

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

SAMSUNG ELECTRONICS CO., LTD.,
SAMSUNG ELECTRONICS AMERICA, INC.,
Petitioner,

v.

NANOCO TECHNOLOGIES LTD.,
Patent Owner.

Case No. IPR2021-00186
U.S. Patent No. 8,524,365

DECLARATION OF BRANDI COSSAIRT, Ph.D

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I, Brandi Cossairt, declare as follows:

I. INTRODUCTION

1. My name is Brandi Cossairt. I have been retained by counsel for Plaintiff Nanoco Technologies Ltd. (“Nanoco”) as a technical expert witness in this proceeding.

2. I submit this declaration based upon my own personal knowledge and, if called upon to testify, would testify to the matters contained in this declaration. The facts and data recited in this declaration are true and accurate to the best of my knowledge and belief.

3. I have been informed that Samsung Electronics Co., Ltd.’s and Samsung Electronics America, Inc.’s (collectively “Samsung” or “Petitioner”) has challenged claims 1-23 (“the challenged claims”) of U.S. Patent Nos. 8,524,365 (“the ’365 Patent”) (Ex. 1001) assigned to Nanoco.

4. I am submitting this declaration at the request of Nanoco, and have been asked by Nanoco to provide my expert testimony and opinions concerning the Grounds raised by Samsung against the challenged claims of the ’365 Patent.

II. BACKGROUND AND QUALIFICATIONS

5. My background, qualifications, and experience are stated fully in my curriculum vitae, attached hereto as Appendix A. I also provide a brief summary of my qualifications here.

6. I am a Professor of Chemistry at the University of Washington, and have been a faculty member in the University of Washington's Department of Chemistry since 2012.

7. I received a B.S. in chemistry in 2006 from the California Institute of Technology where I performed undergraduate research with Professor Jonas C. Peters, but began working in the laboratory of Anthony J. Hynes at the University of Miami Rosenstiel School of Marine and Atmospheric Science while still in high school.

8. I received my Ph.D. in Inorganic Chemistry in 2010 from the Massachusetts Institute of Technology in Cambridge, Massachusetts, where I conducted my doctoral research in the laboratory of Professor Christopher C. Cummins on the niobium-mediated synthesis of phosphorus-rich molecules. Specifically, I examined the activation and transformation of white phosphorus by early transition metals, like niobium, and used these methods to make new P-rich fragments and molecules like the cluster AsP_3 .

9. I'd been fascinated by clusters since I was a PhD student at MIT studying main group clusters containing group 15 elements, including phosphorus

and arsenic. As an example, I published a paper in 2010 titled, “Molecular Gallium Arsenide Phosphide Clusters Prepared from AsP_3 , P_4 , and $[\{\text{GaC}(\text{SiMe}_3)_3\}_4]$ ”¹.

10. After receiving my Ph.D., I received an NIH postdoctoral fellowship to pursue research at Columbia University in the laboratory of Professor Jonathan S. Owen from 2010-2012. In my postdoctoral work, I began learning more about and working on magic-sized clusters and related cluster compounds as models of and precursors to quantum dots. My postdoctoral research focused on the synthesis and properties of semiconductor cluster compounds in the II-VI compound family, primarily CdSe, bearing a variety of supporting ligands.

11. As I prepared to apply to academic jobs in 2011, I wrote a proposal on the synthesis of InP quantum dots that involved my thoughts about the potential use of clusters as precursors and/or seeds for this material. I highlighted a 2002 paper from Cumberland titled “Inorganic Clusters as Single-Source Precursors for Preparation of CdSe, ZnSe, and CdSe/ZnS Nanomaterials” as a source of inspiration. This led me to read several of the early Nanoco patents, which cite this article.

¹ While these compounds do not meet the district court’s construction of a molecular cluster compound (“MCC”) which is limited to metal atoms, they behave like MCCs and would be regarded as molecular clusters in the art.

12. My scientific research since 2012 has focused on the synthesis and properties of phosphide-based nanomaterials, including indium phosphide quantum dots. As our work in this area picked up between 2012 and 2016, a student in my research group at UW routinely referenced the Nanoco patents when designing experiments. It was clear to me then, and it is clear to me now, that these patents, in particular the '828 patent, were foundational to our understanding of the use of clusters in quantum dot synthesis, and in particular their potential utility in the synthesis of InP-based materials. My laboratory's research continues to focus on understanding the mechanisms of nucleation and growth of these materials. I have also worked extensively to examine how surface chemistry impacts nanomaterial properties.

13. I have a strong foundation in the fundamental aspects of quantum dots, including their electronic, structural, and reactivity properties, and manners of synthesizing them.

14. My work has been published in over 75 papers, including more than 40 papers relating to quantum dots.

15. I have been invited to speak at other institutions and at technical meetings over 120 times. The subject of those invited talks has usually been nanomaterials generally or quantum dots specifically, including indium phosphide quantum dots.

16. My grant activity includes support from the National Science Foundation, the United States Department of Energy, and a variety of private foundations. My average annual grant support is approximately \$750,000. This grant support is entirely focused on our nanoparticle work.

17. My scientific advisory and editorial activities include serving as an Associate Editor at the American Chemical Society journal *Inorganic Chemistry*, serving on the Editorial Advisory Board of the American Chemical Society journal *Chemistry of Materials*, and serving on the Editorial Advisory Board of the Royal Society of Chemistry journal *Materials Horizons*. I have trained and mentored over 18 graduate students who are/have conducted their thesis work in my laboratory, 10 of whom are now employed in companies or other universities. I have also trained and mentored 3 postdoctoral fellows and over 20 undergraduate students.

18. I have received the following awards and recognitions:

- 2021 Elected to the Washington State Academy of Sciences
- 2021 Blavatnik Awards for Young Scientists National Finalist
- 2018 National Fresenius Award (American Chemical Society, sponsored by Phi Lambda Upsilon)
- 2017 Camille Dreyfus Teacher Scholar Award (Camille and Henry Dreyfus Foundation)
- 2016 NSF CAREER Award
- 2015 Packard Fellowship for Science and Engineering (David and Lucile Packard Foundation)
- 2015 Sloan Research Fellowship (Alfred P. Sloan Foundation)

19. I am also a co-founder (along with Prof. Jillian Dempsey, UNC Chapel Hill) of the Chemistry Women Mentorship Network, a national network of women in chemistry to provide support, encouragement and mentorship for young women considering continuing their education or pursuing careers in academia

20. I have been retained by Nanoco to provide expert opinions in the related district court proceeding as well as this *inter partes* review. I had previously assisted Nanoco with its patent owner preliminary responses in this and the related quantum dot IPRs filed by Samsung (i.e., IPR2021-00183, IPR2021-00184, and IPR2021-00185).

21. I am being compensated for my time in preparing this declaration at \$350 per hour, which is my regular and customary rate. I am also being separately reimbursed for out-of-pocket expenses. Although I am being compensated, the opinions herein are my own and I have no stake in the outcome of this case. My compensation does not depend in any way on the outcome of this case, or my opinions. I have no ownership or beneficial interest in any of the Parties in this case.

III. MATERIALS CONSIDERED

22. In forming the opinions set forth in this declaration, I have considered and relied upon my education, knowledge of the relevant field, and my years of experience in research involving nanomaterials generally and quantum dots

specifically. Specific materials that I have reviewed in connection with this declaration include the Petition and Institution Decision in this proceeding, along with the following exhibits:

Exhibit	Description
1001	U.S. Patent No. 8,524,365 (“the ’365 patent”)
1002	Declaration of Mark A. Green in Support of Petition for <i>Inter Partes</i> Review of U.S. Patent No. 8,524,365
1003	Curriculum Vitae for Mark A. Green
1004	Prosecution History of U.S. Patent No. 8,524,365
1005	International Patent Publication No. WO 03/097904 to Banin et al. (“Banin”)
1006	A. Zaban et al., <i>Photosensitization of Nanoporous TiO₂ Electrodes with InP Quantum Dots</i> , 14 LANGMUIR 3153 (1998) (“Zaban”)
1007	Olga I. Mičić et al., <i>Synthesis and Characterization of InP Quantum Dots</i> , 98 J. PHYSICAL CHEMISTRY 4966 (1994) (“Mičić”)
1008	V. Ptatschek et al., <i>Quantized Aggregation Phenomena in II–VI–Semiconductor Colloids</i> , 102 BERICHTE DER BUNSEN–GESELLSCHAFT FÜR PHYSIKALISCHE CHEMIE 85 (1998) (“Ptatschek”)
1009	E. Farneth et al., <i>Bulk Semiconductors from Molecular Solids: A Mechanistic Investigation</i> , 4 CHEMISTRY OF MATERIALS 916 (1992) (“Farneth”)
1010	Heng Yu et al., <i>Heterogeneous Seeded Growth: A Potentially General Synthesis of Monodisperse Metallic Nanoparticles</i> , 123 J. AM. CHEMICAL SOC’Y 9198 (2001) (“Yu”)
1011	U.S. Patent No. 7,193,098 to Lucey et al. (“Lucey”)
1012	S.P. Ahrenkiel et al., <i>Synthesis and Characterization of Colloidal InP Quantum Rods</i> , 3 NANO LETTERS 833 (2003) (“Ahrenkiel”)
1015	U.S. Patent No. 6,815,064 to Treadway et al. (“Treadway”)
1016	N. Herron et al., <i>Crystal Structure and Optical Properties of Cd₃₂S₁₄(SC₆H₅)₃₆·DMF₄, a Cluster with a 15 Angstrom CdS Core</i> , 259 SCIENCE 1426 (1993) (“Herron”)
1017	<i>Seven Networks, LLC v. Apple Inc.</i> , C.A. No. 2:19-cv-00115-JRG, Dkt. 313 (Sept. 22, 2020)

Exhibit	Description
1018	Docket Control Order, <i>Nanoco Technologies Ltd. v. Samsung Electronics Co., Ltd.</i> , No. 2:20-cv-00038 (E.D. Tex.)
1019	October 2021 Calendar for Judge Rodney Gilstrap, Eastern District of Texas
1020	Return of summons to Samsung Electronics Co. and Samsung Electronics America, <i>Nanoco Technologies Ltd. v. Samsung Electronics Co., Ltd.</i> , No. 2:20-cv-00038 (E.D. Tex.)
1021	Letter dated November 9, 2020 from M. Pearson to M. Newman re stipulation about invalidity grounds
1022	Infringement contentions, <i>Nanoco Technologies Ltd. v. Samsung Electronics Co., Ltd.</i> , No. 2:20-cv-00038 (E.D. Tex.)
1023	Cover material for Zaban
1024	Cover material for Mičić
1026	Cover material for Farneth
1027	Cover material for Yu
1028	Cover material for Ahrenkiel
1030	Cover material for Herron
1035	Catherine J. Murphy, <i>Optical Sensing with Quantum Dots</i> , 74 ANALYTICAL CHEMISTRY 520A (2002)
1036	U.S. Patent App. No. 2003/0106488 to Huang et al.
1037	NANOPARTICLES: FROM THEORY TO APPLICATION (Günter Schmid ed., March 2004)
1038	Victor I. Klimov, <i>Nanocrystal Quantum Dots</i> , 28 LOS ALAMOS SCI. 214 (2003)
1039	David J. Norris, <i>Electronic Structure in Semiconductor Nanocrystals</i> , in SEMICONDUCTOR AND METAL NANOCRYSTALS 65 (Victor I. Klimov ed., 2003)
1040	U.S. Patent App. Pub. No. 2004/0036130 to Lee et al. (“Lee”)
1041	Andy Watson et al., <i>Lighting Up Cells with Quantum Dots</i> , 34 BIOTECHNIQUES 296 (2003)
1044	Victor K. LaMer et al., <i>Theory, Production and Mechanism of Formation of Monodispersed Hydrosols</i> , 72 J. AM. CHEMICAL SOC’Y 4847 (1950)

Exhibit	Description
1045	Scott L. Cumberland et al., <i>Inorganic Clusters as Single-Source Precursors for Preparation of CdSe, ZnSe, and CdSe/ZnS Nanomaterials</i> , 14 CHEMISTRY OF MATERIALS 1576 (2002)
1046	C. B. Murray et al., <i>Synthesis and Characterization of Nearly Monodisperse CdE (E = S, Se, Te) Semiconductor Nanocrystallites</i> , 115 J. AM. CHEMICAL SOC'Y 8706 (1993)
1047	David Battaglia et al., <i>Formation of High Quality InP and InAs Nanocrystals in a Noncoordinating Solvent</i> , 2 NANO LETTERS 1027 (2002)
1048	Tobias Hanrath et al., <i>Nucleation and Growth of Germanium Nanowires Seeded by Organic Monolayer-Coated Gold Nanocrystals</i> , 124 J. AM. CHEMICAL SOC'Y 1424 (2002)
1049	Jennifer A. Hollingsworth et al., "Soft" Chemical Synthesis and Manipulation of Semiconductor Nanocrystals, in SEMICONDUCTOR AND METAL NANOCRYSTALS 1 (Victor I. Klimov ed., 2003)
1050	Nigel L. Pickett et al., <i>Syntheses of Semiconductor Nanoparticles Using Single-Molecular Precursors</i> , 1 CHEMICAL REC. 467 (2001)
1053	U.S. Patent No. 7,056,471 to Han et al.
1054	U.S. Patent No. 7,588,828
1056	Olga I. Mićić et al., <i>Core-Shell Quantum Dots of Lattice-Matched ZnCdSe₂ Shells on InP Cores: Experiment and Theory</i> , 104 J. OF PHYSICAL CHEMISTRY B 12149 (2000)
1057	Michael L. Steigerwald, <i>Clusters as Small Solids</i> , 13 POLYHEDRON 1245 (1994)
1058	M.L. Steigerwald et al., <i>Application of Phosphine Tellurides to the Preparation of Group II-VI (2-16) Semiconductor Materials</i> , 7 ORGANOMETALLICS 245 (1988)
1059	Uri Banin et al., <i>Tunneling and Optical Spectroscopy of Semiconductor Nanocrystal Quantum Dots: Single-Particle and Ensemble Properties</i> , in SEMICONDUCTOR AND METAL NANOCRYSTALS 327 (Victor I. Klimov ed., 2003)
1060	Arthur J. Nozik, et al., <i>III-V Quantum Dots and Quantum Dot Arrays: Synthesis, Optical Properties, Photogenerated Carrier Dynamics, and Applications to Photon Conversion</i> , in SEMICONDUCTOR AND METAL NANOCRYSTALS 327 (Victor I. Klimov ed., 2003)

Exhibit	Description
1061	Yong Han et al., <i>Synthesis and Characterization of Zinc Sulfide/Gallium Phosphide Nanocomposite Powders</i> , 77 J. AM. CERAMICS SOC'Y 3153 (1994)
1064	U.S. Patent No. 6,864,626 to Weiss et al. ("Weiss")
1065	U.S. Patent No. 7,147,712 to Zehnder et al. ("Zehnder '712")
1066	M. A. Olshavsky, <i>Organometallic Synthesis of GaAs Crystallites Exhibiting Quantum Confinement</i> , 112 J. AM. CHEM. SOC. 9438 (1990)
1067	A. R. Kortan et al, <i>Nucleation and Growth of CdSe on ZnS Quantum Crystallite Seeds, and Vice Versa, in Inverse Micelle Media</i> , 112 J. AM. CHEM. SOC. 1327 (1990)
1068	Holger Borchert et al., <i>Investigation of ZnS Passivated InP Nanocrystals by XPS</i> , 2 NANO LETTERS 151 (2002)
1069	Gregory A. Khitrov, <i>Synthesis, Characterization and Formation Mechanisms of Inorganic Nanomaterials</i> , University of California Santa Barbara (1993)
1070	Frederic V. Mikulec, <i>Organometallic Synthesis and Spectroscopic Characterization of Manganese-Doped CdSe Nanocrystals</i> , 122 J. AM. CHEM. SOC. 2532 (2000)
1071	Stephan Haubold, <i>Strongly Luminescent InP/ZnS Core-Shell Nanoparticles</i> , 2 CHEMPHYSCHEM 331 (2001)
1072	Huheey et al., <i>INORGANIC CHEMISTRY: PRINCIPLES OF STRUCTURE AND REACTIVITY</i> (4th ed. 1993)
1073	Linus Pauling, <i>GENERAL CHEMISTRY</i> (3d ed. revised 1988)
1074	Richard L. Wells et al., <i>Tris(trimethylsilyl)arsine and Lithium Bis(trimethylsilyl)arsenide</i> , 31 INORGANIC SYNTHESSES 150 (Alan H. Cowley ed., 1997)
1091	May 11, 2021 Claim Construction Order from <i>Nanoco Technologies Ltd. v. Samsung Electronics Co., Ltd.</i> , No. 2:20-cv-00038 (E.D. Tex.)

Exhibit	Description
2004	Periodic table of the elements, Encyclopaedia Britannica, Inc., available at https://www.britannica.com/science/periodic-table (last visited Feb. 18, 2021)

Exhibit	Description
2005	Samsung Global Newsroom. Quantum Dot Artisan: Dr. Eunjoo Jang, Samsung Fellow, November 30, 2017
2006	ACS Energy Lett. 2020, 5, 1316-1327. “Environmentally Friendly InP-Based Quantum Dots for Efficient Wide Color Gamut Displays”
2007	Wang, F., Dong, A. and Buhro, W.E., <i>Solution–liquid–solid synthesis, properties, and applications of one-dimensional colloidal semiconductor nanorods and nanowires</i> . Chemical Reviews, 116(18):10888-10933 (2016).
2008	Wang, F., et al., <i>Solution– liquid– solid growth of semiconductor nanowires</i> . Inorganic chemistry, 45(19):7511-7521 (2006).
2009	Madkour, L.H., <i>Synthesis Methods For 2D Nanostructured Materials, Nanoparticles (NPs), Nanotubes (NTs) and Nanowires (NWs)</i> . In <i>Nanoelectronic Materials</i> (pp. 393-456). Springer, Cham. (2019)
2010	Mushonga, P., et al., <i>Indium phosphide-based semiconductor nanocrystals and their applications</i> . Journal of Nanomaterials, 1-11 (2012).
2011	Luo, H., <i>Understanding and controlling defects in quantum confined semiconductor systems</i> , Doctoral dissertation, Kansas State University (2016).
2012	Sinatra, L., et al. <i>Methods of synthesizing monodisperse colloidal quantum dots</i> . Material Matters, 12:3-7 (2017)
2013	Pu, Y., et al., <i>Colloidal synthesis of semiconductor quantum dots toward large-scale production: a review</i> . Industrial & Engineering Chemistry Research, 57(6):1790-1802 (2018).
2014	Rao, C. N. R.; Gopalakrishnan, J., <i>Chapter 3: Preparative Strategies from New Directions in Solid State Chemistry</i> ; Cambridge University Press: Cambridge, UK (1986).
2015	Glossary of Common Wafer Related Terms, BYU Electrical & Computer Engineering Integrated Microfabrication Lab, definition of degenerate semiconductor, available at https://cleanroom.byu.edu/ew_glossary (last visited Feb. 19, 2021)
2016	October 22, 2006 email between Eunjoo Jang and Nigel Pickett Re: Cd free quantum dots
2017	Weare, W.W., Reed, S.M., Warner, M.G. and Hutchison, J.E., <i>Improved synthesis of small (d core ≈ 1.5 nm) phosphine-stabilized gold nanoparticles</i> . Journal of the American Chemical Society, 122(51):12890-12891 (2000).

Exhibit	Description
2018	Samsung's Motion to Stay Pending <i>Inter Partes</i> Review of the Asserted Patents in Case 2:20-cv-00038-JRG, filed on November 30, 2020
2019	Order denying Samsung's Motion to Stay Pending <i>Inter Partes</i> Review in Case 2:20-cv-00038-JRG, filed on January 8, 2021
2020	Standing Order Regarding the Novel Coronavirus (Covid-19) for the Eastern District of Texas Marshall Division, signed March 3, 2020
2021	Standing Order Regarding Pretrial Procedures In Civil Cases Assigned to Chief District Judge Rodney Gilstrap During the Present Covid-19 Pandemic, signed April 20, 2020
2022	Samsung's Preliminary Invalidity Contentions and Disclosures Pursuant To Patent Rules 3-3 and 3-4 (served November 9, 2020)
2023	Merriam-Webster Dictionary, online edition. Definition of "Halogen", available at https://www.merriam-webster.com/dictionary/halogen (last visited Feb. 23, 2021)
2024	Illustrated Glossary of Organic Chemistry, UCLA. Illustration of Halide, available at http://www.chem.ucla.edu/~harding/IGOC/H/halide.html (last visited Feb. 23, 2021)
2025	Mortvinova, N.E., Vinokurov, A.A., Lebedev, O.I., Kuznetsova, T.A., and Dorofeev, S.G., <i>Addition of Zn during the phosphine-based synthesis of indium phosphide quantum dots: doping and surface passivation</i> , Beilstein J Nanotechnol. 2015; 6: 1237-1246.
2026	Samsung's Proposed Claim Constructions (served December 11, 2020)
2027	He, Z., Yang, Y., Liu, J.W. and Yu, S.H., <i>Emerging tellurium nanostructures: controllable synthesis and their applications</i> . Chemical Society Reviews, 46(10): 2732-2753 (2017)
2029	Makkar, M. and Viswanatha, R., <i>Frontier challenges in doping quantum dots: synthesis and characterization</i> . RSC Advances, 8(39):22103-22112 (2018).
2031	July 29, 2021 Deposition of Mark A. Green, Ph.D.
2032	Excerpts from June 10, 2021 Rebuttal Expert Report of Mounji Bawendi, Ph.D.

Exhibit	Description
2033	Xie, L., et al., <i>Characterization of Indium Phosphide Quantum Dot Growth Intermediates Using MALDI-TOF Mass Spectrometry. Journal of the American Chemical Society</i> , 138:13469-13472 (2016). (Bawendi Depo. Exhibit 7)
2034	Excerpts from June 16, 2021 Deposition of Mounji G. Bawendi, Ph.D.
2035	Definition of Monodisperse by The Free Dictionary, Aug. 10, 2021
2036	Panfil, Y.E., Oded, M. and Banin, U., <i>Colloidal quantum nanostructures: emerging materials for display applications. Angewandte Chemie International Edition</i> , 57(16):4274-4295 (2018).
2037	MilliporeSigma, Solid State Synthesis, available at https://www.sigmaaldrich.com/US/en/applications/materials-science-and-engineering/solid-state-synthesis (last visited August 10, 2021).
2038	Fackler Jr, J.P., et al., Californium-252 plasma desorption mass spectrometry as a tool for studying very large clusters; evidence for vertex-sharing icosahedra as components of Au ₆₇ (PPh ₃) ₁₄ Cl ₁₈ . <i>Journal of the American Chemical Society</i> , 111(16):6434-6435 (1989).
2039	Xia, N., & Wu, Z., Controlling ultrasmall gold nanoparticles with atomic precision. <i>Chemical Science</i> , 12(7):2368-2380 (2021).
2040	Anderson, D.P., et al., Chemically synthesised atomically precise gold clusters deposited and activated on titania. Part II. Physical chemistry chemical physics, 15(35):14806-14813 (2013)
2041	Antoine, R., Atomically precise clusters of gold and silver: A new class of nonlinear optical nanomaterials. <i>Frontier Research To-day</i> , 1:1001, 1-11 (2018)
2042	Shweky, I., Aharoni, A., Mokari, T., Rothenberg, E., Nadler, M., Popov, I. and Banin, U., Seeded growth of InP and InAs quantum rods using indium acetate and myristic acid. <i>Materials Science and Engineering: C</i> , 26(5-7):788-794 (2006).
2043	PubChem – Cadmium Sulfide Compound Summary.
2044	New Electronics - <i>Nanoparticles manufacturer receives \$600,000 boost, available at https://www.newelectronics.co.uk/electronics-news/nanoparticles-manufacturer-receives-600-000-boost/26831/</i> (last visited August 10, 2021).

Exhibit	Description
2045	Kangyong Kim, et al., <i>Zinc Oxo Clusters Improve the Optoelectronic Properties on Indium Phosphide Quantum Dots</i> , Chem. Mater. 2020, 32, 2795-2802. (Bawendi Depo. Exhibit 8)

IV. IDENTIFICATION OF INSTITUTED GROUNDS

23. Petitioner alleges that the challenged claims of the '365 Patent are unpatentable on the following grounds:

Ground	Basis	Challenged Claim	Reference(s)
1	35. U.S.C. §102	1, 7-12, 17, 22-23	Banin
2	35. U.S.C. §103	1, 7-12, 15-17, 22-23	Banin
3	35. U.S.C. §103	2-6, 18-21	Banin, Herron
4	35. U.S.C. §103	13, 14	Banin, Treadway
5	35. U.S.C. §103	1-9, 17-23	Zaban, Farneth, Yu
6	35. U.S.C. §103	1-2, 4, 7-12, 17-18, 22-23	Lucey, Ahrenkiel
7	35. U.S.C. §103	13-16	Lucey, Ahrenkiel, Treadway

V. SUMMARY OF OPINIONS

24. My opinions relate to the challenged claims of the '365 patent that are generally speaking, directed to semiconductor nanoparticles and methods for preparing semiconductor nanoparticles. The specific type of semiconductor nanoparticles at issue in this case are commonly referred to as “quantum dots.” In forming my opinions I have considered the viewpoint of a person having ordinary skill in the art (“POSITA”) in the area of nanotechnology or nanoparticle

engineering at the time of the '365 patent. Such a person would have had at least a master's degree in chemistry or a similar science and at least two years of work experience relating to nanotechnology or nanoparticle engineering, or a bachelor's degree in chemistry or a similar science and at least four years of work experience relating to nanotechnology or nanoparticle engineering.

25. In my opinion, the Board should uphold the validity of the challenged claims of '365 Patent. The Board instituted this proceeding under the belief that Samsung's primary reference, Banin, discloses a molecular cluster compound required by all challenged claims. In fact, Banin does not disclose such a cluster compound and instead teaches the use of a molten gold droplets with a range of sizes to access nanomaterials through a distinct mechanism. In addition, where Samsung has relied upon combinations of references in its proposed Grounds, the references do not align. While all are nanotechnology references, they teach different techniques that a person of ordinary skill in the art would not attempt to mix or perform together. Reflective of that fact, Samsung has not adequately explained how the references would have worked together in the proposed combinations, particularly where the Grounds propose combining discrete aspects from references teaching techniques that although well known, are largely incompatible.

26. For example, in certain Grounds, Samsung suggests combining a solution-liquid-solid (“SLS”) based synthesis method that uses as catalyst taught by Banin with references disclosing solid state synthesis or other chemically and mechanistically distinct synthesis methods. Yet Samsung’s expert, Dr. Green, simply concludes without support that combining these disparate teachings will succeed. *See e.g.*, Ex. 1002 (Green), ¶130 (“It is my opinion that a POSITA would have had a reasonable expectation that this combination would succeed in growing an InAs core that includes a Cd-based MCC through a seeded growth reaction.”) (uncited).

27. For these reasons, I do not believe that the Petition demonstrates that any challenged claim of Nanoco’s U.S. Patent No. 8,524,365 (Ex. 1001) (the “’365 patent”) is unpatentable.

28. The ’365 patent is directed to quantum dots and methods of producing quantum dots. The claimed nanoparticles and methods involve creating a quantum dot by using multiple precursors. Precursors are compounds that contain atoms to be incorporated into the quantum dot. For example, the ’365 patent claims require that the core semiconductor material comprise one or more elements not comprised within a molecular cluster compound that seeds the reaction. *See e.g.*, Ex. 1001 at 20:9-13.

29. The *molecular cluster compound* is an important feature of the invention. *See e.g., id.* at 4:51-61. A molecular cluster compound, as defined in the patent and construed by the district court, is a cluster of “three or more metal atoms and their associated ligands of sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular.” Ex. 1091 at 18. As indicated in the patent, the molecular clusters are identical to one another in the same way that one H₂O molecule is identical to another H₂O molecule. Ex. 1001 at 5:19-28.

30. Petitioner’s proposed Grounds 1 and 2 rely on Banin as the sole prior art reference. Banin does not disclose a molecular cluster compound. Banin’s alleged “clusters” are simply small gold nanoparticles that have significant variation in their composition. These metal nanoparticles must necessarily melt to serve their function as catalyst droplets for the Solution-Liquid-Solid (“SLS”) growth of nanorods and lack the sufficiently well-defined chemical structure of a molecular cluster compound. *See* Section XI.A.1 *infra*.

31. Petitioner’s Grounds 3 and 4 rely on Banin as a primary reference, in combination with Herron and Treadway, respectively. Neither Petitioner nor Dr. Green adequately explain how combining Banin with either reference would have worked. Herron discloses semiconductor intermediates that show no evidence of being able to liquefy (i.e., melt) and function as a catalyst in Banin’s SLS method

for growing nanorods, which requires metals not semiconductors. Treadway discloses a hot-injection method without any relation to SLS, nor does Treadway disclose a molecular cluster compound. In my opinion, there is no disclosure in any of these references that would have suggested using them together, nor is there is any explanation as to how the combinations would have worked.

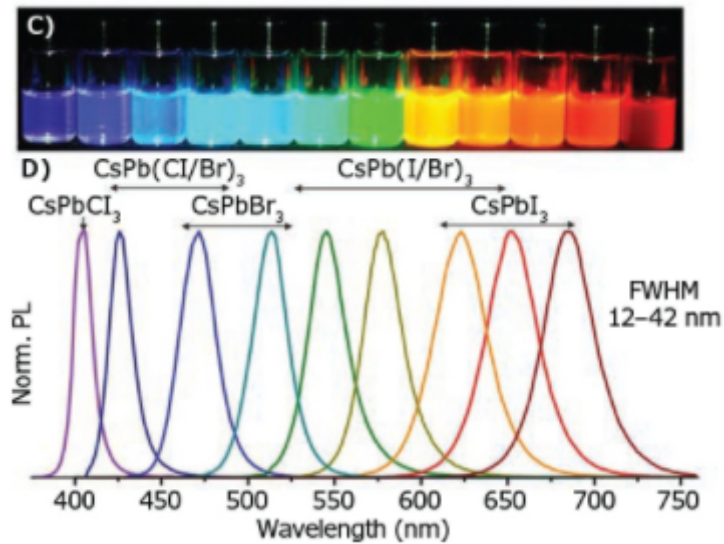
32. Petitioner's Ground 5 relies on Zaban as a primary reference, combined with Farneth and Yu. Petitioner does not allege that Zaban uses any "clusters" at all to make its disclosed quantum dots. Moreover, the cluster disclosed by the secondary reference, Farneth, is an intermediate semiconductor isolated during a solid-state reaction for making bulk zinc sulfide (ZnS). This solid-state zinc sulfide process is very different from the process for growing indium phosphide quantum dots discussed in Zaban. Accordingly, using Farneth's cluster in combination with Zaban would not work. Applying Farneth's zinc-based cluster to Zaban would result in a far greater number of zinc ions in Zaban's quantum dots, fundamentally changing their properties. And another secondary reference, Yu does not relate to semiconductor nanoparticles at all, and has little to do with either Farneth or Zaban and thus is a singularly poor choice for Petitioner's proposed combination.

33. Grounds 6 and 7 rely on Lucey as a primary reference, in combination with Ahrenkiel alone, or Ahrenkiel and Treadway (Ground 7). Lucey uses a hot-

injection method to create InP nanoparticles, while Ahrenkiel uses the SLS method to create quantum rods. Those are completely different techniques and neither Petitioner nor Dr. Green adequately explain why a POSITA would have been motivated to combine these references, nor why a reasonable expectation of success would result. While Treadway also uses the hot-injection method, that reference was added in Ground 7 to addresses specific “ternary and quaternary” claim limitations, and it does not cure the deficiencies presented by the Lucey + Ahrenkiel combination, which is not one that a person of skill in the art would have pursued.

VI. OVERVIEW OF QUANTUM DOTS

34. The challenged claims of the '365 patent are directed to nanoparticles, which include quantum dots. Quantum dots are semiconductor nanoparticles that are extremely small and range in size from 2-100 nanometers (nm). Quantum dots have unique properties and can emit light at very particular wavelengths, dictated by their size-dependent band gap. Thus, the color, of light being emitted depends on the dot size, and this for quantum dots used in lighting and display technologies, the color range can be tuned along the visible spectrum from violet to red color as the dots grow larger in diameter. Ex. 1001 at 1:21-15.

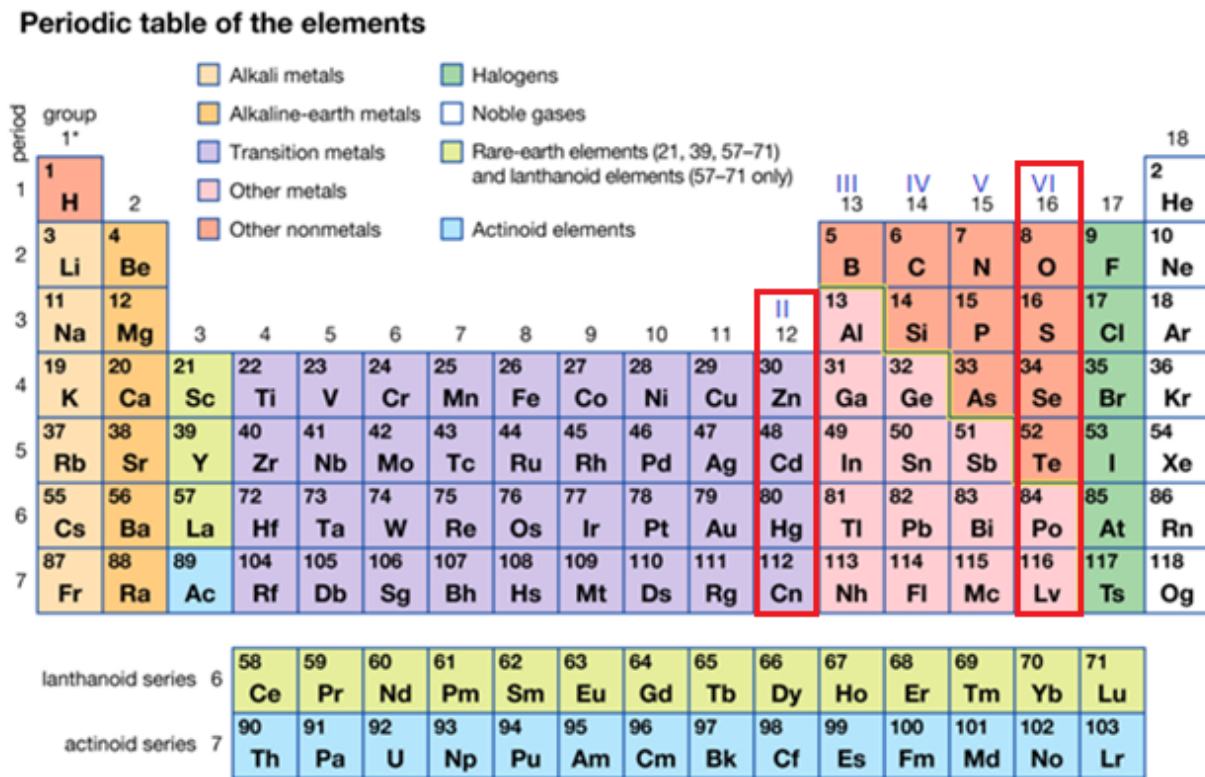


Ex. 2013 at 1792.

35. A key feature of quantum dots used in displays and for related light emitting applications is size uniformity. In order to achieve color precision, all of the quantum dots being used must be sufficiently uniform in size (i.e., “monodisperse quantum dots”). Monodisperse quantum dots are used to enhance the picture quality of televisions due to their fine-tunable color-generating properties. Ex. 1001 at 1:25-32. When quantum dots embedded in a film are positioned in front of a television’s backlight, they enable a wider variety and more saturated range of colors. Nanoco was one of the first companies involved in the manufacture of quantum dots and it developed methods for manufacturing monodisperse quantum dots in commercial quantities for use in displays.

36. Around the time of the invention, cadmium selenide (“CdSe”) was the primary quantum dot material being studied. The size of CdSe quantum dots could

be precisely controlled and this allowed skilled artisans to tune the colors being emitted across the visible spectrum. Ex. 1001 at 1:40-43. CdSe quantum dots are made up of elements from columns 12 and 16 of the periodic table, and they come from a family known as group II-VI quantum dots, which includes other quantum dot combinations from those same columns. *Id.*



*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC). © Encyclopædia Britannica, Inc.

See Ex. 2004 (annotated).

37. A major drawback of cadmium is its toxicity. As a result, it has been banned in many countries from being used in consumer electronics. This created a vacuum in the industry for new methods of making commercial amounts of

cadmium-free (“Cd-free”) quantum dot replacements. These Cd-free quantum dots would also need to be grown to uniform sizes to allow them to be fine-tuned to specific color emissions across the visible spectrum, like their cadmium-containing counterparts.

38. Nanoco developed methods for synthesizing quantum dots using the less toxic elements from columns 13 and 15 of the periodic table (group III-V), such as indium phosphide (“InP”). Ex. 1001 at 8:18-23. A major drawback to these types of Cd-free quantum dots is that they were more difficult and time consuming to prepare using prior art methods. Ex. 1001 at 4:4-7.

39. A primary issue with Cd-free quantum dots from the group III-V family of materials is that they could not be made in commercial quantities with uniform sizing. At the time of the patent, the commercial methods used to make quantum dots included the “hot injection” method, which could successfully grow large quantities of CdSe quantum dots, but not ones made from materials such as InP, outside of lab-scale experiments using small amounts of each solution. The smaller sized lab scale application of the hot injection method allows one solution to be added rapidly to another without significantly changing the temperature of the larger reaction, but that was generally not the case when larger scale productions of group III-V material were attempted. This is because the large injection volumes create a temperature differential throughout the solution that

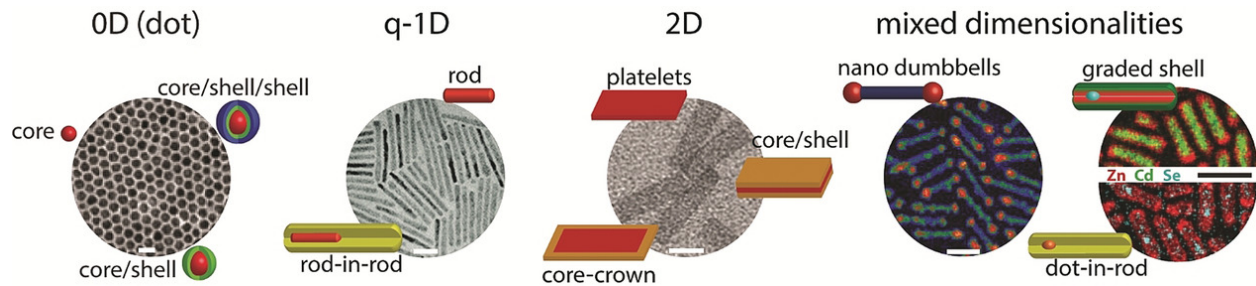
results in quantum dots of many different sizes because nucleation and growth are not temporally distinct in time. Ex. 1001 at 3:54-4:32. A large size distribution creates non-uniform color emission and compromises the utility of the quantum dots. *See* Ex. 1001 at 4:53-56.

40. The methods claimed by the '365 patent solved these problems and enabled the commercial synthesis of uniform Cd-free quantum dots by converting precursors (such as an indium-containing precursor and a phosphorus-containing precursor) into a quantum dot core in the presence of a *molecular cluster compound*. Ex. 1001 at 4:51-61, 5:5-9. This “cluster assisted” growth method eliminates the need for an independent nucleation step, and facilitates the large-scale synthesis of monodisperse Cd-free quantum dots. *Id.* at 5:9-19.

VII. OVERVIEW OF NANOPARTICLE SYNTHESIS METHODS

41. There are a number of different ways to manufacture different kinds of nanoparticles with particular characteristics. These methods often use different chemical agents and mechanistically distinct techniques, yet Petitioner mixes and matches them in each of the proposed grounds. I do not see any rationale in the Petition or Dr. Green's declaration describing how those combinations would work, particularly where each method uses highly specific conditions, reagents, and other requirements to synthesize specific types of nanoparticles. *See generally*, Ex. 1002.

42. While some synthesis methods produce spherical nanoparticles (i.e., quantum dots), other methods are used to produce rod-shaped nanoparticles (nanorods), or other variations including quantum wires, ribbons, tubes, or sheets. Below is an exemplary picture showing some of these different structures:



See Ex. 2036 at 4276.

43. The reaction conditions used in different methods for producing nanoparticles vary widely. Some synthesis methods are conducted at high temperatures, while others can be carried out at room temperature or with mild heating. The methods may utilize single-source precursors (i.e., precursors containing all of the atoms of the nanoparticle), or multiple precursors that each supply a different atom to the nanoparticle. The precursors might be solid, vaporized, or part of a colloidal solution, which is a solution with particles that remain evenly distributed throughout.

44. The different synthesis methods available in the art at the time of the '365 patent each have their own particular set of conditions and requirements—and

they are all targeted to obtain a particular set of characteristics in the resulting nanoparticle (i.e., size, composition, quantity, purity, etc.). I briefly describe some of these methods below.

A. Nanorods and Nanowires

45. Nanorods and nanowires are elongated forms of nanostructures. To achieve their elongated shape, these types of nanoparticles are grown selectively in one dimension. Two common ways of achieving this one-dimensional growth are (1) the Vapor-Liquid-Solid method, and (2) the Solution-Liquid-Solid method.

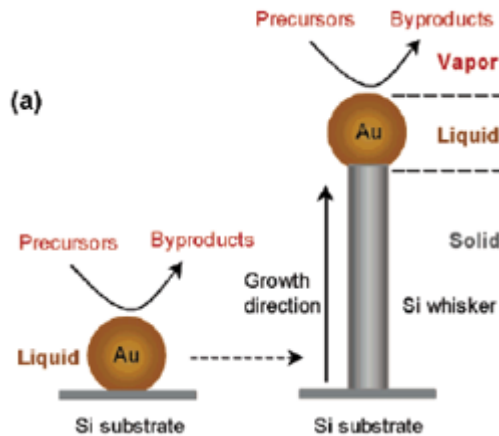
1. Vapor-Liquid-Solid Method

46. The Vapor-Liquid-Solid (“VLS”) method was first discovered when researchers noticed that silicon (Si) “whiskers” would grow on gold (Au) decorated silicon substrates when they were subjected to a process called chemical vapor deposition (“CVD”). *See* Ex. 2008 (Solution-Liquid-Solid Growth of Semiconductor Nanowires) at 7513.

47. As its name suggests, CVD uses a vaporized precursor to deposit silicon atoms directly onto a substrate. At the high temperatures required for this process, the gold melts into various size droplets. Ex. 2008 at 7513. These liquid gold droplets then dissolve silicon atoms until the droplets become supersaturated, at which point crystalline silicon whiskers begin forming at the bottom of the gold droplet (the part of the droplet that is touching the substrate).

48. Because the growing crystals form where the droplet is already touching the silicon, they push the droplet upwards as the elongated crystal forms below it. Growth like this in one dimension creates rod-shaped or wire-shaped nanoparticles. *Id.* The silicon “whiskers” will continue to grow in this manner until the precursors are depleted. *Id.* This process is called “VLS” as an acronym for the three phases involved: vapor-phase (silicon precursors), liquid phase (melted gold droplets, also called the “catalyst”), and solid phase (crystalline whiskers). *Id.*

49. A diagram of the VLS synthesis process is reproduced below:

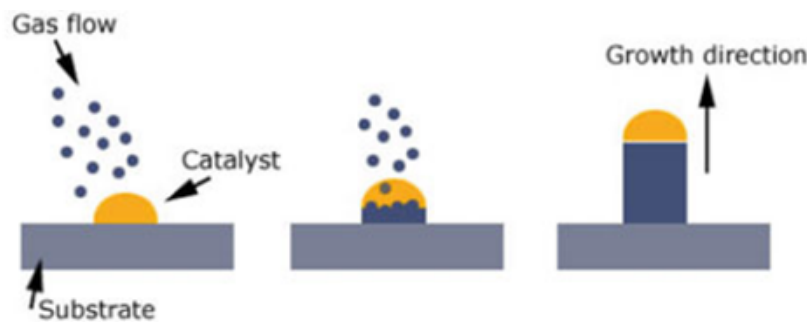


50. While different metals besides gold can be used in VLS, there are very particular requirements that must be considered when choosing metals that will work. Those include:

- (1) A liquid catalyst: the metal must be able to form a liquid solution with the crystalline growth material at the nanowire growth temperature—i.e., the liquid metal (e.g., gold) must be able to dissolve the substrate (e.g., silicon);

- (2) Soluble precursors: the solubility of the precursors must be high enough in the metal that supersaturation can be achieved;
- (3) Vapor pressure: the vapor pressure of the liquid metal catalyst must be small so that the droplet does not vaporize, shrink in volume (and therefore radius), or decrease the radius of the growing wire until growth is finally terminated;
- (4) A catalyst that won't react: the catalyst must be inert to the reaction precursors and products during nanowire growth;
- (5) Compatibility of the components of the reaction: the vapor–solid, vapor–liquid, and liquid–solid interfacial energies must be examined for compatibility before choosing a suitable catalyst.

See Ex. 2009 at 422-427. When these conditions are met, nanoparticle growth fueled by the supersaturated substrate occurs in the direction of the catalyst.

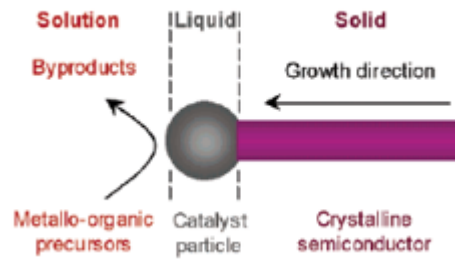


Id. at 423.

2. Solution-Liquid-Solid Method

51. The Solution-Liquid-Solid (“SLS”) method is related and analogous to VLS in that it also uses molten metal to dissolve precursors and drive one dimensional nanoparticle growth. SLS differs however in that it (1) is typically

performed at lower temperatures, (2) replaces the vapor-phase precursor with a solution-phase precursor, and (3) takes place in solution, meaning that the growing nanorods are not bound to a substrate. Ex. 2008 at 7514 (Wang 1). The SLS process is depicted below:



Id.

52. Similar to VLS, there are particular requirements that must be considered when choosing metals to use in the SLS method—including melting points, solvating abilities, and reactivities. Ex. 2008 at 7514. Additionally, at least one of the components of the growing solid phase must be soluble in the catalyst material, so that supersaturation can be achieved and allow the semiconductor material to precipitate to grow the semiconductor crystal nanorod. *Id.* at 7514-7515 (“at least one of the components of the product semiconductor phase must have finite but limited solubility in the catalyst material, so that high supersaturations can be achieved.”). Finally, the catalyst should not react with or form a solid solution with the target semiconductor. *Id.* at 7515.

53. The melting points, semiconductor-component solubilities, and reactivities are important criteria when considering candidate metals or metal alloys as potential SLS-catalyst materials. Ex. 2007 at 10889 (“The melting points, semiconductor-component solubilities, and reactivities are important criteria for judging candidate metals or metal alloys as potential SLS-catalyst materials.”). Nanoparticles made of low melting point metals have proved useful for the SLS growth of semiconductor materials under typical reaction conditions (e.g., 200–300 °C). *See* Ex. 2008 at 7514 (“Catalyst particles must be molten under the reaction conditions.”). The melting point of SLS-catalysts must be lower than the temperature at which the solution evaporates. Ex. 2007 at 10890. In light of these criteria, indium, bismuth, and tin are considered the best metal catalysts for SLS growth of semiconductor crystals. Ex. 2008 at 7515 (“The low melting metals best meeting these [three] criteria seemed to be In, Bi, and Sn.”). I am not aware of any SLS methods that employ semiconductor crystals in place of metal catalysts.

54. Petitioner’s Banin and Ahrenkiel references both use the SLS method to create nanorods. *See* Ex. 1005 at 22:25-30 (describing “rods with gold particles on the end, demonstrating the SLS growth mechanism”); Ex. 1012 at 834 (describing “growth of InP quantum rods and quantum wires by the solution-liquid-solid mechanism...”). Banin disclosed using either TOP or TOPO as the

solvents at temperatures ranging from 200-360 °C and Ahrenkiel taught the use of TOPO/TOP heated at 250 °C. Ex. 1005 at 12:18-24 and Ex. 1012 at 834.

B. Quantum Dots

55. Quantum dots are spherical, as their name suggests. To achieve this shape, quantum dots must grow at equal rates in all directions at the same time. At the time of the '365 patent, a variety of different methods for quantum dot synthesis existed, and each posed its own challenges.

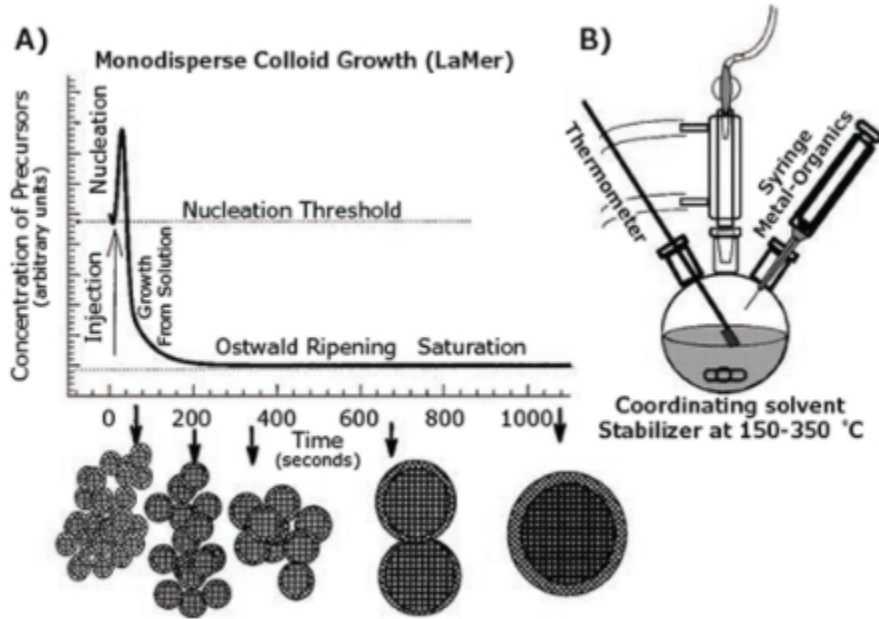
56. One particular challenge in synthesizing quantum dots is the synthesis of uniformly sized (“monodisperse”) and narrowly size-distributed quantum dots, for which a number of different methods have been developed. *See* Ex. 2012 at 1 (Introduction). These include the hot-injection method, the heat-up method, and Nanoco’s patented cluster-assisted method.

1. The Hot-Injection Method

57. The hot-injection method involves the rapid injection of a room temperature solution of precursors into an extremely hot reaction medium in the presence of carefully chosen surfactant molecules. Ex. 2010 (Mushonga) at 2. The rapid injection of the precursor molecules induces a sudden supersaturation of the solution, resulting in a short burst of nucleation (i.e., initial crystals are formed). *Id.* After the reaction temperature drops in response to addition of the cold precursor solution, coupled with the low concentration of the remaining precursor molecules,

further nucleation is halted. Growth of the quantum dots then follows at a lower temperature than that of the nucleation process. This sequential separation of the nucleation and growth processes generally leads to control over the size of the semiconductor nanocrystals.

58. There are different variations of the hot-injection method: including one in which a single precursor containing all the elements to be incorporated into the quantum dot is injected (single-source precursors), and others in which two (or more) distinct precursors are used (dual-injection). Dual-injection can be restrictive because the kinetics of the individual precursors need to be carefully matched and the precursors are injected into the reaction mixture at elevated temperature, and thus they usually cannot be pre-mixed. As a consequence, localized variation of precursor concentration can occur. This can be a major drawback because it can result in broadened size distribution of the initial nucleated crystals. Single-source precursors are therefore have advantages in many instances. Ex. 2011 (Luo) at 11.



Ex. 2012 (LaMer Model) at Fig. 1A.

59. The hot-injection approach remains the most common method by which cadmium-based quantum dots are synthesized. Ex. 2012 at 1. But it has not been successfully employed to produce large scale quantities of cadmium-*free* quantum dots. It is more difficult to separate nanoparticle nucleation and growth via a high temperature dual injection synthesis in certain cadmium-free quantum dots. See Ex. 1037 at 81-82 and Ex. 1047 at 1028. This is, in part, because the bonding in certain cadmium-free quantum dots, such as group III-V quantum dots (such as InP), is more covalent than that in group II-VI quantum dots (such as CdSe). Ex. 1037 at 80; see also Ex. 1001 at 4:4-7.

60. The hot-injection method also presents challenges for larger scale production of quantum dots because the large volumes of solutions that are

required to be rapidly injected create a temperature differential throughout the solution. Ex. 2013 at 1792. This temperature differential results in quantum dots of many different sizes. *Id.* A large size distribution defeats the purpose of quantum dots by eliminating the ability to fine tune the optical properties.

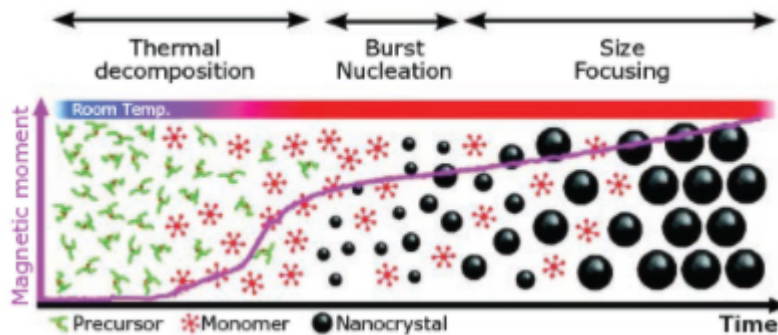
61. Petitioner's Lucey reference uses the hot injection method to make quantum dots from a single-source precursor. *See e.g.*, Ex. 1011 at 10:38-41 ("The initiation of the reactions occurs when the ER_n source is rapidly injected into a heated solution of ML_n source in the non-coordinating solvent."). Petitioner's Treadway reference also employs the hot injection method. Ex. 1015 (Treadway) at 13:53-60 ("In a single rapid injection, the TOP solution was added to the hot TOPO pot after removing the heat from the reaction.").

2. The Heat-Up Method

62. The heat-up method is an approach that involves steadily heating precursors in solution, sometimes for a period of days. *See* Ex. 2012 at 2. The heat-up method is generally considered to be a more easily controlled approach to preparing nanocrystals than hot injection because it allows quantum dots to be prepared in a single pot without an injection step. *Id.* at 2-3.

63. While most heat-up synthesis methods result in quantum dots with a large particle size-distribution (because nucleation events are spread out over an appreciable period of time), it is nevertheless possible to obtain monodisperse

quantum dots with this method if precursors with a suitable level of reactivity are used. Ex. 2012 at 2-3. Similar to hot injection, a key aspect for growing monodisperse quantum dots using the heat-up method is to employ a homogeneous nucleation process through the use of precursors that are highly reactive only after reaching a certain temperature. In general, the precursors should exhibit no or very low reactivity below the desired temperature required to allow growth of the target quantum dots to predominate, as shown below:



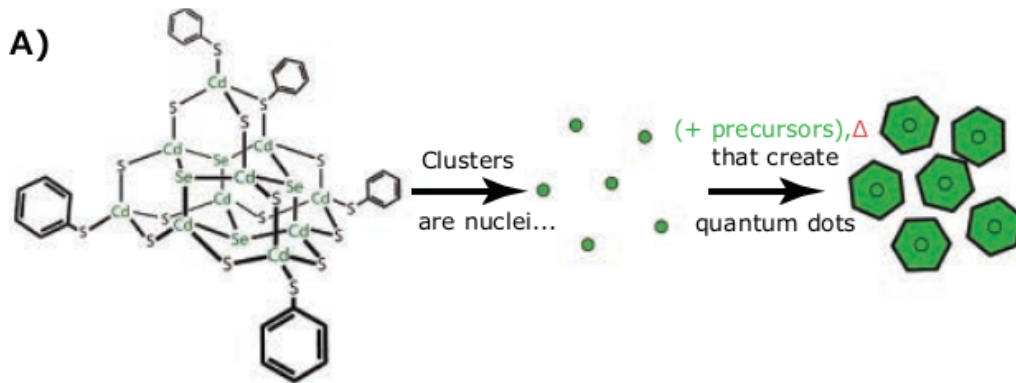
Ex. 2012 (Fig. 3).

64. Petitioner’s Zaban reference uses the heat-up method. Ex. 1006 at 3154 (stating that “the reactants are heated for 3 days at 260-280 °C in the presence of trioctylphosphine oxide (TOPO) and trioctylphosphine (TOP)”).

3. The Molecular Cluster-Assisted Method

65. The molecular cluster-assisted method is a specific type of seeded growth method that Nanoco developed, and the ’365 patent discloses and claims a specific type of cluster-assisted growth. The cluster-assisted method disclosed in

the '365 patent utilizes uniform molecular cluster compounds (“MCCs”) within the reaction system. These MCCs may act as nuclei and induce controlled growth of the nanocrystals. The reaction is typically initiated by combining molecular cluster compounds with an organic solvent in the presence of semiconductor precursors before slowly increasing the temperature. This “seeding” results in the clusters evolving into quantum dot nucleation sites as shown below:



Ex. 2012, at Fig. 4A.

66. Subsequent studies have shown that the presence of MCCs directly impacts the concentration and size of the resulting quantum dots. *See* Ex. 2012 at 4. The concentration of quantum dots correlates to and is almost equal to the number of the cluster seeds (within 10%). *Id.* The number of quantum dots produced by the cluster-assisted method is also reported to be approximately 20 times higher than what can be obtained via a standard rapid injection procedure that employs the same amount of precursors. *Id.*

67. The concentration of MCCs directly affects the yield and quality of the quantum dots. Increasing the MCC concentration generally decreases the size of the quantum dots due to the increasing number of MCC nuclei competing for a finite number of available precursors. *Id.* The cluster-assisted method for growing quantum dots remains a versatile way to control quantum dot concentration, and it can produce a larger quantity of quantum dots from a single reaction than other methods. *Id.*

4. The Solid-State Method

68. I mention the solid-state method for growing bulk semiconductor materials, because some researchers have proposed intermediate cluster compounds that form during this process as having properties similar to quantum dots. *See e.g.*, Ex. 1016 at 1426 (“With such a well-defined molecular cluster, we examined the intrinsic optical properties of a single-sized, 15Å quantum dot without ambiguities from size dispersion or poorly defined surfaces. On photoexcitation, the crystals emit green light at —520 nm (Fig. 2A),” and at 1428 (“Finally, the solubility of this new crystalline cluster may be used in the production of polymer films, such as polyvinylcarbazole, doped with the CdS cluster simply by spincoating from a pyridine solution.”).

69. Unlike solvent-based methods, solid-state preparations of semiconductor materials do not use solvents at all. Solid-state reaction (“SSR”)

methods rely on solid starting materials that are heated before converting to bulk crystalline products. *See e.g.*, Ex. 1016 at 1426 (“We reported previously that when the discrete molecular species $(\text{NMe}_4)_4\text{Cd}_{10}\text{S}_4-(\text{SC}_6\text{H}_5)_{16}$ (Me, methyl) is heated under carefully controlled conditions, the material converts to bulk crystalline CdS.”); Ex. 1009 at 916-917.

70. The solid starting materials are selected to not react with each other at room temperature, but when baked together at much higher temperatures (often 1000 °C or more) the necessary reaction occurs. *See e.g.*, Ex. 2014 at 116 (“The most common method of preparing solids is by the reaction of the component materials at elevated temperatures.”). The feasibility and rate of a solid-state reaction can be influenced by reaction conditions, including the structural properties and surface area of the reactants, the diffusion rate, and the thermodynamic properties associated with the nucleation/reaction. *See* Ex. 2037 at 2; Ex. 2014 at 116 (“It is only by trial and error that one decides appropriate conditions that lead to the completion of the reaction.”).

71. Solid-state reactions also have the drawback of being difficult to monitor, particularly when there is no melting involved. Ex. 2014 at 116 (“When no melt is formed during the reaction, the entire reaction has to occur in the solid state... There is no way of monitoring the progress of the reaction in a ceramic method.”).

VIII. THE CHALLENGED '365 PATENT

72. Nanoco's '365 patent describes a cluster-assisted alternative to the prior art solution-based methods of making quantum dots. *See* Ex. 1001 at 4:4-32. The '365 patent enables the large-scale production of nanoparticles with high purity and a narrow particle size distribution by using “molecular cluster compounds”—a process which is described, for example, as follows:

An important feature of the invention is that conversion of the precursor composition (comprising separate first and second precursor species) to the nanoparticles is effected in the presence of a molecular cluster compound (which will be other than the first or second precursor species). Without wishing to be bound by any particular theory, one possible mechanism by which nanoparticle growth may take place is that each identical molecule of the cluster compound acts as a seed or nucleation point upon which nanoparticle growth can be initiated. In this way, nanoparticle nucleation is not necessary to initiate nanoparticle growth because suitable nucleation sites are already provided in the system by the molecular clusters. The molecules of the cluster compound act as a template to direct nanoparticle growth. ... The use of the molecular cluster compound provides a population of nanoparticles that is essentially monodisperse. By providing nucleation sites which are so much more well defined than the nucleation sites employed in previous work the nanoparticles formed using the method of the present invention possess a significantly more well defined final structure than those obtained using previous methods. *A further significant advantage of the method of the present invention is that it can be more easily scaled-up for use in industry than current methods.*

Ex. 1001 at 5:5-37 (emphasis added).

73. The '365 patent claims nanoparticles (e.g., quantum dots) made by methods that involve converting multiple precursors into a quantum dot core. The

first precursor species contains a first ion (such as indium), and a separate second precursor species contains a second ion (such as phosphorus), with both precursors providing an ion to be incorporated into the growing quantum dot core (such as indium phosphide). Ex. 1001 at 4:51-61; 6:4-34 and 9:39-44.

74. An important feature of the '365 patent is that the aforementioned conversion of the two precursor species into the quantum dot core takes place in the presence of a *molecular cluster compound*. *Id.* at 5:5-9. Unlike methods that utilize single-source precursors, which fragment into separate atoms before being incorporated into a growing semiconductor lattice or grow through an aggregative mechanism, the molecular cluster compound can be a compound separate and distinct from the precursor species. *Id.*

75. The '365 patent discloses that the resulting nanoparticle growth may take place with each identical molecule of the cluster compound acting as a seed or nucleation point upon which nanoparticle growth can be initiated. Ex. 1001 at 5:9-14. "In this way, nanoparticle nucleation is not necessary to initiate nanoparticle growth because suitable nucleation sites are already provided in the system by the molecular clusters." *Id.* at 5:14-17. Under this theory, the molecules of the cluster compound act facilitate the resulting nanoparticle growth. *Id.* at 5:17-19.

76. To synthesize monodisperse nanoparticles in this way, the molecular cluster compounds must be substantially identical. *See e.g.*, Ex. 1001 at 5:19-28.

As such, the molecular cluster compounds should have the same molecular formula and molecular mass.

77. Nanoco's molecular cluster compound approach enables populations of high-quality nanoparticles that are essentially monodisperse to be grown at scale. Ex. 1001 at 5:28-37. In that way, Nanoco's approach of employing a molecular cluster compound solved the problem that previous synthesis methods had with producing commercial quantities of high-quality quantum dots. And Nanoco's cluster approach works even for difficult cadmium-free quantum dots, like indium phosphide.

78. Representative claims 1 and 17 of the '365 patent are reproduced below:

1. A nanoparticle comprising

a molecular cluster compound and a core semiconductor material disposed on the molecular cluster compound,

wherein the semiconductor material comprises one or more elements not comprised within the molecular cluster compound.

17. A nanoparticle according to claim 1, wherein the nanoparticle is prepared by a process comprising:

effecting conversion of a nanoparticle precursor composition to the core semiconductor material,

the precursor composition comprising a first precursor species containing a first ion to be incorporated into the core semiconductor

material and a separate second precursor species containing a second ion to be incorporated into the core semiconductor material, and

wherein the conversion is effected in the presence of the molecular cluster compound that is different from the first precursor species and the second precursor species and wherein the conversion is effected under conditions permitting seeding and growth of the nanoparticles.

Ex. 1001 at 20:9-13; 20:54-67.

IX. CLAIM CONSTRUCTION

79. I understand that claims in an IPR are construed using the same claim construction standard as district court. The term “molecular cluster compound” is described in the ’365 patent specification:

‘Molecular cluster’ is a term which is widely understood in the relevant technical field but for the sake of clarity should be understood herein to relate to clusters of 3 or more metal or non-metal atoms and their associated ligands of sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular mass.

See Ex. 1001 at 5:19-25.

80. In the related district court proceeding, the court has defined a molecular cluster compound as:

[C]lusters of three or more metal atoms and their associated ligands of sufficiently well-defined chemical structure such that

all molecules of the cluster compound possess the same relative molecular formula.

See Ex. 1091 at 18.

81. While I understand that the parties' previously disputed whether "sameness" is measured in terms of the "molecular formula" or "molecular mass" of the cluster compound, I am informed that the district court determined that "the distinction between metals and non-metals is inconsequential for these patents, and there is little meaningful difference between molecular formula and molecular mass." *See* Ex. 1091 at 13; *see also* Ex. 1001 at 5:19-28 (describing molecular cluster compounds to be of "sufficiently well-defined chemical structure" such that "the molecular clusters are identical to one another in the same way that one H₂O molecule is identical to another H₂O molecule"). I agree and believe that the district court's clarification on this issue is important for a faithful and accurate assessment of the Banin reference, which discloses a nebulous distribution of different sized gold particles that cannot meet the definition of a molecular cluster compound.

X. PRIOR ART

82. Below I provide a brief summary of the teachings of the prior art references relied upon in the Proposed Grounds of the Petition.

83. **Banin** is a published patent application purporting to provide a new method for the production of rod-shaped Group III-V semiconductor nanocrystals. *See* Ex. 1005 at Abstract. Banin discloses using the solution-liquid-solid (“SLS”) method to create these group III-V nanorods. *See* Ex. 1005 at 14, 15, 23 (describing Banin’s SLS method). The “solution” in Banin’s SLS method is a “high-boiling point organic solvent” (i.e., above 200 °C) *See* Ex. 1005 at Abstract. The “liquid” in Banin’s SLS method is a melted metal nanoparticle that serves as a catalyst for rod growth. *See* Ex. 1005 at 15 (emphasis added). This liquid metal catalyst acts as a solvent that dissolves the selected precursors to form a supersaturated solution that ultimately induces crystallization wherein one dimensional growth occurs at the liquid droplet-solid crystal interface. Ex. 1005 at 7 (“the reaction precursors *dissolve in the metal nanoparticles* and the semiconductor nanorods grow from these particles.”) (emphasis added); *see also* Ex. 1005 at 19 (discussing the importance of the catalyst’s low melting temperature). The “solid” in Banin’s SLS method is the resulting semiconductor nanorod.

84. Banin discloses examples of using metallic indium, gold, or silver nanoparticles as the metal catalyst, and primarily discusses using gold nanoparticles with a distribution of sizes. *See e.g., id.* at 13:9-19 and 20:12-16. Banin’s reaction proceeds via a solution-liquid-solid (“SLS”) mechanism. *See id.*

at 13:17-14:9. Banin reported that the surprisingly low melting temperature (i.e., above at least 300 °C) of the gold nanoparticles facilitated the reaction at a temperature below the boiling point of the organic solvent trioctylphosphine-oxide (TOPO). *Id.* at 19:6-20.

85. **Zaban** reports on the synthesis of InP quantum dots for use in TiO₂ semiconductor electrodes. *See* Ex. 1023 at 3153 (Abstract). Zaban describes synthesizing quantum dots with “a well-crystallized zinc blende structure” and with a broad range of diameters (i.e., 20 to 80 Å) as a first step before “immersing the porous nanocrystalline TiO₂ electrodes” into a solution of InP quantum dots in hexane or toluene. *Id.* at 3153-54.

86. Zaban stresses the importance of using large InP particles because these adsorb more strongly to the TiO₂ electrodes. *Id.* at 3156. Zaban’s InP quantum dots (i.e. particles) were made using a colloidal method that involved heating for 3 days at 260-280 °C in the presence of trioctylphosphine oxide (TOPO) and trioctylphosphine (TOP). *Id.* at 3154.

87. **Farneth** teaches mechanisms of solid-state growth where bulk II-VI semiconductor solids are the final products. *See* Ex. 1009 at 916. As part of this research, Farneth identified an intermediate semiconductor cluster with unique chemical and physical properties as compared to the bulk structure. *Id.* Farneth

teaches that extended heating converts this intermediate to a bulk metal-sulfide lattice. *See* Ex. 1009 at 917.

88. Farneth discloses that the homogeneous cluster size of the starting material is likely lost during the transition from the intermediate to the extended solid but suggests that the intermediate clusters possess characteristics that might lead to their own use in different applications. Ex. 1009 at 921. Farneth also teaches that its solid-state crystallization method is superior in certain ways to solution-based methods. *See id.* at 921-922.

89. **Yu** is a paper investigating ways of making metal nanoparticles. Specifically, Yu aims to make “nanoparticles of low-melting metals such as Bi, Sn, and In.” *See* Ex. 101 at 9198. Yu attempts to grow these metal nanoparticles using the same gold clusters as Banin, but at a lower temperature such that the gold particles remain solid in the reaction in order to serve as “seeds” to grow the other metal nanoparticles. *Id.*

90. Yu acknowledged that “both homogeneous nucleation and nanoparticle aggregation can interfere with the seeded-growth rationale for size control,” but that “by comparison to the other synthetic methods that we know of, the seeded-growth strategy and results reported here come closest to providing monodisperse metallic nanoparticles of pre-specified sizes.” Yu mentioned potential future directions to make metallic nanoparticles for use in SLS, but did

not mention using the gold “seeds” in semiconductor growth or in the use of other clusters as seeds. *Id.* at 9199.

91. **Lucey** uses the hot-injection method to create nanoparticles composed of elements from either groups 12 and 16 of the periodic table (II-VI) or groups 13 and 15 of the periodic table (III-V). *See e.g.* Ex. 1011 at 3:63-65 and 12:38-41. Lucey uses single-source precursors that contribute all of the atoms for the growing semiconductor core. Ex. 1011 at 1:57-61. Lucey teaches reacting compounds of different specific formulas to homogeneously nucleate III-V or II-VI nuclei and a compound with its own formula that reacts with the nuclei to grow group II-V or II-VI nanocrystals. *Id.* at 6:36-43.

92. Lucey also discloses a process for making group III precursors. *See* Ex. 1011 at 4:31-34. Lucey discloses that these group III precursors solve problems with coordinating solvents or surfactants that may purportedly “obscure the electronic and optical properties of the resultant III-V nanocrystals” after exposure to high temperatures. *Id.* at 5:14-19. Lucey’s method purportedly produces nanocrystals in “near monodispersity” at low reaction temperatures and shorter reaction times. *See e.g., id.* at 4:52-56.

93. **Ahrenkiel** uses the SLS method to create quantum rods. Ex. 1012 at 834. Ahrenkiel teaches the use of single-source precursors that provide both indium and phosphorus to an InP semiconductor. *See* Ex. 1012 at 833. By its own

admission, Ahrenkiel discloses that the indium phosphide quantum rod diameters are broad and range from 60-110 Å in one example and 150-350 Å in a different example *See id.* at 835 (Figure 1 caption).

94. Ahrenkiel discloses a preference for low melting metals, such as indium, for the metallic SLS catalyst. Ahrenkiel comments that since indium has a lower melting point than gold, the disclosed method may have greater flexibility for synthesizing quantum rods with different diameters as compared to processes using gold as the SLS catalyst like Banin. *Id.* at 834. Ahrenkiel also purports to teach a process that allows for the chemical removal of the metallic indium catalyst from the rods, unlike some other SLS methods. *Id.*

95. **Herron** discloses an investigation into the “crystal structure and optical properties” of a “15 Å diameter crystalline fragment of bulk cubic [cadmium sulfide] CdS.” *See* Ex. 1016 (Herron) at 1426. Herron characterizes this intermediate composition after heating the molecular species “(NMe₄)₄Cd₁₀S₄·(SC₆H₅)”. Subsequently heating the intermediate converts that species to bulk crystalline CdS. *See id.* Herron recrystallized this Cd₁₀S₄·(SC₆H₅)₁₂ semiconductor intermediate “over a period of several days at room temperature” from a pyridine solution by the addition of DMF, resulting in Cd₃₂S₁₄(SC₆H₅)₃₆·DMF₄. *Id.*

96. Herron describes the recrystallized intermediate as a “molecular crystal” that “on photoexcitation” would emit green light at 520 nm. *Id.* Herron

suggests that this crystalline semiconductor cluster could be used in polymer films via spincoating, or in the “preparation of materials that go into electronic devices made for this and other thin-film applications.” *Id.* at 1428.

97. **Treadway** relates to an improved process for a making core-shell materials purportedly resulting in superior chemical, photochemical, and/or photophysical properties. *See e.g.*, Ex. 1015 at 2:43-47. Treadway’s method provides an isolated semiconducting core mixed with first and second shell precursors, a solvent, and an additive comprising a selected group 12, 13, 14, 15, or 16 element or Fe, Nb, Cr, Mn, Co, Cu, or Ni. This forms a dispersion that is heated long enough to form an inorganic shell on the semiconductive core. *Id.* at 54-65.

98. Treadway uses hot injection to grow its nanoparticles. Ex. 1015 at 13:53-60. Treadway teaches that “carry-over” precursors from the core synthesis can be used as the additive material during shell formation. *Id.* at 12:14-16. Treadway also discloses that additives can be combined with the cores or may be uniformly distributed throughout the shell or may be distributed as a gradient. *Id.* at 8:26-29 and 12:31-33 and. Treadway purports to create enhanced properties of core-shell structures, although the mechanism is described as being unclear. *See e.g.*, 8:59-9:10.

XI. THE PROPOSED GROUNDS

A. Ground 1: Claims 1, 7-12, 17 and 22-23 Are Not Anticipated by Banin

1. Banin Does Not Disclose a Molecular Cluster Compound

99. Samsung challenges claims 1, 7-12, 17 and 22-23 and asserts that these claims are anticipated by Banin. *See e.g.*, Petition at 22. I disagree.

100. These claims of the '365 patent claims all require “a molecular cluster compound and a core semiconductor material disposed on the molecular cluster compound.” *See e.g.*, Ex. 1001 at 20:9-11. Applying the district court’s definition of “clusters of three or more metal atoms and their associated ligands of sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular formula,” it is clear that Banin does not meet this limitation.

101. Banin does not disclose a molecular cluster compound because it fails to disclose any clusters of sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular formula.”

102. Banin discloses the use of molten gold in a Solution–Liquid–Solid Synthesis (“SLS”) method used to create group III-V nanorods. *See e.g.*, Ex. 1005 at 12:13-14:9 (describing Banin’s SLS method). Banin discusses the importance of gold’s melting point to the success of the SLS method. Ex. 1005 at 20:12-27; *see also id.* at 19:9-12 (“[growth] conditions are *at the onset of melting.*”) (emphasis

added); *id.* at 21:19-20 (“Metal alloy nanoparticles are interesting catalysts for the growth of semiconductor rods ***due to their reduced melting temperature.***”) (emphasis added); *see also* Ex. 2007 at 10889 (“SLS growth is conducted with a *solution* phase (normally employing organic solvents), typically at temperatures of 200–350 °C, in which low-melting metallic nanoparticles (in the molten, liquid form under the reaction conditions) catalyze the decomposition of metalloorganic precursors at the solution–liquid interface and dissolve the semiconductor components so obtained[.]”) (emphasis in original).

103. Banin also describes the SLS method producing nanorods from the melted gold particles, depicted below as “M.”

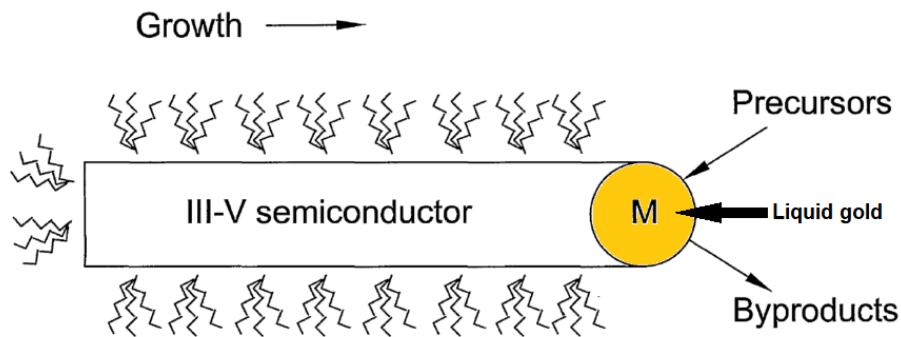


FIG. 1

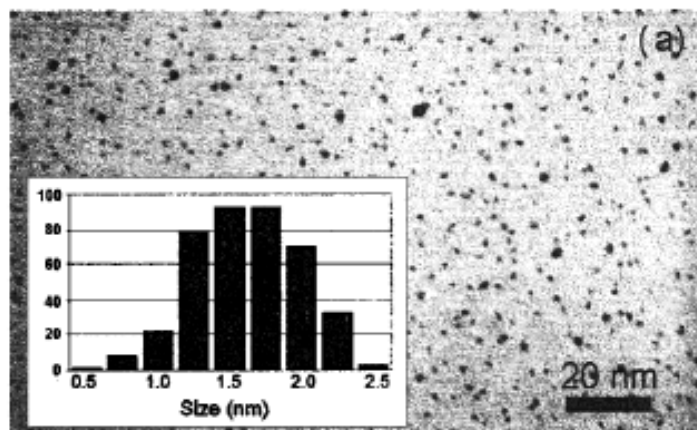
See Ex. 1005 at Figure 1; *see also id.* at 22:29-30 (“The inset of Fig. 10B shows rods with gold particles on the end, demonstrating the SLS growth mechanism.”).

104. Banin teaches that low gold concentrations produce low yields of quantum rods, while high gold concentrations can lead to quantum rods precipitating

too quickly. *Id.* at 23:23-26. Banin theorized that this immediate precipitation was caused by the “**aggregation of the gold clusters** providing large seeds for rapid InAs growth.” *Id.* at 23:26-27 (emphasis added).

105. Nowhere does Banin disclose clusters of “sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular formula.” In fact, the gold catalysts in Banin are not well-defined and were assigned the molecular formula $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_5$ based on a calculation that relied on the average of a wide distribution of particle sizes reported in the literature by Hutchison. *See generally*, Ex. 2017 at 1291. Banin relied and used Hutchison’s method to produce gold-clusters and saw similar results. *See* Ex. 1005 at 2:25-26 and 20:13-16 (citing the published procedures of W.W. Hutchison, S. M. Reed, M. G. Marvin and J.E. Hutchison, *J Am. Chem. Soc.*, 122, 12890 (2000)] (“Hutchison”).”).

106. The Hutchison process creates gold particle agglomerations of many different sizes. This is shown in Figure 1(a) of Hutchison which is a transmission electron microscopy image along with an imbedded histogram that shows the size distribution of the gold particles:



See Ex. 2017 (“Hutchison”) at 12891. As the image shows and the histogram confirms, the sizes of the gold clusters vary considerably with sizes ranging from at least 1.0-2.25 nm. *Id.* A POSITA would not consider these to be “sufficiently well-defined chemical structure[s] such that all molecules ... possess the same relative molecular formula.” As the district court noted, that requirement should result in compounds that have the same molecular mass, which Hutchison’s gold clusters do not. See Ex. 1091 (district court claim construction) at 16 (“By necessity, a compound with the same molecular formula will necessarily have the same molecular mass.”).

107. Hutchison describes the gold clusters as “narrowly disperse” nanoparticles 1.5 nm \pm 0.4 nm in diameter. *Id.* at 12890. What this really means is that on average, there is a distribution of sizes from around 1.1-1.9 nm, but as the histogram of Figure 1 shows, the overall size variation is much broader. Despite that broad mix of sizes, Hutchison attempted to assign a molecular formula to the

synthesized gold clusters. As Hutchison explains, $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_3$ is “an *average* molecular formula” that was “estimated” in order to assign a formula based off of the average 1.5 nm particle size that was observed:

[T]he mass percent of gold calculated by quantification of the XPS data is 75.8%. TGA indicates that 75.5% of the sample is gold by mass (Figure 1c), independently confirming the ratio determined by XPS. To calculate an *average molecular formula* for **1** it is necessary to know the number of gold atoms in the metal core. *Given the average particle size (1.5 nm) this number is estimated* to be 101 by the method of Whetten et al.²¹ and leads to an *estimated formula* of $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_5$.

Ex. 2017 at 12891 (emphasis added).

108. Hutchison’s use of an “average” gold particle size to “estimate” a molecular formula is very different from a situation where all of the molecules of the molecular cluster compound necessarily “possess the same relative molecular formula.” Hutchison characterizes that formula as an “assumed 101 gold atom core” and an “average empirical formula” based on atomic composition measurements by X-ray photoelectron spectroscopy. Ex. 2017 at 12890. Consistent with the uncertain nature of Hutchison’s calculated value, Banin describes $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_3$ as a “suggested formula.” Ex. 1005 at 20:13-16.

109. A POSITA would not confuse assumptions and estimates with a well-defined chemical structure, particularly where the data points used to generate that assumption are so widely varied. This opinion is shared by Samsung’s district court witness, Mounji G. Bawendi, Ph.D., a professor of chemistry at MIT. Commenting

about one of his own papers (Ex. 2033) and why that did not disclose a MCC as defined by the district court at his deposition, Dr. Bawendi explained it this way:

Q. So explain again why it is that the clusters that you talk about in this paper don't, in your opinion, meet the Court's construction of "molecular cluster compound" that you've got in your -- in the chart on page 9 of your report.

A. *These aggregates* of indium and phosphorus that form -- -- indium and phosphorus *span a distribution of masses, and they don't have a molecular formula that's the same for all of them.*

Q. With respect to molecular mass, where is it in your paper that you talk about how these clusters span a distribution of -- of masses?

A. You can -- you can see it in the MALDI figures.

Q. You said you can see it in the MALDI figures?

A. Figures 3 and -- 2 and 3, the low-mass MALDI, and -- which *shows a distribution of mass that is different depending on -- slightly different depending on the different temperatures.* The shape of the distribution is also different.

Q. Okay. And what is it in figure -- what's the evidence in figure 2 that you're referring to?

A. So in the X axis is mass divided by z, which is the charge. And so the X axis gives you the masses that's coming out of the -- of the -- of the MALDI mass spectrometer. *And you see that --and we see an -- a distribution over -- between 8,000 and 12,000 m over z*, for instance, for the lowest one, in blue; and a distribution covers many masses and is somewhat different depending on the conditions. *And so we're creating a mixture of a bunch of things, a bunch of clusters that happen to have a mean around 10 kilodalton.*

Q. And is there information in this paper about molecular formulas, or *is it your position that because these data are indicative of a nonuniform distribution of mass, there has to be a nonuniform distribution of molecular formula as well?*

A. *Yes, one follows from the other.*

Ex. 2034 (excerpt of deposition of Mounji G. Bawendi, Ph.D. - June 16, 2021) at 120:3-123:8 (emphasis added).

110. I agree with Dr. Bawendi's position that clusters having a wide distribution of different masses cannot be considered a MCC, nor does that change if one assigns a "theoretical" molecular formula or mass based on an average value.

111. A person of skill in the art would understand that the claimed molecular cluster compound would, at the very least, need to be able to be chemically characterized to be considered "sufficiently well-defined." Yet none of Hutchison, Banin or Yu are able to actually chemically characterize the gold clusters produced by the Hutchison process. Instead, these references all cite and rely upon an average gold droplet size that is then itself used to generate a suggested formula without actually characterizing any observed particles.

112. By its nature, an average value assigned to a broad distribution of particle sizes cannot be a "sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular formula." Rather, it reflects the opposite.

113. A POSITA looking at the TEM image in Figure 1 of Hutchison would see even with the naked eye that the clusters are a wide variety of different sizes. That's also true of Hutchison's embedded graph, which shows a size difference ranging from 0.75 nm to 2.25 nm. Only after these different sizes were averaged out

could an “assumed” or “estimated” formula be assigned. *See id.* at 12891 (“Given the *average* particle size (1.5 nm) is *estimated* to be ~101 ... leads to an *estimated* formula of $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_5$.”) (emphasis added). The “~” symbol used by Hutchison shows that the approximate formula for an average-sized particle is a guess.

114. Moreover, the particles created by the Hutchison method have significant impurities which contradicts the requirement of clusters having a sufficiently well-defined chemical structure. *Id.* at 12890-12891 (noting that analysis of the nanoparticles shows that “3.7 mass percent of the sample is the impurity $\text{AuCl}(\text{PPh}_3)$ ”). Whether an individual cluster generated by Hutchison has more or less than 3.7% of this impurity further highlights the fact that these cannot be considered MCCs as defined by the district court. Rather, Hutchison’s gold clusters are characteristic of the type of amorphous, impure nanoparticle that the ’365 patent distinguishes from “molecular cluster compounds” in the specification. *See Ex. 1001* at 7:48-53 (noting that molecular clusters may be collections of identical molecules rather than ensembles of small nanoparticles). And by extension, Banin’s gold particles are also ensembles of small nanoparticles; *Ex. 1005* at 23:23-24:2 (discussing the gold particle aggregating to form larger particles).

115. The suggested molecular formula and lack of specificity from Hutchison, and by extension, Banin, is not completely surprising. Hutchison used a

process that was meant to improve on a prior art method of Schmid. *See* Ex. 2017 at 12890 (“Here we describe a safer, that more convenient, and more versatile synthesis of phosphine stabilized nanoparticles analogous to those originally reported by Schmid.”). Hutchison acknowledged that the Schmid’s gold nanoparticles “originally formulated as $\text{Au}_{55}(\text{PPh}_3)_{12}\text{Cl}_6$ ” by Schmid had been disputed in the art. *Id.*; *see also* Ex. 2038 (“Fackler”) at 6434 (noting that Schmid’s formula was “based on elemental analysis and molecular weight measurements” before concluding that samples of it were impure and did not correlate to that molecular formula). This reflects the difficulties that exist to this day in trying to produce monodisperse nanoparticles:

Over the past few decades, extensive efforts have been devoted to modulating gold nanoparticles to control their morphologies and compositions. *Despite narrow dispersion in continuously improved synthesis, gold nanoparticles are still not atomically precise due to their polydisperse sizes and indefinable surface architecture.*

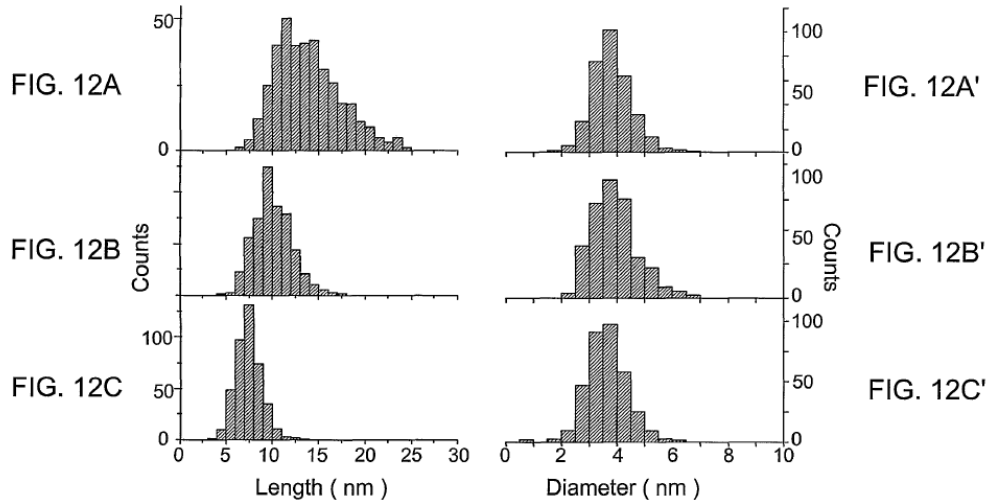
See Ex. 2039 (Xia) at 2368 (emphasis added). Hutchison itself is no different.

116. Relevant literature discussing the Hutchison process confirms that POSITAs practicing the Hutchison process of making these Au_{101} clusters also saw a distribution of sizes and had to rely on the same estimated molecular formula. *See* 2040 (Anderson) at 14808 (“In the present work, the molecular clusters Au_8 and Au_9 contain atomically precise, monodisperse metal cores protected by phosphine ligands. The cluster *Au_{101} is also used which is not atomically monodisperse* but

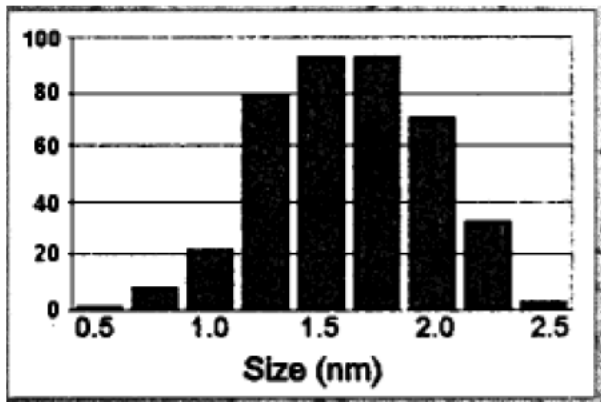
shows a narrow particle size distribution with an average size of approximately 1.5 nm.”) (emphasis added).

117. In contrast to the Au₁₀₁ clusters produced by the Hutchison process, gold clusters made by other methods have been adequately characterized. This is done, for example, by X-ray crystallographic determination (“XRD”), which is a reliable way to determine if a sufficiently well-defined chemical structure can be assigned to gold nanoparticles. *See* Ex. 2041 (Antoine) at 4 (“Concerning the characterization techniques, X-ray crystallography is the ‘holy-grail’ technique to solve the crystal structure of nanoclusters and reveals the nature of bonding and the packing of atoms.”).

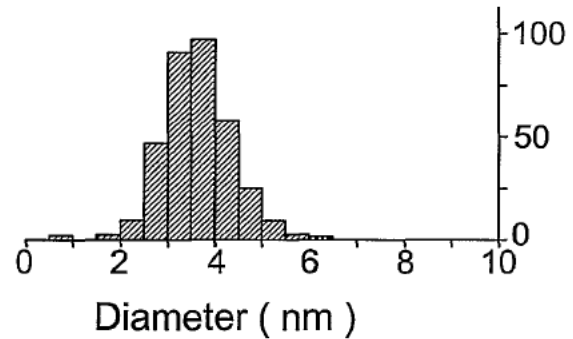
118. In Banin’s SLS method, the diameter of the nanorods is dictated by the size of the gold particle. Perhaps unsurprisingly, the gold clusters used by Banin produced nanorods with a broad distribution of diameters ranging from 2 to ~6 nm. Banin reports that the diameters for these nanorods can vary by up to 25%. Ex. 1005 at 23:17-18 (“[t]he width of the diameter distribution is 20-25%...”); *see also id.* at 15 (Diameter was between 3-4 nm [a 25% difference]); Ex. 2017 at 12890 (“the small size and narrow dispersity (1.4 +- 0.4 nm)”).



This is what a POSITA would expect when using gold particles that are not sufficiently well-defined. A dispersity that varies by 25% is not considered monodisperse in the art. Thus, Banin's process does not achieve a population of nanoparticles that is essentially monodisperse, as taught by the '365 patent. Ex. 1001 at 5:28-29. Rather, the wide size distribution seen in Banin reflects the wide size distribution of the gold particles taught by Hutchison. *See* Ex. 2017 at Fig. 1(a) (showing particles of 1.5 nm \pm 0.4 nm).

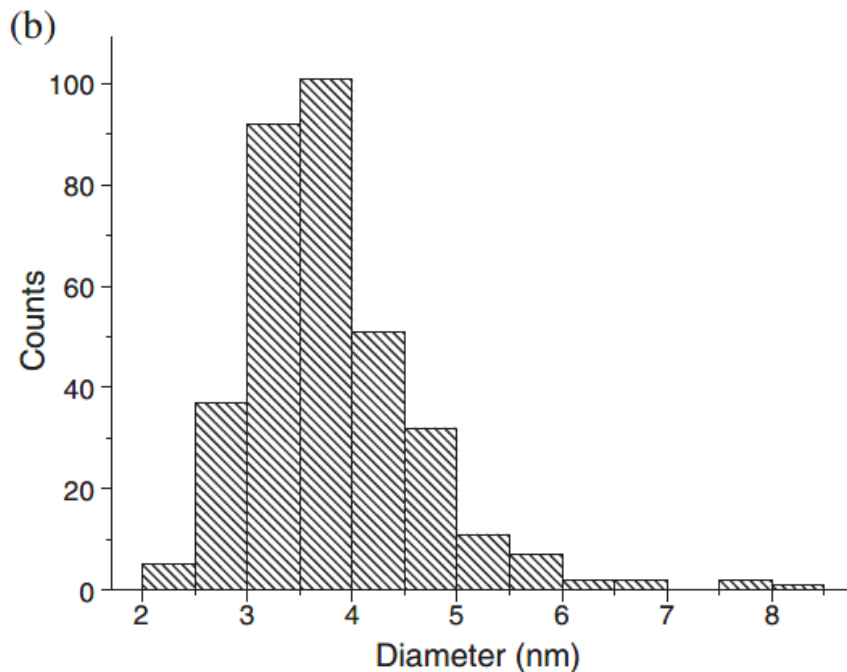


Au101 clusters (Hutchison)



Nanorod diameters (Banin)

119. A subsequent paper by Banin also discloses a broad range of nanorod diameters when Au101 is used in the SLS synthesis method.



And there too, Banin notes that the Au101 formula was *suggested* while reporting a different average cluster size of 1.4 (not 1.5) nm. See Ex. 2042 (Banin 2006) at 789 (“Triphenylphosphine coated Au clusters with diameter of 1.4 nm and the suggested

formula $\text{Au}_{101}(\text{PPh}_3)_{21}\text{Cl}_5$ (denoted as Au_{101}) were synthesized by the published procedures [Hutchison], to serve as seeds for rod growth.”); *see also* Ex. 1005 at 20:13-16.

120. Even if the gold particles in Hutchison were monodisperse, it would not automatically follow that they are molecular cluster compounds. In colloidal chemistry, the term “monodisperse” means “having particles of similar size.” *See e.g.*, Ex. 2035 at 1. Thus, monodisperse populations of nanoparticles can still have a range of sizes such that the particles do not have a sufficiently well-defined structure where all molecules of the cluster compound possess the same relative molecular formula. *See* Ex. 1091 at 18. But a POSITA would understand that the range of monodisperse nanoparticle populations is smaller than narrowly dispersed or widely dispersed populations.

121. Without the disclosure of a gold (or other) cluster with a “sufficiently well-defined chemical structure such that all molecules of the cluster compound possess the same relative molecular formula,” Banin does not disclose a molecular cluster compound.

2. Banin Discourages Conditions Permitting “Seeded” Growth in SLS Reactions

122. Claims 17, and 22-23 of the '365 patent require conversion of a nanoparticle's core semiconductor material “wherein conversion is effected under

conditions permitting seeding and growth of the nanoparticle.” *See* Ex. 1001 at 20:54-67 and 21:10-18. Petitioner and Dr. Green identify Banin’s discussion that the gold particles “provid[e] large seeds for rapid InAs [nanoparticle] growth” and argue that this limitation has been satisfied. *See* Petition at 30; Ex. 1002 at ¶¶ 79, 90-91, 113. This is the lone appearance of the word “seed” in Banin and it does not refer to a successful procedure, but rather an unwanted side effect caused by aggregation of the molten metal droplets. This is clear when that passage is considered in full context.

The relative molar *ratio of gold to (TMS)3As in the precursor solution was varied between 2.5 to 20%*. At low gold cluster content, the chemical yield of rods is low. At high gold cluster content, precipitation took place immediately following the injection. *This is most likely caused by aggregation of the gold clusters providing large seeds* for rapid InAs growth. *An optimal ratio of 10% gold* yielded InAs nanorods with uniform diameters at high yield.

Ex. 1005 at 23:23 – 24:2 (emphasis added).

123. Banin’s disclosure of “large seeds” is not a desired result but rather a description of a problem that results when the quantum rods precipitate too quickly due to “high gold cluster content” because the gold particles aggregate to form even larger particles that serve as seeds and cause problematic immediate precipitation.

Ex. 1005 at 23:23 – 24:2.

124. In other words, when there is “high gold cluster content”, the particles agglomerate to form even larger gold particles with higher melting points. *See* Ex. 1005 at 19:12-15 (“theoretical studies that have revealed that the melting temperature for Au₁₄₆ (diameter about 1.6 nm) was about 350 °C, increasing to about 480 °C in Au₄₅₉ clusters (diameter about 2.5 nm) ...”). When the agglomerated gold particles become large enough, they are no longer able to melt at the 300-380 °C reaction temperature required by Banin’s solvents. *See* Ex. 1005 at 19:6-20 (“Notably, this [gold cluster melting] temperature is below the boiling point of TOPO, a coordinating solvent for synthesis of high quality nanocrystals, allowing for the implementation of this method to achieve rod growth.”). As such, agglomerated particles can no longer serve as an SLS catalyst, but instead serve as seeds and cause immediate precipitation of InAs. *See* Ex. 1005 at 23:25-27.

125. To solve the problem caused by the large seeds, Banin suggests using a *lower* concentration of gold to prevent agglomeration and seeding, and thus expressly discourages seeding. *See* Ex. 1005 at 23:23-24:2; *see also* Ex. 2007 at 10890 (“Additional influential factors to the diameters and diameter distributions are the temperature; *the stability of the catalyst nanoparticles against agglomeration.*”) (emphasis added).

126. The problematic gold seeds identified in Banin are not molecular cluster compounds. While there is no disclosure in Banin even trying to characterize

these larger gold particle agglomerations, it is clear that they have to be larger than the theoretical Au₁₀₁ or they would melt and be unable to serve as “seeds.” *See* Ex. 1005 at 19:6-20 (showing melting temperatures increasing as the gold cluster diameter increased). A POSITA could not faithfully and would not assign the 1.4 nm *average* size to to these gold particle aggregates, meaning even the “*suggested* formula Au₁₀₁(PPh₃)₂₁Cl₅” assigned by Banin would not apply. In addition to being *expressly distinguished* by the ’365 patent as ensembles of small nanoparticles, the gold particle agglomerations identified in Banin are undesired in a SLS method. *See* Ex. 1001 at 7:48-53; Ex. 2007 at 10890. A POSITA could only guess how large these seeds were, as Banin did not characterize them, but the structure and molecular formula of these gold agglomerations is even more nebulous than the already ill-defined gold droplets themselves.

127. Thus, Banin discourages gold cluster contents that lead to aggregates and “large seeds,” and a POSITA applying Banin’s method would be reluctant to follow such a disfavored teaching.

B. Ground 2: Claims 1, 7-12, 15-17, And 22-23 Are Not Rendered Obvious by Banin

128. In the Petition, Samsung argues that “[f]or the same reasons that Banin anticipates claims 1, 7-12, 15-17, and 22-23, as explained above, Banin would also

render those claims obvious to a POSITA.” Petition at 31. As discussed above, Banin does not disclose a molecular cluster compound. *See supra*, ¶¶99-121.

129. I also do not see any discussion from Samsung or any basis as to why the “molecular cluster compound” limitation would have been obvious to a POSITA in light of Banin. Petition at 31. Thus, for the same reasons offered with regard to Ground 1, it is my opinion that Banin does not render claims 1, 7-12, 15-17, and 22-23 of the ’365 patent obvious.

C. Ground 3: Claims 2-6, and 18-21 Are Not Rendered Obvious by Banin in view of Herron

1. Banin Does Not Disclose a Molecular Cluster Compound

130. Samsung challenges claims 2-6, and 18-21 and asserts that these claims are rendered obvious by Banin in view of Herron. *See e.g.*, Petition at 33. These claims of the ’365 patent claims all require a molecular cluster compound which for the reasons described above, Banin does not disclose. *See e.g.*, Ex. 1001 at 20:14-28 and 20:33-21:12; *supra* ¶¶99-121.

2. A POSITA would have no reason to use Herron’s isolated cluster in Banin’s SLS method

The SLS method used by Banin does not involve the type of cluster-assisted growth of quantum dots taught by the ’365 patent. Rather, Banin teaches using the SLS method discussed above in which a *liquid metal* catalyst made of gold is used

to grow nanorods. *See supra* ¶83. The method is expressly depicted in Figure 1 of Banin:

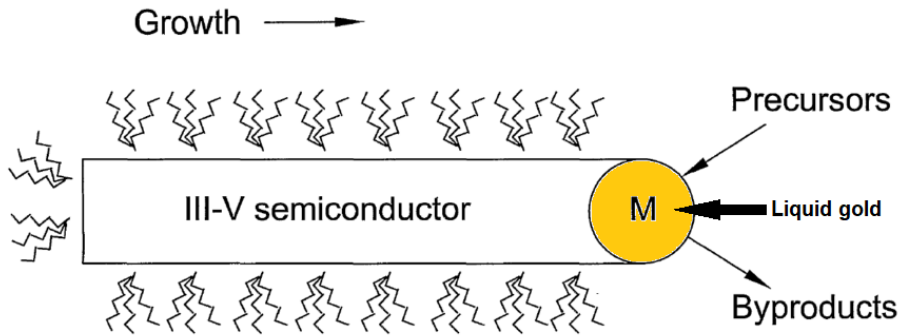


FIG. 1

Ex. 1005 at Figure 1; *see also id.* at 6:6-8 (“[I]t is proposed that the reaction precursors dissolve in the metal nanoparticles and the semiconductor nanorods grow from these particles.”).

131. Those of skill in the art understand that there are there are particular requirements that must be considered when choosing metal catalysts to use in the SLS method disclosed by Banin. *See supra* ¶¶52-53. As Banin acknowledges, the catalysts **must be a metal**. *See* Ex. 1005 at 14:3-9 (“The SLS mechanism **requires** the addition or in-situ formation of a **metal** nanoparticle as a catalyst for rod growth.”) (emphasis added); *see also id.* at 6:9-16 (The **metal** catalyst can be made, for example, of a transition **metal**, ... alloys of such **metals**...or core/shell layered **metal** particle.”) Banin specifies this unequivocally by using the term “metal catalyst” twenty-eight times. *See generally*, Ex. 1005. The remaining use of

“catalyst” in Banin are mostly referring to “metallic,” “gold,” or “indium” catalysts. See e.g., *id.* at 13:9-16.

132. Dr. Green agrees that Banin teaches using metal catalysts. Ex. 1002 at ¶ 79 (“Banin discloses that other ‘metal catalyst[s]’ can be used instead of gold clusters, including ‘a transition metal, e.g., Zn, Cd,...[or] alloys of such metals.’”) (citing Ex. 1005 at 6:9-18). Thus, according to Banin, and confirmed by Dr. Green, the catalysts must be metals.

133. Banin further teaches that the disclosed SLS method does not work unless the metal catalyst has melted. See Ex. 1005 at 19:9-12 (“It was found by the inventors that syntheses at a lower reaction temperature of 300 °C, does not yield one-dimensional growth in this specific case indicating that *the conditions are at the onset of melting.*”) (emphasis added). And a POSITA reading Banin would have understood that the disclosed SLS method required that the melting point of the metal catalyst be lower than the boiling point of the solvent. Banin announced this discovery of a “surprisingly low” melting point for the gold particles as being a key variable for nanorod growth in TOPO:

It should be pointed out that *the reaction temperature in the method described above is surprisingly low* (about 700 degrees below the melting point of bulk gold). This is possible because of the phenomena of decrease in the melting temperature of nanocrystals with reduced size. It was found by the inventors that syntheses at a lower reaction temperature of 300 °C, does not yield one-dimensional growth in this specific case indicating that the conditions are at the onset of melting.

This is consistent with theoretical studies that have revealed that the melting temperature for Au₁₄₆ (diameter about 1.6 nm) was about 350 °C, increasing to about 480 °C in Au₄₅₉ clusters (diameter about 2.5 nm) and prior to melting, there is a region of temperatures where increased atomic diffusion near the surface takes place in the smaller clusters. This may suffice for achieving the required function of the gold particles as catalysts. ***Notably, this temperature is below the boiling point of TOPO, a coordinating solvent for synthesis of high quality nanocrystals, allowing for the implementation of this method to achieve rod growth.***

Ex. 1005 at 19:8-20 (emphasis added).

134. Banin also explains that TOPO is preferred to TOP in the disclosed SLS reaction because it has a higher boiling point of *Id.* at 16:12-14 (“In the method of the invention, both TOP and TOPO can be used as solvents, but TOPO has a higher boiling point than TOP (360 vs 300 °C), and thus enables a higher reaction temperature.”) *see also id.* at 21:1-3 (“2 g TOPO was used as growth solvent and heated to 360 °C prior to precursor injection.”). Thus, the “surprisingly” low melting point of the gold clusters (300 °C) used by Banin facilitated nanorod growth in the TOPO organic solvent, which does not boil at that temperature. If a metal or metal alloy with a higher melting point was used, the solution would boil before the SLS reaction occurred.

135. By contrast, Herron discloses a modified crystalline fragment of bulk cubic cadmium sulfide (CdS) semiconductor material. *See* Ex. 1016 (Herron) at 1426. Herron recrystallized the cluster, which was identified as an intermediate that

formed during a solid-state crystal growth process, from very small crystallites of CdS characterized by a broad x-ray diffraction pattern and derived from heating the well-defined precursor $(\text{NMe}_4)_4\text{Cd}_{10}\text{S}_4(\text{SC}_6\text{H}_5)_{16}$ at 250 °C. *Id.* (describing the carefully controlled conditions, including sustained high heat, used to convert starting materials to bulk crystalline CdS).

136. The $\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}$ cluster disclosed by Herron is not a metal, but is rather a cadmium sulfide *semiconductor* with organic ligands. Dr. Green confirmed the same understanding of the Herron semiconductor intermediate. Ex. 1002 at ¶ 86 (“Herron describes $[\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}]$ as ‘a large, well-characterized *semiconductor* molecular cluster.’”) (citing Ex. 1016 at 1426) (emphasis added).

137. A POSITA would not have been motivated to replace the metal catalysts disclosed in Banin with a semiconductor material disclosed in Herron. Semiconductors are not the same as metals. *See* Ex. 2031 (Green Depo.) at 18:13-15. Moreover, Herron does not disclose any melting point for the modified CdS semiconductor cluster. Bulk CdS will not melt until it reaches approximately 1480 °C. *See* Ex. 2043 at 5. And Herron’s cluster was derived from a material that would normally be heated to form bulk CdS, which itself can be heated to well over 500 °C without melting. *Id.*

138. The Petition does not consider the melting point of Herron’s $\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}$ semiconductor. Dr. Green also did not consider the melting point

of any metal before providing his opinion. *See e.g.* Ex. 2031 (Green Depo.) at 106:7-12 (“Q. And in your opinion, you didn’t consider the melting temperatures of those molecular cluster compounds. Right? A. It wasn’t something that I particularly paid that much attention to, no.”); *see also id.* at 100:19 – 101:5 (admitting no opinion related to melting points of indium, cadmium, bismuth, cadmium sulfide, cadmium selenide, or gold).

139. Petitioner fails to address the key considerations a POSITA would need to account for before choosing a metal catalyst for SLS. These include the metal’s (1) melting point, (2) solvating ability, and (3) reactivity. *See* Ex. 2008 at 7514. Petitioner addresses none of these, and Dr. Green similarly offers no opinion regarding these critical considerations.

140. A person of skill in the art would have recognized that metals with lower melting temperatures were preferable in for nanorod growth using the SLS method. Petitioner’s Ahrenkiel reference (Ex. 1012) expressly contemplated Banin’s gold catalysts and noted that *lower* melting temperatures were desirable. Specifically, Ahrenkiel stated:

After this paper was submitted for publication, a paper by Banin et al. appeared on the formation of InAs quantum rods ... using gold particles as the catalyst. This procedure yields InAs quantum rods with excellent quality and crystallinity. Although this method can also be applied to the synthesis of InP quantum rods, *it requires extremely small gold particles that are about 20 Å in diameter in order to lower the melting point of the gold particles to about 360 °C and initiate catalytic action. Indium has a lower melting point*

than gold, and the method described in this paper has the potential for greater flexibility for the synthesis of quantum rods with different diameters

Ex. 1012 at 834 (emphasis added).

141. In light of Banin's teaching as reflected by Ahrenkiel, it is my opinion that a POSITA would have sought metal catalysts with lower melting temperatures than gold such as indium, bismuth, or tin. This is reflected by the teachings of Yu and Wang, both of which note that the metals with lower melting temperatures are preferable. *See* Ex. 2008 at 7515. ("The low melting metals best meeting these [three] criteria seemed to be In, Bi, and Sn."); Ex. 1010 (Yu) at 9198. The reason that Yu is making metal nanoparticles in the first place (specifically tin, bismuth, and indium nanoparticles) is to use them later as metal catalysts in the SLS process. Ex. 1010 at 9198 ("We are attempting to prepare monodisperse semiconductor quantum wires over a range of controlled diameters (2-20 nm) by the low temperature SLS mechanism, and have therefore sought monodisperse catalyst nanoparticles of low-melting metals such as Bi, Sn, and In having similar, selected sizes"). The Yu authors had already succeeded using the SLS method with different metals and were investigating additional cluster candidates. And Yu discloses a fundamentally different process than Banin in which the gold particles remain solid. Yu teaches using Hutchison's gold clusters to make metal nanoparticles at *low temperatures*. *See* Ex. 1002 (Green Decl.) at ¶ 160 (Yu teaches "sufficiently low

temperatures” ... “ranging from room temperature to 150 °C.”). Such temperatures are so low that the gold particles remain solid in solution and can act as seeds. *See generally*, Ex. 1010.

142. Petitioner contends that the “clusters” disclosed by Banin and Herron are interchangeable due to Banin’s mere mention of possibly using Cd-based *metal alloys* in the disclosed SLS method. Petition at 34. But metal alloys are not what is disclosed in Herron, which describes a semiconductor cluster.

143. Nor does Herron disclose that “ $\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}\cdot\text{DMF}_4$ ” can be used “in the preparation of semiconductors in solution,” as the Petition and Dr. Green claim. *See* Ex. 1002, ¶126; Petition at 34. While Herron discusses the solubility of the intermediate cluster and using solvents to isolate it, it is a paper investigating what occurs during solid-state “bulk cubic CdS” crystal formation. *See generally* Ex. 1016 (Herron). Herron only uses a solvent to precipitate and isolate this intermediate compound. Ex. 1016 at 1426 (“[T]his solid is very soluble in pyridine, and such solutions can be recrystallized by the addition of DMF to the point of incipient precipitation.”). The fact that Herron’s intermediate cluster $\text{Cd}_{10}\text{S}_4(\text{SC}_6\text{H}_5)_{12}$ could be isolated using N,N-dimethylformamide (DMF) to produce “a cluster with a stoichiometry $\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}\cdot\text{DMF}_4$ ” suggests nothing in regard to its possible use in a SLS synthesis method, like the one described by Banin.

144. Herron is a paper investigating what occurs during solid-state “bulk cubic CdS” crystal formation. *See generally* Ex. 1016 (Herron). Herron does describe “[t]he use of very small molecular clusters as synthetic precursors to bulk, extended solids,” but that’s in reference to the solid-state synthesis method which involves a 500 °C heating step. *See* Ex. 1016 at 1426.

145. In terms of utility, Herron describes using the cluster’s solubility as a way to add it (the cluster itself) to films, not to prepare larger semiconductors made in solution. *See* Ex. 1016 at 1428 (“Finally, the solubility of this new crystalline cluster may be used in the production of polymer films, such as polyvinylcarbazole, ***doped with the CdS cluster simply by spincoating from a pyridine solution.***”) (emphasis added).

146. The Petition and Dr. Green’s citations to the teachings of the ’365 patent and statements that suggest that any cluster meeting the court’s definition of a MCC could “act[] as a seed or nucleation point upon which nanoparticle growth can be initiated,” is also misleading. *See e.g.*, Ex. 1002, ¶126; Petition at 34. The ’365 patent does not teach a method where the MCCs serve as molten catalysts, as is taught by Banin in reference to its gold cluster.

147. I also note that Banin sought to grow nanorods and not quantum dots, which is how Herron characterized the CdS intermediate cluster that was isolated using DMF. *Compare* Ex. 1005 (Banin) at 5:7-10 (“There is a need in the art to

facilitate preparation of nanocrystalline semiconductors, especially Group III-V semiconductors, having rod-like shape of controlled dimensions in a controllable and repeatable manner, which are not available to date.”) *with* Ex. 1016 (Herron) at 1426 (“With such a well-defined molecular cluster, we examined the intrinsic optical properties of a single-sized, 15 Å quantum dot without ambiguities from size dispersion or poorly defined surfaces.”). Those research interests are not well aligned.

148. In sum, the Petition offers no credible reason to modify Banin in view of Herron.

3. A POSITA would not have had a reasonable expectation of success in trying to use Herron’s isolated semiconductor cluster in Banin’s SLS method

149. Dr. Green concludes without citations that “a POSITA would also have a reasonable expectation of success that the combination of Banin and Herron “would succeed in growing an InAs core that includes a Cd-based MCC through a seeded growth reaction.” *See* Ex. 1002, ¶130 (uncited). I disagree.

150. As I discussed, the methods of Banin and Herron are very different. *See e.g., supra*, ¶¶131-136. Banin’s SLS method depends upon the existence of physical states of matter (i.e., molten metal) that Herron does not disclose. Banin uses molten gold to serve as a liquid metal catalyst into which precursors dissolve and form growing nanorods along with byproducts. *See* Ex. 1005, 6:3-8, Fig. 1. To

facilitate the SLS method used by Banin, any substitute catalyst would need to be metal, and need to be able to do the same (i.e, melt and dissolve suitable precursor compounds).

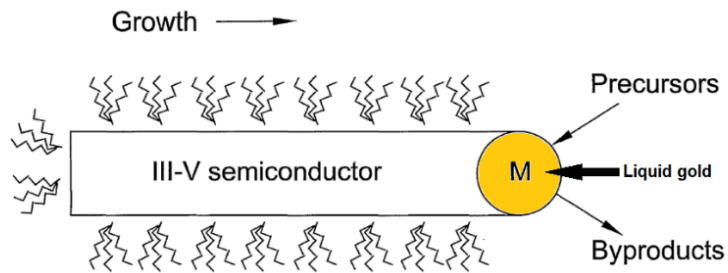


FIG. 1

151. There is nothing in Herron to indicate that it can serve as a substitute for Banin's gold clusters. Herron does not provide a melting point for its $\text{Cd}_{32}\text{S}_{14}(\text{SC}_6\text{H}_5)_{36}\cdot\text{DMF}_4$ cluster. Nor does Herron indicate that this cluster could dissolve and unify elements in precursor compounds to form nanorods. *See generally*, Ex. 1016.

152. Based on my review of the relevant literature, no one has ever tried, let alone succeeded in using a semiconductor as a catalyst in SLS nanorod synthesis. Banin and Herron is a far-fetched combination that a POSITA would look upon as unlikely to be successful.

D. Ground 4: Claims 13 and 14 Are Not Rendered Obvious by Banin in view of Treadway

153. Samsung challenges claims 13 and 14 of the '365 patent and asserts that these claims are rendered obvious by Banin in view of Treadway. *See e.g.*, Petition at 39. I disagree.

154. Treadway uses the hot-injection method. Ex. 1015 (Treadway) at 13:53-55 (“In a single rapid injection, the TOP solution was added to the hot TOPO pot after removing the heat from the reaction.”). As I discussed above, the hot-injection method is very different from the SLS method. The hot-injection method grows quantum dots while SLS is directed to growing nanorods. As the Board correctly noted in the Institution Decision, these are “disparate methods [that] involve markedly different experimental conditions, reactants, and synthetic goals.” *See* Institution Decision at 27.

155. Neither Petitioner nor Dr. Green has adequately explained why Banin and Treadway would be combined in a way to reach the invention claimed by claims 13 and 14 of the '365 patent. Petitioner has pointed to nothing specific in the references or in the general art to support this proposed combination.

E. Ground 5: Claims 1-9 and 17-23 Are Not Rendered Obvious by Zaban in View of Farneth and Yu

156. Petitioner’s fifth proposed ground once again presents a combination of references that teach entirely different things. Zaban was interested in new types

of solar cells and discloses an improved way to create electrodes using a titanium dioxide film embedded with indium phosphide (InP) quantum dots. *See* Ex. 1006 at 3153.

1. A Person of Skill in the Art Would Have No Reason to Combine Zaban’s Group III-V Quantum Dot Process with Farneth’s Group II-VI Solid-State Intermediate

157. Zaban notes at the outset that “[t]he key feature of this system is the use of nanocrystalline TiO₂ films that have an *extremely large surface-to-volume ratio*.” Ex. 1006 at 3153 (emphasis added). Yet unlike previous experiments that prepared and deposited “only very small sized QDs,” Zaban took “a different approach.” As part of that different approach, Zaban teaches that the larger InP quantum dots work much better on titanium dioxide films than smaller ones. *Id.* at 3154 (“We found that large InP particles adsorb better onto TiO₂ nanoparticles than small ones.”).

158. Zaban discloses making these larger InP (group III-V) quantum dots using the heat-up method. *See* Ex. 1006 at 3154 (“Colloidal InP QDs were synthesized by colloidal chemistry methods using indium oxalate and tris(trimethylsilyl)phosphine (P(SiMe₃)₃) as starting reactants; the reactants are heated for 3 days at 260-280 °C in the presence of trioctylphosphine oxide (TOP 0) and trioctylphosphine (TOP).”). Farneth, on the other hand, has nothing to do with group III-V quantum dots. Farneth investigates changes that occur when solid

precursors are heated to form bulk metal using a solid-state (i.e., solvent-free) method. *See* Ex. 1009 at title (“Bulk Semiconductors from Molecular Solids: A Mechanistic Investigation”); *see also id.* at 916 (“In this paper we report on the mechanism of the solid-state conversion of a particular series of II/VI precursors of general formula $(R_4N^+)_4[S_4M_{10}(SPh)_{16}]^{4-}$ (R = Me, Et; M = Cd, Zn) *to the bulk metal sulfide structure.*”) (emphasis added). The purported zinc “precursor” that Petitioner identifies in Farneth is an “intermediate solid” that required extensive purification steps to produce. *See* Ex. 1009 at 917-918 (Experimental Section).

159. Petitioner and Dr. Green contend that a POSITA would be motivated to replace Zaban’s zinc acetate with Farneth’s $Zn_{10}S_6Ph_{12}$ bulk-metal intermediate. *See e.g.*, Petition at 44 (“[A] POSITA would have been motivated to replace Zaban’s Zn-based precursor with Farneth’s Cd-based or Zn-based MCC.”); Ex. 1002 ¶158. I disagree.

160. As an initial matter, a POSITA would not have been looking for zinc-based precursors. As Zaban is synthesizing indium phosphide quantum dots, it has little need to look for zinc-based precursors, let alone ones that require such elaborate purification steps. Zaban’s zinc acetate is also not being used as a “precursor” as the Petition repeatedly claims. *See e.g.*, Petition at 44 and 51. Rather, Zaban used zinc acetate as a carefully metered dopant. *See* Ex. 1006 at 3154 (“p-Type (InP:Zn), n-type (InP:S), and undoped QDs of InP were synthesized as well-crystallized

zincblende nanocrystals.”). A dopant is not a precursor that contributes elemental ions in order to form the core semiconductor material itself. *See e.g.*, Ex. 1049 at 42 (“Dopant ions in [nanoparticles] can end up in the external sample matrix, bound to surface ligands, adhered directly to nanoparticle surfaces, doped into near-surface lattice sites, or doped into core lattice sites.”). That is not what dopants are used for. Dopants are small impurity intentionally added to change the core semiconductor’s electrical properties. *See generally, id.* at 42-44.

161. Zaban uses zinc acetate to carefully dope the quantum dots with a very low and very precise amount of zinc. Specifically, Zaban discloses adding one Zn^{2+} ion per quantum dot, resulting in an indium to zinc ratio of 1000 to 1. Ex. 1006 at 3154 (“For synthesis of p-type InP QDs, indium oxalate was mixed with zinc acetate in a ratio such that the resulting QDs contain on average one Zn^{2+} ion per particle. For example, for 40-Å QDs, the ratio In:Zn is $10^3:1$.”).

162. Petitioner suggests that mere presence of zinc in some molecule is sufficient motivation to use it in place of another zinc-containing molecule. It is not. Chemistry is specific, and as explained above, reagents, precursors, catalysts and other materials must be precisely chosen to obtain the specific result sought. This is especially true with dopants, and to this day zinc acetate is used to dope InP quantum dots. *See* Ex. 2025 at 16 (“[f]or synthesis we used ... zinc acetate dehydrate ($\text{Zn}(\text{OAc})_2$...”)). Moreover, there are many issues and challenges in doping quantum

dots. Solving issues related to doping quantum dots continues to generate great research interests in this field. *See* Ex. 2029 at 22104-105 (discussing the “significant attention” paid to colloidal doping and challenges presented). I am personally involved in and overseeing an NSF-funded materials research science and engineering center that focuses on “defects in nanostructures” and that studies dopants in quantum dots to elicit new functionalities.

163. Generally, dopants could be undesirable as they reduce conductivity and mechanical integrity of the crystalline material. *See* Ex. 2029. In semiconducting nanoparticles, defects could potentially lower their photoluminescent efficiency by creating states that do not result in light emission at desired wavelength. *See* Ex. 2025 at 5. However, in very certain cases, dopants can induce chemical, electrochemical and spectroscopic changes that could be beneficial to various applications. *See* Ex. 2029.

164. A semiconductor can be doped to such high levels that it acts more like a conductor than a semiconductor. This is referred to as a degenerate semiconductor. *See* Ex. 2015. In short, a change in the amount of zinc dopant leads to a change in the properties of the resultant quantum dot. *See* Ex. 2025 at 3 (“Increasing the Zn amount leads to broader peak shapes, which suggests a decrease of the QD size”).

165. Petitioner has not provided an explanation as to why a POSITA would think to combine Farneth’s zinc intermediate into Zaban’s process. Farneth’s zinc

intermediate has *ten* zinc atoms. If Zaban incorporated such a molecule into his quantum dots as suggested, it would result in many times the amount of zinc that Zaban wanted in the quantum dots. Thus, a POSITA would not have been motivated to increase the zinc content of Zaban with Farneth's ten-zinc intermediate. *Id.*

166. The Petition fails to address Zaban's careful ratio of zinc to indium while suggesting that Farneth's zinc-based "precursor" could be used in place of zinc acetate in Zaban's method. *See* Petition at 44, 51. Zaban taught the use of 1 zinc ion for every 1000 indium ions. *See* Ex. 1006 at 3154 ("For synthesis of p-type InP QDs, indium oxalate was mixed with zinc acetate in a ratio such that the resulting QDs contain on average one Zn^{2+} ion per particle. For example, for 40-A QDs, the ratio In:Zn is $10^3:1$."). In contrast, Farneth's $Zn_{10}S_6Ph_{12}$ intermediate, which has no indium ions, would not only introduce sulfur to unknown effects, it would eviscerate the delicately balanced doping ratio and change the nature of Zaban's quantum dots. *Id.* A POSITA would have no reason to make such a modification to Zaban.

2. Yu does not remedy the lack of motivation to combine Zaban and Farneth

167. Petitioner and Dr. Green suggest that a POSITA's knowledge of using MCCs from sources such as Yu, which reportedly taught low-temperature *SLS*, would have motivated using Farneth's *solid-state* Zn-based intermediate instead of zinc acetate in Zaban's *colloidal* process, and then drastically lowering the

temperature to accommodate those changes in a new hybrid seeded-growth process.

See generally, Petition at 42-43.

168. In arguing that a POSITA would have immediately recognized that Farneth's cluster could unlock entirely new synthesis methods, the Petition relies on Banin, which teaches yet another method (SLS) entirely specific to nanorods. *See* Petition at 43 (claiming that it was known to a POSITA "that MCCs are useful to improve the efficiency of solution-based nanoparticle syntheses" while citing Banin). The Petition goes on to argue that because Petitioners' third reference, Yu (Ex. 1010), purportedly discloses "heterogeneous seeded growth" of metallic nanoparticles on gold (Au) seeds at temperatures ranging from room temperature to 150°C, a POSITA would have motivated to invent a hybrid method not taught by any of these three references, in order to promote efficiency. *See, e.g.*, Petition at 44-46.

169. While the Petition relies upon Yu's disclosure of "heterogeneous seeded growth" of metallic nanoparticles on gold (Au) seeds at temperatures ranging from room temperature to 150 °C as purported motivation to make drastic changes to Zaban's method, *see e.g.*, Petition at 46, nothing in the disclosure of Yu, which uses an entirely different method utilizing gold, aligns with Zaban's heat-up colloidal process or Farneth's solid state method. *See generally*, Ex. 1010. If anything, Yu promotes the use of gold clusters as "potent heterogeneous nucleants"

and would not have directed a POSITA in any way to Zaban, or Farneth's solid state method. *See* Ex. 1010 at 9199. Zaban and Farneth do not involve gold, a low-temperature SLS procedure, or seeded growth. If anything, Yu's promotion of gold clusters as "potent heterogeneous nucleants" would have directed a POSITA away from Farneth's solid state method.

170. I also disagree that a POSITA would have been motivated to invent a hybrid method not taught by any of these three references, in order to promote efficiency and cost savings, as Petitioner and Dr. Green contend. *See e.g.*, Petition at 46; Ex. 1002 ¶180. I have a hard time believing that devoting time and effort to synthesizing Farneth's $Zn_{10}S_6Ph_{12}$ intermediate and using that instead of zinc acetate, which is cheap and abundantly available off the shelf, would have provided costs savings.

171. In my opinion, there is no teaching in the references themselves or generally that would lead to Petitioner's rationales for combining Zaban, Farneth, and Yu. Petitioner and Dr. Green have provided only strained logic to justify this combination.

3. A POSITA would not have had a reasonable expectation of success in trying use Farneth's intermediate cluster in Zaban's heat-up method

172. Petitioner argues that Farneth's cluster could unlock entirely new synthesis methods that a POSITA would have immediately recognized. *See* Petition

at 45 (discussing performing Zaban's QD synthesis with the Farneth zinc precursor at "low temperatures" to achieve seeded growth in light of Yu). Yet there is nothing in any of those references to support that assumed result.

173. As discussed above, Zaban used a delicate balance of zinc to indium and Farneth's $Zn_{10}S_6Ph_{12}$ intermediate, which has no indium ions, would have eviscerated that balance. It also would have introduced sulfur to unknown effects.

174. Nothing in the disclosure of Yu, which uses an entirely different method utilizing gold aligns with Zaban's heat-up colloidal process or Farneth's solid state method. All three references teach different methods along with different reaction times and temperatures: Zaban (3 days at 260-280 °C), Farneth ("700-900 °C converts the material to the macrocrystalline, bulk wurtzite phase") and Yu (140-150 °C).

175. Petitioner and Dr. Green acknowledge the reference different reaction conditions, but contradict themselves to try and accommodate the proposed combination. The Petition and Dr. Green argue that a "POSITA [] would have been motivated to perform Zaban's reaction at a lower temperature to accommodate Farneth's Zn-based MCC," but never suggest what that temperature would be. *See* Petition at 44; Ex. 1002, ¶158; *see also* Petition at 45 ("Zn-based clusters like that disclosed in Farneth *are not expected to remain as crystalline solids* or act as seeds *at the reaction temperatures disclosed in Zaban (i.e., 270 °C).*"); Ex. 1002, ¶160

(emphasis added). But then both contradict this by arguing that Farneth teaches that “‘the structural integrity of the clusters appears to be maintained’ as the MCC $\text{Cd}_{10}\text{S}_6\text{Ph}_{12}$ or $\text{Zn}_{10}\text{S}_6\text{Ph}_{12}$ during the reaction *at temperatures around* and below *300 °C.*”) (emphasis added) (citing Ex. 1009, 916, 918, 920). Notably, both of Petitioner’s primary references, Banin and Zaban also use the same solvents (TOP and TOPO) and yet Petitioner and Dr. Green’s arguments about what would have happened to Farneth’s intermediate shift according to what is needed to support the proposed combinations.

176. The Petition also brings in yet another reference, Banin, as purported evidence of reasonable expectation of success in combining Zaban, Farneth and Yu. *See* Petition at 46 (“A POSITA would have reasonably expected such a combination to succeed in achieving improved nanoparticle growth at least because the prior art discloses the successful use of MCCs like the one disclosed in Farneth to grow nanoparticles at the temperatures disclosed in Yu.”) (citing Banin). But Banin teaches yet another method (SLS) specific not to quantum dots like Zaban, but nanorods. *See generally*, Ex. 1005. Banin offers no information to suggest that combining the three other references would have been successful.

177. The Petition also argues that the combination is likely to succeed because “Zaban, Farneth, and Yu all occupy the same field of art as the ’365 patent: nanoparticles and their formation.” Petition at 46. That blanket rationale is no reason

to combine at all, as it could literally be applied to almost any combination of references in the art.

178. Petitioner has pointed to nothing specific in the references or general art to support a reasonable expectation that the proposed combination of Zaban, Farneth, and Yu would have succeeded in reaching the invention claimed by the challenged claims of the '365 patent.

F. Grounds 6 and 7: Claims 1, 2, 4, 7-12, 17-18, and 22-23 Are Not Rendered Obvious by Lucey in View of Ahrenkiel²

1. Lucey Uses the Hot-Injection Method to make Quantum Dots, While Ahrenkiel Uses the SLS Method to Make Quantum Rods

179. Petitioner's Grounds 6 and 7 suggest yet more unlikely combinations of references. Lucey teaches the use of the hot-injection method to create InP nanoparticles. *See* Ex. 1011 at 12:38-41 ("The initiation of the reaction occurs when the ER_n source is rapidly injected into a heated solution of ML_n source in the non-

² Although Ground 7 adds a second reference, Treadway, with respect to the "ternary and quaternary" claim elements of certain dependent claims, Petitioner does not contend that Treadway discloses a molecular cluster compound, a semiconductor material comprising one or more elements not comprised within the molecular cluster compound, or multiple precursors. Thus, the shortcomings persist for the same reasons provided in relation to Ground 6.

coordinating solvent.”). By contrast, Ahrenkiel uses SLS to create quantum rods. *See* Ex. 1012 at 834 (disclosing “[t]he growth of InP quantum rods and quantum wires by the solution-liquid-solid mechanism”). Despite this fundamental difference between the references, Petitioner argues that “a POSITA would have been motivated to replace Lucey’s single group 15 or 16-based precursor with Ahrenkiel’s multiple precursors because it would maximize the optical efficiency of the resulting nanoparticles by affecting their size and shape.” Petition at 55, 63. I disagree.

180. Lucey does not disclose that “the semiconductor material comprises one or more elements not comprised within the molecular cluster compound” as required by all claims of the ’365 patent. *See* Ex. 1001 at 20:9-13. And Petitioner’s alleged molecular cluster compounds in Lucey are actually precursors that contribute atoms to the semiconductor core, and therefore provide exactly *the same* elements comprised in the core, not different ones. *See* Ex. 1011 at 1:57-61

181. Petitioner points to three potential molecular cluster compounds in Lucey: $[\text{Me}_2\text{GaNH}_2]_3$, $[\text{Me}_2\text{GaN}(\text{H})(\text{Me})]_3$, and $[\text{Me}_2\text{GaN}(\text{Me})(\text{Ph})]_3$. *See* Petition at 56. These compounds are not molecular cluster compounds used to seed nanoparticle growth, but precursors that contribute group III atoms (in this case gallium (Ga)) to a group III-V semiconductor core. *See* Ex. 1011 at 1:57-61 (the compounds “may be used as precursors for synthesis of III-V semiconductor nanocrystals”).

182. One aspect of the alleged invention in Lucey is a process for making these group III precursors. Ex. 1011 at 4:31-34 (“Another aspect of the present invention is a process for producing compounds useful as *Group III precursors for producing III-V nanocrystals* in accordance with processes of the present invention”) (emphasis added). Because the clusters serve as precursors and contribute the group III atom to the group III-V semiconductor core, they comprise the same atoms found in the resulting semiconductor, and thus cannot satisfy the claim element “the semiconductor material comprises one or more elements not comprised within the molecular cluster compound.” *See e.g.*, Ex. 1001 at 20:11-13. Even if Lucey’s precursor was replaced with Ahrenkiel’s multiple precursors, the resultant process would still not disclose this claim element.

183. Ahrenkiel’s precursors provide indium phosphide (InP) itself to an InP semiconductor. *See* Ex. 1012 at 833 (“we used an organometallic precursor that decomposes thermally into InP”); *see also id.* at 834 (“we used a mixture of [(t-Bu)2InP(SiMe₃)₂]₂ and [Cl2InP(SiMe₃)₂]₂ precursors”) (emphasis added). Thus, the combination of Lucey with Ahrenkiel does nothing to disclose “the semiconductor material comprises one or more elements not comprised within the molecular cluster compound.” Ex. 1001 at 20:11-13.

184. Moreover, many claims of the ’365 patent require that the first precursor species contains a first ion (such as indium), and a separate second

precursor species containing a second ion (such as phosphorus), with both precursors providing a different ion to be incorporated into the growing quantum dot core. *See e.g.*, Ex. 1001 at 20:57-63 (“the precursor composition comprising a first precursor species containing a first ion to be incorporated into the core semiconductor material and a separate second precursor species containing a second ion to be incorporated into the core semiconductor material”); *see also id.* at 4:51-58. Ahrenkiel’s precursors do not provide separate indium and phosphorus ions to be incorporated into the nanorods, but rather both provide indium phosphide (InP) itself. *See* Ex. 1012 at 833-834 (showing [(t-Bu)2InP(SiMe₃)₂]₂ and [Cl₂InP(SiMe₃)₂]₂ precursors). Because both precursors provide the exact same thing, namely InP, the precursor combination used by Ahrenkiel does not disclose “a first precursor species containing a first ion to be incorporated into the core semiconductor material and a separate second precursor species containing a second ion to be incorporated into the core semiconductor material” of the ’365 patent. Ex. 1001 at 20:58-62; *see also id.* at 4:51-58.

2. Lucey Expressly Discourages Ahrenkiel’s Chlorine-Based Precursors

185. The proposed Lucey-Ahrenkiel combination is further diminished by Lucey’s teachings which expressly discourages using elements found in the Ahrenkiel precursors.

186. Ahrenkiel's second precursor ($[\text{Cl}_2\text{InP}(\text{SiMe}_3)_2]_2$) has chlorine (Cl) atoms in it. Chlorine belongs to a class of elements known as halogens. *See* Ex. 2023 (“Halogen: any of the five elements fluorine, chlorine, bromine, iodine, and astatine that form part of group VIIA”). Compounds that contain halogens such as chlorine are called halides. *See* Ex. 2024 (“Halide: (1) A compound containing a halogen atom”). Lucey is very specific that halide-containing precursors should not be used. *See* Ex. 1011 at 3:53-57 (“The most common precursors are the $\text{Mm}(\text{halides})_3$. When utilizing these precursors, the resultant semiconductor nanocrystals have the propensity to have halide impurities. These impurities hinder the desired electronic or optical properties of the nanocrystals.”); *see also id.* at 5:14-15 (“The Group III precursors prepared in accordance with the present invention ***do not contain halide*** impurities”); *id.* at 8:61-62 (“The following describes the preparation of very pure Group III precursors which ***do not contain halide*** impurities.”) (emphasis added);

187. A POSITA would not combine Ahrenkiel's chlorine-based halogen precursor with Lucey in light of Lucey's clear teaching that such precursors should not be used in Lucey's method. *Id.*

3. There Is No Motivation to Combine Lucey and Ahrenkiel, and No Reasonable Expectation of Success

188. The proposed combination of Lucey and Ahrenkiel also lacks a motivation to combine because Ahrenkiel is directed to the SLS method of creating

quantum rods, while Lucey is directed to the hot-injection method of making quantum dots. *Compare* Ex. 1012 at 834 (Ahrenkiel describing “[t]he growth of InP quantum rods and quantum wires by the solution-liquid-solid mechanism”), *with* Ex. 1011 at 5:49-51 and Fig. 3 (Lucey describing FIG. 3 as the “nanocrystal of the present invention”).

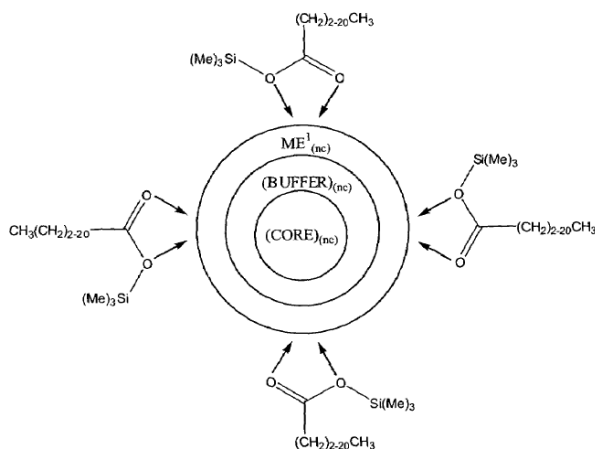


FIGURE 3

189. As discussed above, the SLS method involves a molten metal droplet that dissolves precursors until they are supersaturated and deposited on a growing nanorod. *See* Ex. 2009 at 422. The reason Ahrenkiel uses two precursors is very specific to the chosen SLS method and quantum rods in particular. *See e.g.*, Ex. 1012 at 834 (“The main differences between our synthesis and this work is that we used two precursors, [Cl₂InP(SiMe₃)₂]₂ and [(t-Bu)₂InP(SiMe₃)₂]₂, instead of only [(t-

$\text{Bu}_2\text{InP}(\text{SiMe}_3)_2$ and that a strong stabilizer was in the solution *in order to grow quantum rods.*) (emphasis added).

190. Ahrenkiel's SLS method has no application to the hot-injection methods of Lucey. Ahrenkiel uses its precursors to accomplish two things: (1) the precursors create melted metallic indium droplets to enable the SLS growth method, and (2) the precursors provide the InP to be deposited on the growing nanorod. *See* Ex. 1012 at 834 ("the *solution-liquid-solid* mechanism requires the presence of extremely *small metal indium particles that serve as a catalyst* for the growth of InP. The diameter of the indium particles determines the diameter of the nanorods. Indium particles can be . . . *produced simultaneously during InP growth from an organometallic molecular precursor*..."). Because Lucey does not use the SLS method, there is no need for Lucey to use precursors that thermally decompose into molten indium, *see generally*, Ex. 1011, and a POSITA would want to avoid such a modification while pursuing a homogeneous population of quantum dots.

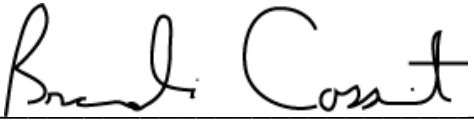
191. Ahrenkiel also discloses a very specific reason for using two precursors. Ahrenkiel explains that "[w]hen only the [one] precursor was present in the system, a large number of indium droplets and short InP fibers were produced." Ex. 1012 at 834. "Because of that," Ahrenkiel added a second InP precursor to the first InP precursor "to increase the total InP precursor concentration and, consequently, the length of the InP nanorods." *Id.*

192. While Ahrenkiel focuses on using two precursors to alter the *length* of the nanorods, their optical properties are dictated by their diameter and shape, not their length. *See* Ex. 1012 at 823 (“The electrical and optical properties of semiconductor nanowires and nanorods are controlled by their diameter and shape.”). Therefore, Petitioner is incorrect that Ahrenkiel’s “multiple precursors allows tailoring the physical dimensions of the nanoparticle and tuning its optical efficiency.” Petition at 55; Ex. 1002 ¶203. A POSITA practicing Lucey’s method to create spherical quantum dots would have no motivation to use precursors that created longer nanorods.

XII. CONCLUSION

193. I do not believe any of Petitioner’s proposed Grounds would have led a person of skill in the art to conclude that the challenged claims were fully disclosed or rendered obvious.

I declare under the pains and penalties of perjury under the laws of the United States of America that all statements made are believed to be true and correct.



Brandi Cossairt
August 12, 2021

APPENDIX A

EDUCATION

- Ph.D., Inorganic Chemistry, Massachusetts Institute of Technology 2006–2010
Dissertation: *Niobium-Mediated Synthesis of Phosphorus-Rich Molecules*
Advisor: Christopher C. Cummins
- B.S., Chemistry with Honors, California Institute of Technology 2002–2006
Advisors: Jonas C. Peters, Jesse L. Beauchamp; Anthony J. Hynes (University of Miami)

EXPERIENCE

- Professor of Chemistry, University of Washington September 2020–Present
- Associate Professor of Chemistry, University of Washington September 2018–August 2020
- Assistant Professor of Chemistry, University of Washington July 2012–August 2018
- NIH NRSA Postdoctoral Fellow, Columbia University July 2010–June 2012
Advisor: Professor Jonathan S. Owen

AWARDS AND HONORS

- 2021 Elected to the Washington State Academy of Sciences
- 2021 Finalist, Blavatnik National Awards for Young Scientists, Blavatnik Family Foundation and the New York Academy of Sciences
- 2018 National Fresenius Award, ACS National Award sponsored by Phi Lambda Upsilon
- 2018 Dalton Lecture in Inorganic Chemistry, UC Berkeley College of Chemistry
- 2018 Finalist, University of Washington Distinguished Teaching Award
- 2018 Associate Editor, *Inorganic Chemistry* (2018–present)
- 2017 Kavli Fellow, National Academy of Sciences
- 2017 Camille Dreyfus Teacher-Scholar Award, The Camille and Henry Dreyfus Foundation
- 2016 Reviewer Award, *Chemistry of Materials*
- 2016 CAREER Award, National Science Foundation
- 2015 Packard Fellowship for Science and Engineering, The David and Lucile Packard Foundation
- 2015 Sloan Research Fellowship, The Alfred P. Sloan Foundation
- 2015 Non-Tenured Faculty Award, 3M
- 2015 Nominee, University of Washington Distinguished Teaching Award
- 2015 Award for Early Career Achievement, Seattle Association for Women in Science
- 2014 University of Washington Innovation Award
- 2010 Ruth L. Kirschstein National Research Service Award, National Institutes of Health
- 2010 Alan Davison Ph.D. Thesis Prize, Massachusetts Institute of Technology
- 2009 Young Investigator Award, Division of Inorganic Chemistry, American Chemical Society
- 2007 Strem Summer Graduate Fellowship in Chemistry, Massachusetts Institute of Technology

- 2006 Award for Outstanding Teaching in Chemistry, Massachusetts Institute of Technology
2006 Richard P. Schuster Memorial Prize, California Institute of Technology

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36. Enright, M. J.; Sarsito, H.; **Cossairt, B. M.*** Quantifying Cation Exchange of Cd²⁺ in ZnTe: A Challenge for Accessing Type II Heterostructures. *Chem. Mater.* **2017**, *29*, 666–672. <https://pubs.acs.org/doi/10.1021/acs.chemmater.6b04215>
35. Gary, D. C.; Petrone, A.; Li, X.; **Cossairt, B. M.*** Investigating the Role of Amine in InP Nanocrystal Synthesis: Destabilizing Cluster Intermediates by Z-Type Ligand Displacement. *Chem. Commun.* **2017**, *53*, 161–164. (Special Issue on Frontiers in Nanocrystal Surface Chemistry) <https://pubs.rsc.org/en/content/articlelanding/2017/CC/C6CC07952K#!divAbstract>
34. **Cossairt, B. M.*** Shining Light on Indium Phosphide Quantum Dots: Understanding the Interplay of Precursor Conversion, Nucleation, and Growth. *Chem. Mater.* **2016**, *28*, 7181–7189. (Up and Coming Perspective)
33. Norris, M. R.; Flowers, S. E.; Mathews, A. M. **Cossairt, B. M.*** H₂ Production Mediated by CO₂ via Initial Reduction to Formate. *Organometallics* **2016**, *35*, 2778–2781. <https://pubs.acs.org/doi/10.1021/acs.organomet.6b00595>
32. Glassy, B. A.; **Cossairt, B. M.*** Resolving the Chemistry of Zn₃P₂ Nanocrystal Growth. *Chem. Mater.* **2016**, *28*, 6374–6380. <https://pubs.acs.org/doi/10.1021/acs.chemmater.6b02782>

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30. Stein, J. L.; Mader, E. A.; **Cossairt, B. M.*** Luminescent InP Quantum Dots with Tunable Emission by Post-Synthetic Modification with Lewis Acids. *J. Phys. Chem. Lett.* **2016**, *7*, 1315–1320. <https://pubs.acs.org/doi/10.1021/acs.jpcelett.6b00177>
29. Gary, D. C.; Flowers, S. E.; Petrone, A.; Li, X.; Kaminsky, W.; **Cossairt, B. M.*** Single-Crystal and Electronic Structure of a 1.3 nm Indium Phosphide Nanocluster. *J. Am. Chem. Soc.* **2016**, *138*, 1510–1513. <https://pubs.acs.org/doi/10.1021/jacs.5b13214>
28. Henckel, D. A.; Lin, Y. F.; McCormick, T. M.; Kaminsky, W.; **Cossairt, B. M.*** A Doubly Deprotonated Diimine Dioximate Metalloligand as a Synthone for Multimetallic Complex Assembly. *Dalton Trans.* **2016**, *45*, 10068–10075. (New Talent Americas Issue) <https://pubs.rsc.org/en/content/articlelanding/2016/DT/C5DT03650J#!divAbstract>
27. Norris, M. R.; **Cossairt, B. M.*** CdSe on a Mesoporous Transparent Conducting Oxide Scaffold as a Photocathode. *J. Mater. Chem. A* **2015**, *3*, 14585–14591 (journal cover). <https://pubs.rsc.org/en/content/articlelanding/2015/TA/C5TA03910J#!divAbstract>
26. Gary, D. C.; Terban, M. W.; Billinge, S. J. L.; **Cossairt, B. M.*** Two-Step Nucleation and Growth of InP Quantum Dots via Magic-Sized Cluster Intermediates. *Chem. Mater.* **2015**, *27*, 1432–1441. <https://pubs.acs.org/doi/10.1021/acs.chemmater.5b00286>
25. Glassy, B. A.; **Cossairt, B. M.*** Ternary Synthesis of Colloidal Zn₃P₂ Quantum Dots. *Chem. Commun.* **2015**, *51*, 5283–5286. (Emerging Investigators Issue 2015) <https://pubs.rsc.org/en/content/articlelanding/2015/CC/C4CC08068H#!divAbstract>
24. Flowers, S. E.; **Cossairt, B. M.*** Mono- and Dimetalation of a Tridentate Bisimidazole-Phosphine Ligand. *Organometallics* **2014**, *33*, 4341–4344. (journal cover) <https://pubs.acs.org/doi/10.1021/om500592u>
23. Gary, D. C.; Glassy, B. A.; **Cossairt, B. M.*** Investigation of Indium Phosphide Quantum Dot Nucleation and Growth Utilizing Triarylsilylphosphine Precursors. *Chem. Mater.* **2014**, *26*, 1734–1744. <https://pubs.acs.org/doi/10.1021/cm500102q>
22. Gary, D. C.; **Cossairt, B. M.*** Role of Acid in Precursor Conversion During InP Quantum Dot Synthesis. *Chem. Mater.* **2013**, *25*, 2463–2469. <https://pubs.acs.org/doi/10.1021/cm401289j>
21. Garcia, R.; Hendricks, M. P.; **Cossairt, B. M.***; Liu, H.; Owen, J. S. Conversion Reactions of Cadmium Chalcogenide Nanocrystal Precursors. *Chem. Mater.* **2013**, *25*, 1233–1249. (Invited review for special issue “Synthetic and Mechanistic Advances in Nanocrystal Growth”) <https://pubs.acs.org/doi/10.1021/cm3035642>

Prior to the University of Washington

20. Velian, A.; **Cossairt, B. M.**; Cummins, C. C. Assembly and Stabilization of {E(cyclo-P₃)₂} (E = Sn, Pb) as a Bridging Ligand Spanning Two Triaryloxyniobium Units. *Dalton Trans.* **2016**, *45*, 1891–1895.
19. Hendricks, M. P.; **Cossairt, B. M.**; Owen, J. S. The Importance of Nanocrystal Precursor Conversion Kinetics: Mechanism of the Reaction between Cadmium Carboxylate and Cadmium Bis(diphenyldithiophosphinate). *ACS Nano* **2012**, *6*, 10054–10062.
18. Daly, A. M.; **Cossairt, B. M.**; Southwood, G.; Carey, S. J.; Cummins, C. C.; Kukulich, S. G. Microwave Spectrum of Arsenic Triphosphide. *J. Mol. Spectrosc.* **2012**, *278*, 68–71.

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16. **Cossairt, B. M.**; Owen, J. S. CdSe Clusters: At the Interface of Small Molecules and Quantum Dots. *Chem. Mater.* **2011**, *23* (12), 3114–3119.
15. Tofan, D.; **Cossairt, B. M.**; Cummins, C. C. White Phosphorus Activation at a Metal-Phosphorus Triple Bond: a New Route to *cyclo*-Triphosphorus or *cyclo*-Pentaphosphorus Complexes of Niobium. *Inorg. Chem.* **2011**, *50* (24), 12349–12358.
14. Schwarzmaier, C.; Noor, A.; Glatz, G.; Zabel, M.; Timoshkin, A. Y.; **Cossairt, B. M.**; Cummins, C. C.; Kempe, R.; Scheer, M. Formation of *cyclo*-E₄²⁻ Units (E₄ = P₄, As₄, AsP₃) by a Complex with a Cr-Cr Quintuple Bond. *Angew. Chem., Int. Ed.* **2011**, *50* (32), 7283–7286.
13. **Cossairt, B. M.**; Cummins, C. C. Molecular Gallium Arsenide Phosphide Clusters Prepared from AsP₃, P₄, and [GaC(SiMe₃)₃]₄. *Chem. Eur. J.* **2010**, *16* (42), 12603–12608.
12. **Cossairt, B. M.**; Cummins, C. C.; Head, A. R.; Lichtenberger, D. L.; Berger, R. J. F.; Hayes, S. A.; Mitzel, N. W.; Wu, G. On the Molecular and Electronic Structures of AsP₃ and P₄. *J. Am. Chem. Soc.* **2010**, *132* (24), 8459–8465.
11. **Cossairt, B. M.**; Cummins, C. C. Radical Synthesis of Trialkyl, Triaryl, Trisilyl, and Tristannyl Phosphines from P₄. *New J. Chem.* **2010**, *34*, 1533–1536 (journal cover).
10. **Cossairt, B. M.**; Piro, N. A.; Cummins, C. C. Early-Transition-Metal-Mediated Activation and Transformation of White Phosphorus. *Chem. Rev.* **2010**, *110* (7), 4164–4177.
9. **Cossairt, B. M.**; Cummins, C. C. Shuttling P₃ from Niobium to Rhodium: The Synthesis and Use of Ph₃SnP₃(C₆H₈) as a P₃⁻ Synthone. *Angew. Chem., Int. Ed.* **2010**, *49* (9), 1595–1598.
8. **Cossairt, B. M.**; Cummins, C. C. Properties and Reactivity Patterns of AsP₃: An Experimental and Computational Study of Group 15 Elemental Molecules. *J. Am. Chem. Soc.* **2009**, *131* (42), 15501–15511.
7. **Cossairt, B. M.**; Diawara, M. C.; Cummins, C. C. Facile Synthesis of AsP₃. *Science* **2009**, *323*, 602.
6. **Cossairt, B. M.**; Cummins, C. C. A Niobium-Mediated Cycle Producing Phosphorus-Rich Organic Molecules from White Phosphorus (P₄) through Activation, Functionalization, and Transfer Reactions. *Angew. Chem., Int. Ed.* **2008**, *47* (46), 8863–8866.
5. **Cossairt, B. M.**; Cummins, C. C. Phosphaalkenes as Long-Lived Phosphorus Cluster Surface Functional Groups: Intramolecular P=C Addition to a Niobium-Supported P₇ Cage. *Inorg. Chem.* **2008**, *47* (20), 9363–9371.
4. **Cossairt, B. M.**; Cummins, C. C. A Reactive Niobium Phosphinidene P₈ Cluster Obtained by Reductive Coupling of White Phosphorus. *Angew. Chem., Int. Ed.* **2008**, *47* (1), 169–172.
3. Williams, M. B.; Campuzano-Jost, P.; **Cossairt, B. M.**; Hynes, A. J. Experimental and Theoretical Studies of the Reaction of the OH Radical with Alkyl Sulfides: 1. Direct Observations of the Formation of the OH–DMS Adduct–Pressure Dependence of the Forward Rate of Addition and Development of a Predictive Expression at Low Temperature. *J. Phys. Chem. A* **2007**, *111* (1), 89–104.
2. Donohue, D. L.; Bauer, D.; **Cossairt, B. M.**; Hynes, A. J. Temperature and Pressure Dependent Rate Coefficients for the Reaction of Hg with Br and the Reaction of Br with Br: A Pulsed Laser Photolysis-Pulsed Laser Induced Fluorescence Study. *J. Phys. Chem. A* **2006**, *110* (21), 6623–6632.

1. Hu, X.; **Cossairt, B. M.**; Brunschwig, B. S.; Lewis, N. S.; Peters, J. C. Electrocatalytic Hydrogen Evolution by Cobalt Difluoroboryldiglyoximate Complexes. *Chem. Commun.* **2005**, 37, 4723–4725.

INVITED PRESENTATIONS

127. Gordon Research Conference on Atomically Precise Nanochemistry, Galveston, TX, February 2022
126. Excitonic Nanomaterials: Synthesis and Applications, Pacificchem, Honolulu, HI, December 2021
125. Main Group Element-Transition Metal Compounds: The Intersection of Molecular and Solid-State Chemistry, Pacificchem, Honolulu, HI, December 2021
124. Department of Chemistry, Rice University, Houston, TX, December 2021
123. University of California Davis Inorganic Chemistry Symposium, Davis, CA, November 2021
122. Department of Chemistry, University of Virginia, Virtual Seminar, September 2021
121. Behold the Main Group, and all its Glory, 2021 IUPAC – CCE Meeting, Montreal, Canada, August 2021
120. P-Chemistry Online Seminar Series, July 2021, <https://phosphorus-chemistry.weebly.com/>
119. 239th Annual Electrochemical Society Meeting, Symposium I03 – Renewable Fuels via Artificial Photosynthesis or Heterocatalysis, May-June 2021
118. nanoGE Summer School on Semiconductor Nanocrystals, May 2021, <https://www.nanoge.org/QDsSCHOOL/home>
117. American Chemical Society Northwest Regional Meeting, Virtual Seminar, May 2021
116. School of Chemistry and Chemical Engineering, Advances in Colloidal Nanomaterials: Challenges and Opportunities Virtual Lecture Series, Nanjing University, April 2021
115. Gabor A. Somorjai Award; symposium honoring Paul Chirik, American Chemical Society, Spring 2021 National Meeting, April 2021
114. Department of Chemistry, Vanderbilt University, Virtual Seminar, April 2021
113. Department of Chemistry, Purdue University, Virtual Seminar, April 2021
112. ACS Axial Webinar, Changing the Culture of Chemistry: Career Planning and Mentorship, March 2021
111. ACS On Campus Inorganic Chemistry Journal Club, <https://www.eventbrite.com/e/acs-journal-club-february-23-tickets-138966629931?aff=website>, February 2021
110. Department of Chemistry, University of California – Los Angeles, Virtual Seminar, November 2020
109. Department of Chemistry, Princeton University, Virtual Seminar, November 2020
108. Virtual Panel, Women in Materials, Metallurgy, and Nuclear Engineering, Colorado School of Mines, October 2020
107. Zoom Main Group Symposium: From Molecules to Materials, organized by Professor Alexander Spokoyny (UCLA), <https://www.organomimetic.com/zoommaingroup.html>, August 2020
106. News in Nanocrystals, Virtual Symposium, jointly organized by University of Colorado Boulder and the Massachusetts Institute of Technology, <https://ninc.mit.edu/>, August 2020
105. Department of Chemical Sciences and Engineering, École Polytechnique Fédérale de Lausanne, Virtual Seminar, Lausanne, Switzerland, May 2020
104. *Department of Chemistry, Texas A&M University, College Station, TX, April 2020; *cancelled due to COVID-19

103. *Molecular Insight in Materials Catalysis (CATL), 259th American Chemical Society National Meeting, Philadelphia, PA, March 2020; *cancelled due to COVID-19
102. *Multimetallic Molecular and Extended Platforms for Energy Applications (INOR), 259th American Chemical Society National Meeting, Philadelphia, PA, March 2020; *cancelled due to COVID-19
101. Department of Chemistry, Penn State University, State College, PA, February 2020
100. Department of Chemistry, University of Chicago, Chicago, IL, January 2020
99. Fundamental Processes in Semiconductor Nanocrystals, nanoGE, Berlin, Germany, November 2019
98. Pauling Medal Symposium in Honor of Catherine Murphy, Oregon State University, Corvallis, OR, October 2019
97. Department of Chemistry, Florida State University, Tallahassee, FL, September 2019
96. Department of Chemistry, University of Florida, Gainesville, FL, September 2019
95. Gordon Research Conference on Crystal Growth & Assembly, Biddeford, ME, June 2019
94. Semiconductor Nanostructures towards Electronic and Opto-Electronic Device Applications VII, Meeting of the European Materials Research Society, Nice, France, May 2019
93. British Columbia Inorganic Discussion Weekend, Keynote Lecture, University of Victoria, British Columbia, Canada, May 2019
92. National Fresenius Award Lecture, 257th American Chemical Society National Meeting, Orlando, FL, April 2019
91. Chemistry of Materials 30th Anniversary Symposium, 257th American Chemical Society National Meeting, Orlando, FL, April 2019
90. ACS Harry Gray Award for Creative Work in Inorganic Chemistry symposium in honor of Jillian Dempsey, 257th American Chemical Society National Meeting, Orlando, FL, April 2019
89. Department of Chemistry, Wayne State University, Detroit, MI, March 2019
88. Department of Chemistry, Colorado State University, Fort Collins, CO, March 2019
87. Department of Chemistry, Northwestern University, Evanston, IL, February 2019
86. Center for Sustainable Nanotechnology, Virtual Seminar, December 2018
85. Solid State Chemistry of Inorganic Materials, Materials Research Society Fall Meeting, Boston, MA, November 2018
84. Department of Chemistry, Cornell University, November 2018
83. Department of Chemistry, Massachusetts Institute of Technology, November 2018
82. Department of Chemistry, Harvard University, Boston, MA, November 2018
81. Dreyfus Foundation Teacher-Scholar Symposium, New York, NY, October 2018
80. Department of Chemistry, University of Pittsburgh, Pittsburgh, PA, October 2018
79. Dalton Lecture, Department of Chemistry, University of California, Berkeley, CA, September 2018
78. Women in Nanotechnology (INOR), 256th American Chemical Society National Meeting, Boston, MA, August 2018
77. Synthesis and Characterization of Nanomaterials for Sustainable Energy Applications (MPPG), 256th American Chemical Society National Meeting, Boston, MA, August 2018
76. Enabling Spectroscopies for Nanomaterials (ANYL), 256th American Chemical Society National Meeting, Boston, MA, August 2018
75. Keynote Speaker, NSERC CREATE, University of British Columbia, Vancouver, BC, August 2018
74. Gordon Research Conference on Organometallic Chemistry, Newport, RI, July 2018

73. Polymetallic Assemblies: From Clusters to Molecular Materials (INOR), 101st Canadian Chemistry Conference and Exhibition, Edmonton, Alberta, May 2018
72. Society for Information Display, Display Week 2018, Los Angeles, CA, May 2018
71. 233rd Annual Electrochemical Society Meeting, Seattle, WA, May 2018
70. Department of Chemistry, Stanford University, Stanford, CA, April 2018
69. Nanomaterials (COLL), 255th American Chemical Society National Meeting, New Orleans, LA, March 2018
68. PCET PhotoCatalysis with Inorganic Molecules and Materials (INOR), 255th American Chemical Society National Meeting, New Orleans, LA, March 2018
67. Department of Chemistry, University of Pennsylvania, Philadelphia, PA, March 2018
66. Department of Chemistry, University of Wisconsin–Madison, Madison, WI, February 2018
65. Department of Chemistry, Portland State University, Portland, OR, February 2018
64. Department of Chemistry, Seattle Pacific University, Seattle, WA, January 2018
63. Department of Chemistry, Johns Hopkins University, Baltimore, MD, November 2017
62. Department of Chemistry, Brown University, Providence, RI, October 2017
61. International Conference on Polymers and Advanced Materials (POLYMAT 2017), Huatulco, Oaxaca, Mexico, October 2017
60. 29th Annual Packard Fellows Meeting, Monterey, CA, September 2017
59. Center for Advanced Solar Photophysics, Los Alamos National Laboratory, NM, August 2017
58. Korean-American Kavli Frontiers of Science Symposium, US National Academy of Sciences & Korean Academy of Science and Technology, Irvine, CA, June 2017
57. Department of Chemistry, California Institute of Technology, Pasadena, CA, June 2017
56. Department of Chemistry, University of California–San Diego, CA, June 2017
55. 3M Science and Engineering Faculty Day, Minneapolis, MN, June 2017
54. Department of Chemistry, University of North Carolina at Chapel Hill, NC, March 2017
53. Department of Chemistry, University of California–Santa Barbara, CA, February 2017
52. Department of Chemistry, University of California–Los Angeles, CA, February 2017
51. Department of Chemistry, University of Colorado–Boulder, CO, February 2017
50. Department of Chemistry, University of Illinois–Urbana-Champaign, IL, January 2017
49. ExxonMobil, Baytown, TX, December 2016
48. Department of Chemistry, Michigan State University, Lansing, MI, November 2016
47. Department of Chemistry, Columbia University, New York, NY, November 2016
46. Department of Chemistry, Princeton University, Princeton, NJ, November 2016
45. Department of Chemistry, University of California–Irvine, CA, October 2016
44. Department of Chemistry, University of Southern California, Los Angeles, CA, October 2016
43. Resnick Sustainability Institute, California Institute of Technology, Pasadena, CA, September 2016
42. 28th Annual Packard Fellows Meeting, Monterey, CA, September 2016
41. DIC Young Investigator Awardees: Where are they now? (INOR), 252nd American Chemical Society National Meeting, Philadelphia, PA, August 2016
40. Metal and Semiconductor Nanoclusters with Atomic Precision: Fundamentals and Applications (PHYS), 252nd American Chemical Society National Meeting, Philadelphia, PA, August 2016
39. Gordon Research Conference on Colloidal Semiconductor Nanostructures, Mount Snow, VT, July-August 2016

38. American Chemical Society Northwest Regional Meeting, Anchorage, AK, June 2016
37. Gordon Research Conference on Inorganic Chemistry, Biddeford, ME, June 2016
36. Applied Physics Laboratory, University of Washington, Seattle, WA, May 2016
35. Department of Chemistry, Iowa State University, Ames, IA, April 2016
34. ACS Award in Pure Chemistry symposium in honor of Jonathan Owen (INOR), 251st American Chemical Society National Meeting, San Diego, CA, March 2016
33. ACS Award in Organometallic Chemistry symposium in honor of Karen Goldberg (INOR), 251st American Chemical Society National Meeting, San Diego, CA, March 2016
32. The Quantum Dots Forum, Newport Beach, CA, March 2016
31. Center for Chemical Innovation (CCI-Solar) Annual Meeting, Newport Beach, CA, February 2016
30. The Art Institutes of Seattle, Winter Lecture Series, Seattle, WA, February 2016
29. Dow Chemical, Shipley Seminar Series, Marlborough, MA, December 2015
28. 3M, Minneapolis, MN, November 2015
27. Department of Chemistry, Western Washington University, Bellingham, WA, November 2015
26. Inorganic Chemistry Lectureship Symposium in honor of Daniel Gamelin (INOR), 250th American Chemical Society National Meeting, Boston, MA, August 2015
25. Board of Regents meeting, University of Washington, Seattle, WA, May 2015
24. NanoLytics 2015, Simon Fraser University, Burnaby, BC, Canada, April 2015
23. Department of Chemistry, Eastern Washington University, Cheney, WA, April 2015
22. From Molecules to Colloidal Compound Semiconductor Nanocrystals: Advances in Mechanism-Enabled Design & Syntheses, Materials Research Society Meeting, San Francisco, April 2015
21. New Catalysis Through Ligand Design (CATL), 249th American Chemical Society National Meeting, Denver, CO, March 2015
20. Design Principles for Functional Macromolecular Materials (PMSE), 249th American Chemical Society National Meeting, Denver, CO, March 2015
19. Gordon Research Conference on Inorganic Reaction Mechanisms, Galveston, TX, March 2015
18. Department of Material Science & Engineering, University of Washington, Seattle, February 2015
17. Department of Chemistry, Pacific Lutheran University, Tacoma, WA, September 2014
16. International Conference on Energy Conversion & Storage (ORCAS), Friday Harbor, WA, September 2014
15. The Chemistry of Inorganic Nanocrystals & Clusters: Structural Characterization & Mechanisms of Growth (INOR), 248th American Chemical Society National Meeting, San Francisco, CA, August 2014
14. Pacific Science Center Science Café, Kirkland, WA, November 2013 ([*online video of talk*](#))
13. Women in Chemical Sciences, University of Washington, Seattle, WA, November 2012

Prior to the University of Washington

12. 238th American Chemical Society National Meeting (INOR), Washington, D.C., August 2009
11. Department of Chemistry, Stanford University, Stanford, CA, January 2012
10. Department of Chemistry, University of Chicago, Chicago, IL, January 2012
9. Department of Chemistry, Barnard College, New York City, NY, January 2012
8. Department of Chemistry & Chemical Biology, Harvard University, Cambridge, MA, December 2011
7. Department of Chemistry, Princeton University, Princeton, NJ, December 2011
6. Department of Chemistry, Yale University, New Haven, CT, December 2011

5. Department of Chemistry, University of Washington, Seattle, WA, December 2011
4. Department of Chemistry, University of California Irvine, Irvine, CA, December 2011
3. Department of Chemistry, University of Southern California, Los Angeles, CA, November 2011
2. Department of Chemistry, Northwestern University, Evanston, IL, November 2011
1. Department of Chemistry, Harvey Mudd College, Claremont, CA, November 2011

CONTRIBUTED PRESENTATIONS

12. Gordon Research Conference on Colloidal Semiconductor Nanocrystals, Smithfield, RI, July 2014
11. Gordon Research Conference on Inorganic Chemistry, Biddeford, ME, June 2014
10. 246th American Chemical Society National Meeting (INOR), Indianapolis, IN, September 2013
9. Gordon Research Conference on Clusters, Nanocrystals & Nanostructures, South Hadley, MA, August 2013
8. 245th American Chemical Society National Meeting (INOR), New Orleans, LA, April 2013

Prior to the University of Washington

7. 243rd American Chemical Society National Meeting (INOR), San Diego, CA, March 2012
6. Gordon Research Conference on Inorganic Chemistry, Biddeford, ME, June 2012
5. Gordon Research Conference on Clusters, Nanocrystals & Nanostructures, South Hadley, MA, July 2011
4. 241st American Chemical Society National Meeting (INOR), Anaheim, CA, March 2011
3. Gordon Research Conference and Seminar on Organometallic Chemistry, Newport, RI, July 2009
2. 235th American Chemical Society National Meeting (INOR), New Orleans, LA, April 2008
1. 234th American Chemical Society National Meeting (INOR), Boston, MA, August 2007

GRANT ACTIVITY

Current

National Science Foundation (PI) <i>Mechanistic Discovery for Materials Synthesis Across Scales using Atomically Precise Cluster Building Blocks</i>	7/2021–6/2024	\$465,556
Department of Energy (co-PI, PI: Munira Khalil) <i>Measuring Vibronic Coupling and Ultrafast Charge Delocalization on Nanocrystal Surfaces Using Ligand-Specific Vibrational Probes</i>	9/2020–8/2022	\$590,957 (Cossairt: \$180,000)
National Science Foundation (co-PI, PI: Kai-Mei Fu) <i>NRT-QL: Accelerating Quantum-Enabled Technologies</i>	9/2020–8/2025	\$3,000,000 (Student training grant)
National Science Foundation (co-PI, PI: Gerald Seidler) <i>Instrument Development: In Operando Capability for Benchtop X-ray Emission Spectroscopy</i>	9/2019–8/2022	\$377,000 (Cossairt: \$135,000)
National Science Foundation (co-PI, PI: Arka Majumdar) <i>QII-TAQS: Strongly Interacting Photons in Coupled Cavity Arrays: A Platform for Quantum Many-Body Simulations</i>	9/2019–8/2024	\$1,500,000 (Cossairt: \$375,000)
Department of Energy (co-PI, PI: Morris Bullock) <i>The Center for Molecular Electrocatalysis</i>	8/2018–7/2022	\$13,000,000 (Cossairt: \$600,000)

Department of Energy (co-PI, PI: François Baneyx) <i>The Center for the Science of Synthesis Across Scales</i>	8/2018–7/2022	\$10,800,000 (Cossairt: \$300,000)
National Science Foundation (co-PI, PI: Daniel Gamelin) <i>MRSEC: University of Washington Molecular Engineering Materials Center</i>	9/2017–8/2023	\$15,599,816 (Cossairt: \$600,000)
Camille Dreyfus Teacher-Scholar Award (PI) <i>The Synthetic Inorganic Chemistry of Sustainable Technologies</i>	4/2017–4/2022	\$75,000
National Science Foundation (PI) <i>CAREER: New Models for Controlling InP Nucleation, Growth, and Luminescence using Magic-Sized Clusters and Targeted Surface Chemistry</i>	2/2016–1/2021	\$680,835

Completed

Packard Fellowship for Science and Engineering (PI) <i>Understanding Nucleation, Growth and Energy Transduction in Colloidal Nanoscale Systems: Inorganic Synthesis for a Sustainable Energy Future</i>	11/2015–10/2020	\$875,000
National Science Foundation (co-PI, PI: Arka Majumdar) <i>QLC: EAGER: Quantum Simulation using Solution Processed Quantum Dots</i>	9/2018–9/2020	\$300,000 (Cossairt: \$150,000)
Cottrell Scholars Collaborative PUI-R1 (co-PI, PI: Mark Bussell) <i>Efficient and Practical Solar Fuels Production Using Earth Abundant Materials</i>	5/2019–4/2020	\$1,000
JCDREAM Seed Funding (co-PI, PI: Mark Bussell) <i>Exchange Visits and Preliminary Research to Explore the Potential for a New Collaboration in Efficient and Practical Solar Fuels Production Using Earth Abundant Materials</i>	5/2019–6/2019	\$10,200
NW Impact (co-PI, PI: Chunlong Chen) <i>Engineering Sequence-Defined Polymers for Controlled Formation of Hybrid Materials</i>	6/2018–5/2019	\$200,000 (Cossairt: \$50K)
Merck Performance Materials (PI) <i>The Introduction of Heteroatoms into InP MSCs for the Formation of Alloyed Nanocrystal Structures</i>	12/2017–12/2018	\$104,283
3M Non-Tenured Faculty Award (PI) <i>Luminescent InP Quantum Dots for Photoluminescence Down-Conversion Technologies</i>	3/2015–2/2018	\$45,000
Sloan Research Fellowship (PI) <i>The Synthetic Inorganic Chemistry of Sustainable Technologies</i>	9/2015–9/2017	\$50,000
UW Innovation Award (PI) <i>Innovations in Quantum Dot Chemistry for Solar Energy Production and Storage</i>	5/2014–4/2017	\$500,000
ACS Petroleum Research Fund (PI) <i>Homogeneous Bimetallic Systems for Syngas Conversion</i>	9/2014–8/2016	\$110,000
Clean Energy Institute Student Training & Exploration (PI) <i>Solution Processable GaAs Thin Films</i>	12/2014–6/2015	\$34,000
UW Royalty Research Fund (PI) <i>Role of Acid in InP-QD Precursor Conversion Reactions and New Strategies for Improved Crystallization</i>	9/2013–8/2014	\$37,000

COLLABORATORS

Aaron Appel	CME EFRC	Pacific Northwest National Laboratory
David Baker	CSSAS EFRC	University of Washington (Biochem)

François Baneyx	CSSAS EFRC	University of Washington (ChemE)
R. Morris Bullock	CME EFRC	Pacific Northwest National Laboratory
Chun-Long Chen	CSSAS EFRC	Pacific Northwest National Laboratory
James De Yoreo	CSSAS EFRC	University of Washington; PNNL
Scott Dunham	MEMC MRSEC	University of Washington (EE)
Andrew Ferguson	CSSAS EFRC	University of Chicago
Daniel R. Gamelin	MEMC MRSEC	University of Washington
David S. Ginger	CSSAS EFRC	University of Washington
Sharon Hammes-Schiffer	CME EFRC	Yale University
Vincent Holmberg	MEMC MRSEC	University of Washington (Chem E)
Samson Jenekhe	CSSAS EFRC	University of Washington (Chem E)
Sergei Kalinin	CSSAS EFRC	Oak Ridge National Laboratory
Werner Kaminsky		University of Washington
Munira Khalil		University of Washington
Xiaosong Li	MEMC MRSEC	University of Washington
Christine Luscombe	MEMC MRSEC	University of Washington (MSE)
Arka Majumdar	NSF EAGER	University of Washington (EE)
David Masiello	QII-TAQS	University of Washington (Chem)
James M. Mayer	CME EFRC	Yale University
Jeffrey T. Miller	CME EFRC	Purdue University
Christopher Mundy	CSSAS EFRC	Pacific Northwest National Laboratory
Peter Pauzauskie	MEMC MRSEC	University of Washington (MSE)
W. James Pfaendtner	CSSAS EFRC	University of Washington (ChemE)
Simone Rauegi	CME EFRC	Pacific Northwest National Laboratory
Thatcher Root	CME EFRC	University of Wisconsin, Madison
Aaron Rossini		University of Iowa
Gerald Seidler	NSF CMI	University of Washington (Physics)
Shannon S. Stahl	CME EFRC	University of Wisconsin, Madison
Yogesh Surendranath	CME EFRC	Massachusetts Institute of Technology
Akif Tezcan	CSSAS EFRC	University of California, San Diego
Michael Toney		SLAC National Accelerator Lab (SiMES)
Eric Wiedner	CME EFRC	Pacific Northwest National Laboratory
Norman Yao	QII-TAQS	University of California, Berkeley
Former		
Simon J. L. Billinge		Columbia University
Jillian L. Dempsey		University of North Carolina, Chapel Hill
Andrew B. Greytak		University of South Carolina
Kannan Krishnan		University of Washington (MSE)
Elizabeth A. Mader		Yale University
Theresa M. McCormick		Portland State University

PROFESSIONAL ACTIVITIES

Consultancies and Industrial Collaborations

Expert Witness Consultant (QD patent matters – via Mintz)	January 2020–Present
Expert Witness Consultant (QD patent matters – via Sterne Kessler)	2019–2020
Research Consultant, Merck Electronic Materials	2016–2019
Research Consultant, QD Vision	2013–2014

Society Leadership, Scientific Advisory and Editorial Boards

Associate Editor, <i>Inorganic Chemistry</i> (ACS)	January 2018–Present
Editorial Advisory Board, <i>Materials Horizons</i> (RSC)	December 2020–Present
Editorial Advisory Board, <i>Chemistry of Materials</i> (ACS)	October 2020–Present
Editorial Advisory Board, SCIENCE CHINA Chemistry (Springer)	January 2019–Present
National Web Editor, Phi Lambda Upsilon Honor Society	2015–Present
Founder and Executive Board Member, <u>Chemistry Women Mentorship Network</u>	2014–Present
ACS COLL Victor K. LaMer Award Committee (3Y Term)	2019–2022
Editorial Advisory Board, ACS In Focus (Primer Series)	2018
Nanoscience Subdivision Chair, ACS Division of Inorganic Chemistry	2017–2018
Nanoscience Subdivision Chair-Elect, ACS Division of Inorganic Chemistry	2016–2017
External Consultant for Inorganic Faculty Hiring, Carroll College	2016–2017
Programming Committee, Society for Information Display (SID)	2016–2018
Scientific Advisory Board, NSF Center for Chemical Innovation (CCI Solar)	2016–2019
Alumni Committee on Community & Equity, Massachusetts Institute of Technology	2016–2019

Conference, Symposium, and Seminar Organization

NanoGE, NCFun21: Fundamental Processes in Nanocrystals and 2D Materials, with Jonathan De Roo, Barcelona, Spain, October 2021	
European Materials Research Society (E-MRS), Scientific Review Committee for Semiconductor Nanostructures toward Electronic and Optoelectronic Device Applications, January 2020–present	
Nanocrystals Northwest, with Daniel Gamelin, Pack Forest, WA, August 2019	
Chemistry at the Interface of Solution-Processed Inorganic Materials, with Andrew Greytak (USC), 257 th American Chemical Society National Meeting, Orlando, FL, March 2019	
International Conference on Energy Conversion & Storage (ORCAS), with Vincent Holmberg (UW MSE), Friday Harbor, WA, September 2018	
Soluble Inorganic Semiconductors: Synthesis, Properties & Applications symposium with Richard Brutchey (USC), 249 th American Chemical Society National Meeting, Denver, CO, March 2015	
Chemistry & Policy: Solving Problems at the Interface symposium (via MIT Graduate Student Symposium Planning Committee), 240 th ACS National Meeting, Boston, MA, August 2010	
Metals in Synthesis seminar series co-coordinator, Massachusetts Institute of Technology (2008–2010)	

Funding Agency Review Panels and Ad-Hoc Reviewing

European Research Council Starting, Consolidator, Advanced, and Synergy Grants	2020
National Science Foundation CAT CAREER Heterogeneous (PO Kenneth Moloy)	2020
National Science Foundation MSN CAREER Nanochemistry (PO Suk-Wah Tam-Chang)	2019
Department of Energy BES CS (PO Viviane Schwartz and Chris Bradley)	2019, 2020
National Science Foundation DMR SSMC (PO Catherine Oertel)	2019
National Science Foundation MSN Nanochemistry (PO Suk-Wah Tam-Chang)	2019
Serrapilheira Foundation (Brazil), Phase 2 and 3 Reviews (PO Bradley Olsen, MIT)	2019, 2020
National Science Foundation CHE Chemical Synthesis (PO John Gilje)	2019
National Science Foundation GRFP	2015
National Science Foundation/EPA NSMDS Catalysis (PO Carol Bessel)	2013
ACS Petroleum Research Fund ND and DNI (PO Nancy Jensen)	2013–Present

Journal Reviews

Chemistry of Materials	Nature Materials
Journal of the American Chemical Society	Nature Chemistry
Science	ACS Nano

Nano Letters	ACS Omega
ACS Applied Materials and Interfaces	Nanoscale
Journal of Physical Chemistry Letters	Small
Journal of Physical Chemistry C	Angewandte Chemie International Edition
Chemical Science	PNAS
Chemical Reviews	ACS Catalysis
Inorganic Chemistry	Molecules
Organometallics	

Professional Memberships

American Association for the Advancement of Science	2016–present
Phi Lambda Upsilon	2014–present
Materials Research Society	2013–present
American Chemical Society	2006–present
Society for Information Display	2016–2018

University Service

UW Faculty Council on Research	2019–present
Clean Energy Institute Faculty Advisory Board	2017–present
CEI WRF Innovation Fellows Review Committee	2017
Center for Advanced Materials and Clean Energy Technology Design Group	2016
Reviewer for Mary Gates Scholar Fellowship	2015, 2017

Department Service

Chair, Chemistry Diversity Committee	2018–Present
Chemistry Diversity Committee	2015–Present
Faculty Counselor, Phi Lambda Upsilon Honor Society (UW Epsilon Chapter)	2014–Present
Faculty Counselor, <u>Inclusion in Chemical Sciences (InCS-UW)</u> student group	2013–Present
Faculty Search Committee	2016–2017; 2018–2019; 2020–2021
Chemistry Awards Committee	2019–2020
Chemistry Graduation Ceremony	2016, 2018, 2019
Chemistry Inorganic Seminar Coordinator	2014–2015, 2017–2018
Chemistry Undergraduate Graduation Speaker Audition Panel	2014, 2016–2019
Chemistry Awards Dinner Speaker	2013, 2016
Chemistry Graduate Admissions Committee	2012–2019
Chemistry Graduate Recruiting Committee	2012–2018

UW Graduate Student Exam Committees

Ph.D. Defense Committees (32)	2012–present
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2012: Tristan Tronic; **2013:** Elizabeth Strein; **2014:** Alina Schimpf, Hirokazu Nagaoka; **2015:** Kelli Ogawa, Carolyn Valdez, Miles Braten; **2016:** Sophia Tran, Julian Rees, Erica Chong, Gerard Carroll, Patrick Whitham, Tyler Stevens, Adam Colbert, Wilson Bailey; **2017:** Jonathan Goldberg, Charles Barrows, Benjamin Leipzig, Sarah Vorpahl, Spencer Williams; **2018:** Heidi Nelson, Kimberly Hartstein, Travis Lekich, Zachary Fox; **2019:** Ryan Kastilani, Maike Blakeley, Jeffrey Buenaflor; **2020:** Michael De Siena, Jose Araujo, Emily Rabe, Timothy Pollock, Maksym Dedushko, Penny Poon

Doctoral Supervisory (Candidacy) Exam Committees (52)	2012–present
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2013: Elizabeth Strein, Carolyn Valdez, Gerard Carroll; **2014:** Miles Braten, Hirokazu Nagaoka, Tyler Stevens, Wilson Bailey, Benjamin Leipzig, Adam Colbert, Erica Chong, Alina Schimpf, Charles Barrows, Jonathan Goldberg; **2015:** Patrick Whitham, Zachary Fox, Kelli Ogawa, Dane De Quillettes, Marie Clement, Heidi Nelson, Sarah Vorpahl, Sophia Tran; **2016:** Kimberly Hartstein, Karena Smoll, Laura Murphy, Travis Lekich, Trevor Martin, Julian Rees, Benjamin Leipzig, Spencer Williams, Olivia Lenz; **2017:** Maksym Dedushko,

Maike Blakely, Braden Zahora, Michael De Siena, Kira Hughes; **2018:** Jose Araujo, Emily Rabe, Jeffrey Buenaflor, Tyler Milstein; **2019:** Ryan Beck, Alexandra Downing, **2020:** Anna Merkulova, Abbie Ganas, Jason Sandwisch, Alex Bard, Joo Yeon (Diana) Roh, Kyle Kluherz, Jessica Kong, Jonathan Kephart, Dylan Rogers, **2021:** Alexis Mills

Chemistry Second-Year Exam Committees (38) 2012–present

2013: Bennett Smith, Charles Barrows, Hirokazu Nagaoka, Marie Clement; **2014:** Michael Pegis, Sarah Vorpahl, Jonathan Goldberg, Kimberly Hartstein; **2015:** Laura Murphy, Karena Smoll, Timothy Pollock, Michael De Siena; **2016:** Christian Erickson, Soon Cheong Kwan, Jarred Olson, Cameron Shishido, Braden Zahora, Abbie Ganas; **2017:** Erin Jedlicka, Alexander Phearman, Chaau Yan (Penny) Poon, Byongjoo Bark, Jeffrey Buenaflor, **2018:** Alexandra Downing, Tyler Milstein, Dylan Rogers, Tianyi Zheng, **2019:** Maria Greiner, Jonathan Kephart, Yukako Sakasaki, Julian Smith-Jones, **2020:** Kendahl Walz, Kelly Walsh, Bennet Karel, Paige Gannon, **2021:** Casey Bisted, Jack Geary, Leo Porter-Zasada

University Graduate School Representative (for students outside of Chemistry) (8) 2015–present

2015: Olivia Lenz (MSE), Trevor Martin (MSE); **2016:** Julieta Gruszko (Physics); **2018:** Joshua Sanchez (Physics), Ryan Kastilani (MSE); **2019:** Guomin Zhou (MSE), Sarah Alamdari (ChemE); **2020:** Yao Long (ECE); **2021:** Yao Long (ECE); Shua Sanchez (Physics); Soohyung Lee (ChemE)

TEACHING

Primary Teaching Assignments by Quarter (Adjusted Median Scores on a 5.0 point scale)

CHEM 165: Honors General Chemistry (Undergraduate)

	SP16	SP17	SP18	SP19
# student respondents	35/36	47/47	46/49	31/41
Course as a whole was:	5.0	4.9	5.0	4.7
Course content was:	5.0	4.8	5.0	4.7
Instructor's contribution to course:	5.2	5.0	4.9	5.0
Instructor's effectiveness at teaching:	5.0	4.9	5.1	4.6
Combined items above:	5.0	4.9	5.0	4.8

CHEM 312: Inorganic Chemistry (Undergraduate)

**Virtual Format*

	WI21*
# student respondents	51/99
Course as a whole was:	4.2
Course content was:	4.3
Instructor's contribution to course:	4.6
Instructor's effectiveness at teaching:	4.6
Combined items above:	4.4

CHEM 416: Transition Metals (Undergraduate)

CHEM 516: Transition Metals (Graduate)

**Virtual Format*

	AU12	AU13	AU14	AU19	AU20*
# student respondents	37/42	45/58	49/59	16/27	36/47
Course as a whole was:	4.6	4.4	4.8	4.6	4.7
Course content was:	4.6	4.4	4.7	4.6	4.6
Instructor's contribution to course:	4.9	4.8	4.8	4.8	4.5
Instructor's effectiveness at teaching:	4.6	4.6	4.8	4.7	4.8
Combined items above:	4.7	4.6	4.8	4.7	4.7

CHEM 466 / MSE 466 / ChemE 440: Energy Materials, Devices, and Systems (Undergraduate)
CHEM 566 / MSE 566 / ChemE 540: Energy Materials, Devices, and Systems (Graduate)

	AU17	AU18
# student respondents	10/14	8/15 & 10/15
Course as a whole was:	4.3	4.8 / 4.1
Course content was:	4.4	4.8 / 4.8
Instructor's contribution to course:	3.8	4.7 / 4.6
Instructor's effectiveness at teaching:	3.8	4.7 / 4.6
Combined items above:	4.1	4.8 / 4.6

CHEM 484: Materials Chemistry (Undergraduate)

CHEM 510: Current Problems in Inorganic Chemistry–Materials Chemistry (Graduate)

	SP13	SP14
# student respondents	25/30	44/63
Course as a whole was:	4.8	4.6
Course content was:	4.8	4.5
Instructor's contribution to course:	4.9	4.6
Instructor's effectiveness at teaching:	4.8	4.5
Combined items above:	4.9	4.6

CHEM 485: Electronic Structure and Application of Materials (Undergraduate)

CHEM 585: Electronic Structure and Application of Materials (Graduate)

	WI15	WI16	WI17
# student respondents	25/25	27/31	17/19
Course as a whole was:	4.9	4.5	4.9
Course content was:	4.8	4.6	4.9
Instructor's contribution to course:	4.9	4.8	5.0
Instructor's effectiveness at teaching:	4.9	4.2	4.9
Combined items above:	4.9	4.5	4.9

Additional University of Washington Teaching Activities

CHEM 416: Transition Metals (Undergraduate): co-taught course in Autumn 2015

CHEM 591: Seminar in Inorganic Chemistry (Graduate): Winter 2013, Winter 2014, Spring 2015

CHEM 500: Grant Proposal and Scientific Writing: Autumn 2016, Autumn 2017

Other Teaching Experience

Teaching Assistant, Massachusetts Institute of Technology 2006–2010

Principles of Chemical Science, Principles of Inorganic Chemistry II, Principles of Inorganic Chemistry III

Teaching College-level Science (5.95J; graduate course), Massachusetts Institute of Technology 2009

RESEARCH MENTORING

Current Graduate Students

Helen Larson	February 2021–Present
Emily Nishiwaki	February 2021–Present
Hao Nguyen	February 2021–Present
Ricardo Rivera-Maldonado	December 2019–Present
Micaela Homer	December 2019–Present
Florence Dou	December 2018–Present

Forrest Eagle	December 2018–Present
Madison Monahan (w/ DeYoreo)	December 2017–Present
Nayon Park	December 2017–Present
Mary Cecilia Johnson	December 2016–Present

Current Postdoctoral Researchers

Dr. Ding-Yuan Kuo	November 2019–Present
Dr. Max R. Friedfeld	August 2016–Present

Current Undergraduate Students

Austin Engstrom	July 2021–Present
Melanie Cash	October 2020–Present
Aditi Kumar	September 2019–Present
Shenwei Wu	September 2018–Present

Graduated Ph.D. Students

Ian Murphy	September 2018–August 2021
Dissertation: <i>Surface Functionalization of Electrode Materials with Aryl-Diazonium Salts: Influence on Electronic Structure and Electrochemical Reactivity</i>	
Andrew Ritchhart	December 2015–August 2020
Dissertation: <i>Quantitative Analysis and Modification of Colloidal Nanoparticle Surfaces and Structures</i>	
David Ung	December 2014–March 2020
Dissertation: <i>Designing the Interface of Transition Metal Phosphides for Electrocatalysis</i>	
M. Elizabeth Mundy	December 2014–March 2020
Dissertation: <i>Aminophosphines as Precursors for Doped and Phase Pure Metal Phosphide Nanocrystals: Synthesis Beyond P(SiMe₃)₃</i>	
Kira Hughes	September 2018–August 2019 (Ph.D., August 2019)
Dissertation: <i>Exploring the Photophysics of Engineered and Intrinsic Charge-Carrier Trapping Processes in Semiconductor Nanocrystals</i> (joint w/ Daniel Gamelin)	
Michael Enright	July 2014–June 2019 (Ph.D., June 2019)
Dissertation: <i>Synthesis of Colloidal Semiconductor Heterostructures</i>	
Jennifer Stein	July 2013–August 2018 (Ph.D., August 2018)
Dissertation: <i>Scratching the Surface of Colloidal InP Nanoparticles: Tuning the Physical and Electronic Structure through Surface Chemistry</i>	
Danielle A. Henckel	July 2012–March 2018 (Ph.D., March 2018)
Dissertation: <i>Photo and Electrochemical Investigations of Solution Processable Molecules and Materials for the Hydrogen Evolution Reaction</i>	
Sarah E. Flowers	December 2012–December 2017 (Ph.D., December 2017)
Dissertation: <i>Preparation, Characterization, and Reactivity of Ruthenium Protic N-Heterocyclic Carbene Complexes</i>	
Benjamin A. Glassy	July 2012–July 2017 (Ph.D., August 2017)
Dissertation: <i>The Role of Precursor Chemistry in the Nucleation and Growth of Zinc Pnictide Based Semiconductor Quantum Dots</i>	
Dylan C. Gary	July 2012–August 2016 (Ph.D., August 2016)
Dissertation: <i>Investigation of the Nucleation and Growth of Colloidal Indium Phosphide: From Molecular Precursors to Semiconductor Nanocrystals through In₃₇P₂₀(O₂CR)₅₁ as a Magic-Sized Intermediate</i>	

Graduated M.S. Students

Tyler Robison December 2017–December 2018
A. Coleman Schwartz December 2013–December 2015

Former Postdoctoral Researchers

Dr. David Ung March 2020–January 2021
Dr. Daniel Kroupa October 2017–September 2018
Dr. Michael R. Norris August 2013–July 2016 Assistant Professor, University of Richmond

Former Undergraduate Students

Victoria Lasch October 2019–March 2020
Talia LoCurto October 2019–March 2020
Dane Johnson June 2017–June 2020
Ingrid Zimmerman January 2019–June 2020
Tigre Falla June–August 2019 (Grays Harbor Community College)
Nicholas Henry June–August 2019 (STAR Teacher in Training)
Nathan Lai January 2017–December 2018
Noushyar Panahpour Eslami July 2016–September 2018
Eric Riesel Summer 2018 (REU, Columbia University)
Kito Gilbert-Bass Summer 2018 (REU, Ithaca College)
Harrison Sarsito June 2016–June 2018
Justin Brown September 2016–June 2017
Ashley Mathews January 2016–June 2017
Dante Magdici November 2015–December 2016
Molly Steimle June 2016–August 2016 (REU, Oberlin College)
Yuting Lin June 2013–June 2016
Douglas Waterman October 2014–July 2015
Tianna Ibea October 2014–July 2015
Emily Reeves February 2014 (REU, St. Olaf College)
Connor McCue January–July 2013

Former College Teachers

Anthony Molinero June–August 2019 (Grays Harbor Community College)

Former High School Students

B. Zephyr Pitre August 2017–August 2018
Mukil Shanmugam Summer 2017
Chloe Pope Spring 2013
Caitlyn Richter November 2012–May 2013

Group Honors & Awards

Florence Dou 2020-21 Clean Energy Institute DIRECT Fellowship
Michael Enright 2019 Renewable Energy Scholarship Foundation Graduate Winner and co-Sir Fraser Stoddart Scholar
2017 Clean Energy Institute Travel Grant
2017 Lloyd E. and Florence M. West Fellowship in Chemistry
2016-17 Nicole A. Boand–ARCS Foundation Endowed Fellowship in Chemistry
2015-16 Clean Energy Institute Graduate Fellowship

	2015 Honorable Mention, NSF Graduate Research Fellowship
	2015 Pacific Northwest National Laboratory Graduate Fellowship
	2014-15 Paul H. & Karen S. Gudiksen Endowed Fellowship in Chemistry
Noushyar Eslami	2017-18 Mary Gates Research Scholarship
Sarah E. Flowers	2012 George & Agnes Irene Cady Endowed Fellowship in Chemistry
Max R. Friedfeld	2018 Mistletoe Foundation Unfettered Research Grant
	2018 Washington Research Foundation Postdoctoral Fellowship
	2017 Clean Energy Institute Travel Grant
Dylan C. Gary	2015-16 Basil G. & Gretchen F. Anex Endowed Fellowship in Chemistry
	2015 Best Graduate Student Oral Presentation, International Conference on Fundamental Processes in Semiconductor Nanocrystals
	2015 Graduate School Fund for Excellence & Innovation Travel Grant
Benjamin A. Glassy	2014-15 Clean Energy Institute Graduate Fellowship
	2014-15 George & Agnes Irene Cady Endowed Fellowship in Chemistry
Danielle A. Henckel	2015-16 Clean Energy Institute Graduate Fellowship
	2014 Honorable Mention, NSF Graduate Research Fellowship
Micaela Homer	2021 Clean Energy Institute Graduate Fellowship
M. Cecilia Johnson	2018-19 Torrance Foundation Tech Due Diligence Program
	2018-19 Clean Energy Institute Graduate Fellowship
	2018 Clean Energy Institute Travel Grant
Dane Johnson	2019-20 Levinson Emerging Scholar Award
	2017-18 Mary Gates Research Scholarship
	2017 Ed. F. and Clara M. Degering Tuition Scholarship
Daniel Kroupa	2018 Forbes' 30 Under 30: Energy
	2018 Mistletoe Foundation Unfettered Research Grant
Nathan Lai	2018 ACS DIC Undergraduate Research Award
Yuting Lin	2013 CENTC Summer Undergraduate Research Fellowship
Ricardo Maldonado	2021 Clean Energy Institute Graduate Research Fellowship
Ashley Mathews	2017 Usha & S. Rao Varanasi Endowed Diversity Scholarship in Chemistry
Marja E. Mundy	2018-19 Clean Energy Institute Graduate Fellowship
	2018 Clean Energy Institute Travel Grant
	2017-18 Alma Mater Travel Award
	2017 Pacific Science Center Science Communication Fellowship
	2014 Clean Energy Institute Distinguished Energy Fellowship
	2014-19 NSF Graduate Research Fellowship
Ian A. Murphy	2018-19 Clean Energy Institute Graduate Fellowship
Nayon Park	2019-20 Clean Energy Institute Graduate Fellowship
Andrew Ritchhart	2019-20 Alma Mater Travel Award
	2018-19 Graduate Student Merit Fellowship
Harrison Sarsito	2017-18 Mary Gates Research Scholarship
A. Coleman Schwartz	2014-15 Clean Energy Institute Graduate Fellowship
Jennifer L. Stein	2016-17 Joseph Bouknight Endowed Fellowship in Chemistry
	2015 Graduate School Fund for Excellence & Innovation Travel Grant
	2014-15 Clean Energy Institute Graduate Fellowship
	2013 Advanced Materials for Energy Distinguished Energy Fellowship
	2013 George Hitchings Endowed Fellowship in Chemistry
David Ung	2018 Torrance Foundation Tech Due Diligence Program
	2018 Clean Energy Institute Travel Grant
	2017-18 Clean Energy Institute Graduate Fellowship

Shenwei Wu 2017 Clean Energy Institute Travel Grant
2019 Mary Gates Research Scholarship

OUTREACH ACTIVITIES

December 2019 Group Outreach at Orca K-8: Crystal Growth
November 2019 Highland Terrace Elementary Science Night
CEI Meet a Scientist
July 2019 **Math Science Upward Bound (MSUB) STEM Outreach Seminar**
DO-IT Summer Study Workshop (Communicating with Faculty)
ALVA Distinguished Speaker Seminar
May 2019 **Materials Science Explorers, Sanislo Elementary School**
April 2019 “Nanoscale and the Art of Solubility”, Sammamish Library Science Saturday
Pacific Science Center, Meet a Scientist
UW Engineering Discovery Days
WiSE Pre-Collegiate Summit (Demo table, Lab tours ,and Demonstrations)
March 2019 Climate Change Discovery Days
Skype a Scientist
December 2018 Highland Terrace Elementary Science Night
September 2018 **MEM-C/Orcas Science Communication workshop**
July 2018 **GenOM ALVA Summer Luncheon Seminar**
March 2018 Shoreline STEM Festival
January 2018 **Colloquium on Engaging American Indian and Alaska Native Undergraduates in Research**
November 2017 Engineer It!
Highland Terrace Elementary Science Night
October 2017 Pacific Science Center Nano Day
Summer 2017 **Siemens Competition in Math, Science, and Technology Research Project Mentor to Mukil Shanmugam (Redmond High School)**
April 2017 University of Washington Engineering Discovery Days
April 2017 Center for Enabling New Technology Through Catalysis outreach on Biodiesel and Alternative Energy Sources at Roosevelt High School
February 2017 Engineer It!
November 2016 University of Washington Introduce a Girl to Photonics Fair
October 2016 **University of Washington Strengthening STEM through Diversity**
October 2016 Museum of Flight Lashes ‘n Lab Coats
April 2016 University of Washington Engineering Discovery Days
April 2016 Center for Enabling New Technology Through Catalysis Outreach on Biodiesel and Alternative Energy Sources at Roosevelt High School
April 2016 University of Washington Paws on Science
March 2016 Seattle Expanding Your Horizons
February 2016 STEM Expo Science Fair
January 2016 Hazel Wolf K-8 Career Day
October 2015 University of Washington-Bothell Inspire STEM Festival
September 2015 Seattle Mini-Maker Fair
June 2015 Clean Energy Institute Everett STEM Expo
April 2015 Center for Enabling New Technology Through Catalysis Outreach on Biodiesel and Alternative Energy Sources at Roosevelt High School
April 2015 University of Washington Paws on Science

March 2015 Technology Access Foundation Academy STEM Out! Solar Demo Day
February 2015 **University Prep High School Solar and Renewable Energy Project**
November 2014 Pacific Science Center Life Sciences Research Weekend
May 2014 Center for Enabling New Technology Through Catalysis Outreach on
Biodiesel and Alternative Energy Sources at Cleveland High School
May 2014 **Lakeside High School Demo Day, Making Quantum Dots**
2013–Present **Created the Synthetic Inorganic Chemistry Facebook group** to introduce
interested members of the public and the broader scientific community to
important tools, techniques, recent literature, and other aspects of the field of
synthetic inorganic chemistry (800+ followers)