131. "Phase separation and the 'coffee-ring' effect in polymer-nanocrystal mixtures", Miller, J. B.; Usselman, A. C. P.; Anthony, R. J.; Kortshagen, U. R.; Wagner, A. J.; Denton, A. R.; Hobbie, E. K. Soft Matter, (2014), published online.
130. "Highly Luminescent ZnO Quantum Dots Made in a Nonthermal Plasma", Felbier, P.; Yang, J.; Theis, J.; Liptak, R. W.; Wagner, A.; Lorke, A.; Bacher, G.; Kortshagen, U. Advanced Functional Materials, (2014), published online.
128. "Quantum confinement in mixed phase silicon thin films grown by co-deposition plasma processing", Fields, J. D.; McMurray, S.; Wienkes, L. R.; Trask, J.; Anderson, C.; Miller,

- P. L.; Simonds, B. J.; Kakalios, J.; Kortshagen, U.; Lusk, M. T.; Collins, R. T.; Taylor, P. C. *Solar Energy Materials and Solar Cells*, (2014), published online.
127. "Plasma-induced crystallization of silicon nanoparticles", Nicolaas Kramer, Rebecca Anthony, Meenakshi Mamunuru, Eray Aydil and Uwe Kortshagen, *J. Phys. D: Appl. Phys.*, accepted, in press (2014).
126. "Propagating Nanocavity-Enhanced Rapid Crystallization of Silicon Thin Films", Wagner, A. J.; Anderson, C. M.; Trask, J. N.; Cui, L.; Chov, A.; Mkhoyan, K. A.; Kortshagen, U. R. *Nano Letters*, **13** (11), 5735-5739, (2013).
125. "Tunable Band Gap Emission and Surface Passivation of Germanium Nanocrystals Synthesized in the Gas Phase", Wheeler, L. M.; Levij, L. M.; Kortshagen, U. R. *Journal of Physical Chemistry Letters*, **4** (20), 3392-3396, (2013).
124. "Hypervalent surface interactions for colloidal stability and doping of silicon nanocrystals." Wheeler, L. M.; Neale, N. R.; Chen, T.; Kortshagen, U. R. *Nature Communications*, **4**, 2197, (2013).
123. "Temperature Dependent Photoluminescence of Size-Purified Silicon Nanocrystals." Van Sickle, A. R.; Miller, J. B.; Moore, C.; Anthony, R. J.; Kortshagen, U. R.; Hobbie, E. K. *Acs Applied Materials & Interfaces*, **5** (10), 4233-4238, (2013).
122. "Phosphorus-Doped Silicon Nanocrystals Exhibiting Mid-Infrared Localized Surface Plasmon Resonance," David J. Rowe, Jong Seok Jeong, K. Andre Mkhoyan, and Uwe R. Kortshagen, *Nano Letters*, **13**, 1317 (2013)
121. "Effects of Water Adsorption and Surface Oxidation on the Electrical Conductivity of Silicon Nanocrystal Films." Rastgar, Neema, David J. Rowe, Rebecca Joy Anthony, Brian A. Merritt, Uwe Richard Kortshagen, and Eray S. Aydil. *The Journal of Physical Chemistry C*, **117** (8), pp 4211–4218 (2013)
120. "Environmental photostability of SF<sub>6</sub>-etched silicon nanocrystals." Liptak, R.W., J. Yang, N.J. Kramer, U. Kortshagen, and S.A. Campbell, *Nanotechnology*, **23**(39): p. 395205 (2012).
119. "Freestanding silicon nanocrystals with extremely low defect content." Pereira, R.N., D.J. Rowe, R.J. Anthony, and U. Kortshagen, *Physical Review B*, **86**(8): p. 085449 (2012).
118. "Ensemble Brightening and Enhanced Quantum Yield in Size-Purified Silicon Nanocrystals." Miller, J.B., A.R. Van Sickle, R.J. Anthony, D.M. Kroll, U.R. Kortshagen, and E.K. Hobbie, *ACS Nano*, **6**(8): p. 7389-7396 (2012).
117. "On the Origin of Photoluminescence in Silicon Nanocrystals: Pressure-Dependent Structural and Optical Studies." Hannah, D.C., J.H. Yang, P. Podsiadlo, M.K.Y. Chan, A.

- Demortiere, D.J. Gosztola, V.B. Prakapenka, G.C. Schatz, U. Kortshagen, and R.D. Schaller, *Nano Letters*, **12**(8): p. 4200-4205 (2012).
116. "An All-Gas-Phase Approach for the Fabrication of Silicon Nanocrystal Light-Emitting Devices,"
- Rebecca J. Anthony, Kai-Yuan Cheng, Zachary C. Holman, Russell J. Holmes, and Uwe R. Kortshagen, *Nano Letters*, **12**, 2822 (2013). DOI: 10.1021/nl300164z (2012).
115. "The 2012 Plasma Roadmap." Samukawa, S., M. Hori, S. Rauf, K. Tachibana, P. Bruggeman, G. Kroesen, J.C. Whitehead, A.B. Murphy, A.F. Gutsol, S. Starikovskaia, U. Kortshagen, J.P. Boeuf, T.J. Sommerer, M.J. Kushner, U. Czarnetzki, and N. Mason, *Journal of Physics D-Applied Physics*, 45(25): p. 253001 (2012).
114. "Hybrid solar cells from MDMO-PPV and silicon nanocrystals." Liu, C.Y. and U.R. Kortshagen, *Nanoscale*, 4(13): p. 3963-3968 (2012).
113. "The energy distribution function of ions impinging on nanoparticles in a collisional low-pressure plasma," Federico Galli, Meenakshi Mamunuru and Uwe R Kortshagen, *Plasma Sources Sci. Technol.* **21**(3), 035002 (2012).
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- R6. "Heat Transfer- A Review of the 2000 literature," R. J. Goldstein, E. R. G. Eckert, W. E. Ibele, S. V. Patankar, T. W. Simon, T. H. Kuehn, P. J. Strykowski, K. K. Tamma, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, S. Garrick, Intl. J. Heat Mass Transf. **45**, 2853 (2002).
- R5. "Heat Transfer- A Review of the 1999 literature," R. J. Goldstein, E. R. G. Eckert, W. E. Ibele, S. V. Patankar, T. W. Simon, T. H. Kuehn, P. J. Strykowski, K. K. Tamma, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, S. Garrick, Intl. J. Heat Mass Transf. **44**, 3579 (2001).
- R4. "Heat Transfer- A Review of the 1998 literature," R. J. Goldstein, E. R. G. Eckert, W. E. Ibele, S. V. Patankar, T. W. Simon, T. H. Kuehn, P. J. Strykowski, K. K. Tamma, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, S. Garrick, Intl. J. Heat Mass Transf. **44**, 253 (2001).
- R3. "Heat Transfer- A Review of the 1997 literature," E. R. G. Eckert, R. J. Goldstein, W. E. Ibele, S. V. Patankar, T. W. Simon, T. H. Kuehn, P. J. Strykowski, K. K. Tamma, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, Intl. J. Heat Mass Transf. **43**, 2431 (2000).
- R2. "Heat Transfer- A Review of the 1996 literature," E. R. G. Eckert, R. J. Goldstein, W. E. Ibele, S. V. Patankar, T. W. Simon, T. H. Kuehn, P. J. Strykowski, K. K. Tamma, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, Intl. J. Heat Mass Transf. **43**, 1273 (2000).
- R1. "Heat Transfer- A Review of the 1995 literature," E. R. G. Eckert, R. J. Goldstein, W. E. Ibele, S. V. Patankar, T. W. Simon, P. J. Strykowski, K. K. Tamma, T. H. Kuehn, A. Bar-Cohen, J. V. R. Heberlein, J. H. Davidson, J. Bischof, F. A. Kulaki, U. Kortshagen, Intl. J. Heat Mass Transf. **42**, 2717 (1999).



**Books edited:**

1. "Electron Kinetics and Applications of Glow Discharges," ed. U. Kortshagen and L. D. Tsendin, NATO ASI Series, Plenum Publishing Corporation, New York, (1998).

**Book articles:**

1. "Experimental and Theoretical Determination of Electron Energy Distribution Functions in Surface Wave Plasmas," U. Kortshagen, in "Microwave Discharges: Fundamentals and Applications," ed. C. M. Ferreira, NATO ASI Series, Plenum Publishing Corporation, New York, p. 303 (1992).
2. "Modeling and Diagnostics of low pressure inductively coupled plasmas," U. Kortshagen, in "Electron Kinetics and Applications of Glow Discharges," ed. U. Kortshagen and L. D. Tsendin, NATO ASI Series, Plenum Publishing Corporation, New York, p. 329 (1998).
3. "Recent progress in the understanding of electron kinetics in low-pressure inductive plasmas," U. Kortshagen, A. Maresca, K. Orlov, and B. Heil, in "Advances in low temperature RF Plasmas: Basis for Process Design," ed. T. Makabe, North-Holland, Amsterdam, NL, p. 244-256, 2002.
4. "Nonthermal Plasma Synthesis of Silicon Nanocrystals," Lorenzo Mangolini and Uwe Kortshagen, in "Silicon Nanocrystals: Fundamentals, Synthesis, and Applications," ed.: Lorenzo Pavesi and Rasit Turan, Wiley-VCH Verlag GmbH and Co, KGaA, Weinheim, 2010.

**Patents:**

**Kortshagen, U.;** Bapat, A.; Mangolini, L.; Thimsen, E.; Jurberg, D. *Process and Apparatus for Forming Nanoparticles Using Radiofrequency Plasmas*. United States Patent 7,446,335 B2, issued Nov. 8, 2008.

**Kortshagen, U.;** Bapat, A.; Mangolini, L.; Thimsen, E.; Jurberg, D. *Process and Apparatus for Forming Nanoparticles Using Radiofrequency Plasmas*. United States Patent 8,016,944 B2, issued Sept. 13, 2011.

**Invited lectures at international conferences or workshops:**

1. "Experimental and Theoretical Determination of Electron Energy Distribution Functions in Surface Wave Plasmas," NATO Advanced Research Workshop, Vimeiro (Portugal), May 11-15, 1992.
2. "Electron and ion distribution function in RF and microwave plasmas," U. Kortshagen, XII. European Sectional Conference on Atomic and Molecular Processes in Ionized Gases (ESCAMPIG), Aug. 23-26, 1994.
3. "Two-dimensional modelling of inductively coupled RF plasmas," U. Kortshagen, Workshop on Plasma Modelling at the XII. European Sectional Conference on Atomic and Molecular Processes in Ionized Gases (ESCAMPIG), Aug. 23-26, 1994.
4. "Elektronen- und Ionenenergieverteilungsfunktionen in HF-Plasmen bei niedrigen Drücken," U. Kortshagen, Spring Meeting of the German Physical Society, Innsbruck, AU, Feb. 23, 1995.
5. "On electron and ion fluxes to the walls of a low pressure inductive discharge," U. Kortshagen, International Workshop on Basic Aspects of Nonequilibrium Plasmas Interacting with Surfaces, Shirahama (Japan), Jan. 25-26 1997.
6. "Modeling and diagnostics of low pressure inductively coupled plasmas," U. Kortshagen, NATO Advanced Research Workshop on "Electron Kinetics and Applications of Glow Discharge Plasmas," St. Petersburg, Russia, May 19-23, 1997.
7. "Two-dimensional self-consistent kinetic modeling of inductively coupled high density RF plasmas," U. Kortshagen, International Colloquium of the "Sonderforschungsbereich 191: Physikalische Grundlagen der Niedertemperaturplasmen." Bochum, Germany, Sept. 1-2, 1997.
8. "An Efficient Kinetic Approach to the Modeling of the Electron Distribution Function in Low-Pressure High-Density Plasma Tools," 25<sup>th</sup> IEEE International Conference on Plasma Science, Rayleigh, NC, June 1-5, 1998.
9. "Modeling of nucleation and coagulation of particles in low-pressure plasmas," Dusty Plasma Workshop, Col de Porte, France, Jan. 20-22, 1999.
10. "Kinetic Modeling and Experimental Studies of Large-Scale Low Pressure Plasmas," topical invited lecture to be presented at the 24<sup>th</sup> International Conference on Phenomena in Ionized Gases (ICPIG), July 11-16, 1999, Warsaw, Poland.
11. "Generation and growth of nanoparticles in low-pressure plasmas," 14<sup>th</sup> International Symposium on Plasma Chemistry, Prague, Czech Republic, Aug. 2-6, 1999.
12. "Generation and Growth of Nanometer-Particles in Processing Plasmas," APS Division of Plasma Physics Meeting, Nov. 11-15, Seattle, WA, 1999.
13. "Modeling of Particle Nucleation in Silane CVD Plasmas," 3<sup>rd</sup> European Dusty Plasma Workshop, Playa da Caparica, Portugal, June 3-5, 2000.
14. "Electron Kinetics in Low-Pressure Discharges," Gordon Research Conference on Plasma Processing Science, Tilton, NH, Aug. 13-18, 2000.
15. "Electron Kinetics in Inductively Coupled and Positive Column Plasmas," International Workshop on Electron Kinetics, University of Greifswald, Germany, Sep. 14, 2000.

16. "Low Temperature ICP Modeling on the Basis of the Boltzmann Equation," International Workshop on the Basis for Low Temperature Plasma Applications, Hakone, Japan, July 23-25, 2001.
17. "Low-pressure plasma synthesis of crystalline silicon nanoparticles for novel electronic devices," International Workshop on Plasma Nano-Technology and its Future Vision, Takayama, Japan, Feb. 5-6, 2004.
18. "Plasma synthesis of single crystal silicon nanoparticles for novel electronic device applications," European Physical Society Conference, June 28-July 2, 2004, London, England.
19. "Low Pressure Plasmas as a Source for Monodisperse, Single-Crystal Semiconductor Nanoparticles," 2nd International Symposium on System Construction of Global-Network-Oriented Information Electronics, Jan. 31-Feb. 2, 2005, Sendai, Japan.
20. "Low pressure plasmas: Silicon nanocrystals made easy," 58<sup>th</sup> Gaseous Electronics Conference, Oct. 16-20, 2005, San Jose, CA.
21. "Plasma synthesis of nanocrystals for electronic and solid-state lighting applications," 2<sup>nd</sup> International Symposium on Nanotechnology and Occupational Health, Oct. 3-6, 2005, Minneapolis, MN.
22. "Plasma synthesis and organic surface passivation of high quantum yield silicon quantum dots," Symposium D of the European Materials Research Society meeting, May 29-June 1, 2006, Nice, France.
23. "Special Interest Topic: Nano-Energy", 4<sup>th</sup> AMSE Nano Training Bootcamp, July 10-14, 2006, University of Minnesota, MN.
24. "Plasma synthesis of semiconductor nanocrystals for photovoltaics and light emission," Gordon Research Conference on Plasma Processing Science, Mount Holyoke College, South Hadley, MA, July 16-21, 2006.
25. "Plasma synthesis of silicon and germanium nanocrystals and their application to thin semiconductor films," Symposium A, Materials Research Society Symposium, April 9-13, 2007, San Francisco, CA.
26. "Plasma-particle interactions and their role in nanocrystal formation in plasmas," 2007 American Physical Society—Division of Atomic, Molecular, and Optical Physics Meeting, June 5-9, 2007, Calgary, Can.
27. "Cluster, particles and powders in plasmas," 18<sup>th</sup> International Symposium on Plasma Chemistry, August 23-27, 2007, Nagoya, Japan.
28. "Plasma synthesis and functionalization of group IV nanocrystals for photovoltaic applications," ASME 2<sup>nd</sup> Energy Nanotechnology International Conference, San Jose, Sept. 3-6, 2007.
29. "Plasma synthesis, functionalization, and luminescent properties of silicon nanocrystals", Electrochemical Society Symposium on Nanocrystal Embedded Dielectrics, Washington, DC, Oct. 4-5, 2007.
30. "Plasma synthesis, functionalization, and luminescent properties of silicon nanocrystals." Excited state processes in electronic and bio nanomaterials (ESP-2007), Los Alamos Natl. Lab, October 1-4, 2007.
31. "Doped Silicon Nanocrystal Inks for Low-cost Photovoltaics and Printed Electronics," 5<sup>th</sup> Annual Conference on Foundations of Nanoscience, April 22-25, 2008, Snowbird, UT.

32. "Plasma syntheses of quantum dots for luminescence and PV application," 35<sup>th</sup> European Physical Society Conference on Plasma Physics, Crete, June 9-13, 2008.
33. "Nano-Energy," ASME Nano Training Summer School, June 30-July 3, 2008, London, England.
34. "Applications of Nanoparticles in Energy Technology," Tutorial for AAAR 2008 Meeting, Oct. 20-24, 2008, Orlando, FL.
35. "Silicon Nanocrystal Inks: Plasma Processing as a Route to Solution-Processed Silicon Films" 55<sup>th</sup> AVS International Symposium and Exhibition, October 19-24, 2008, Boston, MA.
36. Invited Lecture: "Silicon and Germanium Nanocrystal Electronic Devices," Nanomanufacturing Summit 2009, Boston, MA.
37. Keynote Lecture: "Nonthermal plasmas synthesis of nanomaterials for renewable energy applications," Symposium on Next Generation of Plasma Science and Technology, Kyoto University, Japan, May 30, 2009.
38. Plenary Lecture: "The physics of semiconductor nanocrystal synthesis in plasmas and nanocrystal applications in renewable energy technology," 29th International Conference on Phenomena in Ionized Gases, Cancun, MX, July 12-17, 2009.
39. Invited Lecture: "Plasma synthesis of silicon nanocrystal inks for low-cost photovoltaics," 62<sup>nd</sup> Annual Gaseous Electronics Conference Tuesday-Friday, October 20-23, 2009; Saratoga Springs, New York
40. Invited Lecture: "Plasma-Produced Silicon Inks: A New Route Towards Printed, Flexible Silicon Technology and Its Applications in Photovoltaics and Thermoelectrics" 18<sup>th</sup> Nisshin Engineering Particle Technology International Seminar, Hakone, Japan, Dec. 6-8, 2009.
41. "Novel plasma actuators for improved thrust," Uwe Kortshagen, Song Guo, Terry Simon, Doug Ernie, AFOSR-UFL Joint DBD Plasma Actuator Workshop, Gainesville, FL, Feb. 14-15, 2010.
42. "Plasma assisted synthesis of silicon nanocrystal inks," International Symposium on Disperse Systems for Electronics, Erlangen, Germany, March 1-2, 2010.
43. Keynote: "Plasma Synthesized Nanocrystals for Photovoltaics," Uwe Kortshagen, Xiaodong Pi, Chin-Yi Liu, ISPlasma 2010, 2nd International Symposium on Advanced Plasma Science and its Applications for Nitrides and Nanotechnology, Nagoya, Japan, March 7-10, 2010.
44. Plasma Synthesis of Silicon Nanocrystal Inks and their Applications in Printed Silicon Technology and Hybrid Solar Cells, 217th Symposium of the Electrochemical Society, April 25-30, 2010, Vancouver, BC.
45. "Plasma Synthesis and Applications of Silicon Nanocrystals," DARPA workshop on Applications of Atmospheric Pressure Plasmas, Princeton University, Princeton, NJ, Aug. 22-24, 2011.
46. "Gas Phase Synthesis of Group IV Nanocrystals and Applications to PV," American Chemical Society Meeting, Denver, CO, Aug. 28-Sept. 1, 2011.
47. "Hybrid quantum dot/polymer solar cells based on silicon nanocrystals," American Vacuum Society Meeting, Nashville, TN, Oct. 31-Nov. 4, 2011.
48. "Energy Distribution of Ions hitting Nanoparticles in Nonthermal Plasmas," Federico Galli, Meenakshi Mamunuru, and Uwe Kortshagen, Workshop on Plasma Kinetics, Salt Lake City, UT, Nov. 14, 2011.
49. "The physics and applications of nanomaterials produced with nonthermal plasmas," 64<sup>th</sup> Gaseous Electronics Conference, Salt Lake City, UT, Nov. 14-18, 2011.

50. "Ligand-less Group IV colloids," International Conference on Quantum Dots (QD 2012), May 13-18, 2012, Santa Fe, NM.
51. "Plasma synthesis and surface functionalization of silicon nanocrystals," University of Minnesota Nanotechnology Conference, Nov. 7, 2012, Minneapolis, MN.
52. "Gas Phase Synthesis of Semiconductor Nanocrystals: Current Progress and Future Research Needs," Center for Advanced Solar Photophysics, Annual meeting, Golden, CO, Aug. 27-29, 2012.
53. "Plasma synthesis of semiconductor nanocrystals and first results on their plasmonic properties," DOD MURI workshop, Arlington, VA, Sept. 11-12, 2012.

**Invited colloquia or seminar lectures:**

1. "The Electron Distribution Function in Surface Wave Produced Plasmas," Faculty of Physics, University Sofia (Bulgaria), April 3, 1991.
2. "Modellierung eines oberflächenwellenerzeugten HF-Plasmas," Plasma physics seminar of the University Kiel, April 24 1991.
3. "Modellierung von HF-Plasmen," Seminar of the Physical-Technical Institute Jena, Sept. 10, 1991.
4. "Modelling of Radio-Frequency Plasmas," FOM-Instituut voor Plasmafysica, Rijnhuizen (Netherlands), Jan. 30, 1992.
5. "Measurement and Modelling of Electron Distribution Functions in Microwave Plasmas," Université Paris-Sud, April 4, 1992.
6. "Experimentelle und theoretische Untersuchung der Elektronenkinetik in HF-angeregten Niedertemperaturplasmen," Seminar of the ASDEX-Upgrade-Team, Max-Planck-Institut für Plasmaphysik in Garching, Germany, April 13, 1994.
7. "Experimentelle und theoretische Untersuchung des Einflusses der räumlichen Inhomogenität auf die Elektronenkinetik in Niedertemperaturplasmen," Joint colloquium of the Sonderforschungsbereich 191 und 198, July 14, 1994.
8. "Der Einfluß der räumlichen Inhomogenität von Niedertemperaturplasmen auf die Elektronenkinetik," Colloquium of the faculty of physics and astronomy of the Ruhr-Universität Bochum, Oct. 10, 1994.
9. "Electron and ion distribution functions in high frequency plasmas," Atomic physics seminar, Dept. of Physics, University of Wisconsin-Madison, 27. Oct. 1994.
10. "Elektronen- und Ionenverteilungsfunktionen in HF-Plasmen," Colloquium of the faculty of electrical engineering of the University Stuttgart, Nov. 24, 1994.
11. "Hochfrequenzplasmen: technische Anwendungen, Diagnostik und Modellierung," Colloquium of the faculty of physics of the University Kiel, Dec. 20, 1994.

12. "Experimentelle und theoretische Untersuchung verschiedener hochfrequenzangeregter Plasmen," Colloquium of the faculty of electrical engineering of the University Stuttgart, July 6, 1995.
13. "Experimental Investigation and Modeling of Low Pressure Inductively Coupled Plasmas," Plasma-aided manufacturing seminar, Engineering Research Center, University of Wisconsin-Madison, Sep. 22, 1995.
14. "Kinetic Modeling and Experiment on Planar Low Pressure ICPs," Plasma Physics seminar, Dept. of Physics, University of Wisconsin-Madison, 3. Oct. 1995.
15. "Experimental Study and Kinetic Modeling of Low Pressure Inductively Coupled Plasmas," University of Minnesota-Minneapolis, Dept. of Mechanical Engineering, Special Seminar, 17. Nov. 1995.
16. "Experimentelle Untersuchung und Modellierung von induktiv gekoppelten HF-Entladungen bei niedrigen Drücken," Heinrich-Heine-University Düsseldorf, Institute of laser- and plasma physics, 11. Jan. 1996.
17. "Experimentelle Untersuchung und Modellierung von induktiv gekoppelten Niederdruck-HF-Entladungen," Colloquium of the Max-Planck-Institute of Plasma Physics, Garching, 5. July 1996.
18. "Kinetic Modeling and Diagnostics of High-Density Low-Pressure Plasma," Seminar of the Plasma Physics and Modeling Group, Dept. of Electrical Engineering, Keio University, Yokohama (Japan), Jan. 31, 1997.
19. "Modeling and diagnostics of low pressure inductively coupled plasmas," U. Kortshagen, NATO Advanced Research Workshop on "Electron Kinetics and Applications of Glow Discharge Plasmas," St. Petersburg, Russia, May 19-23, 1997.
20. "Two-dimensional self-consistent kinetic modeling of inductively coupled high density RF plasmas," U. Kortshagen, International Colloquium of the "Sonderforschungsbereich 191: Physikalische Grundlagen der Niedertemperaturplasmen." Bochum, Germany, Sept. 1-2, 1997.
21. "Improved Kinetic Modeling and Diagnostics of Particle Fluxes from Low Pressure ICP," Engineering Research Center for Plasma Aided Manufacturing, Madison, Wisconsin, Nov. 14, 1997.
22. "Kinetische Effekte in induktiv gekoppelten HF-Plasmen," University of Greifswald, Germany, Dept. of Physics, Colloquium, April 1, 1998.
23. "Elektronenkinetik und Nanoteilchen in HF-Niederdruckplasmen.," Max-Planck Institute for Plasma Physics, Garching, Germany, Seminar of Experimental Physics Division 3, Aug. 31, 1998.
24. "Electron Kinetics in Plasmas used for Plasmas Processing of Semiconductors," Dept. of Physics, University of Minnesota, March 2. 1999.
25. "Particle Nucleation and coagulation in low pressure silane plasmas," Colloquium of the Sonderforschungsbereich 191, University of Bochum, April 19, 2001.
26. "Synthesis and Potential Applications of Silicon Nanoparticles in Low Pressure Plasmas," Joint ME Department seminar and seminar of the IGERT for Nanoparticle Science and Engineering, Nov. 20, 2002.
27. "Non-Equilibrium Plasmas: Research between Physics and Applications," Introduction to Research Seminar, Department of Physics, University of Minnesota, Nov. 22, 2002.
28. "Plasmaprozesse zur Erzeugung von Silizium-Nanopartikeln," Seminar of the Department of Electrical Engineering, Gerhard-Mercator-University Duisburg, Germany, Nov. 28, 2002.

29. "Low Pressure Plasmas Synthesis of Silicon Nanoparticles and Potential Applications," University Texas, Austin, Dept. of Aerospace Engineering and Engineering Mechanics, April 3, 2003.
30. "Turning the Evil into Good: Plasma Synthesis of Silicon Nanoparticles and Potential Applications," North California Chapter of AVS, Plasma Etch User Group, Oct. 9, 2003.
31. "Plasmaprozesse zur Erzeugung von Nanopartikeln," Seminar of the Institute for Plasma Physics, University of Stuttgart, Germany, Nov. 6, 2003.
32. "Plasma deposition of nanostructured amorphous silicon films for photovoltaics," Minisymposium on "Organic and Inorganic Photovoltaic Technologies" sponsored by the Materials Research Science and Engineering Center, U of MN, Jan. 14, 2005.
33. "Synthesis of Semiconductor Nanocrystals in Low-pressure Plasmas," Dept. Seminar, Dept. of Chemical Engineering and Materials Science, U of MN, Sept. 6, 2005.
34. "Semiconductor Nanocrystal Synthesis in Low-pressure Plasmas," Faculty Seminar, Dept. of Chemical Engineering, Technical University of Delft, NL, Nov. 7, 2005.
35. "Nanodusty Plasmas: New Opportunities for "Old" Technologies," Dept. Seminar, Dept. of Mechanical Engineering, U of MN, Feb. 1, 2006.
36. "Plasma synthesized silicon nanocrystals for luminescent and photovoltaic applications," 3M Inorganic Materials Group, Sep. 2006.
37. "Plasma synthesis of brightly luminescent silicon nanocrystals," Dept. Seminar, Dept. of Chemistry, UC Davis, Dec. 7, 2006.
38. "Optical and structural characterization of silicon nanocrystals," MNnano workshop on Characterization of Nanomaterials, Jan. 31, 2007, Minneapolis, MN.
39. "Silicon and Germanium Nanocrystals for photovoltaics," MNnano workshop on Nanomaterials in Energy, April 26, 2007, Minneapolis, MN.
40. "Nonthermal Plasma Synthesis of Semiconductor Nanocrystals," Spring course on semiconducting nanocrystals: synthesis and applications, University of Duisburg-Essen, May 9-11, 2007.
41. "Group IV nanocrystal inks for photovoltaics," IPRIME workshop on Nanoparticle-based Materials for Photovoltaics, May 29, 2007.
42. "Silicon Nanocrystal Inks for Photovoltaics," 3rd Annual University of Minnesota Nanotechnology Conference, Nov. 13-14, 2007.
43. "Group IV nanocrystal inks," Iprime workshop on Materials, Devices and Coating Processes for Printed Electronics, Minneapolis, MN, Jan. 16, 2008.
44. "Silicon nanocrystals: synthesis, doping, functionalization, and applications." Chemical Engineering Seminar, Caltech, April 3, 2008.
45. "Plasma Synthesis of Nanomaterials for Renewable Energy Applications," Department Seminar, Texas A&M University, College Station, TX, Feb. 11, 2009.
46. "Plasma Synthesis of Nanomaterials for Renewable Energy Applications," Department Seminar, University of Texas, Austin, TX, Feb. 12, 2009.
47. "Physics and Applications of Nanoparticles in Plasmas," Kolloquium, Princeton Plasma Physics Laboratory, May 26, 2010.
48. "Mechanical Engineering at the University of Minnesota," Presentation at the College of Mechanical Engineering, Tsinghua University, Beijing, China, June 8, 2011.
49. "Overview of the Industrial Partnership for Research in Interfacial and Materials Engineering-Iprime," Evonik Corporate Headquarters, Essen, Germany, June 28, 2011.

50. "Silicon Nanocrystals for Photovoltaics and Light Emission," CENIDE Seminar, University of Duisburg-Essen, Duisburg, Germany, June 29, 2011.
51. "Plasma synthesis and applications of silicon nanocrystals," Dow Corning Science and Technology Seminar, Midland, MI, Aug. 4, 2011.
52. "Mechanical Engineering in the 21<sup>st</sup> Century: Nanotechnology and Society's Grand Challenges," Seminar for the ASME local Twin Cities chapter, Oct. 12, 2011.
54. "Plasma synthesis, surface functionalization, and applications of silicon nanocrystals," Iprime Webcast, Dec. 17, 2012, Minneapolis, MN.
55. "Nonthermal plasma synthesis of semiconductor nanocrystals for photovoltaics and light emission," Anniversary colloquium of the Nanotechnology Graduate Program, University of Duisburg-Essen, July 22, 2012.



**Contributions to scientific conferences (published, peer-reviewed proceedings, presenting author underlined):**

1. "Electron Energy Distribution Functions in Surface Wave Produced Plasmas," U. Kortshagen, H. Schlüter and A. Shivarova, Proc. Xth European Sectional Conference on the Atomic and Molecular Physics in Ionized Gases (ESCAMPIG), Aug. 28-31, 1990, Orleans (France), p. 163.
2. "On the Influence of Coulomb Collisions on the Electron Energy Distribution Function of Surface Wave Produced Plasmas," U. Kortshagen and H. Schlüter, Proc. XXth International Conference on Phenomena in Ionized Gases (ICPIG), July 8-12, 1991, Pisa (Italy), p. 5-1111.
3. "Electron Energy Distribution Functions in Surface Wave Produced Plasmas," U. Kortshagen and H. Schlüter, Proc. 10th International Symposium on Plasma Chemistry (ISPC), Aug. 4-9, 1991, Bochum (Germany), p. 2.1-57.
4. "Electron Energy Distribution Functions of Surface Wave Produced Radio Frequency and Microwave Plasmas," U. Kortshagen and H. Schlüter, in "Radio Frequency Power in Plasmas" (Charleston, SC, USA), AIP Conference Proceedings, ed. D.B. Batchelor, AIP, New York, p. 352 (1991).
5. "Durch Oberflächenwellen erzeugte Plasmen," U. Kortshagen and H. Schlüter, 1992, Kleinheubacher Berichte Band 35, Deutsche Bundespost Telekom, Forschungsinstitut, Darmstadt, p. 169.
6. "Influence of Metastable Atoms on the Characteristics of Surface Wave Produced Plasmas," U. Kortshagen and H. Schlüter, 1992, International Conference on Plasma Physics, June 29 - July 3, 1992, Innsbruck (Austria), Contributed Papers, Vol. 16C, Part III, p. 2145.
7. "Electron Energy Distribution Functions in Surface Wave Produced Plasmas in Different Gases," U. Kortshagen, XIth European Sectional Conference on the Atomic and Molecular Physics in Ionized Gases (ESCAMPIG), Aug. 25-28, 1992, St. Petersburg (Russia), p. 145.
8. "Experimental and Theoretical Investigation of the Ion Energy Distribution Function at the Electrode of a Capacitively Coupled RF-Discharge," U. Kortshagen and M. Zethoff, XXIth International Conference on Phenomena in Ionized Gases (ICPIG), Sept. 19-24, 1993, Bochum (Germany), p. I-73.
9. "On the Influence of the Space Charge Electric Field on the Electron Energy Distribution Function in Surface Wave Produced Plasmas," U. Kortshagen and L.D. Tsengin, XXIth International Conference on Phenomena in Ionized Gases (ICPIG), Sept. 19-24, 1993, Bochum (Germany), p. I-75.
10. "Experimental and Theoretical Investigation of the Influence of Excited Atoms on the Modelling of a Surface Wave Produced Argon Discharge," A. Böhle and U. Kortshagen, XXIth International Conference on Phenomena in Ionized Gases (ICPIG), Sept. 19-24, 1993, Bochum (Germany), p. I-43.
11. "Electron and Ion Distribution Functions in Microwave and RF Plasmas," U. Kortshagen, invited lecture, XIIth European Sectional Conference on the Atomic and Molecular Physics of Ionized Gases (ESCAMPIG), Aug. 23-26, 1994, Noordwijkerhout (Netherlands), ed. M. C. M. van de Sanden, (European Physical Soc.) p. 13.
12. "Investigation of the Radial Uniformity of Planar Inductively Coupled RF Discharges using a Self-Consistent Two-dimensional Kinetic Model," U. Kortshagen, 22. IEEE International Conference on Plasma Science, June 5-8, 1995, Madison (WI, USA), p. 126.

13. "Microwave Discharges Maintained by Surface Waves: Modelling and Experiments," Yu. M. Aliev, I. Ganashev, S. Grosse, U. Kortshagen, H. Schlüter and A. Shivarova, 22. IEEE International Conference on Plasma Science, June 5-8, 1995, Madison (WI, USA), p. 151
14. "Investigation of the Ionization Front Advance in a Pulsed Discharge Produced by High Power Surface Waves," A. Böhle, O. Ivanov, A. Kolisko, U. Kortshagen, H. Schlüter and A. Vikarev, XXII Conference on Phenomena in Ionized Gases (ICPIG), July 31- August 4, 1995, Hoboken (NJ, USA), p. 2-145.
15. "The RF Voltage Dependence of the Electron Sheath Heating in Low Pressure Capacitively Coupled RF Discharges," U. Buddemeier, U. Kortshagen and I. Pukropski, XXII Conference on Phenomena in Ionized Gases (ICPIG), July 31- August 4, 1995, Hoboken (NJ, USA), p. 4-113.
16. "Numerical Resolution of the Spatially Dependent Electron Boltzmann Equation in Cylindrical Geometry," L. L. Alves, C. M. Ferreira, C. Busch and U. Kortshagen, XXII Conference on Phenomena in Ionized Gases (ICPIG), July 31- August 4, 1995, Hoboken (NJ, USA), p. 4-217.
17. "Fast Self-Consistent Kinetic Modelling of Low Pressure RF Discharges," S. V. Berezhnoi, I. D. Kaganovich, U. Kortshagen and L. D. Tsendin, 12th International Symposium on Plasma Chemistry, August 21-25, 1995, Minneapolis (MN, USA), p. 385.
18. "On the Electrical Charging of Dust Particles in a Capacitively Coupled RF Plasma," U. Kortshagen and G. Mümken, 12th International Symposium on Plasma Chemistry, August 21-25, 1995, Minneapolis (MN, USA), p. 1373.
19. "Fast two-dimensional kinetic modeling and diagnostics of low pressure inductively coupled plasmas," U. Kortshagen, G. Mümken, I. Pukropski, M. Zethoff and L. D. Tsendin, Proceedings 3rd International Conference on Reactive Plasmas, Nara (Japan), Jan. 21.-24, 1997, p. 103.
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**Contributions to the plasma physics conference of the German physical society (DPG):**

27 Contributions.

**Contributions to the German Conference on Plasma Technology: 3 Contributions.**