UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

BOE TECHNOLOGY GROUP CO., LTD.,
Petitioner,

v.

138 EAST LCD ADVANCEMENTS LIMITED,
Patent Owner.

Case No. IPR2024-00976
U.S. Patent No. 7,502,079

DECLARATION OF E. FRED SCHUBERT, PH.D.

I, E. Fred Schubert, of Troy, New York, declare that:

I. ASSIGNMENT

1. I have been retained by Robins Kaplan LLP on behalf of 138 East LCD Advancements Ltd. ("138 East") as an expert with regard to this matter. I understand that Petitioner BOE Technology Group Co., Ltd. ("BOE" or "Petitioner") is requesting that the Patent Trial and Appeal Board ("Board") institute *inter partes* review (IPR) of U.S. Pat. No. 7,502,079 ("the '079 patent") (Ex. 1001).

2. In my capacity as an expert, I have been asked to provide my independent analysis and opinions regarding the '079 patent, the prosecution history of the '079 patent and related applications as applicable, the alleged prior art relied upon by Petitioner, the meaning of various claim terms from the '079 patent from the perspective of a person of ordinary skill in the art ("POSITA"), and the opinions offered by Petitioner's expert, Mr. Richard Flasck, in his declaration ("Flasck Declaration") (Ex. 1002). My opinions and conclusions are fully discussed in later sections of this declaration.

3. I am an independent consultant, and I am not, and have never been, an employee of 138 East or BOE. I received no compensation for this declaration beyond my normal hourly compensation ($600) based on my time spent analyzing

the ’079 patent, the prosecution history of the ’079 patent and related applications, the prior art publications relied upon by Petitioner, the Flasck Declaration, and other related materials. I will not receive any added compensation based on the outcome of any IPR or other proceedings involving the ’097 patent.

4. This declaration and my opinions are in support of Patent Owner’s Preliminary Response, and I understand that the content of this declaration may be expressed and reproduced in the POPR.

II. BACKGROUND AND QUALIFICATIONS

5. I am currently an active, tenured, full professor in the Department for Electrical, Computer, and Systems Engineering at the Rensselaer Polytechnic Institute (RPI) located in Troy, New York.

6. I also held other positions at RPI. For example, from 2002 to 2012, I was a professor in the Department of Physics, Applied Physics, and Astronomy. In 2008-2009, I served as the founding director for RPI’s Engineering Research Center for Smart Lighting, which was funded by the U.S. National Science Foundation (NSF).

7. Before I moved to RPI, I was a professor in the Department of Electrical and Computer Engineering at Boston University, from 1995 to 2002. I also served as the director of Boston University’s Semiconductor Devices Research Laboratory.

8. Prior to my university career, I was a post-doctoral member of the technical staff, member of the technical staff, principal investigator, and member of management at AT&T Bell Laboratories in Holmdel and Murray Hill, New Jersey, from 1985 to 1995.

9. I earned my Ph.D. in 1986, Master of Science in 1981, and Bachelor's degree in 1978, all in Electrical Engineering, at the University of Stuttgart, Germany.

10. My Curriculum Vitae ("CV") is attached as **Appendix A**. As shown by my CV, I have substantial experience in the design and implementation of flat panel display devices, including the design, fabrication, processing, and packaging of the components that are commonly used in liquid crystal displays (LCDs) and light emitting diode (LED) displays.

11. I have published over 300 technical articles, mostly at competitive technical conferences and rigorously refereed technical journals. These articles relate to Liquid Crystal Displays (LCDs), LEDs, semiconductor electronics (e.g., field-effect transistors and bipolar junction transistors), semiconductor lasers, and photo-detectors, that is, the technologies which form the foundations of flat panel displays.

12. As an example of my research activities in the field of LCDs, I refer to a U.S. patent issued in 2012: Jaehee Cho, E. Fred Schubert, and Xing Yan

"Liquid crystal display with refractive index matched electrodes" US Patent No. 8,164,727; filed on April 28, 2010; issued on April 24, 2012. During my tenure in industry (AT&T Bell Laboratories), I was part of a working group on LCDs. I have also performed technical consulting services in the field of LCDs and associated TFTs (thin film transistors). One project concerned the enhancement of the carrier mobility in amorphous silicon TFTs. At my university (RPI), I regularly teach courses on microelectronic devices and displays, including TFTs and LCDs. Light emitting diodes are routinely used as a back lighting source for LCDs and I have worked on and developed LEDs for backlighting units.

13. I am also the author or editor of several books. For example, I authored the textbook "Light-Emitting Diodes," (1st, 2nd, 3rd, and 4th editions) initially published by Cambridge University Press, Cambridge, UK, with the later editions published on Google Books. In the LED book, I provide a comprehensive review of the state-of-art technologies for designing, fabricating, processing, and manufacturing LEDs, all of which are relevant to LCDs, specifically the associated back-lighting units.

14. In addition to my research, I have been teaching for more than 25 years. I have taught numerous undergraduate and advanced graduate courses in integrated optoelectronics, microelectronics technology, solid-state devices, semiconductor devices, display devices, and light-emitting diodes, all pertinent to

the subject matter in the present case. I have also advised close to 50 Ph.D. and M.S. students while at the RPI and Boston University, in areas such as LEDs, semiconductor electronics, semiconductor lasers, and solar cells.

15. I am the co-inventor of more than 35 issued U.S. patents and associated foreign patents. I was identified as one of the top 1% inventors in the field of optoelectronics, in a 2011 study conducted by Professor Erica Fuchs of Carnegie Mellon University under the support of NSF. Examples of my issued U.S. patents include:

- U.S. Patent No. 7,560,746; issued on July 14, 2009, titled "Light emitting diodes and display apparatuses using the same."
- U.S. Patent No. 8,164,727, issued on April 24, 2012, titled "Liquid crystal display with refractive index matched electrodes."

16. I have been actively involved in multiple technical societies, including the American Physical Society (APS), Institute of Electrical and Electronics Engineers (IEEE), Optical Society of America (OSA), Society for Optical Engineering (SPIE). I have served in the organizing committee of multiple technical conferences, including, for example:

- Program committee member and chair of "Display and Solid-State Lighting Devices" conference for OSA/IEEE Conference on Lasers and Electro-Optics (CLEO), 2003 – 2005.

- Member of the International Advisory Committee of First International Conference on Display LEDs (ICDL), Seoul, Korea, January 31 – February 2, 2007.
- Sub-Committee Chair of Track 6: Displays, Solid-State Lighting, Photovoltaics, and Energy-Efficient Photonics of Asia Communications and Photonics Conference (ACP), Shanghai, China, November 11 – 14, 2014. ACP is the largest and the most influential conference in Asia and Pacific Rim for communications and photonics technologies.

17. My research has been recognized by multiple organizations, universities, and institutions. The following list includes examples of honors that I have received:

- Elected Fellow of the IEEE in 1999. According to the IEEE definition, "the grade of Fellow is one of unusual professional distinction conferred by the Board of Directors only upon a person of extraordinary qualifications and experience."
- Elected Fellow of the SPIE in 1999. According to the Society's bylaws, a Fellow "shall be distinguished through his achievements and shall have made outstanding contributions in the field of optics, or optoelectronics, or in a related scientific, technical, or engineering field."
- Elected Fellow of the OSA in 2001. OSA Fellows are elected by the OSA

Board of Directors.

- Elected Fellow of the APS in 2001.
- Honored with RPI Medal as Senior Constellation Chair in 2002.
- Recipient of "Scientific American 50 Award" of 2007, as published in the January 2008 issue of Scientific American.
- Received "Rensselaer Polytechnic Institute Trustee Faculty Achievement Award" in 2002, 2008, and 2012.

18. My qualifications and accomplishments are further detailed in my CV, submitted as Appendix A.

III. LEVEL OF SKILL IN THE ART AND BASIS FOR OPINIONS

19. Mr. Flasck contends that a POSITA in the field of the '079 patent would have "at least a four-year undergraduate degree in electrical engineering, computer science, physics, or a similar field and at least two years of experience designing semiconductor display devices, including LCD displays. Additional education could substitute for professional experience and vice versa. For example, a master's degree in electrical engineering, computer science, physics, or a similar field can be a substitute for two years of experience designing semiconductor display devices." I understand that Petitioner has adopted that definition of a POSITA. Ex. 1002, ¶97; Petition at 26.

20. For purposes of this Declaration, I do not dispute the level of skill for

a POSITA as set forth by Mr. Flasck and adopted by Petitioner. I note, however, that a bachelor's degree recipient (in electrical engineering, computer science, physics, or a similar field) with two years of working experience in semiconductor display devices, or master's degree recipient (in electrical engineering, computer science, physics, or a similar field) with no experience in the field of semiconductor display devices, has, in my opinion, a relatively low level of skills in the relevant field.

21. Based on my experience and record of accomplishments, I am qualified to render opinions regarding the technology claimed and described in the '079 patent. Based on my expertise and qualifications, I am qualified to provide an opinion as to what a POSITA would have understood, known, or concluded as of approximately 2002.

22. In reaching my opinions and conclusions, I have relied upon my education, my work experience in the relevant field, and my training, and considered and relied upon my review and analysis of the Petition and all Exhibits.

IV. RELEVANT LEGAL PRINCIPLES

23. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to my analysis and opinions. I have applied these legal principles in rendering my opinions below.

A. Claim Construction

24. I understand that the ordinary and customary meaning of a claim term is the meaning that the term would have to a POSITA at the time of the invention.

25. In the absence of an express intent on the part of the inventor to give a special meaning to the claim terms, the words are presumed to take on the ordinary and customary meanings attributed to them by a POSITA.

26. I understand that it is the use of the words in the context of the written description, and as customarily used by those skilled in the relevant art, that accurately reflects both the ordinary and the customary meaning of the terms in the claims.

27. I understand that the basis for a term's ordinary and customary meaning may be derived from a variety of sources, including the words of the claims themselves, the remainder of the specification, the prosecution history, and extrinsic evidence concerning relevant scientific principles, the meaning of technical terms, and the state of the art at the time of the invention.

28. I have been instructed that dictionary definitions or definitions from technical references can be used to inform or confirm the ordinary and customary meaning of words found in a claim, but that in construing claim terms, the general meanings gleaned from reference sources, such as dictionaries, must always be compared against the use of the terms in the context of the claim itself.

29. I understand that a patent applicant is entitled to be his or her own lexicographer (in other words, provide his or her own meaning to a word or phrase) and may rebut the presumption that claim terms are to be given their plain and ordinary meaning. To do so, the applicant must clearly set forth a definition of the term that is different from its ordinary and customary meaning. Where the applicant provides an explicit definition for a term, that definition will control interpretation of the term as it is used in the claim in which it appears. I understand that the specification can also be relied on for more than just explicit lexicography to determine the meaning of a claim term. For example, I understand that the meaning of a particular claim term may also be determined by implication, that is, according to the usage of the term in the context of the specification.

B. Obviousness

30. I understand that under U.S. patent law, 35 U.S.C. § 103, a claim is invalid as obvious if the differences sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

31. I am informed that an obviousness analysis requires an assessment of the scope and content of the prior art, the differences between the art and the claims at issue, and the level of ordinary skill in the art. I am told that it is against

this backdrop that obviousness is assessed.

32. I am informed that a POSITA is a hypothetical person who is presumed to be aware of all the pertinent prior art. I am also informed that an obviousness analysis may take account of the inferences and creative steps that a POSITA would employ.

V. BACKGROUND OF THE '079 PATENT

A. '079 Patent Overview

33. The '079 patent, titled "Electro-optical device and electronic apparatus," describes arrangements of scan lines, data lines, and capacitive lines in a liquid crystal display device that result in improved optical performance. Broadly, the '079 patent recognizes a need for precision in driving the thin-film transistors (TFTs) connected to the pixel electrodes in the liquid crystal electro-optical device while simultaneously miniaturizing the electro-optical components for a compact design. Ex. 1001, 1:42-48.

34. TFTs comprise a semiconductor layer with a channel area; source and drain areas; a gate insulating film; and a gate electrode covering at least a part of the channel area. *Id.*, 1:49-52. Applying a voltage to the gate electrode causes an electric field in the gate insulating film, which induces free electrons in the TFT channel so as to enable current flow through the TFT. *Id.*, 1:52-55. The ON and OFF states of the TFTs are therefore controlled by the gate electrode: when a

voltage is applied to the gate electrode, the TFT is ON. Without a voltage applied to the gate electrode, the TFT is OFF. The TFT functions as an ON / OFF switch that connects a data line and associated data signal (image information) to a pixel electrode. The gate electrode, in turn, is part of or otherwise connected to the scan line. *Id.*, 1:61-64.

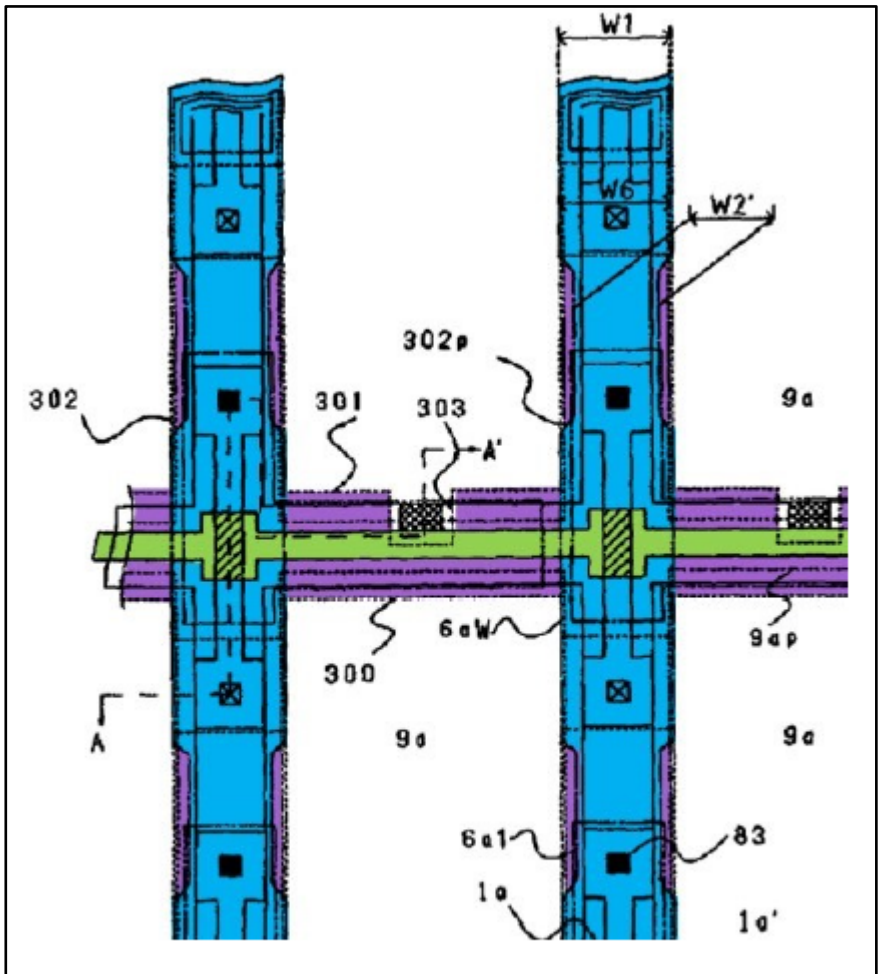
35. The ’079 patent teaches that both the length of the channel area in the TFT (the “channel length”) and the arrangement of the gate electrode on the channel area are important factors in determining the characteristics of the TFTs. *Id.*, 1:56-61. The ’079 patent describes the importance of arranging the TFT in relation to the scanning line so as to achieve precision in driving the TFTs. *Id.*, 1:66-2:4. But the ’079 patent also describes detrimental effects associated with light-induced leakage currents, which are generated by light entering the channel area. *Id.*, 2:10-12. The ’079 patent teaches that the TFTs should be placed as far as possible from light-transmitting areas of the LCD device such as pixel electrodes. *Id.*, 2:12-16. This restriction on TFT placement also restricts the scan line/TFT arrangement, which can compromise the precision with which the device can be operated. *Id.*, 2:17-20.

36. The ’079 patent solves these problems by providing scan lines that have broad-width portions where they face the channel area and act as the gate electrode, and that have narrow-width portions elsewhere. *Id.*, 2:42-45. Through

this arrangement, the channel areas of the TFTs can be placed far from the pixel corners to protect them from incident light. Yet the channel areas still have adequate length for precision control, while realizing device miniaturization through the narrow scan lines away from the channel areas. *Id.*, 2:50-3:5. Because the broad-width portion of the scan line extends with the channel area, the gate electrode is better formed to the channel, and the electric field can be more precisely applied in the channel area. *Id.*, 3:52-59.

37. The ’079 patent further discloses forming storage capacitors connected to the pixel electrodes by providing capacitive lines that extend along both the scan lines and the data lines. *Id.*, 7:56-67. According to the ’079 patent, the portion of the capacitive line extending along the data line should have a width equal to or broader than that of the data line. *Id.*, 7:63-67. The broader capacitive line not only has a low resistance, but its breadth compared to the data line shields stray light reflecting off the back side of the data line that can enter the TFT and contribute to the light-induced leakage current. *Id.*, 8:7-10, 8:29-39.

38. I have included below an annotated version of Figure 16 of the ’079 patent, which appears in the Petition. The figure illustrates the above-described features:



Ex. 1001, Fig. 16

Petition at 9.

39. Figure 16 depicts the channel areas (1a'), scan lines (3a), data lines (6a) and capacitive lines (300) discussed above. In the particular embodiment shown, the data lines are formed with broad-width portions 6aW that overlap the TFTs; the portions of the capacitive lines overlapping the TFTs are likewise broad, although not as broad as the data lines in those regions. Away from the TFTs, the data lines are formed with narrow-width portions, and the portions of the

capacitive lines in these areas are at least as broad as the data lines. This geometry provides shielding of stray light reflecting off the back side of the data line, as discussed above.

40. These novel aspects of the ’079 patent disclosure are reflected in independent claim 2, which recites as follows (adding the Petitioner’s enumerations in brackets, for ease of reference):

> 2[pre] An electro-optical device, comprising:
>
> 2[a] a thin-film transistor having a channel area that extends in a direction and that intersects a predetermined direction that intersects the direction;
>
> 2[b] a pixel electrode formed correspondingly to the thin-film transistor;
>
> 2[c] a data line extending in the direction in which the channel area extends, the data line having a broad portion that overlaps the thin-film transistor and a non-broad portion that does not overlap the thin-film transistor, the broad portion being wider than the non-broad portion;
>
> 2[d] a scanning line extending in the predetermined direction and intersecting the data line and the channel area of the thin-film transistor, the scanning line having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion;

> 2[e] a storage capacitor including a pixel-potential capacitor electrode, a fixed-potential capacitor electrode, and a dielectric film interposed between the pixel-potential capacitor electrode and the fixed potential capacitor electrode; and
>
> 2[f] a capacitive line having a portion that serves as the fixed-potential capacitor electrode of the storage capacitor, the capacitive line having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line.

Id., 26:24-53.

41. The ’079 patent also discloses contact holes 81 that connect the semiconductor layer 1a of the TFT to the data line 6a, as shown in Figure 16 above. *Id.*, 23:56-62. According to the ’079 patent, no capacitive line can be formed here because of the need to connect the data line and semiconductor layer. *Id.*, 23:59-62. The data line is therefore kept broad from the TFT to the formation position of the contact hole to maintain light shielding performance. *Id.*, 23:66-24:8. This further aspect is reflected in independent claim 1 of the ’079 patent, which recites as follows:

> 1[pre] An electro-optical device, comprising:

1[a] a thin-film transistor having a channel area that extends in a direction and that intersects a predetermined direction that intersects the direction;

1[b] a pixel electrode formed correspondingly to the thin-film transistor;

1[c] a data line extending in the direction in which the channel area extends, the data line having a broad-width portion that overlaps the channel area in plan view;

1[d] a scanning line extending in the predetermined direction and intersecting the data line and the channel area of the thin-film transistor, the scanning line having a broad-width portion in a portion overlapping the channel area of the thin-film transistor in plan view and a narrow width portion in another portion;

1[e] a storage capacitor including a pixel-potential capacitor electrode, a fixed-potential capacitor electrode, and a dielectric film interposed between the pixel-potential capacitor electrode and the fixed-potential capacitor electrode;

1[f] a capacitive line having a portion that serves as the fixed-potential capacitor electrode of the storage capacitor, the capacitive line having a portion extending along the scanning line and a portion extending along the

> data line, the portion extending along the data line having a width that is equal to or broader than a width of the data line; and
>
> 1[g] a contact hole electrically connecting the data line and the thin film transistor, the contact hole being positioned at a portion of the broad-width portion of the data line that extends beyond the channel area in a direction extending from the channel area toward the contact hole.

Id., 25:51-26:23.

42. Claim 3 depends from claim 2 and adds a contact hole limitation similar to that of claim 1:

> 3. The electro-optical device according to claim 2, further comprising a contact hole that electrically connects the thin-film transistor and the data line, the data line being continuously broad from the broad portion that overlaps the thin-film transistor a portion where the contact hole is located.

43. In my opinion, none of the asserted references or combinations disclose the claimed layouts that deliver the benefits of the ’079 inventions, for reasons that I discuss further below.

B. Related District Court Litigation

44. I am aware of a related District Court case involving the same parties, and where the ’079 patent has been asserted and validity of the ’079 patent claims has been challenged.

VI. ANALYSIS OF KURASHINA AND THE COMBINATION OF KURASHINA WITH SATO OR TAKAHARA (GROUNDS 1 AND 2)

A. Overview of Kurashina

45. JP-2002-090721A to Kurashina ("Kurashina") is primarily focused on shielding transistor elements from leakage-current-inducing light[1] emanating from the corner portions of pixels in liquid crystal projector displays. Ex. 1008 at 1, ¶[0016]. Kurashina recognizes that in "an extremely powerful light source such as a projector," even light reflecting off the substrate rear-surface side can enter the TFT channel and alter the switching characteristics of the device. *Id.*, ¶[0017]. To solve this problem, Kurashina teaches "a light-shielding film layered between the transistor and the pixel electrode" with "a wide width in the vicinity of the transistor" that "shield[s] a corner portion of the pixel electrode." *Id.*, ¶[0019].

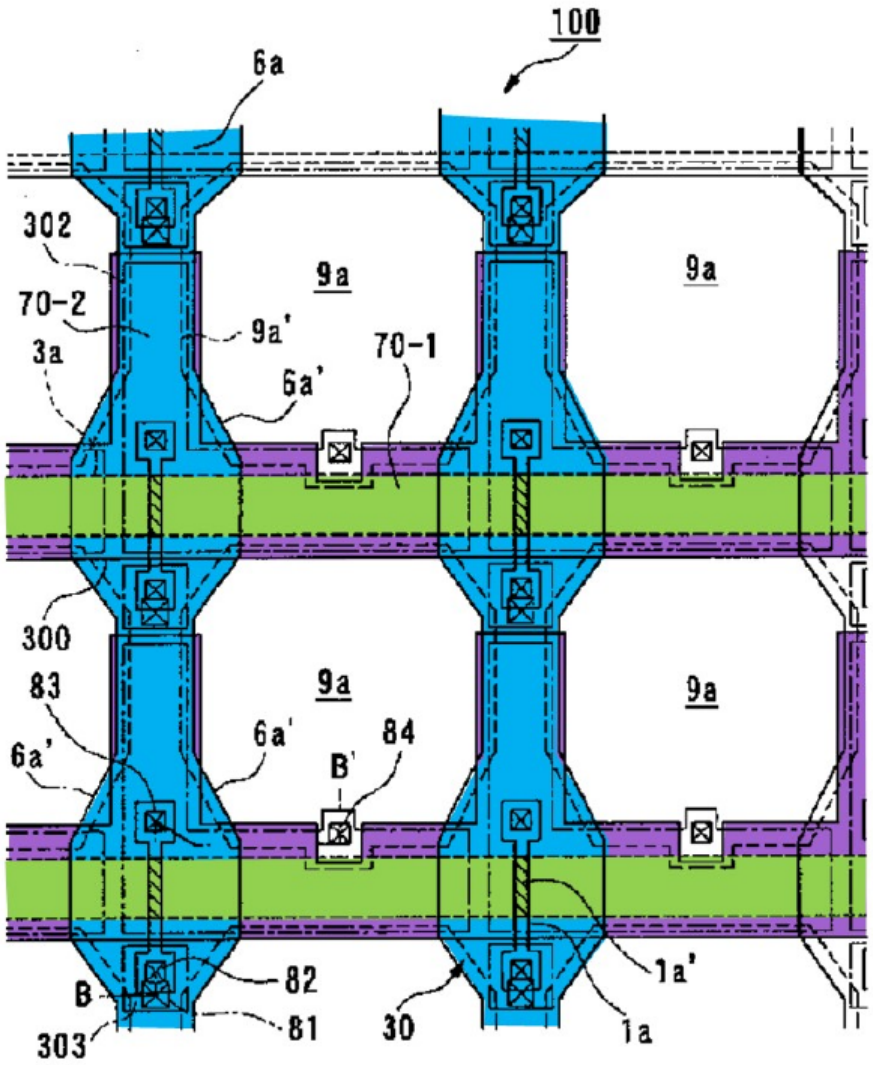
46. Kurashina recognizes performance tradeoffs in the disclosed configuration: for instance, Kurashina notes that shielding the corner portions of the pixel electrode narrows its aperture area, which results in less transmitted light. *Id.*, ¶[0020]. According to Kurashina, however, the tradeoff is the ability to block light from the pixel electrodes arriving at the TFT from oblique directions, as doing so maintains the switching characteristics of the TFT. *Id.*

47. Kurashina also teaches using capacitor lines or data lines as the light-

[1] Light reaching the TFT channel can result in a TFT leakage current when the TFT is in the OFF state.

shielding films for the corner portions of the pixels. *Id.*, ¶[0021]. Where the light-shielding capacitor lines overlap the scan lines, Kurashina notes, "it is possible to make the width of the capacitor lines take up the entire interval between pixels," and to thereby "increase storage capacitance." *Id.*, ¶[0024].

48. Figure 3 of Kurashina is exemplary of the main aspects that I described above; the annotated version of Figure 3 below is reproduced from the Petition and is the primary figure discussed therein:



Kurashina, Fig. 3

Petition at 8; *see also* Ex. 1008 at 14.

49. As shown in Figure 3, the capacitor lines 300 "overlap the scan lines 3a and are provided in the left-right direction in the paper plane along the boundaries of the pixel electrodes 9a." Ex. 1008, ¶ [0057]. The capacitor lines further form two sets of storage capacitors: a first set 70-1 formed by the overlap

between the L-shaped drain electrodes 302 and portions of the capacitor lines 300 overlapping the scan lines; and a second set 70-2 formed by the overlap between the drain electrodes 302 and the portions of the capacitor lines 300 overlapping the data lines. *Id.*, ¶ [0058]. According to Kurashina, in this way the "spaces apart from the aperture regions . . . are effectively used to increase the storage capacitance of the pixel electrodes 9a," and the increased storage capacitance is used "to stabilize the display screen." *Id.*, ¶ [0059].

B. The teachings of Kurashina do not satisfy all elements of any of claims 1-3 of the '079 patent.

50. Mr. Flasck contends that Kurashina alone teaches the limitation "a capacitive line having a portion that serves as the fixed potential capacitor electrode of the storage capacitor, the capacitive line having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line." Ex. 1002, ¶¶ 147-153. Mr. Flasck does not contend that a POSITA would need to combine Kurashina with any other reference or otherwise modify Kurashina to satisfy this claim limitation. *Id.*

51. In particular, Mr. Flasck contends Kurashina alone discloses the geometric feature "the portion [of the capacitor line] extending along the data line

having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line." Ex. 1002, ¶¶ 151-152. Mr. Flasck relies entirely on Figure 3 of Kurashina—which he annotates himself—for this disclosure. Ex. 1002, ¶ 151. Mr. Flasck acknowledges that Kurashina does not "provide specific dimensions for its components," but opines that Kurashina "clearly shows a POSITA that the capacitive line projection is wider than a non-broad portion of the data line."

52. I disagree with Mr. Flasck's opinions on this issue. Mr. Flasck appears to miss an important disclaimer in Kurashina regarding its figures. Kurashina states, "[n]ote that, in the various drawings of the embodiments, the various layers and members are scaled differently, not identically, so that the various layers and various members are large enough to be recognizable in the drawings." Ex. 1008, ¶ [0028]. Kurashina therefore makes very clear that its figures are not to scale, and that different layers may be drawn at different scales so as to be recognizable in the figures.

53. In view of this express disclaimer in Kurashina, which Mr. Flasck does not address, whether a portion of the capacitor line is drawn slightly wider than a portion of the data line as in Mr. Flasck's annotated figure—and particularly slightly wider than a portion of the data line that otherwise *blocks* the capacitor line in plan view—cannot be interpreted to convey any design information. Kurashina

is just as likely drawing the capacitor line and the data line at different scales so that the capacitor line is visible in plan view—that is, "so that the various layers and various members are large enough to be recognizable in the drawings," as Kurashina explains. Ex. 1008, ¶ [0028].

54. I therefore also disagree with Mr. Flasck's general conclusion that a POSITA would understand "illustrated relative widths to convey general design information," and further that Kurashina's figures "are intended to communicate different relative widths." Ex. 1002, ¶ 152. A POSITA reading Kurashina in view of its express statement that different layers are drawn at different scales would reach the opposite conclusion: that relative widths do *not* convey general design information, but rather are drawn so as to provide visibility through different layers in plan view.

55. In view of Kurashina's disclaimer, not addressed by Mr. Flasck, a POSITA would recognize that Kurashina does not teach the limitation "the portion [of the capacitor line] extending along the data line having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line."

56. Because Kurashina does not teach all elements of claim 2 of the '079 patent, it also does not teach all limitations of claim 3, which depends from claim 2.

57. Kurashina does not teach all elements of claim 1 either. In particular, Kurashina does not teach the limitation of claim 1 "a capacitive line . . . having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is equal to or broader than a width of the data line," for the same reasons I explained above with regard to claim 2.

58. Referring back to claim 2, Mr. Flasck contends that the portion of Kurashina's capacitor line that extends along the data line is broader than "the width of the data line," as claimed, because it is "broader than the non-broad portion of the data line." Ex. 1002, ¶ 65. As I previously stated with respect to claim 2, however, Kurashina's drawings cannot be relied on to show the relative widths of different layers because the different layers are not drawn to scale. Therefore, in view of Kurashina's disclaimer (which is not addressed by Mr. Flasck), a POSITA would recognize that Kurashina does not teach the limitation "a capacitive line . . . having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is equal to or broader than a width of the data line."

C. The teachings of Kurashina in view of Sato do not satisfy all elements of any of claims 1-3 of the '079 patent.

59. Mr. Flasck does not assert that Kurashina discloses the limitation "a

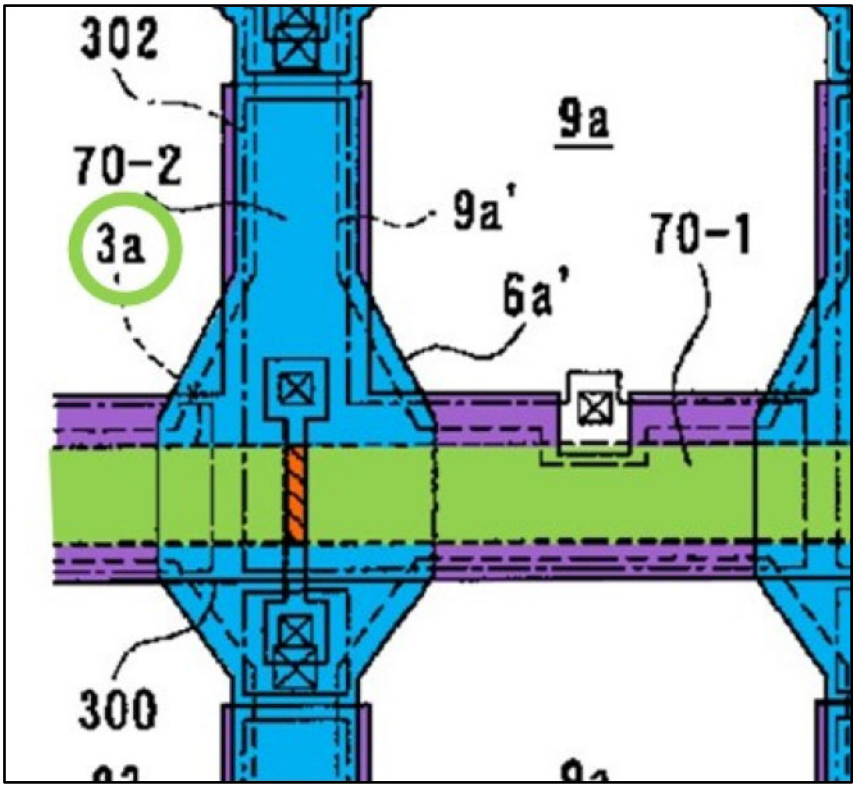
scanning line . . . having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion" in claim 2 of the '079 patent. Ex. 1001, ¶ 128. Instead, in Ground 1, Mr. Flasck contends that this limitation would have been obvious over Murade-109 in view of Sato.[2] *Id.*, ¶¶ 128-141. In particular, Mr. Flasck—acknowledging that Kurashina does not teach a scanning line with variable width—contends that providing a scanning line with a "broad-width portion" would have been obvious in view of Sato. *Id.*, ¶ 130.

60. Mr. Flasck, however, does not point in his declaration to any specific reason why a POSITA would have sought to modify Kurashina's design to provide a broader scanning line in the channel area. Instead, Mr. Flasck simply states that Sato "reflects the art's understanding that a scanning line must have a certain minimum dimension at the gate area, even if other portions of the scanning line are narrowed to improve pixel pitch and aperture ratio." *Id.*, ¶ 136. Mr. Flasck fails to address, however, that Kurashina's scanning line already has the required minimum dimension at the gate area, because the scanning line is depicted as being the same width as the channel area. Therefore, whether or not Mr. Flasck's generalization about certain minimum scan line dimensions is true, it would not motivate a POSITA to broaden Kurashina's scanning line in the gate area.

---

[2] Mr. Flasck makes similar arguments regarding Kurashina in view of Takahara for Ground 2, which I respond to below.

61. More particularly, as shown below in an annotated version of Kurashina's Figure 3 included in the Petition, Kurashina's scanning line 3a is sized to the channel area, shaded in orange.[3]



Petition at 32. Acknowledging that the scanning line may not be exactly the same width as the channel area, because Kurashina's drawings are not to scale as I discussed above in § VI.B, nothing in the figure suggests that the scanning line is substantially narrower (or substantially broader) than the channel area.

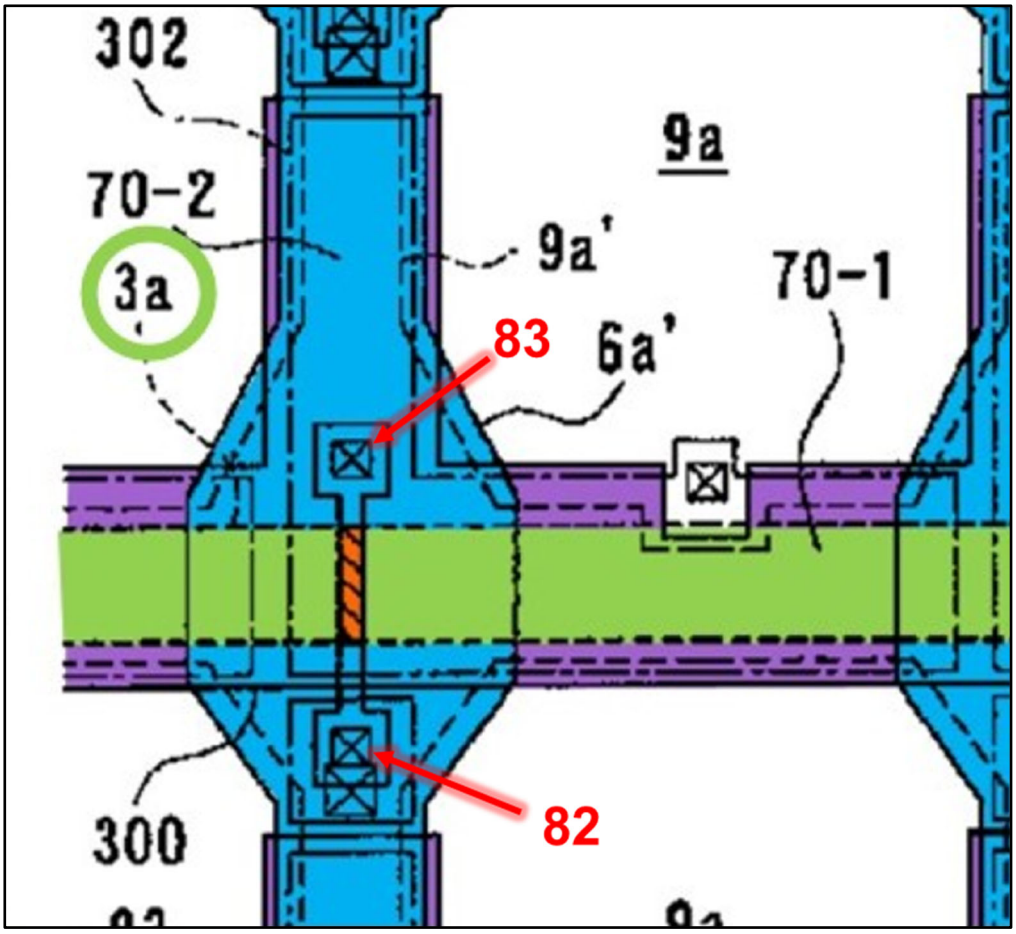
[3] As I have already noted, Kurashina's drawings are not to scale, so I cannot conclude that the width of the scan line is exactly the same as the length of the channel area. But this is the drawing on which Mr. Flasck relies in showing the scanning line structure in Kurashina, and I am simply responding to his opinions regarding the structure shown.

62. Given that the scanning line is at least roughly the same width as the channel area, a POSITA would not have been motivated to make Kurashina's scanning line any wider. Broadening the scanning line beyond the channel would not provide any light-shielding advantages in Kurashina's design either, because the data lines are already formed wide in the channel area to block light coming from the corner portions of the pixel electrodes.

63. To the contrary, a POSITA would have recognized that broadening Kurashina's scanning line beyond the channel area would negatively impact device performance. Widening the scanning line would interfere with and modify the access regions of the TFTs. The access regions are located between the source and gate electrodes, as well as between the gate and drain electrodes. The access regions include lightly doped regions (source-side LDD region 1b and drain-side LDD region 1c) as well as heavily doped regions (high-density source region 1d and the high-density drain region 1e). Modifying the width of the gate electrode region (scanning line) would modify the spatial relationships of channel region 1a', source-side LDD region 1b, drain-side LDD region 1c, and heavily doped regions 1d and 1e, thereby degrading the properties of the TFT. In other words, contrary to the suggestion of Mr. Flasck that this modification would have been "simple" or "obvious and straightforward" (Ex. 1002, ¶¶ 139-140), the spatial relationships among the regions 1a', 1b, 1c, 1d, and 1e cannot be modified (for example by

widening the gate electrode) without negatively affecting the TFT characteristics.

64. Widening the scanning line would also shorten the distance of the scanning line from the contact holes 82 and 83 shown in the annotated drawing below.



Ex. 1008, Fig. 3 (annotations added).

The contact holes 82 electrically connect the source electrodes 303 and high-density source regions 1d of the semiconductor layers 1a. Ex. 1008, ¶ [0032]. The contact holes 83 electrically connect the drain electrodes 302 and high-density drain regions 1e of the semiconductor layers 1a. *Id.* As the distance between the

scanning lines and the contact holes decreases, the TFT performance degrades due to the modification of the TFT's access regions, as discussed above.

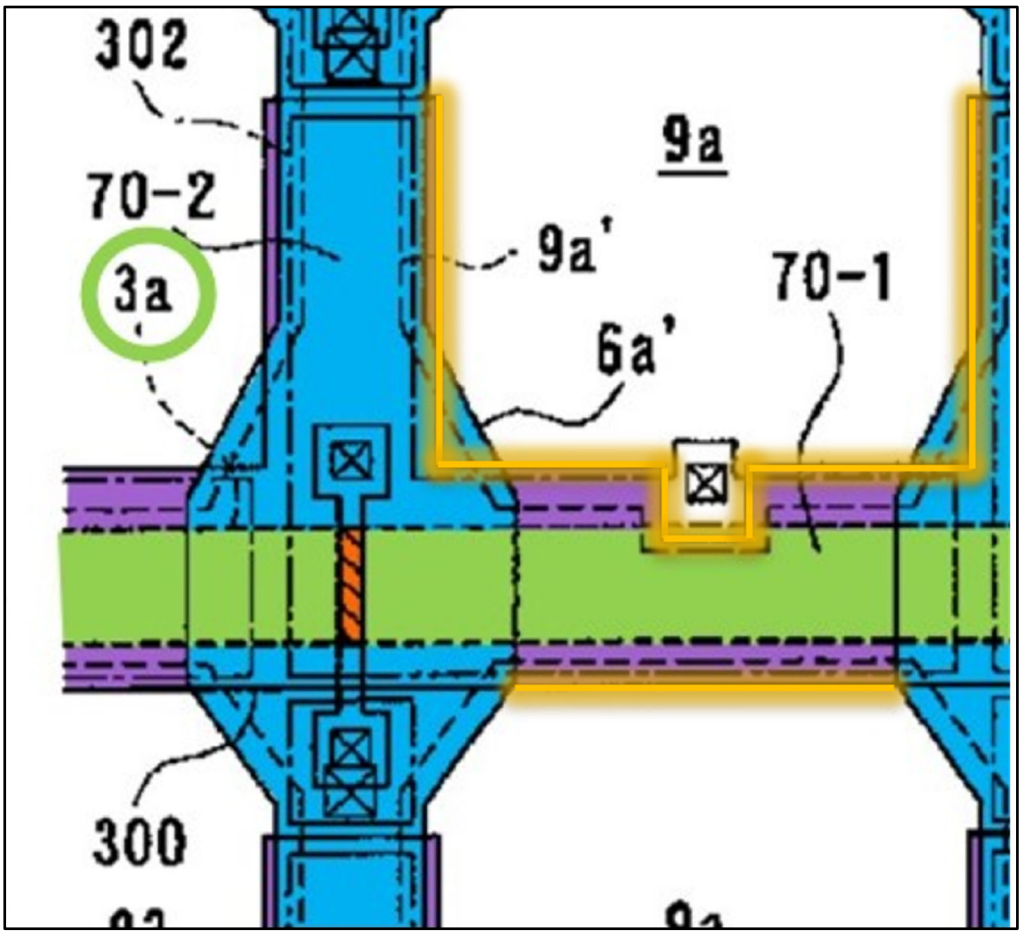
65. Later in his declaration, Mr. Flasck refers to benefits of "Sato's narrow scanning line with a wide gate portion." Ex. 1002, ¶ 139. Mr. Flasck nowhere expressly states that Kurashina could also obtain this geometry by narrowing the scanning line away from the channel area instead of widening the scanning line in the channel area. But doing so would at least in theory achieve the "narrow scanning with a wide gate portion" that Mr. Flasck describes, and Mr. Flasck contends that Kurashina would realize benefits in having a narrow scanning line, including "a higher-density pixel configuration with larger pixel apertures." *Id.* But while Sato has a narrow scanning line at least in part to avoid the contact hole at the east/west mid-point of the pixel electrode, Kurashina's corresponding contact hole is further north, meaning that Kurashina's scanning line does not have to be narrow to avoid the contact hole. All other factors the same, in my opinion a POSITA would not have been motivated to narrow Kurashina's scanning line away from the channel area, because doing so would actually compromise device performance, while having no effect whatsoever on pixel pitch or aperture ratio, which are set instead by Kurashina's capacitive line.

66. First, a POSITA would have recognized certain disadvantages in narrowing Kurashina's scanning line away from the channel area. Reducing the

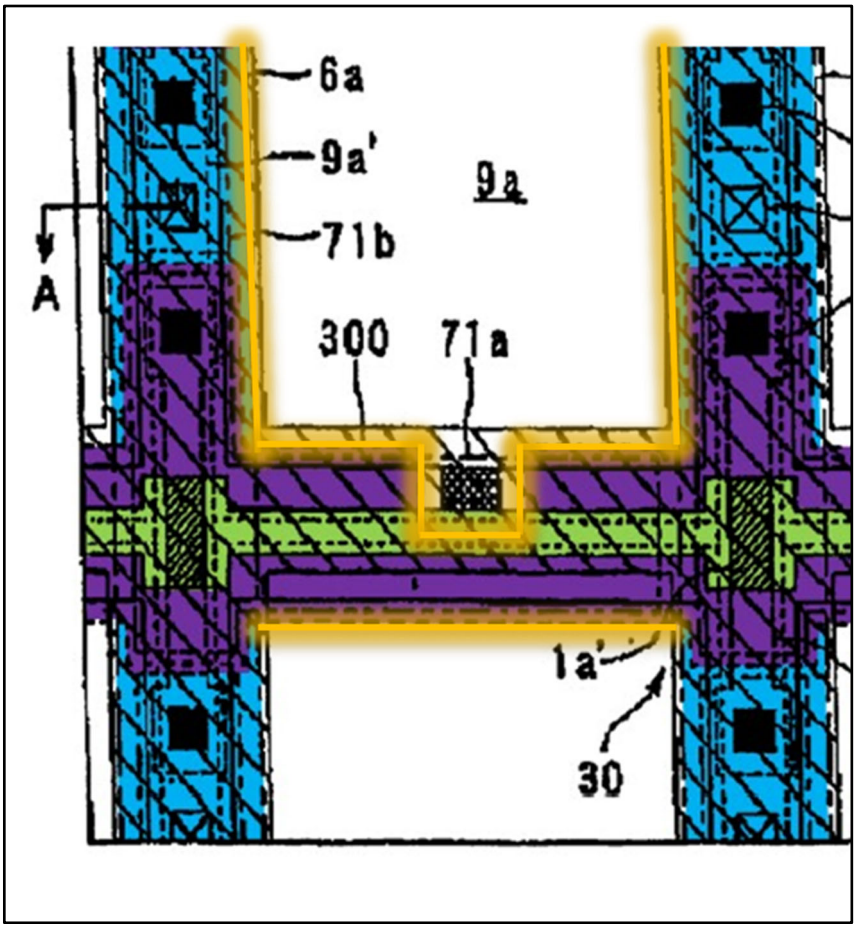
width of the scanning line away from the channel area would increase the resistance of the scan line in the narrower portion. The scanning line resistance is inversely proportional to its width. Reducing the width, for example by a factor of two, increases the scanning line resistance by a factor of two. Higher resistance in those portions of the scan line, in turn, would decrease the response time of the display and negatively affect its frame rate. The response time is the product of R (resistance) and C (capacitance). Accordingly, an increase in scanning line resistance would undesirably increase the response time by the same factor.

67. Mr. Flasck states in his declaration that modifying Kurashina's scan line configuration with Sato's wide gate and narrow scan line would result in a higher-density pixel configuration with larger pixel apertures. Ex. 1002, ¶ 139. Mr. Flasck does not explain any reasons justifying his opinion, and in any case, I disagree with Mr. Flasck on this point for the following reasons.

68. As shown in the annotated figure below, the aperture ratio of Kurashina's pixels is set by the protruding portion of the capacitive line (302, depicted with purple shading, with outline depicted in orange), not by the scanning line (3a, depicted with green shading). Any change to pixel pitch or aperture ratio would therefore require adjusting the width of the *capacitive* line, not the scanning line.



69. Similarly, as I show below, the aperture ratio of the pixels in Sato is set almost entirely by the capacitor line (300) along top and bottom, and by the data lines (6a) along the sides, as depicted by the orange line below:



70. Because the pixel aperture ratio in both Kurashina and Sato is limited by the arrangement of the capacitive line rather than the scan line, nothing in those references would have motivated a POSA to reduce the width of the scanning line, as doing so would not have any impact on the pixel aperture ratio.

71. In my opinion, therefore, Kurashina in view of Sato does not teach or render obvious "a scanning line . . . having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion," and this is another reason that Kurashina—alone or in combination with Sato—does not teach all limitations of claim 2.

72. Because Kurashina does not teach all elements of claim 2 of the ’079 patent, it also does not teach all limitations of claim 3, which depends from claim 2.

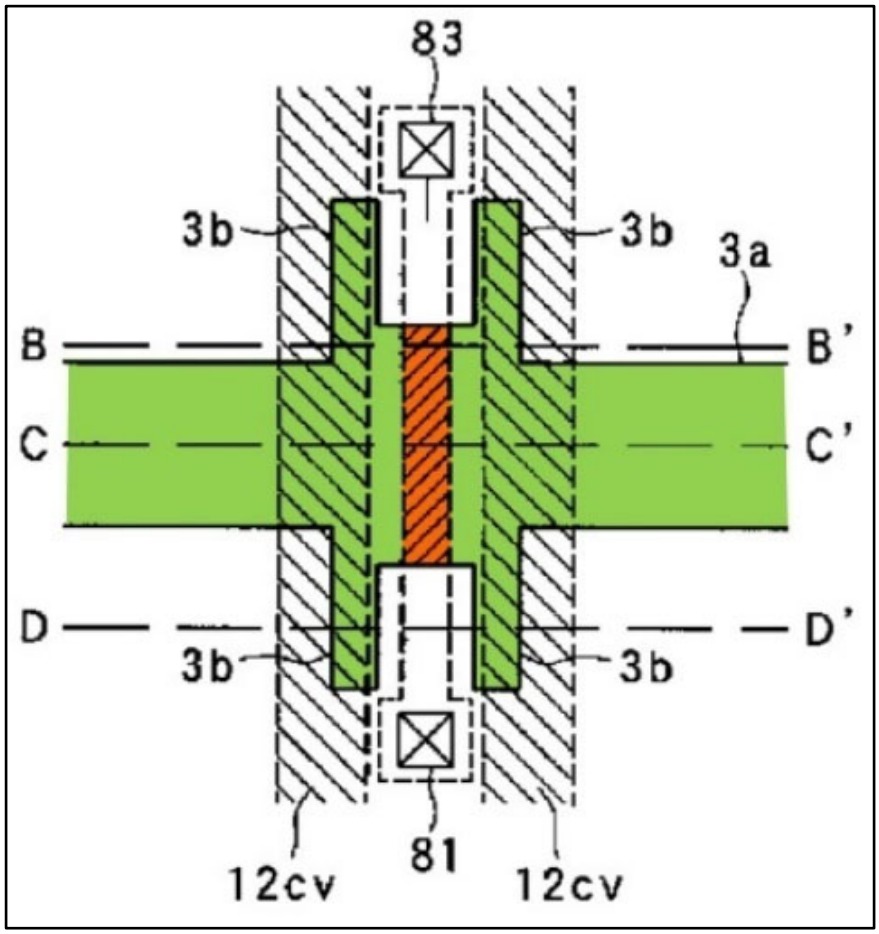
73. Kurashina does not teach all elements of claim 1 either. In particular, Kurashina in view of Sato does not teach the limitation of claim 1 “a scanning line . . . having a broad-width portion in a portion overlapping the channel area of the thin-film transistor in plan view and a narrow width portion in another portion,” for the same reasons I explained above with regard to claim 2. Although claim 1 uses the term “overlapping” the channel area instead of “facing” the channel area and specifies that the overlap is in “plan view,” this slight difference in verbiage does not impact any of my analysis above.

D. The teachings of Kurashina in view of Takahara do not satisfy all elements of any of claims 1-3 of the ’079 patent.

74. As I noted previously, Mr. Flasck does not assert that Kurashina discloses the limitation “a scanning line . . . having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion” in claim 2 of the ’079 patent. Ex. 1001, ¶ 128. Instead, in Ground 2, Mr. Flasck contends that this limitation would have been obvious over Murade-109 in view of Takahara. *Id.*, ¶¶ 169-181. In particular, Mr. Flasck—acknowledging that Kurashina does not teach a scanning line with variable

width—contends that providing a scanning line with a "broad-width portion" would have been obvious in view of Takahara. *Id.*, ¶ 169.

75. I disagree with Mr. Flasck for many of the same reasons I described above for Ground 1, Kurashina in view of Sato. Like the scan line in Sato, the wide-width portion of Takahara's scan line that actually faces the channel area—that portion that functions as the gate electrode—is no wider than the channel area, which is depicted by orange shading in Petitioner's annotated drawing below:

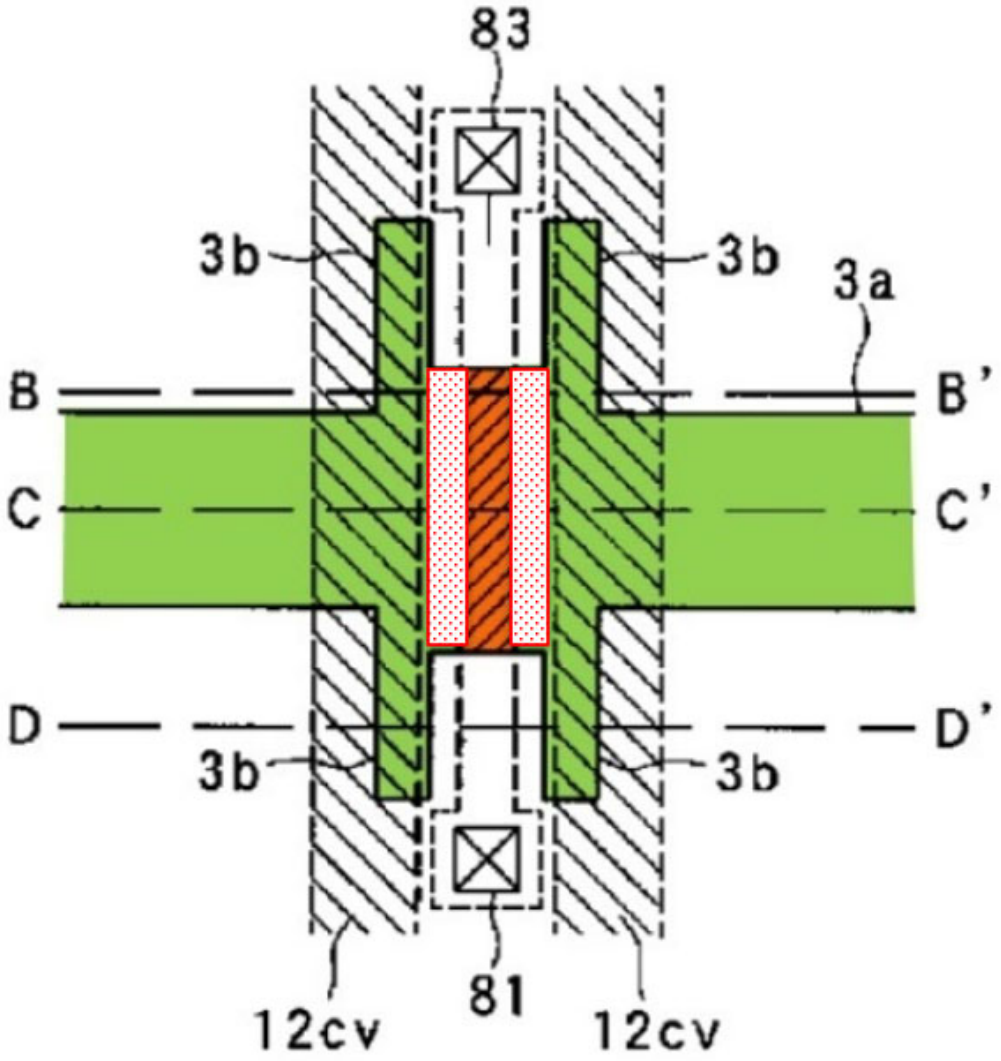


Petition at 57.

76. If not for the projecting portions 3b shown in the drawing (and which

I address further below), Takahara's scan line would look just like that of Sato. Because Takahara's scan line—apart from the protruding portions—otherwise has the same geometry as Sato's, Kurashina in view of Takahara fails to teach this claim element for at least the reasons I addressed in § VI.C above.

77. Mr. Flasck next points to Takahara's disclosure of "protruding portions 3b" and contends that they are "in a portion facing the channel area of the thin-film transistor," and that the claim limitation is met for this additional reason. Ex. 1002, ¶ 175. I disagree with Mr. Flasck. The broad-width portions of the scan line formed by protruding portions 3b do not face the channel area, as recited by this claim element. Rather, those protruding portions are *displaced* from the channel area by the segments of the scan line depicted by red hatching below:



78. Therefore, even if Kurashina's scanning line geometry were modified to have Takahara's protruding portions, the portion of Kurashina's scan line that actually faces the channel area would be no wider, because the protruding portions in Takahara do not face the channel area. Modifying Kurashina's scan line design in view of Takahara would therefore not result in the '079 claim element, which is "a scanning line . . . having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion." Ex.

1001, 26:37-40 (emphasis added).

79. In my opinion, therefore, Kurashina in view of Takahara does not teach or render obvious "a scanning line . . . having a broad-width portion in a portion facing the channel area of the thin-film transistor and a narrow width portion in another portion."

80. Because Kurashina does not teach all elements of claim 2 of the '079 patent, it also does not teach all limitations of claim 3, which depends from claim 2.

81. Kurashina does not teach all elements of claim 1 either. In particular, Kurashina in view of Takahara does not teach the limitation of claim 1 "a scanning line . . . having a broad-width portion in a portion overlapping the channel area of the thin-film transistor in plan view and a narrow width portion in another portion," for the same reasons I explained above with regard to claim 2. Although claim 1 uses the term "overlapping" the channel area instead of "facing" the channel area and specifies that the overlap is in "plan view," this slight difference in verbiage does not impact any of my analysis above.

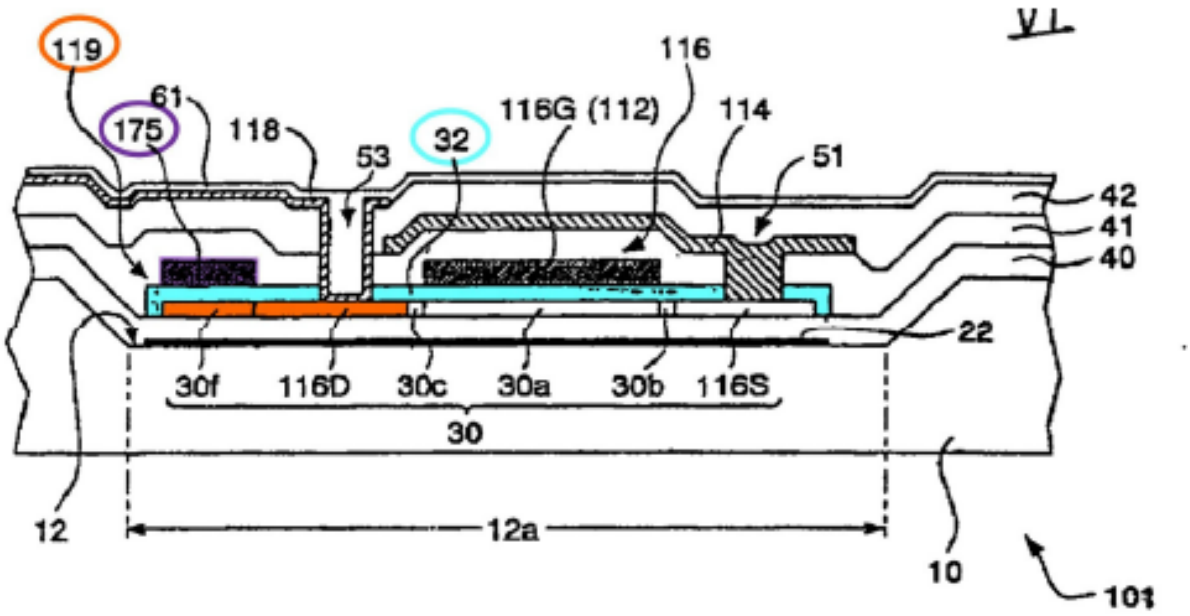
VII. ANALYSIS OF MURADE-109 AND THE COMBINATION OF MURADE-109 WITH MURADE-125 (GROUND 3)

A. Overview of Murade-109 and Murade-125

82. U.S. Pub. No. 2001/0048109A1 to Murade ("Murade-109") is

primarily concerned with minimizing the difference in levels between two different surfaces of an electro-optical device substrate; this design promotes uniformity in rubbing treatment and an improved display quality. Ex. 1011, ¶¶ [0009]-[0011].

83. The annotated Murade-109 Figure 6 from the Petition, shown below, indicates several of the key features taught. Petition at 70. These include a pixel electrode (118), which connects directly to the heavily-doped drain region (116D) through a contact hole (53); a data line (114); a scan line (112), which forms the gate electrode (116G); a capacitive line (175); a heavily-doped drain region (30f); and an insulating film (32). The capacitive line and heavily-doped drain region, sandwiching the insulating film (32) between them, form a storage capacitor (119) connected to the pixel electrode. Ex. 1011, ¶ [0140].

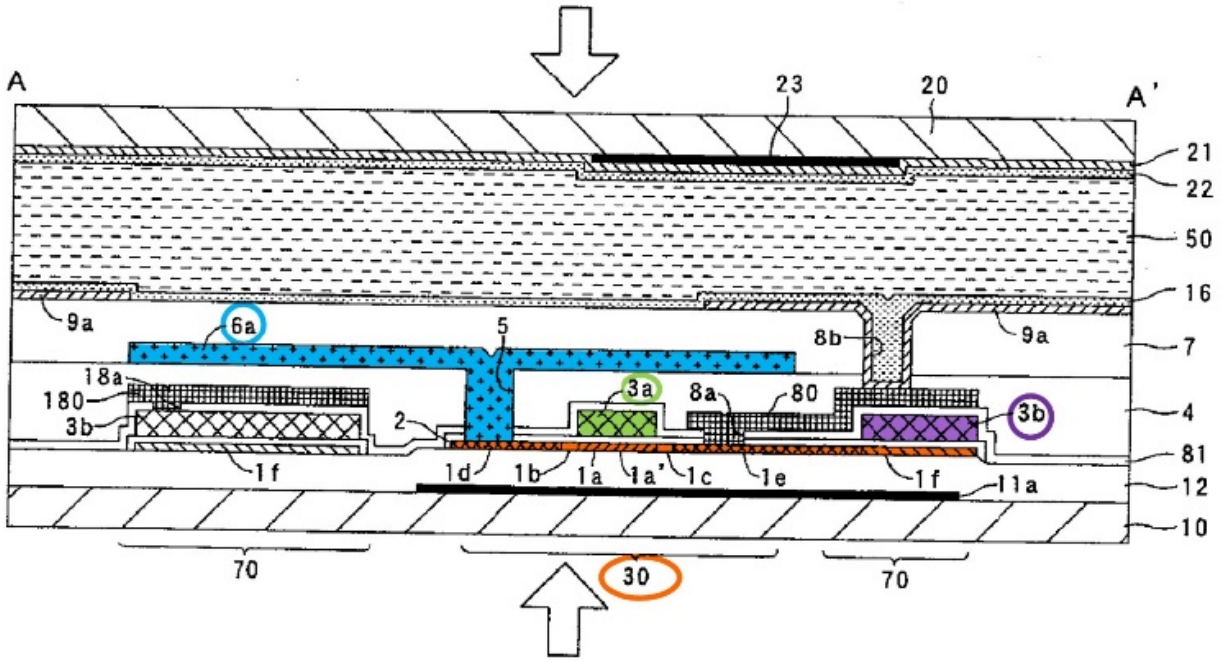


Petition at 70.

84. Unlike Murade-109, Murade-125 is primarily directed to solving problems caused by intermediate conductive layers, which are provided in certain electro-optical devices to improve conduction between the pixel electrode and the TFT. Ex. 1012, ¶ [0001]. According to Murade-125, these intermediate conductive layers result in more layers in the overall structure and more contact holes as well, which leads to alignment irregularities and makes it more difficult to incorporate storage capacitors into the device design. *Id.*, ¶ [0005]. Murade-125 teaches connecting the pixel electrode to the drain region of the semiconductor layer via an intermediate conductive layer, which establishes a good connection using comparatively small contact holes; these smaller contact holes in turn facilitate a larger pixel aperture ratio. *Id.*, ¶ [0008].

85. The annotated Murade-125 Figure 3 from the Petition, shown below, indicates several of the key features taught. Petition at 78. These include a pixel electrode (9a), which connects to the drain region (1e) via a first intermediate conductive layer (80) and contact hole (8a); a data line (6a); a scan line (3a), which forms a gate electrode; a capacitor line (3b); a capacitor electrode (1f) extending from the drain region (1e); a second intermediate conductive layer (180); and a first interlayer insulating film (81) and insulating thin film (2). The storage capacitor (70) includes electrode (1f), insulating thin film (2), capacitor line (3b), first interlayer insulating film (81), and second intermediate conductive layer

(180), yielding a conductor-insulator-conductor-insulator-conductor capacitor with a large storage capacitance (70). *Id.*, ¶ [0068].



Petition at 78.

86. The design of Murade-109 differs substantially from Murade-125, at least in that Murade-109 does not disclose an intermediate conductive layer. While the pixel electrode in Murade-125 connects to the drain via the first intermediate conductive layer 80, the pixel electrode in Murade-109 connects directly to the drain, as I previously described, rather than through an intermediate conductive layer.

B. The teachings of Murade-109 in view of Murade-125 do not satisfy all elements of claim 2 of the ’079 patent

87. Mr. Flasck does not assert that Murade-109 discloses the limitation “a

capacitive line having a portion that serves as the fixed potential capacitor electrode of the storage capacitor, the capacitive line having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line" in claim 2 of the '079 patent. Ex. 1001, ¶¶ 205-221. Instead, Mr. Flasck contends that this limitation would have been obvious over Murade-109 in view of Murade-125. *Id.*, ¶ 205. In particular, Mr. Flasck—acknowledging that Murade-109 does not teach making the protruding portion of its capacitor line wider than the non-broad portion of the data line—contends that widening the protruding portion of the capacitor line to be wider than the non-broad portion of the data line would have been obvious in view of Murade-125. *Id.*, ¶ 210.

88. Mr. Flasck does not address several teachings from Murade-109 and Murade-125 that would discourage a POSITA from modifying Murade-109 to arrive at this claim limitation. In particular, Mr. Flasck does not address fundamental design differences between Murade-109 and Murade-125 that make the references incompatible for teaching this claim limitation.

89. I explained in § VII.A above that Murade-109 teaches a pixel electrode that connects directly to the drain of the TFT. I explained that Murade-109 further teaches storage capacitors connected to the pixel electrodes, and that

those storage capacitors comprise the capacitor line and heavily-doped drain region as the two electrodes with an insulating film in between them.

90. I also explained in § VII.A above that Murade-125 is directed to a different LCD design compared to Murade-109, a design in which intermediate conductive layers are provided in the device to improve conduction between the pixel electrode and the TFT. I explained that Murade-125 teaches a pixel electrode that connects to the drain of the TFT through an intermediate conductive layer, rather than connecting directly to the drain as in Murade-109. I also explained that Murade-125 teaches storage capacitors connected to the pixel electrodes. I explained that these storage capacitors comprise the capacitor line and two intermediate conductive layers, rather than the capacitor line and the heavily-doped drain region as in Murade-109.

91. Mr. Flasck does not address this key design difference between Murade-109 and Murade-125. He therefore makes several erroneous assumptions in arriving at his conclusion that this claim limitation would have been obvious over Murade-109 in view of Murade-125.

92. In particular, Mr. Flasck states that "a POSITA further would understand Murade-125's relatively wide capacitor line protruding portion to achieve desirable improvements in performance." Ex. 1002, ¶ 214. But this assertion is based on two inaccurate statements that Mr. Flasck makes elsewhere in

the same paragraph. First, Mr. Flasck suggests that Murade-125 discloses that "[w]idening the capacitive line relative to the data line (a) 'attenuates multiply reflected light caused by internal reflection as described above.'" Mr. Flasck is incorrect: Murade-125 discloses attenuating multiply reflected light by widening the intermediate conductive layer relative to the data line—not by widening the capacitive line relative the data line. Second, Mr. Flasck states that "a 'larger storage capacitor can be constructed using the capacitor electrode and the intermediate conductive layer, which are wider than the data line.'" *Id.* This is true of Murade-125. But insofar as Mr. Flasck's statement is meant to describe performance improvements that would extend to Murade-109, it is inaccurate. The benefit of a larger storage capacitor would not carry over to Murade-109, because Murade-109 does not have an intermediate conductive layer.

93. Here I address Mr. Flasck's first inaccurate statement, which I identified above, relating to multiply reflected light. Murade-125 nowhere teaches that widening the capacitor line relative to the data line attenuates multiply reflected light caused by internal reflection, as Mr. Flasck contends. Instead, Murade-125 teaches providing shielding against incident light from the opposing substrate using the data line and the *intermediate conductive layer*, not the capacitor line. Ex. 1012, ¶ [0042]. Murade-125 explains that the data line is often made of an aluminum film having extremely high

reflectivity such that, when the TFT is light-shielded solely by the data line, multiple reflection off the back side of the data line may allow light to reach the channel area. *Id.* Murade-125 then explains that "the intermediate conductive layer provided beneath the data line is formed from a low-reflective, high-melting-point metal film or a polysilicon film, thus making it possible to adopt a configuration that attenuates multiply reflected light caused by internal reflection as described above." *Id.* Similarly, Murade-125 later explains as follows:

> [M]ultiply reflected light resulting from internal reflection as described above can be attenuated by forming the first intermediate conductive layer 80 and the second intermediate conductive layer 180 from a low reflectivity refractive metal film or from a polysilicon film, and by forming the second intermediate conductive layer 180 so as to be wider than the data line 6a (Wd < Wm).

Ex. 1012, ¶ [0094]. According to Murade-125, therefore, it is the intermediate conducting layer—not the capacitor line, as Mr. Flasck contends—that shields the channel area from light reflected off the back side of the data line.

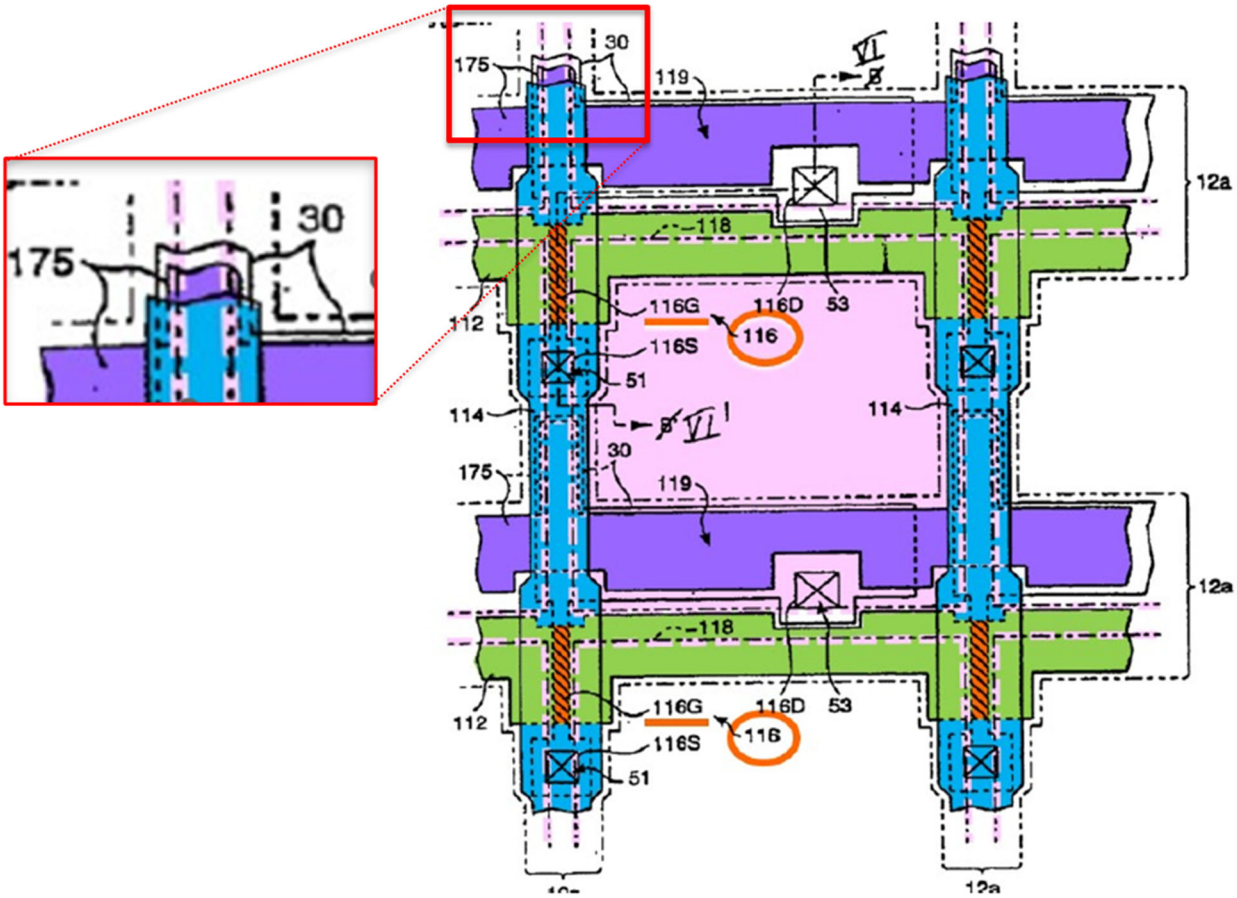
94. Murade-125 then explains that "a larger storage capacitor can be constructed using the capacitor electrode and the intermediate conductive layer, which are wider than the data line." Ex. 1012, ¶ [0042]. According to Murade-125,

then, the reason for making the capacitor line wider than the data line is not to provide additional light shielding, but rather to form a larger storage capacitor with the intermediate conductive layer.

95. Mr. Flasck points to this teaching of Murade-125 that a larger storage capacitor can be formed from a wider capacitive line and wider intermediate conductive layer: that is the second inaccurate statement that I described above.

96. Here I address the second inaccurate statement of Mr. Flasck. He contends that Murade-125's teachings would result in a larger storage capacitor and that forming a larger storage capacitor would be a design improvement. *See* Ex. 1002, ¶ 214. However, Mr. Flasck's statement is inaccurate because it is wholly inapplicable to Murade-109. The teachings of Murade-125 concerning a larger storage capacitor cannot be extended to Murade-109, because the two references have incompatible designs. In particular, because the device described in Murade-109 does not have an intermediate conductive layer, widening the capacitor line in Murade-109 will not result in the claim element "the portion [of the capacitor line] extending along the data line having a width that is . . . wider than the non-broad portion of the data line," for the following reasons.

97. As I show below in an annotated version of Murade-109 Figure 5, both the protruding portion of the capacitor line 175 and the semiconductor layer 30 are narrower than the non-broad portion of the data line:



Therefore, even if the capacitor line 175 in Murade-109 were broadened to be the same width as the semiconductor layer 30 (the mating electrode in Murade-109), it would still be narrower than the non-broad portion of the data line 114, and the claim limitation "the portion [of the capacitor line] extending along the data line having a width that is . . . wider than the non-broad portion of the data line" would not be met.

98. Further, a POSA would not have been motivated to broaden the capacitor line beyond the width of the semiconductor layer. This design change would not provide any more capacitance in Murade-109 because capacitance

comes only from the regions of the capacitor line and semiconductor layer 30 that overlap. Mr. Flasck himself acknowledges this general property of capacitors at ¶ 215 of his declaration. In explaining why, in his opinion, a POSITA would not have been motivated to make the capacitor line protrusion wider than the broad portion of the data line, he states that "widening the capacitor line will increase capacitance only to the extent it overlaps its mated electrode (30f), meaning no increase in capacitance would be achieved by unduly increasing the capacitor width significantly beyond the width of the data line portion it overlaps." Ex. 1002, ¶ 215. Yet he does not apply the same logic in considering areas of the device containing the non-broad portions of the data line. Here, making the capacitor line in Murade-109 broader than the semiconductor layer 30—its "mated electrode"—would provide no additional capacitance, and a POSITA therefore would not have been motivated to make this design change in Murade-109.

99. Finally, a POSITA would not have been motivated to make the semiconductor layer 30 in Murade-109 broader in accordance with the capacitor line 175. While broadening the intermediate conductive layer (and capacitor line) beyond the data line in Murade-125 provided light shielding benefits, the same does not translate to Murade-109. A broader semiconductor layer 30 would not provide any light shielding—rather, it is the semiconductor layer itself that must be *shielded* from stray light to reduce light-induced leakage currents. Further,

broadening the semiconductor layer 30 would increase its area, which would make it even more susceptible to stray light and light-induced leakage currents. Again, the incompatibility in designs between Murade-109 and Murade-125 would have discouraged a POSITA from modifying Murade-109 in view of Murade-125.

100. To summarize, Mr. Flasck contends that a POSITA would have been "motivated to implement the reflection-attenuating and capacitor enhancing features of Murade-125 with the design of Murade-109 to achieve improved performance" because, according to him, Murade-125 teaches widening the capacitive line relative to the data line **(1)** to attenuate multiply reflected light and **(2)** to create a larger storage capacitor. Ex. 1002, ¶ 214. But Mr. Flasck's conclusion cannot follow from his premises. The first premise (that Murade-125 teaches widening the capacitive line relative to the data line to attenuate multiply reflected light) is incorrect: Murade-125 teaches widening the intermediate conductive layer—not the capacitor line—to attenuate multiply reflected light. And the second premise (that Murade-125 teaches widening the capacitive line relative to the data line to create a larger storage capacitor) is meaningless because it is inapplicable to Murade-109, which does not disclose an intermediate conductive layer. Instead, a POSITA would have recognized that the different designs of Murade-109 and Murade-125, and particularly the fact that Murade-125 discloses an intermediate conductive layer while Murade-109 does not, make the references

incompatible with regard to modifying the width of Murade-109's capacitor line.

101. Further, broadening the capacitor line in Murade-109 would still not result in the claim element "the portion [of the capacitor line] extending along the data line having a width that is . . . wider than the non-broad portion of the data line" because of these incompatible designs. Even if a POSITA widened the capacitor line in Murade-109, they would not have been motivated to make it wider than the non-broad portion of the data line because doing so would not provide any additional capacitance.

102. In my opinion, therefore, Murade-109 in view of Murade-125 does not teach or render obvious "a capacitive line . . . having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data line having a width that is narrower than the broad portion of the data line and that is wider than the non-broad portion of the data line."

103. Because Murade-109 does not teach all elements of claim 2 of the '079 patent, it also does not teach all limitations of claim 3, which depends from claim 2.

104. Murade-109 does not teach all elements of claim 1 either. In particular, Murade-109 in view of Murade-125 does not teach the limitation of claim 1 "a capacitive line . . . having a portion extending along the scanning line and a portion extending along the data line, the portion extending along the data

line having a width that is equal to or broader than a width of the data line," for the same reasons I explained above with regard to claim 2. Although claim 1 recites a capacitive line "equal to or broader than a width of the data line," while claim 2 recites a capacitive line "wider than the non-broad portion of the data line," this difference in verbiage does not impact any of my analysis above. A POSITA would not have been motivated to make Murade-109's capacitor line as broad as, or broader than, the data line, for the same reasons I discussed.

VIII. ADDITIONAL REMARKS

105. I reserve any right that I may have to supplement this declaration if further information becomes available or if I am asked to consider additional information or to submit an additional declaration if *inter partes* review is instituted. Furthermore, I reserve any right that I may have to consider and comment on any additional expert statements and testimony of Petitioner's expert in this matter.

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

patents issued thereon.

Dated: September 20, 2024

E. Fred Schubert, Ph.D.

APPENDIX A

Curriculum Vitae: E. Fred Schubert

Contact information

Department of Electrical, Computer, and Systems Engineering
Rensselaer Polytechnic Institute
110 Eighth Street, Troy, NY 12180
Telephone 518-276-8775 (office); Cell phone 518-253-3762
Email: EFSchubert@rpi.edu Homepage: http://www.rpi.edu/~schubert

Citizenship

Born in Stuttgart, Germany (1956)
Naturalized United States Citizen (1995)

Education

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

Current appointment

2002 – present: Professor, Department of Electrical, Computer, and Systems Engineering; Rensselaer Polytechnic Institute, Troy NY

Previous appointments

2002 – 2015: Head and Founder of the Future Chips Constellation; Rensselaer Polytechnic Institute

2002 – 2015: Wellfleet Senior Constellation Professor, Future Chips (Chaired Professor); Rensselaer Polytechnic Institute

2002 – 2012: Professor Department of Physics, Applied Physics, and Astronomy; Rensselaer Polytechnic Institute

2008 – 2009: Director, Founding Director, and Principal Investigator, NSF Engineering Center for Smart Lighting, Rensselaer Polytechnic Institute

2002 – 2003: Adjunct Professor, Boston University

1995 – 2002: Professor, Boston University, Department of Electrical and Computer Engineering; Director of the Semiconductor Devices Research Laboratory; Affiliated Faculty of the Photonics Center.

1988 – 1995: Member of Technical Staff; Principal Investigator; and Member of Management at AT&T Bell Laboratories in Murray Hill, New Jersey

1985 – 1987: Post-Doctoral Member of Technical Staff at AT&T Bell Laboratories in Holmdel, New Jersey.

1981 – 1985: Scientific Member of Staff in the Department of Solid-State Chemistry at the Max Planck Institute for Solid-State Research in Stuttgart, Germany. Ph.D. Dissertation title: "Modern Schottky gate field-effect transistors based on III–V semiconductors"

Fields of Technical Expertise, Hands-on Experience, and Teaching

- Expertise, hands-on experience, and teaching in semiconductor opto-electronics including the following devices: LED, semiconductor laser, vertical cavity surface-emitting laser (VCSEL), solar cell, photo-detector, LED displays, micro-LED displays, LCD displays, and OLED displays. The activities include the design, fabrication, processing, and packaging of the devices, and the use of the devices in circuits and systems. (1981 to present)
- Expertise, hands-on experience, and teaching in semiconductor electronics including the following devices: MESFET, HFET, MOSFET, CMOS-FET, LDD MOSFET, LD MOS FET, FinFET, GAA FET, Vertical MOSFET (high-power MOSFET), thyristor, GTO thyristor, and IGBT. The activities include the design, fabrication, processing, and packaging of the devices, and the use of the devices in discrete and integrated circuits. (1979 to present)
- Expertise, hands-on experience, and teaching in thin-film deposition of metal, semiconductor, and insulator films by PVD (physical vapor deposition) and CVD (chemical vapor deposition) including PECVD (plasma enhanced CVD), MOCVD (metal-organic CVD), ALE (atomic layer epitaxy), ALD (atomic layer deposition), and bulk crystal growth (AlN, GaN, and sapphire). Epitaxial growth of silicon, III-V arsenide, phosphide and nitride epitaxial layers on GaAs, sapphire, Si, and GaN substrates by epitaxy including molecular beam epitaxy (MBE),

Patent Owner 138 East Ex. 2001
Page 055

metal-organic chemical vapor deposition (MOCVD), and vapor-phase epitaxy (VPE). High-k materials, low-k-materials, phosphors, resins, polymers, encapsulants, alloy semiconductors and their deposition technologies such as epitaxy, CVD, and PVD. Doping of semiconductors by various means including delta doping and atomic monolayer doping. (1981 to present)

- Expertise, hands-on experience, and teaching in the design, operation, and usage of semiconductor devices in lighting systems, communication systems, and power-supply systems and in the analysis and development of LED power supplies using Boost and Buck Converters. (1993 to present)

Technical Research Activities

- Design, development and fabrication of a Si pressure sensor based on the piezo-resistivity of Si using a bridge configuration of four thin-film Si resistors (1979 – 1980)
- Design of a electro-optic Mach-Zehnder Interference Modulator based on Lithium niobate ($LiNbO_3$) operating at a wavelength of 1300 nm (1980 – 1981)
- First study of hot electron effects in selectively doped $Al_xGa_{1-x}As$/GaAs heterostructures (1983)
- Demonstration and elimination of parallel conduction in $Al_xGa_{1-x}As$/GaAs heterostructures (1984)
- First analysis of semiconductors doped with simultaneously shallow and deep donors (1984).
- Development and use of thyristor circuits (including GTO thyristor circuits) for the control of a lamp heating system (1984 – 1985)
- Proposal and demonstration of the δ-doped field-effect transistor. Short-channel effects in sub-micron field-effect transistors can be reduced to their theoretical minimum by using δ-doped structures (1985)
- Development of the theory of alloy broadening in luminescence spectra of alloy semiconductors such as $Al_xGa_{1-x}As$. The current understanding of the low-temperature spectral linewidths of ternary and quaternary alloy semiconductors is based on this theoretical model. The publication analyzing the phenomenon of alloy broadening has been referenced far in excess of 100 times (1984)
- First demonstration of a light-emitting diode with a doping superlattice active region (1985)
- Application of δ-doping to selectively doped heterostructures; Demonstration of high-electron-mobility transistors (HEMTs) with highest free electron concentrations; Analysis of structures by SEM, TEM, and SIMS (1986).
- Demonstration of delta-doped non-alloyed ohmic contacts with very low contact resistance and subsequent demonstration of self-aligned field-effect transistor with delta-doped non-alloyed ohmic contacts (1986)
- Demonstration of the spatial localization of dopants within 20 Å for a number of doping elements in delta-doped semiconductors including GaAs and Si for MESFET and lightly-doped drain (LDD) MOSFET applications and the analysis of delta-doped structures by SIMS (secondary ion mass spectrometry) (with colleague Henry S. Luftman, 1983-1995)
- Significant improvement of the optical properties of doping superlattices by employment of delta doping. Improvement is demonstrated by the first observation of quantized interband transitions in the absorption (1988) and in the emission spectra (1989)
- First demonstration of tunable doping superlattice laser (1989)
- First quantitative analysis of the capacitance-voltage (CV) profiling technique in semiconductors with quantum-confined carriers. Demonstration that resolution of CV profiles in quantum-confined semiconductors is not limited to the Debye screening length (1990)
- Invention and demonstration a new concept by which heterojunction band discontinuities occurring between two different semiconductors are eliminated. The *elimination of heterojunction barriers* is based on parabolic compositional grading of doped heterojunctions. This concept is widely used in the fabrication of vertical cavity surface emitting lasers and other heterojunction devices (1991)
- Invention and first demonstration of resonant cavity light-emitting diode (RCLED) which uses photon quantization in microcavities to enhance the spontaneous emission properties (1992)
- Demonstration of giant enhancement of luminescence intensity in Er-doped Si-SiO_2 microcavities (1992)
- First demonstration of a resonant-cavity detector which is useful for wavelength-selective detection (1993)
- Demonstration of resonant-cavity light-emitting diode (RCLED) with very high brightness. The experimental brightness of the RCLED is five times higher than that of conventional LEDs. Based on calculations, the brightness of RCLEDs is expected to exceed that of conventional LEDs by more than a factor of ten (1994)
- Demonstration of delta doping in silicon for the fabrication of shallow junctions in scaled-down Si lightly-doped drain (LDD) MOSFETs for integrated circuits (Si ICs) (with colleague Dr. H. J. Gossmann, 1990 – 1995)
- Invention of a new concept, *superlattice doping*, for enhanced p-type doping of GaN. All acceptors in GaN are deep, resulting in a low electrical acceptor activation of only 5 %. The new concept of superlattice doping is expected to increase the electrical activation of acceptors by more than a factor of ten (with post-doctoral associate Dr. W. Grieshaber, 1995)

Patent Owner 138 East Ex. 2001
Page 056

- Investigation of yellow luminescence in GaN and the use of microcavity effects in Ag / GaN / sapphire structures to determine the refractive index of GaN (with post-doctoral associate Dr. W. Grieshaber, 1996)
- Demonstration of the first GaN / GaInN double heterostructure laser. The laser has cleaved facets and was optically pumped. Laser action was demonstrated by (*i*) a threshold in the light-versus-current characteristic, (*ii*) spectral narrowing below *kT* above threshold, (*iii*) a TE / TM polarization ratio greater than one hundred above threshold, and (*iv*) increased slope efficiency with increasing back-side facet reflectivity (with graduate student D. A. Stocker, 1997)
- Co-inventor of photonic-crystal light-emitting diode, PC-LED, jointly with group of Prof. John D. Joannopoulos at MIT (publication by Shanhui Fan *et al*. appeared in *Physical Review Letters* in 1997; US patent 5,955,749 was issued in 1999)
- First demonstration of crystallographic etching of GaN (with graduate student D. A. Stocker, 1998). The discovery, crystallographic etching, can be implemented by wet chemical etching, including photo-enhanced electrochemical (PEC) wet etching. The discovery is widely used in the LED industry to strongly enhance light extraction from LED chips and is found in LED light bulbs.
- Experimental demonstration of a ten-fold enhancement of p-type doping activation in $Al_xGa_{1-x}N$/GaN doped superlattices as compared to bulk GaN and $Al_xGa_{1-x}N$ (with graduate students D. A. Stocker and I. D. Goepfert, 1999)
- Invention and demonstration of the photon-recycling semiconductor light-emitting diode (PRS-LED) which emits *white* light and many other colors with very high luminous performance of > 300 lm/W (with graduate students X. Guo and J. W. Graff, 1999). Invention of the monolithically integrated GaInN/GaN PRS-LED (with graduate students X. Guo and J. W. Graff, 2000)
- Invention and demonstration of polarization-enhanced ohmic contacts in p-type and n-type GaN (with graduate students Y.-L. Li and J. W. Graff 2000)
- Invention and demonstration of AlGaInP light-emitting diode with omni-directional reflector (ODR) for high light extraction efficiency (with post-doctoral associate Th. Gessmann and graduate student J. W. Graff, 2001)
- Developed novel model for high diodes ideality factors (n >> 2.0) in UV LEDs based on multiple rectifying elements (with graduate student J. M. Shah and Prof. Th. Gessmann, 2003)
- Developed new class of materials, low-refractive index materials, or low-*n* materials, with an unprecedented low refractive index of n < 1.10; use of these materials as low-*k* materials for inter-metal-layer dielectrics in Si lightly-doped drain (LDD) MOSFETs in conjunction with ALD-deposited high-*k* gate dielectric MOSFETs for integrated circuits (Si ICs) (with Dr. Jong Kyu Kim, "JQ" Xi, Professors Joel Plawsky, Bill Gill, starting in 2003)
- Developed theory for temperature coefficient of forward voltage in light-emitting diodes, particularly UV light-emitting diodes (with graduate student Yangang "Andrew" Xi, Dr. Jong Kyu Kim, and collaborators at Sandia National Laboratories, 2004, 2005)
- Invented highly efficient "remote phosphor configurations" in white light-emitting diodes (with Jong Kyu Kim, Hong Luo, and collaborators at SAIT-Samsung) (2004, 2005)
- Discovered whispering gallery modes in white LEDs with remote phosphors (with graduate student Hong Luo, Jong Kyu Kim, Yangang "Andrew" Xi, and collaborators at SAIT-Samsung, 2005)
- Developed graded-index antireflection coatings that, unlike conventional anti-reflection coatings, have broadband omni-directional characteristics; the graded-index antireflection coatings use novel low-*n* materials (with Jingqun "JQ" Xi, Jong Kyu Kim, 2007)
- Developed efficiency-droop reducing GaInN / GaInN and GaInN / AlGaInN LED active regions grown by MOCVD and ALE that were demonstrated to reduce the efficiency droop by as much as 40% (with Jong Kyu Kim, Martin F. Schubert, Di Zhu, Jiuru Xu, Mary Crawford, and Dan Koleske, starting in 2007)
- Developed analytic model for efficiency droop based on drift-induced reduction of the carrier-injection efficiency (with Guan Bo Lin, Jaehee Cho, and others, 2012)

Honors and awards

- Google Scholar profile, including the Hirsch-index (h-index) can be found at < http://scholar.google.com > under profile "E. Fred Schubert"
- Elected to *Senior Member* of the *IEEE* "in recognition of professional standing" (1993)
- Recipient of the Literature Prize of the *Verein Deutscher Elektrotechniker* (*VDE*) for "Doping in III–V semiconductors" (Cambridge University Press, Cambridge, 1993). Citation: "The book concerns all aspects of doping in III–V semiconductors. Fundamental, practical, and technological issues of doping are addressed. The book covers the basic theory of shallow donors, shallow acceptors, deep levels, and their influence on the free carrier concentration. It also discusses doping during growth, epitaxy, diffusion, and ion implantation. In the field of semiconductor devices, the book emphasizes applications requiring highly controlled doping distributions. It is an excellent monograph equally suited for study, research, and industry" (1994)

Patent Owner 138 East Ex. 2001
Page 057

- Elected as a member of the *Bohemian Physical Society* (Cornell University, Ithaca, NY). Citation: "For seminal contributions to the control of spontaneous emission by use of wavelength-size optical cavities, specifically the first demonstration in a glass host using rare earth implanted Si/SiO_2 resonant microcavities" (1994)
- Listed in "Who's Who In Science And Engineering" and "Who's Who in America" published by *Marquis Who's Who*, publishers of the original *Who's Who in America*. (*Marquis Who's Who*, New Providence, NJ) ISBN 0-8379-5755-9 (1996 – present)
- Elected Fellow *of the SPIE* "For pioneering research in semiconductor doping and sustained contributions to the development of high-efficiency light-emitting diodes and lasers". According to the Society's bylaws, a Fellow "shall be distinguished through his achievements and shall have made outstanding contributions in the field of optics, or optoelectronics, or in a related scientific, technical, or engineering field" (1999)
- Recipient of the *Alexander von Humboldt Senior Research Award* of the Alexander von Humboldt Foundation, a Bonn-based non-profit organization promoting the exchange of scientific knowledge between German and highly qualified foreign scholars. According to the Alexander von Humboldt Foundation, academic qualification is the only selection criterion for the award. The award resulted in two extended visits with the Microoptics Laboratory of Professor Jürgen Jahns at the University of Hagen, Germany (1999)
- Elected to *Fellow of the IEEE* "for contributions to semiconductor doping and resonant-cavity devices". According to the IEEE definition "the grade of Fellow is one of unusual professional distinction conferred by the Board of Directors only upon a person of extraordinary qualifications and experience" (1999)
- Listed in the "Dictionary of International Biography, 29th Edition" published by the *International Biography Center*, Cambridge, United Kingdom (2000)
- Recipient of the 2000 *Discover Magazine Award for Technological Innovation* presented by the *Christopher Columbus Foundation* in the category "Energy". The prize was awarded "for the invention and demonstration of the photon recycling semiconductor light-emitting diode", an all-semiconductor LED capable of emitting white light with very high efficiency, see < www.discover.com/awards > (2000)
- Recipient of the *RD100 Award* of the R&D Magazine that honors the "100 most technologically significant products of the year" (with Klaus Streubel of Osram-Sylvania Corp. and Rickard Marcks von Wurtemberg of Mitel Corp.). The prize was awarded for the "*Resonant-cavity light-emitting diode*" that uses enhanced spontaneous emission occurring in resonant cavities. The device is used in plastic optical fiber communication links, in telescopes for rifles, and many other applications (2000).
- Elected to *Fellow of the OSA* "for the invention and demonstration of the resonant-cavity LED and the photon-recycling semiconductor LED". OSA Fellows are elected by the OSA Board of Directors (2001)
- Recipient of the Boston University Provost Innovation Fund Award (Provost Dennis D. Berkey) valued at $ 25,000 for research and development of promising technologies (2001)
- Elected to *Fellow of the APS* "for pioneering contributions to the doping of semiconductors including delta doping, doping of compositionally graded structures resulting in the elimination of band discontinuities, and superlattice doping to enhance acceptor activation" (2001)
- Honored with RPI Medal as Senior Constellation Chair during Investiture Ceremony (2002)
- Received "2002 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award" (2002)
- Inducted as Wellfleet Senior Constellation Professor, Future Chips, Rensselaer Polytechnic Institute, November 21 (November 2003)
- Distinguished Lecturer of the IEEE Electron Devices Society (2003–2006)
- Elected member in Eta Kappa Nu (2004)
- "Best Oral Presentation Award" was won by Ph. D. student Hong Luo (who was the presenter), J. K. Kim, Y. A. Xi, J. M. Shah, Th. Gessmann and E. F. Schubert "Improvement of extraction efficiency of GaInN light-emitting diodes by employment diffuse omni-directional reflectors" *Connecticut Microelectronics & Optoelectronics Consortium (CMOC)*, 14th annual symposium, New Haven CT, March 17 (March 2005).
- "Best Student Poster Award" of the *International Semiconductor Device Research Symposium (ISDRS)* was won by Ph. D. student J.Q. Xi (presenter), Jong Kyu Kim, Dexian Ye, Jasbir S. Juneja, T.-M. Lu, Shawn-Yu Lin, and E. Fred Schubert "Optical Thin Films with Very Low Refractive Index and Their Application in Photonic Devices", *International Semiconductor Device Research Symposium (ISDRS)*, Dec. 7 – 9, Bethesda, MD (December 2005)
- "MRS Silver Award" of the Materials Research Society was won by Ph. D. student Yangang Andrew Xi (who was the presenter), K. X. Chen, F. Mont, J. K. Kim, C. Wetzel, E. F. Schubert, W. Liu, X. Li, J. A. Smart "Extremely high quality AlN grown on (0001) sapphire by using metal-organic vapor-phase epitaxy" *Materials Research Society (MRS) Fall Meeting*, Boston MA, November 27 – December 1 (2006) Boston MA (December 2006)
- "25 Most Innovative Micro- and Nano-Products of 2007 Award" in July 2007 issue of *R&D Magazine* and *Micro/Nano Newsletter*. This recognition was given for the "Non-Reflective Coating" product that was published in *Nature Photonics* in 2007; full citation: Xi, J.-Q., Martin F. Schubert, J. K. Kim, E. F. Schubert,

Patent Owner 138 East Ex. 2001
Page 058

Minfeng Chen, Shawn-Yu Lin, Wayne Liu, and Joe A. Smart "Optical thin-film materials with low refractive index for broadband elimination of Fresnel reflection" *Nature Photonics* **1**, 176, March 2007 (July 2007)

- "Scientific American 50 Award" of 2007, as published in the January 2008 issue of *Scientific American*. According to the *Scientific American Magazine*, this award "celebrates visionaries from the worlds of research, industry and politics whose recent accomplishments point toward a brighter technological future for everyone" (January 2008)
- "Editors' Choice" of *Science Magazine*, *Science*, Volume **319**, page 1163, February 29 (February 2008). This distinction was awarded for the publication: Jong Kyu Kim et al., "Light-extraction enhancement of GaInN light-emitting diodes by graded-refractive-index indium tin oxide anti-reflection contact" that appeared in *Advanced Materials* **20**, 801, 2008 (February / March 2008)
- Received "2008 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award" (2008)
- "Best Oral Presentation Award" won by David J. Poxson (who was the presenter), Frank W. Mont, Jong Kyu Kim, and E. Fred Schubert "Multilayer nano-structured anti-reflection coating with broad-band omni-directional characteristics" *Connecticut Microelectronics and Optoelectronics Conference* (*CMOC*), University of Connecticut, Storrs, Connecticut, April 9 (April 2008)
- "Best Oral Presentation Award" for presentation: David Meyaard, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Jong Kyu Kim, Daniel D. Koleske, and Mary H. Crawford "Temperature-dependent light-output characteristics of GaInN light-emitting diodes with different dislocation densities" *Connecticut Microelectronics and Optoelectronics Consortium* (CMOC) Symposium, New Haven CT, March 2 (March 2011)
- Identified as top 1% of patentees in the field of optoelectronics by study conducted by Professor Erica Fuchs of Carnegie Mellon University under a study supported by the US National Science Foundation (July 2011)
- Received "2012 Rensselaer Polytechnic Institute Trustee Faculty Achievement Award" (November 2012)
- My "LinkedIn" profile was one of the top 10% most viewed "LinkedIn" profiles during 2012 (January 2013)
- My graduate student, Mr. Ming Ma, received the $ 30,000.00 Lemelson-Rensselaer Student Prize for the invention entitled "Graded-refractive-index (GRIN) structures for brighter and smarter light-emitting diodes"; The Prize is awarded annually by the Lemelson Foundation (March 2013)
- Received the IEEE Life Fellow Award (2022)

Service to the technical community

- Current or former member of the *American Physical Society* (Member of the *Division of Materials Physics*, Member of the *Division of Condensed Matter Physics*), *Institute of Electrical and Electronics Engineers*, *Materials Research Society*, *Optical Society of America*, *Society for Optical Engineering* (*SPIE*), and the *Verein Deutscher Elektrotechniker*
- Co-author of hundreds of research articles, co-inventor of more than 30 United States patents, and numerous foreign patents (1981 – present)
- Gave many invited talks at scientific conferences organized by the *American Physical Society*, *Institute of Electrical and Electronic Engineers*, *Materials Research Society*, *SPIE* (*The International Society for Optical Engineering*), *Electrochemical Society*, *American Vacuum Society*, *Engineering Foundation*, and other professional societies (1985 – present).
- Co-editor (with A. M. Glass) of a Special Issue of the *Journal of Optical and Quantum Electronics* (Vol. **22**, 1990) on "Charge-transport assisted optical non-linearities in semiconductors" (1990)
- Symposium chair of the *American Vacuum Society Greater New York and New Jersey Chapter* on "Epitaxially grown semiconductors with atomic level control" (1991).
- Moderator of MRS Internet discussion on "Doping and Dopants in GaN" (MRS Internet Journal, 1995 – 1997)
- Member of review panels of the National Science Foundation (1995 – present)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1997)
- Technical work has been featured in popular journals, magazines and newspapers including the New Scientist, Discover Magazine, Wall Street Journal, Boston Globe, Focus, and on National Public Radio (1996 – present)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1998)
- Program Committee Member: IEEE IEDM, International Electron Devices Meeting (1999 and 2000)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (1999)
- Program Committee Member: ISBLLED, International Symposium on Blue Laser and Light-Emitting Diodes, Berlin, Germany, March 5 – 10 (2000)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (2000)

Patent Owner 138 East Ex. 2001
Page 059

- Conference Chair and Co-Organizer of the TMS- and ONR-sponsored conference on "Doping, Dopants, and Low Field Carrier Dynamics in Wide Gap Semiconductors", Copper Mountain, Colorado, April 2 - 6 (2000)
- Chair, IEEE LEOS, Central New England Chapter. During my tenure as Chair, the Central New England Chapter won the IEEE LEOS Chapter award for the highest membership growth (1999 – 2000)
- Expert Witness involving semiconductor materials, devices, and packaging including elemental and compound semiconductors such as Si, SiGe, SiC, as well as III–V arsenides, phosphides and nitrides (1998 – present)
- Member of the Board of Governors, IEEE Laser and Electro-Optics Society (LEOS) (1999 – 2000)
- Member of the Optoelectronics Industry Development Association (OIDA) Roadmap Panel on Solid-State Lighting, Albuquerque NM Oct. 26 – 28 (2000)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (2001)
- Panel Member of National Research Council meeting on "Solid-State Lighting:" held at NAS and NAE, Washington DC, March 26 (2001)
- Program Committee Member of SPIE Photonics West conference on "Laser and LED Applications" chaired by Dr. Kurt Linden, San Jose CA Jan (2002)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose, CA (2002)
- Program Committee Member: ISBLLED, International Symposium on Blue Laser and Light-Emitting Diodes, Cordoba, Spain, March 11–15 (2002)
- Program Committee Member for subcommittee on "Semiconductor lasers and LEDs" for OSA Conference on Lasers and Electro-Optics and Quantum Electronics and Laser Science Conference (CLEO / QELS) (2002 – 2003) Baltimore MD June 1–6 (2003)
- Reviewer for the National Research Council of report entitled "Partnerships for Solid-State Lighting: Report of a Workshop" authored by the Board on Science, Technology, and Economic Policy. This report is forwarded to the US Congress for the initiation of a national Solid-State Lighting Initiative. (2002)
- Program Committee Member "Lester Eastman conference on high performance devices" University of Delaware, Newark, Delaware, August 6 – 8 (2002)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose CA (2003)
- OIDA Next Generation Lighting (NGL) Consortium. Member of "Light-Emitting Diode" Committee (2003)
- Program Committee Member, International Semiconductor Device Research Symposium (ISDRS) Washington DC, Dec. 8 – 12 (2003)
- Program Committee Member of "Display and Solid-State Lighting Devices" conference for OSA/IEEE Conference on Lasers and Electro-Optics (CLEO) (2003 – 2004)
- Elected Member of the IEEE Electron Device Society Administration Committee (IEEE AdCom) (2003 – 2008)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose CA (2004)
- Program Committee Member "Fourth International Conference on Solid-State Lighting" August 2 – 6 Denver, CO (2004)
- Program Committee Member for the "Blue 2004: Advanced LEDs and Lasers Conference" Hsinchu, Taiwan, May 10 – 12 (2004)
- Conference Chair of SPIE Photonics West conference on "Light-emitting diodes: Research, Manufacturing, and Applications" San Jose CA (2005)
- Program Committee Member "International Semiconductor Device Research Symposium" December 7 – 9 Washington, DC (2005)
- Chair of "Display and Solid-State Lighting Devices" conference of OSA/IEEE Conference on Lasers and Electro-Optics (CLEO) (2005)
- Best Oral Presentation Award (Presenter: Hong Luo) at *Connecticut Microelectronics & Optoelectronics Consortium* (CMOC), 14th annual symposium, New Haven CT, March 17 (March 2005)
- Conference Chair of MRS Spring meeting "Symposium DD: Solid-State Lighting Materials and Devices" San Francisco, April 17 – 21 (April 2006)
- Member on the International Advisory Committee of *First International Conference on Display LEDs* (ICDL 2007), Seoul, Korea, January 31 to February 2 (2007)
- Member, Program Committee of *SPIE Photonics West* conference "Light-Emitting Diodes: Research, Manufacturing, and Applications XI" San Jose, CA, January 20 – 25 (2007)
- Program Chair of *SPIE Photonics West* conference "Semiconductor Lasers and LEDs" San Jose, CA, January 20 – 25 (2007)
- Member, Executive Organizing Committee *SPIE Photonics West* conference "LASE 2007" San Jose, CA, January

20 – 25 (2007)

- Opto Track Chair of *SPIE Photonics West* conference "Semiconductor Lasers and LEDs" San Jose, CA, January 21 – 24 (January 2008)
- Member, Program Committee, Light-emitting diodes: Research, Manufacturing, and Applications, SPIE Photonics West 2008, San Jose, California, January 19 – 24 (January 2008)
- Program Committee Member of the 7th International Symposium on Semiconductor Light Emitting Devices (ISSLED-2008) held in Phoenix, Arizona (USA), April 27 – May 2 (April 2008)
- Member, Program Committee, China SSL 2008, Shenzhen Convention & Exhibition Center, China, July 24 – 26 (July 2008)
- Member, Program Committee, International Workshop on Nitride Semiconductors, IWN 2008, Montreux, Switzerland, October 6 – 10 (October 2008)
- Opto Track Chair of *SPIE Photonics West* conference "Semiconductor Lasers and LEDs" San Jose, CA, January 25 – 29 (January 2009)
- Guest Editor of Special Issue on *Solid-State Lighting* published in the *IEEE Journal of Selected Topic in Quantum Electronics*, July / August edition (August 2009)
- Honorable Conference Chair, 6th China International Forum on Solid-State Lighting (China SSL), Shenzhen Convention & Exhibition Center, China, October 14 – 16 (October 2009)
- Program Committee Member, International Conference on Nitride Semiconductors (ICNS), Jeju, South Korea, October 18 – 23 (October 2009)
- Program Committee Member, The Second International Conference on White LEDs and Solid-State Lighting, Taipei, Taiwan, December 13 – 16 (December 2009)
- Editor, *Compound Semiconductors and Energy Applications and Environmental Sustainability*, Materials Research Society (MRS) Symposium Proceedings Volume 1167 (MRS, Warrendale PA, 2009)
- Conference Chair, OPTO, *SPIE Photonics West 2010*, San Francisco, California, January 23 – 27 (January 2010)
- Guest Editor of Special Issue on *Light-Emitting Diodes* published in the *IEEE Transactions on Electron Devices* (January 2010)
- Program Committee Member, *8th International Symposium on Semiconductor Light Emitting Devices* (ISSLED), Beijing, China, May 16 – 21 (May 2010)
- International Advisory Committee Member of the 16th *Microoptics Conference* (MOC'10) held in Hsinchu, Taiwan, sponsored and endorsed by OSA and IEEE/Photonics Society and organized by National Chiao Tung University, Oct. 31 to Nov. 3 (October 2010)
- Member of Academic Committee of *China Solid-State Lighting Conference* (CHINA SSL 2010) Shenzhen, China, October 14 – 16 (October 2010)
- Conference Co-Chair, OPTO, *SPIE Photonics West 2011*, San Francisco, California, January 22 – 27 (January 2011)
- Executive Organizing Committee OPTO, *SPIE Photonics West 2011*, San Francisco, California, January 22 – 27 (January 2011)
- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid-State Lighting XV *SPIE Photonics West 2011*, San Francisco, California, January 22 – 27 (January 2011)
- Member of CLEO Subcommittee 15, entitled "LEDs, Photovoltaics and Energy-Efficient ("Green") Photonics" for the 2011 Conference on Lasers and Electro-Optics (CLEO), Baltimore, Maryland May 1 – 6 (May 2011)
- Member of the Academic Committee of the 8th China International Forum on Solid-State Lighting (CHINA-SSL-2011) Guangzhou November 8 – 10 (November 2011)
- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid-State Lighting XV *SPIE Photonics West 2012*, San Francisco, California, January 21 – 26 (January 2012)
- Member of CLEO Subcommittee 15, entitled "LEDs, Photovoltaics and Energy-Efficient ("Green") Photonics" for the 2012 Conference on Lasers and Electro-Optics (CLEO), San Jose, California, May 6 – 11 (May 2012)
- Member of Academic Committee of the 9th China International Forum on Solid-State Lighting (CHINA SSL 2012), Guangzhou, China, November 5 – 7, 2012 (November 2012)
- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid-State Lighting XVI *SPIE Photonics West 2013*, San Francisco, California, 2 – 7 February 2013 (February 2013)
- Member of CLEO Subcommittee in the topic area: "Science & Innovation 15: LEDS, Photovoltaics and Energy-Efficient ("Green") Photonics" for the CLEO 2013 conference, April 28 – May 3, 2013 in Baltimore, Maryland (May 2013)
- Member, International Advisory Committee of the International Conference on Advanced Electromaterials (ICAE 2013) held on Jeju Island, Korea, from November 12 – 15, 2013 (November 2013)

Patent Owner 138 East Ex. 2001
Page 061

- Program Committee Member, *Solid-State and Organic Lighting* (*SOLED*), OSA Topical Meeting, 3 – 7 November 2013, Marriott Tucson Star Pass, Tucson, Arizona, USA (November 2013)
- Co-Chair, OPTIC International Conference, Chung Li, Taiwan, National Central University, December 5 – 7, 2013 (December 2013)
- Program Committee Member of conference entitled: "Light-Emitting Diodes: Materials, Devices, and Applications for Solid-State Lighting XVII" *SPIE Photonics West* 2013, San Francisco, California, 1 – 8 February (2014)
- Publication Committee Member, *5th International Conference on White LEDs and Solid-State Lighting* (White LEDs), Jeju Island, Korea, May 25 – 28, 2014 (May 2014)
- Sub-Committee Chair of Track 6: Displays, Solid-State Lighting, Photovoltaics, and Energy-Efficient Photonics of *Asia Communications and Photonics Conference 2014* (ACP 2014). ACP is the largest and the most influential conference in Asia and Pacific Rim for communications and photonics technologies. ACP 2014, Shanghai International Convention Center, Shanghai, China, November 11 – 14 (2014)
- International Consultant of technical seminar of the 11th China International Forum on Solid-State Lighting (SSL-China 2014) Guangzhou, China, November 6 – 8 (2014)
- Member of the International Advisory Committee of the 11th International Symposium on Semiconductor Light Emitting Devices (ISSLED 2017) held in Banff, Canada on October 8 – 13 (2017)
- Assisting the US Judicial Government Branch (various US District Courts), the USPTO (US Patent and Trademark Office) and the ITC (International Trade Commission) by serving as an independent Technical Expert Witness (1997 to present)

Books

- ***Doping in III-V semiconductors*** (author) Hardback and paperback, 628 pages (Cambridge University Press, Cambridge, UK, 1993). The following excerpt is from a book review by D. L. Miller, *University of Pennsylvania*, University Park PA, which appeared in *Physics Today*, Oct. 1994, p. 71: "[...] Fred Schubert has written a book that very nicely fills two roles: It serves as a reference volume for those of us who use III-V materials, and it provides enlightening explanations of interesting and important problems in semiconductor physics. [...] Schubert, who is employed by AT&T Bell Laboratories, brings his extensive research involvement with III-V materials physics straight to this book. His lucid explanations of some of the important physics of doped semiconductors is a major strength. For example, the chapter on deep centers provides the clearest treatment of the DX center I can remember reading, and it uses the large lattice distortion model and configurational coordinates introduced for the DX center to describe the EL2 deep level. This book can also serve as an excellent reference volume, because it briefly describes epitaxial growth techniques and the doping methods used with them, catalogs dopant-related phenomena, describes characterization techniques and provides 45 pages of citations to published articles and books. [...] I will use it to help my graduate students in the physics of semiconductors. [...] It will certainly be available on my bookshelf, in part to remind me what the Burstein-Moss shift is and in part for the literally hundreds of references that it provides on nearly every topic related to III-V semiconductor doping. Because of its clarity in treating some interesting phenomena of modern semiconductor physics, you too might want to get a copy of this book, even if you believe that Ga and As are just poor alternatives for doping silicon"
- ***Delta doping in semiconductors*** (editor) Hardback and paperback, 616 pages (Cambridge University Press, Cambridge, U. K., 1996)
- ***Light-emitting diodes*** (author) Hardback and paperback, 328 pages (Cambridge University Press, Cambridge, UK, 2003). The following excerpt is from a book review by David Bour, *Agilent Laboratories*, Palo Alto CA, which appeared in *Physics Today*, Nov. 2004, p. 66: "[...] In "*Light-emitting diodes*", E. Fred Schubert provides an excellent review of the physics and technology of semiconductor LEDs. […] Interesting anecdotes like [the first demonstration of electroluminescence], clearly written by someone with a broad perspective and expertise, appear throughout the book, making it enjoyable to read. […] Schubert provides an excellent description of the undesirable [non-radiative] recombination pathway. […] Schubert has made pioneering contributions to those devices, and this variety of LEDs may become more widely used in the future. […] Overall, "*Light-emitting diodes*" is an excellent examination of the physics and technology of semiconductor LEDs. The narration is simple and direct, and the book is well referenced for those seeking a deeper understanding of the topic. Written for the graduate level, the text will appeal to a broad audience; and for specialists who make semiconductor LEDs and laser diodes, it will serve as a useful connection to the scientific literature."
- ***Light-emitting diodes, second edition*** (author) Hardback, 422 pages (Cambridge University Press, Cambridge, UK, 2006)
- ***Physical Foundations of Solid-State Devices*** (author) eBook, 275 pages, ISBN-13: 978-0-9863826-2-8 (Google Books, Mountain View CA, 2015)

Patent Owner 138 East Ex. 2001
Page 062

- ***Light-emitting diodes, 3rd edition*** (author) eBook, 672 pages with hundreds of colored illustrations, ISBN: 978-0-9 863826-6-6 (Google Books, Mountain View CA, 2018) "The 1st edition of the book "Light-Emitting Diodes" was published in 2003. The 2nd edition was published in 2006. The current 3rd edition of the book is a substantial expansion of the second edition and has 37 chapters. The book includes a thorough discussion of white light-emitting diodes (LEDs), phosphor materials used in white LEDs, packaging technology, and the various efficiencies and efficacies encountered in the context of LEDs. The background of light, color science, and human vision is provided as well. The fully colored illustrations of the 3rd edition are undoubtedly beneficial given the prominent role of light and color in the field of LEDs. The book is a comprehensive discussion of the LED, particularly its semiconductor physics, electrical, optical, material science, thermal, mechanical, and chemical foundations. The 3rd edition is published in electronic format in order to make the book affordable and easily accessible to a wide readership."

Courses and laboratories developed at Boston University

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

Courses taught at Boston University

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

Courses taught at Rensselaer Polytechnic Institute

- Graduate Course "Semiconductor devices and models II" (ECSE-6290)
- Undergraduate course "Microelectronics technology" (ECSE-2210)
- Undergraduate course "Fields and Waves 1" (ECSE-2100)
- Graduate course "Quantum mechanics applied to semiconductor devices" (ECSE-6968)
- Graduate course "Physical foundations of solid-state devices" (SC-6960)
- Graduate course "Light-emitting diodes and solid-state lighting" (SC-6961)
- Undergraduate course "Introduction to Electronics" (ECSE-2050)
- Other courses "Research", "Guided Study", "Master Thesis", and "Dissertation"

Teaching evaluations and students' comments

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

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

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

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

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

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

2002 – Students made the following comments: "Always prepared … presented difficult material in a manner that was easy to understand … presented everything neatly … very helpful and organized … presents subjects in a very easy and friendly format … very well qualified … great experience … very detailed notes … well organized … very useful … very good diagrams and explanations … he knows the material extremely well … notes given to us

are extremely helpful … professor was very knowledgeable … was able to answer any of our questions … very informative course … very knowledgeable and a great teacher … the instructor is enthusiastic to teach students … the instructor can explain the theory very clearly …"

2003 – Students made the following comments: "Great overall knowledge … good organization skills … demonstrations were very interesting and useful … effective instructor … handouts were extremely useful and organized … good course for completely understanding many points of fiber optics …"

2004 – SPIE short course: "Encouraged questions and handled them well … excellent short course … I really appreciated and enjoyed this course … good course – covered very broad matters … the instructor was very knowledgeable on the topic … excellent! …"; RPI Semiconductor devices and models II (ECSE 6290): Overall excellence of teacher: 4.8 out of 5.0. Student comments: "course was very well prepared … [course] was very organized … this is an excellent course … I learned a lot from this course … the course was very good … thanks Prof. Schubert for a wonderful course … it's been a great course … thank you …" RPI Microelectronics Technology (ECSE 2210): Overall excellence of teacher: 4.7 (average 4.2). Overall excellence of course: 4.3 (average 3.9). Student comments: "Understandable presentation … great job [of] Prof. Schubert … very nicely done class … very helpful throughout the entire course … provided timely explanations to complicated material … very informative … course was fun and interesting … very interesting lecturer … very down to earth and easy to ask for help … [instructor] did a good job in presenting [material] … good course … fun course … excellent instructor … he is a great guy and very knowledgeable … I would definitely take a class from him again" **Book review** by Neal Oldham (San Jose, CA, USA) on "Doping in III–V semiconductors" (E. F. Schubert, Cambridge University Press, Cambridge UK, 1993) on amazon.com (May 17, 2002): "[This is the] best book I've encountered in the semiconductor field. This is, no question, the best book that I've encountered in the entire field of semiconductor physics. It is expertly organized and indexed, easy to follow, complete in its treatment of electrical and materials-science aspects of III-V semiconductor production and measurement, well-written ... worth every penny if you even have the most remote interest in the subject." **Book review** by Debdeep Jena (Santa Barbara, CA, United States) on "Doping in III–V semiconductors" (E. F. Schubert, Cambridge University Press, Cambridge UK, 1993) on amazon.com (July 6, 2001): "Very useful text for semiconductor crystal growers. Doping is a big, big issue in semiconductors; this text does appreciable justice in its treatment of the issue. In addition, Schubert treats heterostructure physics appreciably well (in fact better than many textbooks on semiconductor physics!). Perusal of this book has proved very rewarding for me, and I expect it will do the same wonder for you too."

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

2006 – SPIE Photonics West short course student feedback: "Excellent, knowledgeable … excellent presentation …" (numerical score 3.91 out of 5.0). ECSE 6961 (Light-emitting diodes and solid-state lighting): "excellent … Informative, comprehensive and interesting … the best part of this course, in terms of my learning experience, has been the course materials … just an outstanding class … so much is newly discovered and so much is current on-going research and commercially relevant … Dr. Schubert is obviously a leading researcher and did a great job of conveying his experience and understanding to the class … a highly technical topic that still makes a good general conversational topic … I liked the course material … I liked the fact that Prof. Schubert lectured directly from the textbook … I liked the structure of the course … I learned a lot about lasers and LEDs and other optical devices … it is a basic and fundamental class … the instructor gives ideas, concepts, and samples very clearly … very good course … students interested in LEDs and solid-state lighting are strongly recommended to take it … liked the overall coverage … the teaching pace was good … he covered a lot of material that is

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

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

2008 – SPIE Photonics West short course feedback: "Very good … clear … very nice … answered questions readily …" (numerical score 4.3 out of 5.0) … ECSE 6961 (Light-emitting diodes and solid-state lighting) feedback: "It was great for me to have the opportunities to take two consecutive classes, *Physical Foundation* and *LEDs*, from you … both these classes have taught me a lot … they were very well organized … thank you for all the help … I have really enjoyed your classes … relevant material … very good professor …" (numerical scores: 4.3 out of 5.0) … Internet educational materials feedback: "I recently came across your course notes while trying to get a basic understanding about semiconductors and I wanted to thank you. Your notes for course "ECSE-2210 Microelectronics Technology" are the most useful and informative thing I have found on semiconductors on the Internet. I'm a chemist by trade and this is a great introduction for me …" 2007 Chautauqua Short Course and High School Teacher Summer Course, held at RPI June 26 and July 12, 2007 (numerical average of scores: 9 out of 10) … ECSE 6968 (Physical Foundations of Solid-State Devices) feedback: "Prof. Schubert is one of the best professors I've ever had … his ability to explain difficult and complex materials in a clear and concise manner is unmatched … the presentations, although time consuming, I felt were a great idea … thanks for your efforts professor! … I have really enjoyed taking this course …" By email: "Thank you professor … it has been a pleasure taking this course with you …" (numerical scores: 4.4 out of 5.0)

2009 – SPIE Photonics West short course feedback by students: "One of the best short courses I have taken … it was very nice to hear about the history of LEDs … very interesting but also very theoretical …" (numerical score 4.1 out of 5.0). ECSE 2210 (Microelectronics Technology) "Great course … instructors were excellent … encourages students to stay up to date with the subject matter … Thanks for this well-organized class … [the instructor] tries

to get students to come out with the best grade possible … this was a good class …" ECSE 6968 (Physical Foundations of Solid-State Devices) feedback by students: "It is really an excellent course … clear hand script … great professor! …" (numerical scores: 4.7 out of 5.0)

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

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

2012 – Feedback on Internet-based materials: "I'm Cheng Liu [Wuhan National Laboratory for Optoelectronics, China], currently a graduate student major in Physical Electronics … I deeply admire your profound knowledge on this field and your unselfish sharing of it …"; … SPIE Photonics West short course feedback: "Dr. Schubert was very clear and very patient with people who had questions … the materials were comprehensive …"; Feedback on Internet-based materials: "Supremely-rich course contents posted on your website. Thank you very much for showing such awesome materials for the world to see …" (Prof. Natee Tangtrakarn, Thailand) … ECSE 6962 (Light-Emitting Diodes and Solid-State Lighting) feedback: "… very interesting course … Professor Schubert did a great job explaining the material … his textbook is very clear and understandable … nice course … I learned a lot of new things by taking it …" (numerical scores: 4.7 out of 5.0)

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

Patent Owner 138 East Ex. 2001
Page 067

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

2015 – *SPIE Photonics West Short Course SC-052 titled Light Emitting Diodes*, Verbatim comments: "I was very satisfied with this short course" Numerical score of students' evaluations: 4.53 out of 5.0; ***RPI Course ECSE-6960 Light-Emitting Diodes***; Verbatim comments: "the class has been excellent! ... I've learned a good amount about LEDs ... Also I'd like to thank you for a great semester and say that you've peaked my interest in the LED field! ... I would like to add that the course was an excellent experience for me and that I really enjoyed learning about LED technology! ... Thank you very much for teaching such a wonderful class ... It was a great learning course" Numerical score of students' evaluations: 5.0 out of 5.0. ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments: "This class is going perfectly and I love the way it's run ... The material is great and understandable ... the pace is perfect ... I like the pacing of the course and the fact that we spend time really developing an understanding of the theory and concepts that we will be using ... I like the Professor ... The lectures are great ... I really enjoy this professor and he is very understanding of the students' levels of learning and focused on that ... Professor Schubert is clear and easy to understand ... Overall a very good professor ... very knowledgeable and helpful ... I thought the professor was very knowledgeable and was an excellent instructor ..." Numerical score of students' evaluations of instructor: 4.17 out of 5.0.

2016 – *SPIE Photonics West Short Course SC-052 titled Light Emitting Diodes*, Verbatim comments: "This has been my favorite course (over 3 years) ... Well-structured presentation, and well given ... I was surprised by how much I didn't know. I learned a lot ... Explained difficult concepts in a clear and simple manner ... Able to go "off script" to clarify during questions." Numerical score of students' evaluations: 4.56 out of 5.0; ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments: "This is cool material ... This class was one of the most well put together I have ever taken in terms of lecture pace, lecture clarity, TA support, and quality of teaching and communication ... The lectures never felt too long or too short, the pace was good, I never felt lost or without an option to turn for help ... The homework was neither too long nor too short, and was well balanced with conceptual and quantitative questions ... Prof. Schubert's lecture style was very clear, concise, and to the point, with many useful examples in real life scenarios which made the material more interesting ... Very well done ... Great class ... I liked the pace of the class ... it helps with understanding the material a lot ... The labs [...] were fun and very educational ... Overall, I learned a lot from this course ... The speed of the class is perfect ... I really got a chance to learn ... This professor is very good ... Also, [in] the lab section I was able to really break down what I learned in class ... Schubert has the neatest handwriting of any professor I've ever had in my 3 years here ... His diagrams are extremely neat and he is easy to understand verbally too ... Lots of conceptual knowledge covered ... Overall [...] it was an enjoyable class ..." Numerical score of students' evaluations: 5.0 out of 5.0. ***RPI Course ECSE-2210 Microelectronics Technology***; Verbatim comments: "So far, this has been one of my favorite courses at RPI … I'm a huge fan of Prof. Schubert's ability to clearly describe concepts both conceptually and mathematically … Class activities […] were really helpful! … Otherwise the class is great! … Prof Schubert knows his stuff … Best professor I have had … This course was well taught … Professor Schubert's explanations were very clear and understandable … he took time to address student questions with in-depth answers … I feel as though I gained a lot from this course, especially with regards to explanations of why certain things in ECSE-2050 (Intro to Electronics) occur the way they do like where the diode property comes from and how material properties of electronic components give rise to the very real circuit characteristics we see in ECSE-2050 labs … In this sense, Microelectronics Tech is a very good companion class to Intro to Electronics, and I highly recommend future students take them at the same time … this was a quite good class … Best MET instructor … I was so actively engaged during the lectures that it was kind of scary ... The lecture notes and lectures were mostly great … The material covered in it was succinct and interesting,

yet still covered the knowledge needed to tackle engineering problems in semiconductors …" Numerical score of students' evaluations: 4.64 out of 5.0.

2017 – ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments: "I thoroughly enjoy this class … Schubert is awesome! … Enjoyed the class … He is a good teacher … Most teachers talk really fast making it hard to follow … Schubert talks slow and explains things really well … Professor Schubert is an excellent professor, and has been one of my favorites at RPI so far … He made a difficult topic approachable, interesting and understandable … I hope I have him as a professor in the future … Thank you … I enjoyed this class, especially the labs … Lectures were good too … great class! … The professor does a great job of engaging the students by asking questions and making students ask questions to make them think about the labs … This course is overall excellent in that the professor does know the pace of class and gives feedback appropriately …"; Numerical score of students' evaluations: 4.63 out of 5.0. ***SPIE Photonics West Short Course SC-052 titled Light Emitting Diodes***, Verbatim comments: "the course covered a wide variety of concepts …" Numerical score of students' evaluations: 4.03 out of 5.0.

2018 – ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments: "Professor Schubert is great and very entertaining to listen to in the lab and in lecture … Really appreciate how Prof. Schubert structures lectures … Schubert is great! … The professor is excellent at relaying concepts … This course is very interesting and it goes at a good pace … One of the better professors here at RPI … He cares about his students and helps them to learn the most through lectures and labs … Fantastic course that goes into great detail into not only knowing the material but also understanding the material … [the course] has been clarified and allowed for a greater learning process." Numerical score of students' evaluations of instructor: 4.17 out of 5.0. ***RPI Course ECSE-6220 Physical Foundations of Solid-State Devices***; Verbatim comments: "Perfect professor, no complaints." Numerical score of students' evaluations (median): 5.0 out of 5.0.

2019 – ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments by students: "Schubert is excellent in relating information in a practical manner especially in the lab … Overall, both the professor and TAs prioritize if students understand material over semantics in reports and homework, which is really helping me in the course, and feedback given is incredibly helpful in both … Schubert is a mystery. He speaks very slowly and clearly, but you somehow learn everything at a very fast rate … Class […] being just the right amount focused and adequately paced … Overall great class … Labs were educational and we were allowed to have fun with it … Otherwise great lectures, notes were available and understandable … this was one of my favorite classes … Very well run by Schubert … lectures were informative and easy … labs were fun … The TA's were allowed to have personalities and interact with the students … 10/10 would take again … Schubert was okay … The best parts about the course for me were everything was online and I could copy the notes at my leisure with my busy schedule … I also liked that exams were open book and we had a lot of opportunities for practice … I have nothing but good things to say about both TAs and Professor Schubert – this has been my favorite class this semester … Though challenging, I have found the course material very interesting and all teachers have been excellent … Course was good … I like Professor Schubert's class notes online. They're super well written and helpful." Numerical score of students' evaluations of instructor: 4.63 out of 5.0 (average) and 5.0 out of 5.0 (median).

2019 – ***RPI Course ECSE-6280 Light Emitting Diodes***; Verbatim comments by students: "This was a great course … I learned a lot during the semester … Great class … Really enjoyed Professor Schubert's expertise on the subject … Gives both in-depth technical knowledge as well as high level background to better understand the driving factors of the LED industry … Would highly recommend it to anyone in ECSE." Numerical score of students' evaluations: 4.83 out of 5.0 (average) 5.0 out of 5.0 (median).

2020 – ***RPI Course ECSE-2100 Fields and Waves 1***; Verbatim comments by students: "I really enjoyed this class … the cool labs with good help and good lectures made me really enjoy this class and help the information stick in my head better … The labs provided a great use to show theory in practice and how certain concepts are applied to real-life applications … The laboratory session was also a great time to ask questions and have in-depth talks about the material … I would have already commended this professor for class organization and material availability prior to online courses (course material easily available, organized well, and easy to understand; interactive lectures; interactive labs better than most other ECSE courses), Prof. Schubert handled the change to online coursework best of all of my professors and maintained the quality of lecture almost perfectly … The 'live' online classes were interactive and courteous by students and the professor, organized, and just as in-depth as before, even including miniature homemade demonstrations and experiments … The course was taught very fundamentally which allowed me to think and learn more … Thank you, Professor Schubert … I really missed your live lectures and labs! … Professor Schubert made the best of the situation of online learning … Great class … I learn a lot from this class … I enjoy lab sessions and try never to miss any class … Prof. Schubert is really good!" Numerical score of students' evaluations: 4.75 out of 5.0 (average) 5.0 out of 5.0 (median).

2020 – ***RPI Course ECSE-2050 Introduction to Electronics***; Verbatim comments by students: "I really enjoyed how easy it was to follow along with the lecture … I really enjoyed the content of this course, and I feel that the

applications of this content in the lab were extremely effective to help students understand the content … the concepts in general were extremely interesting … I liked how the lecture sessions for this class provided much more room for discussion and examples than nearly any other ECSE course I have taken at RPI so far … Schubert was very aware of the students ability to fully comprehend the topic ... He was very patient with the students that needed extra explaining … I learned a lot about the course material … I liked the one-on-one attention we received in the in-person lab … I enjoyed the in person laboratory sessions, they were a good place to get all my questions answered … I really like the lecture notes and the detailed diagrams / graphs that help explain the concepts … Professor Schubert does a great job of breaking down the material, he always tries to engage the students in every lecture … Very clear notes, responded quickly, answered any confusing questions really well, and very nice and accommodating towards the current COVID situation everyone is going through … He had very organized notes that helped especially with the difficulties of online learning … I loved the explanation of diodes, it's never been so clear to me before! … Examples were excellent … The course was great! … I learned a lot and this course stimulated my interest … Very engaging … stimulates participation … Professor Schubert was a refreshing exception … the professor was very knowledgeable in the subject area … explanations were clear and easy to understand … I really like the format of this class compared to my other classes … I really enjoyed the format … Very detailed lecture, very helpful with students, made very complex material easy to understand … Prof is really understanding and cares about his students … He is really willing to work with us which I found is really rare at RPI ... He is easily one of the best professors I have had … He cares most about whether we are learning and understanding, rather than following his desired schedule perfectly ... Cannot say anything bad about Prof Schubert … Class is great" Overall instructor rating: 4 out of 5. Overall course rating: 4 out of 5.

2021 – ***RPI Course ECSE-2050 Introduction to Electronics***; Verbatim comments by students: "Class has been going smoothly … Professor Schubert includes real world-examples of devices in his lectures, showing the importance of our course materials … He is always very considerate of students, trying to adapt to what would help people most … He engages students in lectures." Overall instructor rating: 4.8 out of 5.0. Overall course rating: 4.6 out of 5.0.

2021 – ***RPI Course ECSE-2050 Introduction to Electronics***; Verbatim comments by students: "Professor is always able to conceptually answer our questions, and run through circuit analysis with us if the results we're measuring don't match up … I tried taking this class once before, and I failed it. This time around, I feel like I know everything about everything. I had never imagined just what a difference teaching style could make in my ability to learn information, but this class is so much more welcoming to me this time around. It was with a different professor the first time. I much prefer Professor Schubert and the way he conveys information so effortlessly. He also seems like he's passionate about teaching the information and his handwritten notes are astonishingly detailed … Great professor! I appreciate Professor Schubert taking the time to clarify different topics and always checking in with the students. He seems to genuinely care about our education. He is strict about deadlines, more so than other professors at least, but I think he has earned that … Professor Schubert is very friendly to his students … He was very helpful and one of the few professors who actually stays and talks to students all throughout the lab period. It was very helpful because often I would think that I fully understood a concept and then he would ask a question that would either stump me or reinforce information. Additionally he kept lectures short and to-the-point, which I appreciate." Overall instructor rating: 4.3 out of 5.0. Overall course rating: 4.3 out of 5.0.

2022 – ***RPI Course ECSE-2050 Introduction to Electronics***; Verbatim comments by students: "Great professor! … Handwriting is amazing … His notes are flawless and easy to understand … This course covers much more than most other EE courses I've taken, and yet I feel as though this has been the easiest EE course due to his teaching abilities … Professor Schubert is a very knowledgeable professor … It's clear that he wants his students to learn …" Overall instructor rating: 4.3 out of 5.0. Overall course rating: 4.4 out of 5.0.

2022 – ***RPI Course ECSE-2210 Microelectronics Technology***; Verbatim comments by students: "I think Schubert does a great job of teaching … He makes the pn junctions as interesting as he can … I also love the chalk-board! So great, every professor should be forced to use it, because you can follow the work so smoothly (not like powerpoints) … I would not change the class … I also like how Prof. Schubert asks for feedback from everyone after class … Course was at a great pace and the level of difficulty … Professor Fred Schubert is one of my most favorite professors at RPI … I am sad to see in the course schedule for Spring 2023 that he is not teaching any 4000 level ECSE courses … I think that the department and students are missing out by not having someone as knowledgeable as him teaching more conceptually hard topics because Professor Schubert does that exceptionally … Best ever lecture experience, clear structure of lecture notes, comprehensive homework that helps to improve students' understandings, and always eager to solve students' questions … Thanks for another great course Professor!"

2024 – ***RPI Course ECSE-2050 Introduction to Electronics***; Verbatim comments by students: "... It's great to learn how a component works and learn "Iconic Circuits" that use those components … I really appreciated the

Homeworks, they were well thought out and helped me understand the content … I liked the open notes exams, they allowed me to use the notes I took in class and demonstrate how I can apply the concepts we learned in class to a different problem … I appreciated [Professor Schubert] talking to everyone in [the] lab one-on-one … I also liked that he showed interest in all the students and answered our questions promptly and thoroughly … Very nice and understanding professor, one of the best in the ECSE department … Professor Schubert seems to know what he is talking about … Professor Schubert is very nice and during labs walks around and asks students questions making sure we understand the concepts … He also introduced some applications not taught in the previous versions of the course and even added a lecture on class-D amplifiers to attempt to keep the course up with modern technology … The last few lectures left a good impression though and were extremely engaging …"

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

Dr. Li-Wei Tu	Post-Doctoral Fellow	1988–1990
Dr. Neil Hunt	Post-Doctoral Fellow	1991–1993
Dr. Matthias Passlack	Post-Doctoral Fellow	1993–1995
Dr. Wolf Grieshaber	Post-Doctoral Fellow	1995–1997
Dr. Thomas Gessmann	Post-Doctoral Fellow	2000–2002
Dr. Jong Kyu Kim	Post-Doctoral Fellow	2003–2005
Dr. Min Ho Kim, SEMCo	Visiting Engineer	2007–2008
Prof. Ji-Myon Lee, Sunchon Univ.	Visiting Professor	2007–2008
Dr. Jaehee Cho	Post-Doctoral Fellow	2008–2009
Dr. Yongjo Park, Samsung LED	Visiting Vice President	2010–2012
Dr. Yangang Andrew Xi	Visiting Scientist	2013–2014
Dr. Guan-Bo Lin	Post-Doctoral Fellow	2014–2015

Graduate students for which I served as Major Research Advisor

Dr. Dean A. Stocker	Ph.D. Dissertation	Ph. D. completed in 1999
Xiaoyun (Jane) Guo	Master Thesis	M.S.E.E. completed in 1999
John W. Graff	Master Thesis	M.S.E.E. completed in 1999
Dr. Ian D. Goepfert	Ph.D. Dissertation	Ph. D. completed in 2000
Yun-Li Li	Master Thesis	M.S.E.E. completed in 2000
Dr. Xiaoyun (Jane) Guo	Ph.D. Dissertation	Ph. D. completed in 2001
Dr. John W. Graff	Ph.D. Dissertation	Ph. D. completed in 2002
Dr. Erik L. Waldron	Ph.D. Dissertation	Ph. D. completed in 2002
Jay M. Shah	Master Thesis	M.S.E.E. completed in 2002
Dr. Yun-Li Li	Ph.D. Dissertation	Ph. D. completed in 2003
Jingqun ("JQ") Xi	Master Thesis	M.S. completed in 2003
Yangang Andrew Xi	Master Thesis	M.S. completed in 2003
Ronald Jackson	Master Thesis	M.S. completed in 2004
Sameer Chhajed	Master Thesis	M.S. completed in 2004
Hong Luo	Master Thesis	M.S. completed in 2005
Xiaolu Li	Master Thesis	M.S. completed in 2005
Kaixuan Chen	Master Thesis	M.S. completed in 2005
Dr. Jay M. Shah	Ph.D. Dissertation	Ph. D. completed in 2006
Frank Mont	Master Thesis	M.S.E.E. completed in 2006
Dr. Hong Luo	Ph.D. Dissertation	Ph. D. completed in 2006
Dr. Jingqun ("JQ") Xi	Ph.D. Dissertation	Ph. D. completed in 2006
Dr. Yangang Andrew Xi	Ph.D. Dissertation	Ph. D. completed in 2006
Won Seok Lee	Master Thesis	M.S. completed in 2007
Qi Dai	Master Thesis	M.S. completed in 2007
Di Zhu	Master Thesis	M.S. completed in 2007
Jiuru Xu	Master Thesis	M.S. completed in 2007
Ahmed Noemaun	Master Thesis	M.S. completed in 2007
Roya Mirhosseini	Master Thesis	M.S. completed in 2008

David Poxson	Master Thesis	M.S. completed in 2008
Qifeng Shan	Master Thesis	M.S. completed in 2009
Ming Ma	Master Thesis	M.S. completed in 2010
Xing Yan	Master Thesis	M.S. completed in 2010
Dr. Roya Mirhosseini	Ph.D. Dissertation	Ph. D. completed in 2010
Dr. Sameer Chhajed	Ph.D. Dissertation	Ph. D. completed in 2010
Dr. Jiuru Xu	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Frank Mont	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Wonseok Lee	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Di Zhu	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Qi Dai	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Ahmed Noemaun	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. David Poxson	Ph.D. Dissertation	Ph. D. completed in 2011
Dr. Qifeng Shan	Ph.D. Dissertation	Ph. D. completed in 2012
Dr. Ann Mao	Ph.D. Dissertation	Ph. D. completed in 2013
Dr. Xing Yan	Ph.D. Dissertation	Ph. D. completed in 2013
Dr. Ming Ma	Ph.D. Dissertation	Ph. D. completed in 2013
Dr. David Meyaard	Ph.D. Dissertation	Ph. D. completed in 2013
Dr. Guan-Bo Lin	Ph.D. Dissertation	Ph. D. completed in 2013

Expert Witness Consulting Service

1997 ***Case***: Hewlett-Packard Company versus CEO of United Epitaxy Company (Taiwan)
Nature: Trade secret misappropriation
Venue: U.S. District Court.
Law firm: Morrison & Foerster LLP, Washington DC.
Role: I served as technical expert witness on behalf of United Epitaxy (Defendant). I wrote one or more expert reports.

1998 ***Case***: Hewlett-Packard Company versus United Epitaxy Company (Taiwan)
Nature: Patent infringement.
Venue: U.S. District Court for the Northern District of California.
Law firm: Quinn Emanuel Urquhart Oliver and Hedges LLP
Role: I served as technical expert witness on behalf of United Epitaxy (Defendant). I wrote one or more expert reports.

2006 ***Case***: Kerr Company versus 3M and Dentsply International Company.
Nature: Patent infringement.
Venue: U.S. District Court for the Western District of Wisconsin.
Law Firm: Woodcock Washburn LLP, Philadelphia, Pennsylvania.
Role: I served as technical expert witness on behalf of Dentsply (Defendant). I wrote one or more expert reports.

2006 ***Case***: Nichia Corporation (Japan) versus Seoul Semiconductor Company (Korea).
Nature: Design patent infringement.
Venue: U.S. District Court for Northern District of California, San Francisco Division.
Law firm: Foley & Lardner LLP Washington DC.
Role: I served as technical expert witness on behalf of Nichia (Plaintiff). I wrote one or more expert reports; I was deposed.

2008 ***Case***: Seoul Semiconductor (SSC) Company LTD (Korea) versus Nichia Corporation (Japan).
Nature: Patent infringement.
Venue: U.S. District Court for the Eastern District of Texas, Beaumont Division.
Law firm: Morrison & Foerster LLP, Palo Alto, California.
Role: I served as technical expert witness on behalf of Nichia (Defendant). I wrote one or more expert reports; I testified in District Court during the claim construction / Markman hearing.

2008 ***Case***: Professor Gertrude Rothschild versus Toshiba Company (Japan).
Nature: Patent infringement.
Venue: U.S. International Trade Commission (ITC), Washington DC.
Law firm: DLA Piper LLP, San Francisco California.
Role: I served as technical expert witness on behalf of Toshiba (Defendant). I wrote one or more expert reports; I was deposed.

2008 ***Case***: Honeywell Company versus Cree Company and Lumileds Company.
Nature: Patent infringement and Reexamination of patent.
Venue: U.S. District Court for the Eastern District of Texas, Marshall Division. Reexamination before the USPTO's Patent Trial and Appeal Board.
Law firms: Paul Hastings LLP, Washington DC and Ingrassia, Fisher & Lorenz PC, Washington DC.
Role: I served as technical expert witness on behalf of Honeywell (Plaintiff). I wrote one or more expert reports. I testified at the USPTO during a re-examination hearing.

2010 ***Case***: Landmark Screens Company versus MLB Company and Kohler.
Nature: Mishandling of a patent application.
Venue: U.S. District Court for the Northern District of California, San Jose Division.
Law firm: Keker & Van Nest LLP, San Francisco, California.
Role: I served as technical expert witness on behalf of MLB and Kohler (Defendant). Negligence in conjunction with a patent application; I wrote one or more expert reports.

2011 ***Case***: Koninklijke Philips Electronics N.V. versus Seoul Semiconductor (SSC) Company LTD.
Nature: Patent infringement.
Venue: U.S. District Court for the Central District of California Southern Division
Law firm: Latham & Watkins LLP, Washington DC.
Role: I served as technical expert witness on behalf of SSC (Defendant). I wrote one or more expert reports.

2011 ***Case***: Jeou-Nan Tseng versus Home Depot USA Inc. and Guangde LEDup Enterprise Inc.
Nature: Patent infringement.
Venue: U.S. District Court for the Western District of Washington at Seattle.
Law firm: DLA Piper, Philadelphia, Pennsylvania.
Role: I served as technical expert witness on behalf of Home Depot (Defendant). I wrote one or more expert reports.

2011 ***Case***: Lightpanels Ltd. Company versus Fuzhou F&V Photographic Company.
Nature: Patent infringement.
Venue: U.S. International Trade Commission (ITC), Washington DC.
Law firm: Locke Lord LLP, New York, New York.
Role: I served as technical expert witness on behalf of Fuzhou F&V and Nanguang Photographic (Defendant). I wrote one or more expert reports; I was deposed.

2012 ***Case***: Osram Company versus LG Company.
Nature: Patent infringement.
Venue: U.S. International Trade Commission (ITC), Washington DC.
Law firm: Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, Washington DC.
Role: I served as technical expert witness on behalf of LG (Defendant). I wrote one or more expert reports; I was deposed; I testified at the ITC Hearing.

2012 ***Case***: Osram Company versus LG Company and Samsung Company.
Nature: Patent infringement.
Venue: U.S. International Trade Commission (ITC), Washington DC.
Law firm: Covington & Burling LLP, Washington DC.
Role: I served as technical expert witness on behalf of LG and Samsung (Defendant). I wrote one or more expert reports; I was deposed; I testified at the ITC Hearing.

2013 ***Case***: Chao Tai Electron Co. LTD. versus LEDup Enterprise Inc. and others.
Nature: Patent infringement.
Venue: U.S. District Court for the Central District of California.
Law firm: Hunton & Williams LLP, Washington DC.
Role: I served as technical expert witness on behalf of LEDup Enterprise Inc. and others (Defendants). I wrote one or more expert reports.

2013 ***Case***: Nichia Corporation versus Everlight Company and Emcore Company.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.

Law firm: Foley & Lardner LLP, Washington DC.
Role: I served as technical expert witness on behalf of Nichia Corporation (Petitioner). I wrote one or more expert reports; I was deposed.

2014 ***Case***: Everlight Electronics Co. LTD. versus Nichia Corporation.
Nature: Patent infringement.
Venue: U.S. District Court for the Eastern District of Michigan, Southern Division.
Law firm: Foley & Lardner LLP, Washington DC.
Role: I served as technical expert witness on behalf of Nichia Corporation (Defendant). I wrote one or more expert reports; I was deposed; I testified at Phase 1 of trial (jury trial) and I testified at Phase 2 of trial (bench trial).

2014 ***Case***: LEDup Company versus Nicolas Holiday Company.
Nature: Patent infringement.
Venue: U.S. District Court for the Central District of California.
Law firm: Pendleton, Wilson, Hennessey, and Crow PC, Denver, Colorado.
Role: I served as technical expert witness on behalf of LEDup (Plaintiff). I wrote one or more expert reports.

2014 ***Case***: Nichia Corporation versus Everlight Electronics Co. LTD.
Nature: Patent infringement.
Venue: U.S. District Court for the Eastern District of Texas, Marshall Division.
Case number: 02:13-cv-702-JRG (E.D. Texas).
Law firm: Rothwell, Figg, Ernst & Manbeck PC, Washington DC.
Role: I served as technical expert witness on behalf of Nichia (Plaintiff). I wrote one or more expert reports; I was deposed; I testified at trial (bench trial).

2015 ***Case***: Cree Company versus Unity Opto, Unity Microelectronics, and Feit Electric Company
Nature: Patent infringement.
Venue: U.S. International Trade Commission (ITC), Washington DC.
Law firm: Alston & Bird LLP, Silicon Valley, East Palo Alto, California.
Role: I served as expert witness on behalf of Unity Opto Technology *et al*. (Defendants). I wrote one or more expert reports; I was deposed; I testified at trial (ITC Hearing).

2015 ***Case***: Honeywell International Inc. versus Cree Inc.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.
Law firm: Arnold & Porter LLP, San Francisco, California.
Role: I served as expert witness on behalf of Honeywell International Inc. (Plaintiff). I wrote one or more expert reports.

2015 ***Case***: Honeywell International Inc. versus Cree Inc.
Nature: Patent infringement.
Venue: U.S. District Court for the District of New Jersey.
Law firm: Arnold & Porter LLP, San Francisco, California.
Role: I served as expert witness on behalf of Honeywell International Inc. (Plaintiff).

2015 ***Case***: Cree Inc. versus Kingbright Electronic Co. LTD and SunLED Corporation.
Nature: Patent infringement.
Venue: U.S. District Court for the Western District of Wisconsin.
Law firm: Hansen Reynolds Dickinson Crueger LLC, Milwaukee, Wisconsin.
Role: I served as technical expert witness on behalf of Kingbright and SunLED (Defendants). I wrote one or more expert reports; I was deposed.

2016 ***Case***: Acuity Brands Lighting Inc. versus Lynk Labs Inc.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.
Law firm: Haynes Boone LLP, Chicago, Illinois.
Role: I served as technical expert witness on behalf of Lynk Labs (Plaintiff). I wrote one or more expert reports.

2016 ***Case***: Godo Kaisha IP Bridge 1 Company versus Broadcom Company and others.
Nature: Patent infringement.
Venue: U.S. District Court for the Eastern District of Texas, Marshall Division.
Law firm: Ropes and Gray LLP, New York City, New York.
Role: I served as technical expert witness on behalf of IP Bridge 1 (Plaintiff). I wrote one or more expert reports; I was deposed.

2016 ***Case***: TSMC Company versus Godo Kaisha IP Bridge 1 Company.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.
Law firm: Greenblum & Bernstein, P.L.C., Reston, Virginia.
Role: I served as technical expert witness on behalf of IP Bridge (Patent Owner). I wrote one or more expert reports; I was deposed.

2017 ***Case***: Harvard University versus Micron Technology Company.
Nature: Patent infringement.
Venue: U.S. District Court for MA, Boston; U.S. District Court for Delaware, Wilmington.
Law firm: Weil Gotshal & Manges LLP, Redwood Shores, California.
Role: I served as technical expert witness on behalf of Micron Technology Company (Defendant). I wrote one or more expert reports; I was deposed.

2017 ***Case***: Seoul Viosys Company versus P3 Company.
Nature: Patent infringement.
Venue: U.S. District Court, Southern District of New York, New York City.
Law firm: Holland & Knight LLP, New York City, New York.
Role: I served as technical expert witness on behalf of Seoul Viosys (Plaintiff). I wrote one or more expert reports.

2017 ***Case***: Nitride Semiconductor Company versus Rayvio Company.
Nature: Patent infringement.
Venue: US District Court for the Northern District of California.
Law firm: Dentons LLP, Palo Alto, California.
Role: I served as technical expert witness on behalf of Rayvio (Defendant).

2018 ***Case***: CRX Tech LLC versus Samsung Electronics Co. LTD.
Nature: Patent infringement.
Venue: U.S. District Court for the Eastern District of Texas, Marshall Division.
Law firm: Arnold & Porter LLP, Los Angeles, California.
Role: I served as technical expert witness on behalf of Samsung (Defendant).

2018 ***Case***: Macom Technology Solutions Holdings Inc. versus Infineon Technologies AG.
Nature: Patent infringement.
Venue: U.S. District Court Central District of California Western Division, Los Angeles.
Law firm: Perkins Coie LLP, Denver, Colorado.

Role: I served as technical expert witness on behalf of Macom (Plaintiff). I wrote one or more expert reports; I was deposed.

2018 ***Case***: Vizio Inc. versus Nichia Corporation.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.
Case number: Case No. IPR-2017-01608 and IPR-2017-01623 (PTAB).
Law firm: Rothwell, Figg, Ernst & Manbeck, P.C., Washington DC.
Role: I served as technical expert witness on behalf of Nichia Corporation (Patent Owner). I wrote one or more expert declarations.

2018 ***Case***: Lowe's Companies Inc. versus Nichia Corporation.
Nature: Inter Partes Review (IPR).
Venue: USPTO Patent Trial and Appeal Board.
Case number: Case No. IPR2017-02014 (PTAB).
Law firm: Rothwell, Figg, Ernst & Manbeck, P.C., Washington DC.
Role: I served as technical expert witness on behalf of Nichia Corporation (Patent Owner). I wrote one or more expert declarations.

2018 ***Case***: Ultravision Technologies LLC versus Prismaflex USA Inc.
Nature: Patent infringement.
Venue: US International Trade Commission (ITC), Washington DC.
Case number: Investigation No. 337-TA-1114 (ITC)
Law firm: Womble Bond Dickinson LLP, Winston-Salem, NC
Role: I served as technical expert witness on behalf of Prismaflex USA (Defendant). I wrote one or more expert reports. I was deposed.

2019 ***Case***: Carl Zeiss AG versus Nikon USA Inc.
Nature: Patent infringement.
Venue: US International Trade Commission (ITC), Washington DC.
Case number: Investigation No. 337-TA-1129 (US ITC)
Law firm: Morrison & Foerster LLP, Los Angeles CA.
Role: I served as technical expert witness on behalf of Nikon USA (Defendant). I wrote one or more expert reports. I was deposed.

2019 ***Case***: ASM IP Holding B.V. versus Hitachi Kokusai Electric Inc.
Nature: Arbitration related to IP licensing dispute.
Venue: ICDR (International Center for Dispute Resolution), Palo Alto CA.
Case number: Case No. ICDR 01-17-0005-1963 (Palo Alto CA)
Law firm: Quinn Emanuel Urquhart & Sullivan LLP, San Francisco CA.
Role: I served as technical expert witness on behalf of ASM IP Holding B.V. (Complainant). I authored multiple witness statements. I testified at the Arbitration Hearing.

2019 ***Case***: Power Integrations Inc. versus C. W. Park.
Nature: Breach of employment contract.
Venue: US District Court, Northern District of California, San Jose Division.
Case number: 5:16-cv-02366-BLF (Northern District of California)
Law firm: Miclean Gleason LLP, San Mateo CA.
Role: I served as technical expert witness on behalf of Power Integrations Inc. (Complainant). I performed analyses relating to switched-mode power supplies (SMPS) including flyback transformers. The matter ended in settlement.

2019 ***Case***: Omni MedSci Inc. versus Apple Inc.
Nature: Patent infringement.
Venue: US District Court, Eastern District of Texas, Marshall Division.
Case number: Civil Action No. 2:18-cv-134-RWS (E.D. Texas)
Law firm: Sidley Austin LLP, Washington DC.
Role: I served as technical expert witness on behalf of Apple Inc. (Defendant). I performed a non-infringement analysis relating to the heart rate monitor of the Apple Watch, authored an expert report, and testified at a deposition.

2019 ***Case***: Fluxwerx Illumination Inc., versus OKT Lighting USA LLC
Nature: Design patent infringement.
Venue: US District Court, Southern District of Texas, Houston Division.
Case number: Civil Action No. 4:19-CV-01113 (S.D. Texas)
Law firm: Burns & Levinson LLP, Boston MA.
Role: I served as technical expert witness on behalf of Fluxwerx Illumination, Inc. (Plaintiff). I performed an infringement analysis.

2020 ***Case***: Lighting Science Group Corporation versus Nichia Corporation and others
Nature: Patent infringement.
Venue: US ITC, Office for Unfair Import Investigations, Washington DC
Case number: Investigation No. 337-TA-1168
Law firm: Shearman & Sterling LLP, New York, NY.
Role: I served as technical expert witness on behalf of Nichia Corporation. I performed a non-infringement analysis, authored an expert report, was deposed, and testified at the ITC hearing as key technical witness on behalf of Nichia and Respondents (6 hours live testimony).

2020 ***Case***: Regents of the University of California versus Amazon, Walmart, Ikea, Target, and others
Nature: Patent infringement.
Venue: US ITC, Office for Unfair Import Investigations, Washington DC
Case number: Investigation No. 337-TA-1172
Law firm: Nixon Peabody LLP, Los Angeles CA.
Role: I served as technical expert witness on behalf of the Regents of the University of California. I performed an infringement analysis, authored an expert report, and was deposed.

2020 ***Case***: Samsung Electronics Company versus Acorn Technologies Company.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case numbers: IPR-2020-01183 ('261), IPR-2020-01182 ('423), IPR-2020-01204 ('336), IPR-2020-01264 ('336), IPR-2020-01205 ('167), IPR-2020-01241 ('167), IPR-2020-01206 ('691), IPR-2020-01279 ('691), IPR-2020-01207 ('395), and IPR-2020-01282 ('395)
Law firm: Desmarais LLP, New York NY.
Role: I served as technical expert witness on behalf of Samsung Electronics Company. I authored several expert declarations and was deposed multiple times.

2020 ***Case***: Satco Company versus The Regents of the University of California.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: IPR-2020-00579, IPR-2020-00695, IPR-2020-00780, and IPR-2020-00813.
Law firm: Nixon Peabody LLP, Los Angeles CA.
Role: I served as technical expert witness on behalf of The Regents of the University of California. I authored several expert declarations and was deposed.

2020 ***Case***: Godo Kaisha IP Bridge 1 Company versus Micron Technology Company.
Nature: Patent infringement.
Venue: US District Court for the Western District of Texas, Waco Division.
Case number: C.A. No. 6:20-cv-178-ADA.
Law firm: Orrick Herrington & Sutcliffe LLP, Menlo Park CA.
Role: I served as technical expert witness on behalf of Micron Technology Company. I authored multiple expert reports and was deposed.

2020 ***Case***: Nichia Company versus Healthe Company and Lighting Science Group Company.
Nature: Patent infringement.
Venue: US District Court for the Middle District of Florida, Orlando Division.
Case number: 6:19-cv-1332-RBD-EJK and 6:19-cv-1333-RBD-EJK.
Law firm: Rothwell, Figg, Ernst & Manbeck, PC, Washington DC.
Role: I served as technical expert witness on behalf of Nichia Company. I authored one or more expert reports.

2020 ***Case***: Semiconductor Energy Laboratory (SEL) Co., Ltd. versus BOE Technology Group Co., Ltd.
Nature: Patent infringement.
Venue: US District Court for the Northern District of California.
Case number: 3:20-cv-04297-EMC, N.D. Cal.
Law firm: Fish and Richardson, P.C., Redwood City CA.
Role: I served as technical expert witness on behalf of SEL.

2021 ***Case***: The University of California versus General Electric, Ikea, Home Depot and others
Nature: Patent infringement.
Venue: US ITC, Office for Unfair Import Investigations, Washington DC
Case number: Investigation No. 337-TA-1220
Law firm: Nixon Peabody LLP, Los Angeles CA.
Role: I served as technical expert witness on behalf of the University of California. I performed multiple analyses, authored several expert reports, was deposed multiple times, and testified at trial.

2021 ***Case***: Tianma Microelectronics Co., Ltd. versus Japan Display Inc. (JDI)
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA
Case numbers: IPR-2021-01029, IPR-2021-01057 and IPR-2021-01058
Law firm: Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, Washington DC.
Role: I served as technical expert witness on behalf of Tianma. I performed multiple analyses and authored several declarations.

2021 ***Case***: Japan Display Inc. (JDI) versus Tianma Microelectronics Co., Ltd.
Nature: Patent infringement.
Venue: US District Court for the Eastern District of Texas, Marshall Division.
Case numbers: Civil Action No. 2:20-cv-00283-JRG; 2:20-cv-00284-JRG; and 2:20-cv-00285-JRG
Law firm: Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, Washington DC.
Role: I served as technical expert witness on behalf of Tianma. I performed multiple analyses, authored several expert reports, and was deposed multiple times.

2022 ***Case***: Satco Products Inc. versus The Regents of the University of California.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: IPR-2021-00662.
Law firm: Nixon Peabody LLP, Los Angeles CA.

Role: I served as technical expert witness on behalf of The Regents of the University of California, authored one expert declaration, and was deposed.

2022 ***Case***: Samsung Electronics Co. Ltd. versus Bishop Display Tech LLC.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case numbers: IPR-2022-00500 and IPR-2022-00502.
Law firm: Baker Botts LLP, New York City NY.
Role: I served as technical expert witness on behalf of Samsung Electronics and have authored two expert declarations.

2022 ***Case***: Semiconductor Energy Laboratory (SEL) Co. Ltd. versus TCL China Star Optoelectronics Technology Co., Ltd.
Nature: Patent infringement.
Venue: US District Court for the Central District of California, Southern Division.
Case number: 8:21−cv−00554−JAK−ADS.
Law firm: Fish and Richardson, P.C., Redwood City CA.
Role: I served as technical expert witness on behalf of SEL, authored two expert reports, and was deposed.

2022 ***Case***: Nvidia Corporation versus Ocean Semiconductors LLC.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: IPR2022-01288.
Law firm: Sheppard Mullin LLP, Menlo Park CA.
Role: I served as technical expert witness on behalf of Nvidia and authored one expert declaration.

2022 ***Case***: Nicor, Inc. versus SourceBlue LLC and InfiniLux Corporation.
Nature: Patent infringement.
Venue: US District Court for the Central District of California.
Case number: 2:21-cv-05876-AB(PDx) (C.D. Cal.).
Law firm: Loza & Loza IP LLP, Upland CA.
Role: I served as technical expert witness on behalf of Nicor, Inc., authored three expert reports, and was deposed.

2023 ***Case***: Dr. Shimon Maimon versus Lockheed Martin Corporation.
Nature: Dispute relating to a License Agreement.
Venue: JAMS ADR (Alternative Dispute Resolution).
Case number: JAMS Ref. No. 1460005932.
Law firm: Finnegan, Henderson, Farabow, Garrett & Dunner, LLP, Washington DC.
Role: I served as technical expert witness on behalf of Lockheed Martin Corporation, authored three expert reports, was deposed, and testified at the Hearing.

2023 ***Case***: Samsung Electronics Co. Ltd. versus Daedalus Prime LLC.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: IPR2023-00536 and IPR2023-00653.
Law firm: Fish & Richardson PC, Minneapolis MN.
Role: I served as technical expert witness on behalf of Samsung Electronics and authored two expert declarations.

2023 ***Case***: Seoul Semiconductor Co. Ltd., et al. versus GE Healthcare Inc.
Nature: Patent infringement.
Venue: United States District Court for the District of Delaware.
Case number: Civil Action No. 1:22-cv-01455.
Law firm: Shearman & Sterling LLP, New York, NY.
Role: I served as technical expert witness on behalf of GE Healthcare.

2023 ***Case***: Efficient Power Conversion Corp. versus Innoscience (Zhuhai) Technology Company.
Nature: Patent infringement.
Venue: US International Trade Commission (ITC), Washington DC.
Case number: Investigation No. 337-TA-1366.
Law firm: Blank Rome LLP, Washington DC
Role: I served as technical expert witness on behalf of EPC, authored multiple expert reports, was deposed, and testified at the ITC Hearing.

2023 ***Case***: Xu Peicheng (Hong Kong) Optoelectronic Technol. Co. versus SemiSilicon Technol. Corp.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: IPR2024-00156 and IPR2024-00157 (US Patent 8,124,988 and US 8,884,546)
Law firm: Rimon La PC, McLean VA.
Role: I served as technical expert witness on behalf of Xu Peicheng and authored two expert declarations.

2024 ***Case***: Seasonal Specialties, LLC versus LEDUP Manufacturing Group LTD.
Nature: Patent infringement.
Venue: US District Court, Central District of California, Western Division.
Case number: 2:23-cv-06318-SB-AS.
Law firm: Fairfield & Woods PC, Denver CO.
Role: I served as technical expert witness on behalf of LEDUP Manufacturing Group and composed multiple Invalidity Claim Charts.

2024 ***Case***: Wuxi Autowell Technology Co. Ltd. versus Teamtechnik Maschinen und Anlagen GmbH.
Nature: USPTO Inter Partes Review.
Venue: USPTO, Patent Trial and Appeal Board, Alexandria VA.
Case number: US patent numbers 8,247,681 and 8,253,009.
Law firm: Novick, Kim & Lee, PLLC, (NKL Law), Fairfax VA.
Role: I served as technical expert witness on behalf of Wuxi Autowell Technology and composed one expert declaration.

2024 ***Case***: Greenthread LLC versus Omnivision Technologies, Inc., and Texas Instruments, Inc.
Nature: Patent infringement.
Venue: US District Court, Eastern District of Texas, Marshall Division.
Case numbers: 2:23-cv-00212-JRG and 2:23-cv-00157-JRG.
Law firms: Benesch Friedlander Coplan & Aronoff LLP and Caldwell Cassady & Curry PC
Role: I served as technical expert witness on behalf of Omnivision Technologies and Texas Instruments, composed one expert declaration, and was deposed.

2024 ***Case***: Lian Li Industrial Co. Ltd. and CHEN, Chien-Hao versus Thermaltake Technology Co. Ltd.
Nature: Patent infringement.
Venue: US District Court, Central District of California.
Case numbers: 2:23-cv-07470.
Law firm: The Gikkas Law Firm, PC

Role: I served as technical expert witness on behalf of Thermaltake Technology, composed one expert declaration, and was deposed.

United States Patents

1. A. Fischer, Y. Horikoshi, K. Ploog, and E. F. Schubert "Semiconductor devices with at least one monoatomic layer of doping atoms" European Patent No. 0183 146 A2; US Patent No. 4,882,609; issued on November 15 (1985)
2. J. E. Cunningham, E. F. Schubert, and W. T. Tsang "Delta doped ohmic metal to semiconductor contacts" US Patent No. 4,772,934; issued on September 20 (1988)
3. J. E. Cunningham, E. F. Schubert, and W. T. Tsang "Field-effect transistor having a delta-doped ohmic contact" US Patent No. 4,780,748; issued on October 25 (1988)
4. J. E. Cunningham, E. F. Schubert, and W. T. Tsang "Method for fabricating a field-effect transistor with a self-aligned gate" US Patent No. 4,784,967; issued on November 15 (1988)
5. E. Fred Schubert "Optical communications modulator device" US Patent No. 4,929,064; filed on July 21 (1988) issued on May 29 (1990)
6. J. E. Cunningham, A. M. Glass, and E. F. Schubert "Devices having asymmetric delta-doping" US Patent No. 4,974,044; issued on November 27 (1990)
7. J. E. Cunningham, A. M. Glass, and E. F. Schubert "Devices having asymmetric delta-doping" US Patent No. 5,031,012; issued on July 9 (1991)
8. J. E. Cunningham, T. D. Harris, E. F. Schubert, and J. P. van der Ziel "Optical system including wavelength tunable semiconductor laser" US Patent No. 4,980,892; issued on December 25 (1990)
9. R. F. Kopf, J. M. Kuo, H. S. Luftman, and E. F. Schubert "Doping procedures for semiconductor devices" US Patent No. 5,024,967; issued on June 18 (1991)
10. D. G. Deppe, R. D. Dupuis, and E. F. Schubert "Vertical cavity semiconductor lasers" US Patent No. 5,018,157; issued on May 21 (1991)
11. D. G. Deppe, L. C. Feldman, R. F. Kopf, E. F. Schubert, L.-W. Tu, and G. J. Zydzik "Vertical cavity surface emitting lasers with electrically conducting mirrors" US Patent No. 5,068,868; issued on November 26 (1991)
12. D. G. Deppe, E. F. Schubert, L.-W. Tu, and G. D. Zydzik "Optical devices with electron-beam evaporated multilayer mirror" US Patent No. 5,206,871; issued on April 27 (1993)
13. R. F. Kopf, E. F. Schubert, H. O'Brian, L.-W. Tu, Y. H. Wang, and G. J. Zydzik "Vertical cavity surface emitting lasers with transparent electrodes" US Patent No. 5,115,441; issued on May 19 (1992)
14. E. F. Schubert, L.-W. Tu, and G. J. Zydzik "Elimination of heterojunction band discontinuities" US Patent No. 5,170,407; issued on December 8 (1992)
15. S. W. Downey, A. B. Emerson, R. F. Kopf, and E. F. Schubert "Devices having repetitive layers" US Patent No. 5,226,055; issued on July 6 (1993)
16. A. Y. Cho, E. F. Schubert, L.-W. Tu, and G. J. Zydzik "Resonant cavity light emitting diode" US Patent No. 5,226,053; issued on July 6 (1993)
17. L. C. Feldman, N. E. J. Hunt, D. C. Jacobson, J. M. Poate, E. F. Schubert, A. M. Vredenberg, Y. H. Wong, and G. J. Zydzik "Erbium-doped optical devices" US Patent No. 5,249,195; issued on September 28 (1993)

18. R. F. Kopf and E. F. Schubert "PN junction devices with group IV element-doped group III-V compound semiconductors" US Patent No. 5,268,582; issued on December 7 (1993)

19. N. E. J. Hunt and E. F. Schubert "Single mirror light-emitting diodes with enhanced intensity" US Patent No. 5,362,977; issued on November 8 (1994)

20. N. E. J. Hunt, E. F. Schubert, and G. J. Zydzik "Photodetector with a resonant cavity" US Patent No. 5,315,128; issued on May 24 (1994)

21. A. M. Glass, N. E. J. Hunt, J. M. Poate, E. F. Schubert, and G. J. Zydzik "Absorption resonant rare-earth-doped microcavities" US Patent No. 5,363,398; issued on November 8 (1994)

22. N. E. J. Hunt, M. Passlack, E. F. Schubert, and G. J. Zydzik "Electron beam deposition of gallium oxide thin films using a single high purity crystal source" US Patent No. 5,451,548; issued on September 19 (1995)

23. N. K. Dutta, R. J. Fischer, N. E. J. Hunt, M. Passlack, E. F. Schubert, and G. J. Zydzik "Gallium oxide coatings for optoelectronic devices using electron beam evaporation of a high purity single crystal $Gd_3Ga_5O_{12}$ source" US Patent No. 5,550,089; issued on August 27 (1996)

24. U. K. Chakrabarti, J. de Jong, E. F. Schubert, J. Wynn, and G. J. Zydzik "Mechanical fixture and procedure for in-vacuum coating of semiconductor laser facets" US Patent No. 5,719,077; issued on February 17 (1998)

25. E. F. Schubert "Enhanced p-type doping of wide-gap semiconductors" US Patent No. 5,932,899; issued on August 3 (1999)

26. J. D. Joannopoulos, S. Fan, P. R. Villeneuve, and E. F. Schubert "Light emitting device utilizing a periodic dielectric structure" US Patent No. 5,955,749; issued on September 21 (1999)

27. E. F. Schubert and D. A. Stocker "Crystallographic wet chemical etching on GaN" US Patent No. 6,294,475; issued on September 25 (2001)

28. E. F. Schubert "Light-emitting diode with omni-directional reflector" US Patent No. 6,784,462; issued on August 31 (2004)

29. Jaehee Cho, Hong Luo, Jong Kyu Kim, Yong Jo Park, Cheolsoo Sone, and E. Fred Schubert "Light emitting device having protection element and method of manufacturing the light emitting device" US Patent No. 7,411,221 B2; issued on August 12 (2008)

30. Jaehee Cho, Frank Wilhelm Mont, Cheolsoo Sone, Jong-kyu Kim, June-o Song, E. Fred Schubert "Optical thin film, semiconductor light emitting device having the same and methods of fabricating the same" US Patent No. 7,483,212; issued on January 27 (2009)

31. Jaehee Cho, Martin F. Schubert, E. Fred Schubert, Jong Kyu Kim, Cheolsoo Sone "Light emitting diodes and display apparatuses using the same" US Patent No. 7,560,746; issued on July 14 (2009)

32. Martin F. Schubert, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, and Jaehee Cho "Reflector shapes for light-emitting diode-polarized light sources" US Patent No. 7,766,495; filed on June 24 (2008); issued on August 3 (2010)

33. Martin F. Schubert, Ahmed Noemaun, Sameer Chhajed, Jong Kyu Kim, E. F. Schubert, Cheolsoo Sone "Encapsulant shapes for light emitting devices lacking rotational symmetry designed to enhance extraction of light with a particular linear polarization" US Patent No. 7,819,557; filed on June 24 (2008); issued on October 6 (2010)

34. Jaehee Cho, Jong-Kyu Kim, Cheolsoo Sone, and E. F. Schubert "LED device having diffuse reflective surface" US Patent No. 7,816,855; filed on December 28 (2005); issued on October 19 (2010)

35. Jaehee Cho, E. Fred Schubert, and Xing Yan "Liquid crystal display with refractive index matched electrodes" US Patent No. 8,164,727; filed on April 28, 2010; issued on April 24 (2012)

36. Mary H. Crawford, Daniel Koleske, Jaehee Cho, Di Zhu, Ahmed Noemaun, Martin F. Schubert, and E. Fred Schubert "High efficiency III-Nitride light-emitting diodes" US Patent No. 8,451,877; filed on March 17, 2011; issued on May 28 (2013)

37. Min-ho Kim, Martin F. Schubert, Jong Kyu Kim, E. Fred Schubert, Yongjo Park, Cheolsoo Sone, and Sukho Yoon "Nitride semiconductor light-emitting device" US Patent No. 8,502,266; filed on September 8 (2010); issued on August 6 (2013)

38. David J. Poxson, Frank W. Mont, E. Fred Schubert, and Richard W. Siegel "Tunable nanoporous film on polymer substrates, and method for their manufacture" US Patent No. 9,732,427; filed on April 23 (2013); issued on August 15 (2017)

39. Sameer Chhajed, Jong Kyu Kim, Shawn-Yu Lin, Mei-Ling Kuo, Frank W Mont, David J Poxson, E Fred Schubert, Martin F Schubert "Ultra-low reflectance broadband omni-directional anti-reflection coating" US Patent No. 11,088,291; filed on July 22 (2016); issued on August 10 (2021)

Patent Licensing: Several patents listed above have been licensed to companies, including the Luminus Devices Company, Samsung Company, Epistar Company, Cree Company, Osram Company, and Lumileds Company.

Journal Publications

1982

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

1984

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

1985

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

1986

16. E. F. Schubert, A. Fischer, and K. Ploog "The delta-doped field-effect transistor" *IEEE Transactions on Electron Devices,* **ED-33**, 625 (1986)
17. E. F. Schubert and K. Ploog "Interpretation of capacitance-voltage profiles from delta-doped GaAs grown by molecular-beam epitaxy" *Japanese Journal of Applied Physics* **25**, 966 (1986)
18. E. F. Schubert and W. T. Tsang "Photoluminescence line shape of excitons in alloy semiconductors" *Physical Review B, Rapid Communications*, **B34**, 2991 (1986)
19. E. F. Schubert, J. E. Cunningham, W. T. Tsang, and T. H. Chiu "Delta-doped ohmic contacts to n-GaAs" *Applied Physics Letters* **49**, 292 (1986) and *Applied Physics Letters* **49**, 984 (1986)
20. K. Ploog, A. Fischer, and E. F. Schubert "Preparation and properties of a new GaAs sawtooth doping superlattice" *Surface Science* **174**, 120 (1986)
21. B. I. Miller, E. F. Schubert, U. Koren, A. Ourmazd, A. H. Dayem, and R. J. Capik "High quality narrow GaInAs/InP quantum wells grown by atmospheric organometallic vapor phase epitaxy" *Applied Physics Letters* **49**, 1384 (1986)
22. E. F. Schubert, Cunningham J. E., and Tsang W. T. "Self-aligned enhancement and depletion-mode GaAs field-effect transistors employing the delta-doping technique" *Applied Physics Letters* **49**, 1729 (1986)

Patent Owner 138 East Ex. 2001
Page 086

23. W. T. Tsang, E. F. Schubert, A. H. Dayem, J. E. Cunningham, T. H. Chiu, J. A. Ditzenberger, J. Shah, and J. L. Zyskind "Very high quality GaInAs grown by chemical beam epitaxy" *Journal of Electronic Materials* **15**, 307 (1986)
24. W. T. Tsang and E. F. Schubert "Extremely high quality GaInAs/InP quantum wells grown by chemical beam epitaxy" *Applied Physics Letters* **49**, 220 (1986)
25. W. T. Tsang, A. H. Dayem, T. H. Chiu, J. E. Cunningham, E. F. Schubert, J. A. Ditzenberger, J. Shah, J. L. Zyskind, and N. Tabatabaie "Chemical beam epitaxial growth of extremely high quality GaInAs on InP" *Applied Physics Letters* **49**, 170 (1986)
26. E. F. Schubert, A. Fischer, and K. Ploog "Photoconductivity in selectively n- and p-doped AlGaAs/GaAs heterostructures" *Solid-State Electronics 29*, 173 (1986)

1987

27. E. F. Schubert, J. E. Cunningham, and W. T. Tsang "'Type A' sawtooth doping superlattice: realization of the Esaki-Tsu type superlattice" *Physical Review B Rapid Communications* **B36**, 1348 (1987)
28. E. F. Schubert, J. E. Cunningham, and W. T. Tsang "Electron-mobility enhancement and electron-concentration enhancement in delta-doped n-GaAs at T = 300 K" *Solid-State Communications* **63**, 591 (1987)
29. W. T. Tsang, E. F. Schubert, T. H. Chiu, J. E. Cunningham, E. G. Burkhardt, J. A. Ditzenberger, and E. Agyekum "Growth of high-quality GaInAsP by chemical beam epitaxy" *Applied Physics Letters* **51**, 761 (1987)
30. J. E. Cunningham, W. T. Tsang, T. H. Chiu, E. F. Schubert, and J. A. Ditzenberger "MBE grown high purity GaAlAs" *J. Vac. Sci. Technol*. **A5**, 761 (1987)
31. W. T. Tsang, E. F. Schubert, T. H. Chiu, J. E. Cunningham, and J. A. Ditzenberger "Chemical beam epitaxial growth of very high quality GaInAs and GaInAs/InP quantum well heterostructures" *GaAs and Related Compounds* (1987) Ed. by W. T. Lindley.
32. J. E. Cunningham, W. T. Tsang, T. H. Chiu, and E. F. Schubert "Molecular beam epitaxial growth of high purity AlGaAs" *Applied Physics Letters* **50**, 769 (1987)
33. Y. Horikoshi, A. Fischer, E. F. Schubert, and K. Ploog "High-mobility two-dimensional electron gas from delta-doped asymmetric AlGaAs/GaAs/AlGaAs quantum wells" *Japanese Journal Applied Physics* **26**, 263 (1987)
34. T. H. Chiu, E. Agyekum, J. A. Ditzenberger, A. Robertson, E. F. Schubert, W. T. Tsang, and C. W. Tu "Growth and characterization of (001) GaAs epilayers by chemical beam epitaxy" *Journal of Electronic Materials* **16**, A21 (1987)
35. E. F. Schubert, J. E. Cunningham, and W. T. Tsang "Perpendicular electronic transport in doping superlattices" *Applied Physics Letters* **51**, 817 (1987)
36. E. F. Schubert, J. E. Cunningham, W. T. Tsang, and G. L. Timp "Selectively delta-doped AlGaAs/GaAs heterostructures with two-dimensional electron-gas concentrations $n_{2DEG} \geq 1.5 \times 10^{12}$ cm^{-2} for field-effect transistors" *Applied Physics Letters* **51**, 1170 (1987)
37. T. H. Chiu, W. T. Tsang, E. F. Schubert, and E. Agyekum "Chemical beam epitaxial growth of high-purity GaAs using trimethylgallium and arsine" *Applied Physics Letters* **51**, 1109 (1987)

1988

38. B. Ullrich, E. F. Schubert, J. Stark, and J. E. Cunningham "Localization of impurities in delta-doped n-type GaAs" *Applied Physics* **A47**, 123 (1988)
39. E. F. Schubert, J. Stark, T. H. Chiu, and B. Tell "Diffusion of atomic silicon in gallium arsenide" *Applied Physics Letters* **53**, 293 (1988)
40. E. F. Schubert, J. Stark, B. Ullrich, and J. E. Cunningham "Spatial localization of impurities in delta-doped GaAs" *Applied Physics Letters* **52**, 1508 (1988)
41. J. E. Cunningham, G. Timp, E. F. Schubert, W. T. Tsang, P. G. N. DeVegvar, T. H. Chiu, and E. Agyekum "Enhancements in two-dimensional electron gas density and mobility in delta-doped AlGaAs heterostructures" *Proceedings Materials Research Society Symposium* **102** (1988)
42. T. H. Chiu, E. F. Schubert, J. E. Cunningham, and B. Tell "Diffusion studies of the Si delta-doped GaAs by capacitance-voltage measurements" *Journal of Applied Physics, Rapid Communication* **64**, 1578 (1988)
43. T. Y. Kuo, J. E. Cunningham, E. F. Schubert, W. T. Tsang, T. H. Chiu, F. Ren, and C. G. Fonstad "Selectively delta-doped quantum well transistor grown by gas source molecular beam epitaxy" *Journal of Applied Physics* **64**, 3324 (1988)
44. E. F. Schubert, B. Ullrich, T. D. Harris, and J. E. Cunningham "Quantum-confined interband absorption in GaAs sawtooth doping superlattices" *Physical Review* **B38**, 8305 (1988)

Patent Owner 138 East Ex. 2001
Page 087

45. T. H. Chiu, E. F. Schubert, J. E. Cunningham, W. T. Tsang, and B. Tell "Chemical beam epitaxial growth and capacitance-voltage characterization of Si-doped GaAs" *Proceedings Materials Research Society Symposium* **102**, 475 (1988)
46. E. F. Schubert and J. E. Cunningham "Photonic switching by tunneling-assisted absorption modulation in a GaAs sawtooth structure" *Electronics Letters* **24**, 980 (1988)
47. E. F. Schubert, T. H. Chiu, J. E. Cunningham, B. Tell, and J. B. Stark "Spatial localization and diffusion of atomic silicon in delta-doped GaAs" *Journal of Electronics Materials*, **17**, 527 (1988)
48. R. J. Malik, R. Nottenburg, E. F. Schubert, J. F. Walker, and R. W. Ryan "Carbon doping in molecular beam epitaxy of GaAs from a heated graphite filament" *Applied Physics Letters* **53**, 2661 (1988)
49. E. F. Schubert, T. D. Harris, and J. E. Cunningham "Minimization of dopant-induced random potential fluctuations in sawtooth doping superlattices" *Applied Physics Letters* **53**, 2208 (1988)
50. T. Y. Kuo, J. E. Cunningham, E. F. Schubert, W. T. Tsang, T. H. Chiu, and C. G. Fonstad "Experimental and theoretical characterization of the delta-doped quantum well transistor grown by gas source molecular beam epitaxy" *IEEE Transactions on Electron Devices* **35**, 2449 (1988).

1989

51. E. F. Schubert, J. E. Cunningham, T. H. Chiu, J. B. Stark, B. Tell, and C. W. Tu "Spatial localization and diffusion of Si in delta-doped GaAs and AlGaAs and its application to electron-mobility optimization in selectively doped heterostructures" *GaAs and Related Compounds* Ed. J. S. Harris. (1989)
52. E. F. Schubert, T. D. Harris, J. E. Cunningham, and W. Jan "Multi-subband photoluminescence in sawtooth doping superlattices" *Physical Review* **B39**, 11011 (1989)
53. J. E. Cunningham, G. Timp, A. M. Chang, T. H. Chiu, W. Jan, E. F. Schubert, and W. T. Tsang "Spatial localization of Si in selectively delta-doped AlGaAs/GaAs heterostructures for high mobility and density realization" *Journal Crystal Growth* **95**, 253 (1989)
54. B. Ullrich, C. Zhang, E. F. Schubert, J. E Cunningham., and K. von Klitzing "Transmission spectroscopy on sawtooth doping superlattices" *Physical Review* **B39**, 3776 (1989)
55. E. F. Schubert, J. E. Cunningham, T. H. Chiu, J. B. Stark, B. Tell, and C.W Tu. "Spatial localization and diffusion of Si in delta-doped GaAs and AlGaAs and its application to electron-mobility optimization in selectively doped heterostructures" *GaAs and Related Compounds 1988* (Institute Physics Conference Series **96**, Bristol, 1989) p. 33
56. A. M Glass., E. F. Schubert, B. A. Wilson, C. E. Bonner, J. E. Cunningham, D. H. Olson, and W. Jan "A novel photo-voltaic delta-doped GaAs superlattice structure" *Applied Physics Letters* **54**, 2247 (1989)
57. E. F. Schubert, L. Pfeiffer, K. W. West, and A. Izabelle "Dopant distribution for maximum carrier-mobility in selectively doped $Al_{0.30}Ga_{0.70}As$/GaAs heterostructures" *Applied Physics Letters* **54**, 1350 (1989)
58. J. E. Cunningham, G. Timp, T. Chiu, W. T Tsang., E. F. Schubert, and W. Jan "Mobility and density enhancement in delta-doped $Al_{0.30}Ga_{0.70}As$/GaAs heterostructures" *GaAs and Related Compounds 1988* (Institute Physics Conference Series, **96**, Bristol, 1989) p. 33
59. E. F. Schubert, C. W. Tu, R. Kopf, J. M. Kuo and L. M. Lunardi "Diffusion and drift of Si-dopants in delta-doped n-type AlGaAs" *Applied Physics Letters* **54**, 2592 (1989)
60. E. F. Schubert, J. P. van der Ziel, J. E. Cunningham, and T. D. Harris "Tunable stimulated emission of radiation in GaAs doping superlattices" *Applied Physics Letters* **55**, 757 (1989)
61. E. F. Schubert, T. D. Harris, and J. E. Cunningham "Quantum-confined optical interband transitions in delta-doped doping superlattices" *Proceedings of Mats. Research Society* Editors: C. W. Tu and A. C. Gossard **145**, 21 (1989)
62. D. G. Deppe, A. Y. Cho, K. F. Huang, R. J. Fischer, K. Tai, E. F Schubert, and Y. K. Chen "AlGaAs-GaAs and AlGaAs-GaAs-InGaAs vertical cavity surface emitting lasers with Ag mirrors" *Journal of Applied Physics* **66**, 5629 (1989)
63. W. S. Hobson, Pearton S., Schubert E. F., and Cabaniss G. "Zinc delta-doping of GaAs by organometallic vapor phase epitaxy" *Applied Physics Letters* **55**, 1546 (1989)

1990

64. (**Invited**) E. F. Schubert, J. M. Kuo, and R. F. Kopf "Theory and experiment of capacitance-voltage profiling on semiconductors with quantum confinement" *Journal Electronic Materials, Special Issue on "Artificially Structured Materials"* **19**, 521 (1990)
65. (**Invited**) E. F. Schubert "Delta-doping of III-V compound semiconductors: Fundamentals and device applications" *Journal of Vacuum Science and Techn*ology, **A8**, 2980 (1990)
66. (**Invited**) E. F. Schubert "Optical properties of delta-doped doping superlattices" *Surface Science*, **228**, 240 (1990)

Patent Owner 138 East Ex. 2001
Page 088

67. E. F. Schubert, J. M. Kuo, R. F. Kopf, H. S. Luftman, L. C. Hopkins, and N. J. Sauer, "Beryllium delta-doping of GaAs grown by molecular beam epitaxy" *Journal of Applied Physics* **67**, 1969 (1990)
68. D. G. Deppe, N. D. Gerrard, C. J. Pinzone, R. D. Dupuis, and E. F. Schubert "Quarter-wave Bragg reflector stack of InP/$In_{0.53}Ga_{0.47}As$ for 1.65 μm wavelength" *Applied Physics Letters* **56**, 315 (1990)
69. E. F. Schubert, J. M. Kuo, R. F. Kopf, A. S. Jordan, H. S. Luftman, and L. C. Hopkins "Fermi-level-pinning induced dopant redistribution in semiconductors during growth by molecular beam epitaxy" *Physical Review* **42**, 1364 (1990)
70. E. F. Schubert, R. F. Kopf, J. M. Kuo, H. S. Luftman, and P. A. Garbinski "Spatial resolution of the capacitance-voltage profiling technique on semiconductors with quantum confinement" *Applied Physics Letters* **57**, 497 (1990)
71. (**Invited**) E. F. Schubert "Optical and electronic properties of delta-doped doping superlattices" *Journal of Optical and Quantum Electronics*, **22**, S141 (1990)
72. E. F. Schubert, L.-W. Tu, R. F. Kopf, G. J. Zydzik, and D. G. Deppe "Low threshold vertical cavity surface emitting lasers with metallic reflectors" *Applied Physics Letters*, **57**, 117 (1990)
73. E. F. Schubert, F. Capasso, A. L. Hutchinson, S. Sen, and A. C. Gossard "Observation of charge storage and intra-subband relaxation in resonant tunneling via a high sensitivity capacitance technique" *Applied Physics Letters*, **57**, 2820 (1990)
74. H.-J. Gossmann, E. F. Schubert, D. J. Eaglesham, and M. Cerullo "Low temperature Si molecular beam epitaxy: Solution to the doping problem" *Applied Physics Letters*, **57**, 2440 (1990)
75. S. W. Downey, R. F. Kopf, E. F. Schubert, and J. M. Kuo "Resonance ionization mass spectrometry of AlGaAs: Resolution, sensitivity, and matrix effect" *Applied Optics*, **29**, 4938 (1990)
76. L.-W. Tu, E. F. Schubert, R. F Kopf., G. J., Zydzik M. Hong, S. N. G. Chu, and J. P. Mannaerts "Vertical cavity surface emitting lasers with semitransparent metallic mirrors and high quantum efficiencies" *Applied Physics Letters*, **57**, 2045 (1990)
77. E. F. Schubert, H. S. Luftman, R. F. Kopf, R. L Headrick., and J. M. Kuo "Secondary ion mass spectroscopy on delta-doped GaAs grown by molecular beam epitaxy" *Applied Physics Letters*, **57**, 1799 (1990)
78. H.-J. Gossmann, E. F. Schubert, D. J. Eaglesham, and M. Cerullo "Si molecular beam epitaxy at room temperature: Solution to the Si doping problem" *Proceedings of the International Conference on Electronic Materials*, 11541-9008-48TM

1991

79. (**Invited**) E. F. Schubert and R. F. Kopf "Delta-doping in III-V semiconductors" *Materials Science Forum*, 65 & 66, 53 (Trans Tech Publications, Zürich, 1991)
80. L.-W. Tu, Y. H. Wang, E. F. Schubert, B. E. Weir, G. J. Zydzik, and A. Y. Cho "High temperature performance of three-quantum-well vertical-cavity top-emitting lasers" *Electronics Letters* **27**, 457 (1991)
81. L.-W. Tu, E. F. Schubert, H. M. O'Brian, Y.-H. Wang, B. E Weir., G. J. Zydzik, and A. Y. Cho "Transparent conductive metal-oxide contacts in vertical-injection top-emitting quantum well lasers" *Applied Physics Letters* **58**, 790 (1991)
82. L. Pfeiffer, E. F. Schubert, K. W. West, and C. W. Magee "Si dopant migration and the AlGaAs/GaAs inverted interface" *Applied Physics Letters* **58**, 2258 (1991)
83. E. F. Schubert "Doping distributions in III-V semiconductors" *Advanced Processing and Characterization Technologies, American Vacuum Society Series* **10**, 5 (American Institute of Physics, New York, 1991)
84. R. F. Kopf, E. F Schubert, T. D Harris., and R. S. Becker "Photoluminescence of GaAs quantum wells grown by molecular-beam epitaxy with growth interruptions" *Applied Physics Letters* **58**, 631 (1991)

1992

85. W. T. Tsang, E. F. Schubert, and J. E. Cunningham "Doping in semiconductors with variable activation energy: A new concept and demonstration" *Applied Physics Letters* **60**, 115 (1992)
86. E. F. Schubert "Smart doping of III-V semiconductor heterostructure devices" *Proceedings 180th Electrochem. Society Mtg., State-of-the-Art Program on Compound Semiconductors* **92-19**, 85 (1992)
87. E. F. Schubert, L.-W. Tu, G. J. Zydzik, R. F. Kopf, A. Benvenuti, and M. R. Pinto "Elimination of heterojunction band discontinuities by modulation doping" *Applied Physics Letters* **60**, 466 (1992)
88. E. F. Schubert, Y.-H. Wang, A. Y. Cho, L. W. Tu, and G. J. Zydzik "Resonant cavity light emitting diode" *Applied Physics Letters* **60**, 921 (1992)
89. R. F. Kopf, E. F. Schubert, S. W. Downey, and A. B. Emerson "P- and n-type dopant profiles in distributed Bragg reflector structures and their effect on resistance" *Applied Physics Letters* **61**, 1820 (1992)

Patent Owner 138 East Ex. 2001
Page 089

90. E. F. Schubert, A. M. Vredenberg, N. E. J. Hunt, Y. H. Wong, P. C. Becker, J. M Poate., D. C. Jacobson, L. C. Feldman, and G. J. Zydzik "Giant enhancement of luminescence intensity in Er-doped Si/SiO_2 resonant cavities" *Applied Physics Letters* **61**, 1381 (1992)
91. N. E. J. Hunt, E. F. Schubert, R. A Logan., and G. J. Zydzik "Enhanced spectral power density and reduced linewidth at 1.3 μm in an InGaAsP quantum-well resonant-cavity light-emitting diode" *Applied Physics Letters* **61**, 2287 (1992)
92. R. F. Kopf, E. F. Schubert, S. W. Downey, and A. B. Emerson "Resonance ionization of device materials" *Institute of Physics Conference Series* **128**, 255 (1992)
93. N. E. J. Hunt, E. F. Schubert, D. L. Sivco, A. Y. Cho, and G. J. Zydzik "Power and efficiency limits in single mirror light emitting diodes with enhanced intensity" *Electronics Letters* **28**, 2169 (1992)
94. N. E. J. Hunt, E. F. Schubert, R. A. Logan, and G. J. Zydzik "Extremely narrow spectral widths from resonant cavity light-emitting diodes (RCLEDs) suitable for wavelength-division multiplexing at 1.3 μm and 1.55 μm" *Proceedings of the International Electron Devices Meeting (IEDM)* **1992**, 651 (1992)
95. A. M. Vredenberg, N. E. J. Hunt, E. F. Schubert, P. C. Becker, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Erbium implantation in optical microcavities for controlled spontaneous emission" *Proceedings Ion Implantation Technology - 92*

1993

96. (**Book**) E. F. Schubert "Doping in III-V semiconductors" *Cambridge University Press*, ISBN 0-521-41919-0, 606 pages (1993)
97. E. F. Schubert and R. F. Kopf "Selective n- and p-type C-doping in $Ga_{0.47}In_{0.53}As$ superlattices" *Journal Crystal Growth*. **127**, 1037 (1993)
98. H. Yao, E. F. Schubert, and R. F. Kopf "Raman and ellipsometric studies of delta-doped GaAs" *Materials Research Society Symposium Proceedings* **261**, 57 (1993)
99. (**Invited**) H.-J. Gossmann and E. F. Schubert "Delta doping in silicon" *CRC Critical Reviews in Solid-State and Materials Sciences* **18**, 1 (1993)
100. A. M. Vredenberg, N. E. J. Hunt, E. F. Schubert, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Controlled atomic spontaneous emission from Er^{3+} in a transparent Si/SiO_2 microcavity" *Physical Review Letters* **71**, 517 (1993)
101. (**Invited**) E. F. Schubert, R. F. Kopf, and T. D. Harris "Interface configurations of AlGaAs /GaAs quantum wells probed by photoluminescence spectroscopy" *Materials Research Society Symposium Proceedings* **280**, 203 (1993)
102. R. F. Kopf, E. F. Schubert, T. D. Harris, R. S. Becker, and G. H. Gilmer "Modification of GaAs/AlGaAs growth-interrupted interfaces through changes in ambient conditions during growth" *Journal of Applied Physics* **74**, 6139 (1993)
103. N. E. J. Hunt, E. F. Schubert, and G. J. Zydzik "A resonant-cavity p-i-n photodetector utilizing an electron-beam evaporated Si/SiO_2 microcavity" *Applied Physics Letters* **63**, 391 (1993)
104. N. E. J. Hunt, E. F. Schubert, R. F. Kopf, D. L. Sivco, A. Y. Cho, and G. J. Zydzik "Increased fiber communications bandwidth from a resonant cavity light emitting diode emitting at λ = 940 nm" *Applied Physics Letters* **63**, 2600 (1993)
105. E. F. Schubert, N. E. J. Hunt, A. M. Vredenberg, T. D. Harris, J. M. Poate, D. C Jacobson., Y. H Wong., and G. J. Zydzik "Enhanced luminescence by resonant absorption in Er-doped Si/SiO_2 microcavities" *Applied Physics Letters* **63**, 2603 (1993)

1994

106. E. F. Schubert, N. E. J. Hunt, M. Micovic, R. J. Malik, D. L. Sivco, A. Y. Cho, and G. J. Zydzik "Highly efficient light-emitting diodes with microcavities" *Science* **265**, 943 (1994)
107. (**Invited**) E. F. Schubert "Delta-doping of semiconductors: electronic, optical, and structural properties of materials and devices" in *Artificially Structured Semiconductors*, Vol. **40**, Ed. by Gossard A. C. in Semiconductors and Semimetals, Editors: Willardson R. K., Beer A. C., and Weber E. R. (1994)
108. (**Invited**) E. F. Schubert, N. E. J. Hunt, D. L. Sivco, and A. Y. Cho "Resonant-cavity light-emitting devices" *Brazilian Journal of Physics*. **24**, 445 (1994)
109. E. F. Schubert, M. Passlack, M. Hong, J. Mannaerts, R. L. Opila, L. N. Pfeiffer, K. W. West, C. G. Bethea, and G. J. Zydzik, "Properties of Al_2O_3 optical coatings on GaAs produced by oxidation of epitaxial AlAs/GaAs films" *Applied Physics Letters* **64**, 2976 (1994)
110. E. F. Schubert, L. Pfeiffer, K. W. West, H. S. Luftman, and G. J. Zydzik "Si delta-doping of ⟨011⟩ oriented GaAs and AlGaAs grown by molecular beam epitaxy" *Applied Physics Letters* **64**, 2238 (1994)

Patent Owner 138 East Ex. 2001
Page 090

111. M. Passlack, N. E. J. Hunt, E. F. Schubert, G. J. Zydzik, M. Hong, J. P. Mannaerts, R. L. Opila, and R. J. Fischer "Dielectric properties of electron-beam deposited Ga_2O_3 films" *Applied Physics Letters* **64**, 2715 (1994)
112. E. F. Schubert, L. Pfeiffer, K. W. West, H. S. Luftman, and G. J. Zydzik "Si delta-doping of ⟨011⟩-oriented GaAs and AlGaAs grown by molecular-beam epitaxy" *Applied Physics Letters* **64**, 2238 (1994)
113. E. F. Schubert "Doping in III-V semiconductors" *Materials Research Society Proceedings* (1994/1995) Ed. Tu C. W.
114. E. F. Schubert, S. W. Downey, C. Pinzone, and A. B. Emerson "Evidence of very strong inter-epitaxial-layer diffusion in Zn doped GaInPAs/InP structures" *Applied Phys A* June (1995)
115. E. F. Schubert and N. E. J. Hunt "Highly efficient light-emitting diodes with microcavities" *Proceedings of the International Symposium on Compound Semiconductors* (1994/1995)

1995

116. (**Invited**) N. E. J. Hunt, E. F. Schubert, D. L. Sivco, A. Y. Cho, R. F., Kopf Logan R. A., and Zydzik G. J. "High efficiency, narrow spectrum resonant cavity light-emitting diodes" in *Confined Electrons and Photons* Editors: Burstein E. and Weisbuch C. (Plenum Press, New York, 1995)
117. (**Invited**) N. E. J. Hunt, A. M. Vredenberg, E. F. Schubert, P. C. Becker, D. C. Jacobson, J. M. Poate, and G. J. Zydzik "Spontaneous emission control of Er^{3+} in Si/SiO_2 micro-cavities" in *Confined Electrons and Photons*; Editors: E. Burstein and C. Weisbuch (Plenum Press, New York, 1995)
118. M. Passlack, M. Hong, E. F. Schubert, J. R. Kwo, J. P. Mannerts, S. N. G. Chu, N. Moriya, and F. A. Thiel "In situ fabricated Ga_2O_3-GaAs structures with low interface recombination velocity" *Applied Physics Letters* **66**, 625 (1995)
119. E. F. Schubert and N. E. J. Hunt, Ed. H. Goronkin, and U. Mishra "Highly efficient light-emitting diodes with microcavities" *Compound Semiconductors 1994*. Proceedings of the Twenty-First International Symposium, p. xxvii+912, 489 (1995)
120. M. Passlack, M. Hong, E. F. Schubert, J. R. Kwo, J. P. Mannerts, W. S. Hobson, N. Moriya, J. Lopata, and G. J. Zydzik "Ga_2O_3 films for insulator/III-V semiconductor interfaces" *Institute Physics Conference Series No*. **141**: Chapter 5, 597 (1995)
121. M. Passlack, M. Hong, E. F. Schubert, J. P. Mannaerts, W. S. Hobson, N. Moriya, J. Lopata, and G. J. Zydzik, H. Ed. Goronkin and U. Mishra "Ga_2O_3 films for insulator/III-V semiconductor interfaces" *Compound Semiconductors 1994*. Proceedings of the Twenty-First International Symposium, p. xxvii+912, 597 (1995)
122. L.-W. Tu, E. F. Schubert, Y. H. Wang, B. E. Weir, G. J. Zydzik, and A. Y. Cho "Superior output linearity of optimized double heterostructure vertical-cavity top-emitting lasers" *Applied Physics Letters* **66**, 2315 (1995)
123. E. F. Schubert and J. M. Poate "Er-doped Si/SiO_2 microcavities" *Proceedings of the SPIE- The International Society for Optical Engineering* (USA), Vol. **2397**, p. 495 (1995)
124. M. Passlack, C. G. Bethea, W. S. Hobson, J. Lopata, E. F. Schubert, G. J. Zydzik, D. T. Nichols, J. F. de Jong, U. K. Chakrabarti, and N. K. Dutta "Infrared microscopy studies on high-power InGaAs-GaAs-InGaP lasers with Ga_2O_3 facet coatings" *IEEE Journal on Selected Topics Quantum Electronics* **1**, 110 (1995)
125. E. F. Schubert, S. W. Downey, C. Pinzone, and A. B. Emerson "Evidence of very strong inter-epitaxial-layer diffusion in Zn-doped GaInPAs/InP structures" *Applied Physics A* **60**, 525 (1995)
126. E. F. Schubert, C. J. Pinzone, and M. Geva "Phenomenology of Zn diffusion and incorporation in InP grown by organometallic vapor-phase epitaxy" *Applied Physics Letters* **67**, 700 (1995)
127. N. K. Dutta, W. S. Hobson, J. Lopata, E. F. Schubert, and M. Passlack "Single mode, high power lasers emitting at 980 nm" *Proceedings SPIE - Int. Society Opt. Eng*. (USA), Proceedings of the SPIE - The International Society for Optical Engineering, **2382**, 138 (1995)
128. M. Passlack, E. F. Schubert, W. S. Hobson, M. Hong, N. Moriya, S. N. G. Chu, K. Konstadinidis, J. P. Mannaerts, M. L. Schnoes, and G. J. Zydzik "Ga_2O_3 films for electronic and optoelectronic applications" *Journal of Applied Physics* **77**, 686 (1995)

1996

129. (**Book**) E. F. Schubert, Editor "Delta Doping of Semiconductors" 604 pages, Cambridge University Press, Cambridge ISBN 0-521-48288-7 (1996)
130. E. F. Schubert, N. E. J. Hunt, R. J. Malik, M. Micovic, and D. L. Miller "Temperature and Modulation Characteristics of Resonant-Cavity Light-Emitting Diodes" *IEEE J. Lightwave Technology* **14**, 1721 (1996)
131. W. Grieshaber, E. F. Schubert, I. D. Goepfert, R. F. Karlicek Jr., M. J. Schurman, and C. Tran "Competition between band gap and yellow luminescence in GaN and its relevance for optoelectronic devices" *Journal of Applied Physics* **80**, 4615 (1996)
132. L.-W. Tu, E. F. Schubert, M. Hong, and G. J. Zydzik "In-vacuum cleaving and coating of semiconductor laser facts using thin Si and a dielectric" *Journal of Applied Physics* **80**, 6448 (1996)

Patent Owner 138 East Ex. 2001
Page 091

133. E. F. Schubert, W. Grieshaber, and I. D. Goepfert "Enhancement of deep acceptor activation in semiconductors by superlattice doping" *Applied Physics Letters* **69**, 3737 (1996)
134. E. F. Schubert "GaAs light-emitting diodes" in *Gallium Arsenide, 3rd Ed*., edited by Brozel M. R. and Stillman G. E. (INSPEC, The Institution of Electrical Engineers, London, 1996)

1997

135. W. Grieshaber, E. F. Schubert, R. F. Karlicek Jr., M. J. Schurman, and C. Tran "Relevance of the GaN yellow luminescence for light-emitting diodes" *Proceedings SPIE*, "Light-Emitting Diodes: Research, Manufacturing, and Applications" Vol. **3002**, 40 (1997)
136. M. Passlack, M. Hong, E. F. Schubert, G. J. Zydzik, J. P. Mannaerts, W. S. Hobson, and T. D. Harris "Equilibrium and non-equilibrium transport properties of metal - Ga_2O_3-GaAs MOS structures" *Journal of Applied Physics* **81**, 7647 (1997)
137. S. Fan, P. R. Villeneuve, J. D. Joannopoulos, and E. F. Schubert "High extraction efficiency of spontaneous emission from slabs of photonic crystals" *Physical Review Letters*, **78**, 3294 (1997)
138. A. Billeb, W. Grieshaber, D. Stocker, E. F. Schubert, and R. F. Karlicek Jr. "Microcavity effects in GaN epitaxial layers" *Applied Physics Letters* **70**, 2790 (1997)
139. S. Fan, P. R. Villeneuve, J. D. Joannopoulos, and E. F. Schubert "Photonic crystal light emitting diodes" *Proceedings SPIE*, "Light-Emitting Diodes: Research, Manufacturing, and Applications" Vol. **3002**, 67 (1997)
140. L.-W. Tu, E. F. Schubert, M. Hong, and G. J. Zydzik "In-situ cleaving and coating of semiconductor laser facets" *Proceedings of the March Meeting of the American Physical Society*, Kansas, MO, March 17 – 21 (1997)
141. E. F. Schubert, Editor, *SPIE Proceedings Series*, Vol. **3002** "Light-Emitting Diodes: Research, Manufacturing, and Applications" (1997)
142. E. F. Schubert, I. D. Goepfert, W. Grieshaber, and J. M. Redwing "Optical properties of Si-doped GaN" *Applied Physics Letters* **71**, 921 (1997)
143. E. F. Schubert, I. Goepfert, and J. M. Redwing "Evidence of compensating centers as origin of yellow luminescence in GaN" *Applied Physics Letters* **71**, 3224 (1997)
144. T. Peng, J. Piprek, G. Qiu, J. O. Olowolafe, K. M. Unruh, C. P. Swann, and E. F. Schubert "Band gap bowing and refractive index spectra of polycrystalline AlInN films deposited by sputtering" *Applied Physics Letters* **71**, 2439 (1997)
145. Shanhui Fan, P. R. Villeneuve, J. D. Joannopoulos, and E. F. Schubert "High extraction efficiency of spontaneous emission from slabs of photonic crystals" *Physical Review Letters*, **78**, 3294 (1997)
146. D. A. Stocker, E. F. Schubert, W. Grieshaber, J. M. Redwing, K. S. Boutros, J. S. Flynn, and R. P. Vaudo "Fabrication and optical pumping of laser cavities made by cleaving and wet chemical etching" *Material Research Society Conference Proceedings*, Fall (1997)
147. I. D. Goepfert, E. F. Schubert, and J. M. Redwing "Luminescence properties of Si-doped GaN and evidence of compensating defects as the origin of the yellow luminescence" *Mater. Research Society Conference Proceedings*, Fall (1997)
148. I. D. Goepfert, E. F. Schubert, and J. M. Redwing "Luminescence properties of Si-doped GaN and evidence of compensating defects as the origin of the yellow luminescence" *Mater. Research Society Conference Proceedings* Vol. **482**, page 679, Fall (1997)
149. D. A. Stocker, E. F. Schubert, W. Grieshaber, J. M. Redwing, K. S. Boutros, J. S. Flynn, and R. P. Vaudo "Fabrication and optical pumping of laser cavities made by cleaving and wet chemical etching" *Mater. Research Society Conference Proceedings*, Vol. **482**, 1009 (1997)

1998

150. E. F. Schubert and N. E. J. Hunt "15,000 hours stable operation of resonant-cavity light-emitting diodes" *Applied Physics A* **66**, 319 (1998)
151. D. A. Stocker, E. F. Schubert, K. S. Boutros, J. S. Flynn, R. P. Vaudo, V. M. Phanse, and J. M. Redwing "Optically pumped InGaN/GaN double heterostructure lasers with cleaved facets" *Electronics Letters* **34**, 373 (1998)
152. L. W. Tu, Y. C. Lee, D. Stocker, and E. F. Schubert "Spatial distributions of near-band-gap UV and yellow emission on MOCVD grown GaN epifilms" *Physical Review B*, **B58**, p. 10696 (October 1998)
153. L. W. Tu, Y. C. Lee, S. J. Chen, I. Lo, D. Stocker, and E. F. Schubert "Yellow luminescence depth profiling on GaN epifilms using reactive ion etching, *Applied Physics Letters* **73**, 2802 (November 1998)
154. D. A. Stocker, E. F. Schubert, W. Grieshaber, K. S. Boutros, and J. M. Redwing "Facet roughness analysis for InGaN/GaN lasers with cleaved facets" *Applied Physics Letters* **73**, 1925 (October 1998)
155. D. A. Stocker, E. F. Schubert, and J. M. Redwing "Crystallographic wet chemical etching of GaN" *Applied Physics Letters* **73**, 2654 (November 1998)

Patent Owner 138 East Ex. 2001
Page 092

156. E. F. Schubert, W. Grieshaber, K. S. Boutros, and J. M. Redwing "Yellow luminescence in MOCVD-grown n-type GaN" SPIE Proceedings **3279** (edited by E. F. Schubert), 59 (March 1998)
157. D. A. Stocker, E. F. Schubert, W. Grieshaber, K. S. Boutros, J. S. Flynn, R. P. Vaudo, V. M. Phanse, and J. M. Redwing "InGaN/GaN double heterostructure laser with cleaved facets" *Proceedings of the SPIE Photonics West Conference* (March 1998)

1999

158. (**Invited**) E. F. Schubert and N. E. J. Hunt "Enhancement of Spontaneous Emission in Microcavities" in *Vertical-Cavity Surface-Emitting Lasers*, edited by Carl W. Wilmsen, Henryk Temkin, and Larry A. Coldren, ISBN 0 521 59022 1, p. 68 (Cambridge University Press, Cambridge, April 1999)
159. (**Invited**) E. F. Schubert and J. N Miller "Light-Emitting Diodes - An Introduction" *Encyclopedia of Electrical Engineering*, edited by John G. Webster, Vol. **11**, p. 326 (John Wiley and Sons, New York, March 1999)
160. I. D. Goepfert, E. F. Schubert, A. Osinsky, and P. E. Norris "Demonstration of efficient p-type doping in AlGaN/GaN superlattice structures" *Electronics Letters* **35**, 1109 (June 1999)
161. D. A. Stocker, E. F. Schubert, K. S. Boutros, and J. M. Redwing "Fabrication of smooth GaN-based laser facets" *MRS Internet Journal Nitride Semiconductor Research* **4S1**, G7.5 (March 1999)
162. X. Guo, J. W. Graff, and E. F. Schubert "Photon Recycling Semiconductor Light Emitting Diode" *IEDM Technical Digest*, **IEDM-99**, 600 (December 1999)

2000

163. D. A. Stocker, I. D. Goepfert, E. F. Schubert, K. S. Boutros, and J. M. Redwing "Crystallographic wet chemical etching of p-type GaN" *Journal of the Electrochemical Society* **147**, 763 (February 2000)
164. I. D. Goepfert, E. F. Schubert, A. Osinsky, and P. E. Norris "Efficient acceptor activation in AlGaN/GaN doped superlattices" accepted by the *MRS Internet Journal Nitride Semiconductor Research*, *see* http://nsr.mij.mrs.org/5S1/W3.85/ (March 2000)
165. X. Guo, J. W. Graff, E. F. Schubert, and R. F. Karlicek Jr. "Photon Recycling Semiconductor Light Emitting Diode" *SPIE Photonics West Proceedings Series* Vol. **3938**, p. 60 "Light-Emitting Diodes: Research, Manufacturing, and Applications" (March 2000)
166. Y.-L. Li, E. F. Schubert, J. W. Graff, A. Osinsky, and W. F. Schaff "Low-resistance ohmic contacts to p-type GaN" *Applied Physics Letters* **76**, 2728 (May 2000)
167. X. Guo, J. W. Graff, and E. F. Schubert "Photon recycling for high brightness LEDs" *Compound Semiconductors* **6** (4) page 1 (May 2000)
168. J. W. Graff and E. F. Schubert "Flat free-standing silicon diaphragms using silicon-on-insulator (SOI) wafers" *Sensors and Actuators A* **84**, 276 (August 2000)
169. I. D. Goepfert, E. F. Schubert, A. Osinsky, P. E. Norris, and N. N. Faleev "Experimental and theoretical study of acceptor activation and transport properties in *p*-type $Al_xGa_{1-x}N$/GaN superlattices" *Journal of Applied Physics* **88**, 2030 (August 2000)
170. L. Chernyak, A. Osinsky, V. Fuflyigin, and E. F. Schubert "Electron-beam induced increase of electron diffusion length in p-type GaN and AlGaN/GaN superlattices" *Applied Physics Letters* **77**, 875 (August 2000)
171. J. W. Graff, E. F. Schubert, A. Osinsky "On the reduction of base resistance in GaN-based heterojunction bipolar transistors" Proceedings of the 2000 IEEE/Cornell Conference on High-Performance Devices, p. 28, ISBN 0-7803-6381-7 (October 2000)
172. A. Osinsky, V. Fuflyigin, L. D. Zhu, A. B. Goulakov, J. W. Graff, and E. F. Schubert "New concepts and preliminary results for SiC bipolar transistors: $ZnSiN_2$ and $ZnGaN_2$ heterojunction emitters" Proceedings of the 2000 IEEE/Cornell Conference on High-Performance Devices, p. 168, ISBN 0-7803-6381-7 (October 2000)
173. D. A. Stocker, E. F. Schubert, and J. M. Redwing "Optically pumped InGaN/GaN lasers with wet-etched facets" *Applied Physics Letters* **77**, 4253 (December 2000)
174. E. L. Waldron, E. F. Schubert, J. W. Graff, A. Osinsky, M. J. Murphy, and W. F. Schaff "Evidence of polarization effects in doped AlGaN/GaN superlattices" Proceedings of MRS Fall Conference (December 2000)

2001

175. J. W. Graff, E. F. Schubert, and A. Osinsky "GaN/SiC mesa junctions for HBTs fabricated using selective photoelectrochemical etching" *Electronics Letters* **37**, 249 (February 2001)
176. X. Guo, E. F. Schubert, and J. Jahns, "Current crowding and optical saturation effects in GaInN/GaN LEDs grown on insulating substrates" *SPIE Photonics West Proceedings Series*. Vol. 4278, p. 133 "Light-Emitting Diodes: Research, Manufacturing, and Applications" (February 2001)
177. L. Chernyak, A. Osinsky, V. Fuflyigin, J. Graff, and E. F. Schubert "Minority Electron Transport Anisotropy in p-type $Al_xGa_{1-x}N$/GaN Superlattices" *IEEE Transactions on Electron Devices* **48**, 433 (March 2001)

Patent Owner 138 East Ex. 2001
Page 093

178. X. Guo and E. F. Schubert "Current crowding and optical saturation effects in GaInN/GaN light-emitting diodes" *Applied Physics Letters* **78**, 3337 (May 2001)
179. X. Guo, Y.-L. Li, and E. F. Schubert "Efficiency of GaN/InGaN light-emitting diodes with interdigitated mesa geometry" *Applied Physics Letters* **79**, 1936 (Sept. 2001)
180. E. L. Waldron, J. W. Graff, and E. F. Schubert "Improved mobilities and resistivities in modulation doped p-type AlGaN/GaN superlattices" *Applied Physics Letters* **79,** 2737 (October 2001)
181. E. L. Waldron, J. W. Graff, and E. F. Schubert "Influence of doping profiles on p-type AlGaN/GaN superlattices," *Physica Status Solidi* (*A*) **188**, 889 (November 2001)
182. Y.-L. Li, J. W. Graff, E. L. Waldron, T. Gessmann, and E. F. Schubert "Novel polarization enhanced contacts to *n*-type GaN" *Physica Status Solidi (A)* 188, 359 (November 2001)

2002

183. T. Gessmann, Y.-L. Li, E. L. Waldron, J. W. Graff, and E. F. Schubert "Ohmic contacts to p-type GaN mediated by polarization fields in thin InGaN capping layers" *Applied Physics Letters* **80**, 986 (Feb 2002)
184. L. Chernyak, A. Schulte, J. W. Graff, and E. F. Schubert "Influence of electron injection on performance of GaN photodetectors" *Applied Physics Letters* **80**, 926 (Feb 2002)
185. T. Gessmann, Y.-L. Li, E. L. Waldron, and E. F. Schubert "Novel type of ohmic contacts to p-doped GaN using polarization fields in thin $In_xGa_{1-x}N$ capping layers" *Journal of Electronic Materials* **31**, 416 (May 2002)
186. T. Gessmann, J. W. Graff, Y.-L. Li, E. L. Waldron, and E. F. Schubert "Ohmic contact technology in III-V nitrides using polarization effects in cap layers" Proceedings of the *Lester Eastman conference on high-speed devices* (Sep 2002)
187. T. Gessmann, J. W. Graff, Y.-L. Li, E. L. Waldron, and E. F. Schubert "Ohmic contacts to III-V nitrides using polarization effects of cap layers" *Journal of Applied Physics* **92**, 3740 (October 2002)

2003

188. E. L. Waldron, E. F. Schubert, and A. M. Dabiran "Multisubband photoluminescence in p-type modulation-doped AlGaN/GaN superlattices" *Physical Review B* **67**, 045327 (January 2003)
189. (**Book**), E. F. Schubert "Light-emitting diodes" 328 pages, 154 line diagrams, 21 half-tones, 21 tables, Hardback ISBN: 0521823307 Paperback ISBN: 0521533511 (Cambridge University Press, Cambridge UK, May 2003)
190. T. Gessmann, Y.-L. Li, E. F. Schubert, J. W. Graff, and J. K. Sheu "GaInN light-emitting diodes with omni-directional reflectors", *SPIE Proceedings Series* **4996** "Light Emitting Diodes: Research, Manufacturing, and Applications VII" p. 26 (July 2003)
191. T. Gessmann, E. F. Schubert, J. W. Graff, and K. Streubel "AlGaInP light-emitting diodes with omni-directionally reflecting submount", *SPIE Proceedings Series* **4996** "Light Emitting Diodes: Research Manufacturing, and Applications VII" p. 139 (July 2003)
192. E. F. Schubert, K. J. Linden, H. Yao, D. J. McGraw (Editors) "Light-Emitting Diodes: Research, Manufacturing, and Applications VII" *SPIE Proceedings Series* **4996**, SPIE-International Society for Optical Engineering ISBN: 081944796X Paperback, 278pp (July 2003)
193. Y.-L. Li, T. Gessmann, E. F. Schubert, and J. K. Sheu "Carrier dynamics in nitride-based light-emitting p-n junction diodes with two active regions emitting at different wavelengths" *Journal of Applied Physics* **94**, 2167 (August 2003)
194. J. M. Shah, Y.-L. Li, T. Gessmann, and E. F. Schubert "Experimental analysis and theoretical model for anomalously high ideality factors ($n >> 2.0$) in AlGaN/GaN p-n junction diodes" *Journal Applied Physics* **94,** 2627 (August 2003)
195. T. Gessmann, E. F. Schubert, J. W. Graff, K. Streubel, and C. Karnutsch "Omni-directionally reflective contacts for light-emitting diodes" *IEEE Electron Devices Letters* **24**, 683 (November 2003)
196. E. L. Waldron, Y.-L. Li, E. F. Schubert, J. W. Graff, and J. K. Sheu "Experimental study of perpendicular transport in weakly coupled $Al_xGa_{1-x}N$/GaN superlattices and theoretical model based on sequential tunneling" accepted for publication in *Applied Physics Letters* **83**, 4975 (2003)

2004

197. J. M. Shah, Y. Li, T. Gessmann, and E. F. Schubert "Experimental analysis and a new theoretical model for anomalously high ideality factors ($n >> 2.0$) in GaN-based p-n junction diodes" *Mater. Research Society Symposium Proceedings* **798**, 113 (January 2004)
198. T. Gessmann, H. Luo, J.-Q. Xi, K. P. Streubel, and E. F. Schubert "Light-emitting diodes with integrated omnidirectionally reflective contacts" *Proceedings of SPIE "Light-emitting diodes: Research, Manufacturing and Applications VIII*" **5366**, 53 (January 2004)

Patent Owner 138 East Ex. 2001
Page 094

199. T. Gessmann and E. F. Schubert "High-efficiency AlGaInP light-emitting diodes for solid-state lighting applications" *Journal of Applied Physics* **95**, 2203 (March 2004)
200. J. K. Kim, E. L. Waldron, Y.-L. Li, T. Gessmann, E. F. Schubert, H. W. Jang, and J.-L. Lee "P-type conductivity in bulk $Al_xGa_{1-x}N$ and $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ superlattices with average Al mole fraction > 20 %" *Applied Physics Letters* **84**, 3310 (May 2004)
201. J. K. Kim, T. Gessmann, H. Lu, and E. F. Schubert "GaInN light-emitting diodes with RuO_2/SiO_2/Ag omni-directional reflector" *Applied Physics Letters* **84**, 4508 (May 2004)
202. Y.-L. Li, J. M. Shah, P.-H. Leung, T. Gessmann, and E. F. Schubert, "Performance characteristics of white light sources consisting of multiple light-emitting diodes" *Proceedings of the SPIE - The International Society for Optical Engineering* **5187**, 178 (August 2004)
203. Y. Xi and E. F. Schubert "Junction-temperature measurement in GaN ultraviolet light-emitting diodes using diode forward-voltage method" *Applied Physics Letters* **85**, 2163 (Sept. 2004)
204. Y. Xi and E. F. Schubert "Junction-temperature measurement in GaN UV light-emitting diodes using the diode forward voltage" *2004 Proceedings of the Lester Eastman Conference on High-Performance Devices – Selected Topics in Electronics and Systems* edited by Robert E. Leoni III, Vol. **35**, p. 84 (December 2004)
205. J.-Q. Xi, M. Ojha, W. Cho, T. Gessmann, E. F. Schubert, J. L. Plawsky, and W. N. Gill "Omni-directional reflector using a low refractive index material" *2004 Proceedings of the Lester Eastman Conference on High-Performance Devices – Selected Topics in Electronics and Systems* edited by Robert E. Leoni III, Vol. **35**, p. 102 (December 2004)
206. (**Invited**) J. K. Kim, J. Q. Xi, H. Luo, T. Gessmann, and E. F. Schubert "High-Reflectivity Omni-Directional Reflectors for Light-Emitting Diodes" *Proceedings of the IEDMS* (December 2004)

2005

207. Y. Xi, J.-Q. Xi, T. Gessmann, J. M. Shah, J. K. Kim, E. F. Schubert, A. J. Fischer, M. H. Crawford, K. H. A. Bogart, and A. A. Allerman "Junction and carrier temperature measurements in deep-ultraviolet light-emitting diodes using three different methods" *Applied Physics Letters* **86**, 031907 (January 2005)
208. Y. Xia, E. Williams, Y. Park, I. Yilmaz, J. M. Shah, E. F. Schubert, and C. Wetzel "Discrete steps in the capacitance-voltage characteristics of GaInN/GaN light-emitting diode structures" in "GaN, AlN, InN, and Their Alloys", edited by C. Wetzel, B. Gil, M. Kuzuhara, and M. Manfra, *Materials Research Society (MRS) Symposium Proceedings* **831**, E3.38 (MRS, Warrendale PA, January 2005)
209. Y. Xi, J.-Q. Xi, T. Gessmann, J. M. Shah, J. K. Kim, E. F. Schubert, A. J. Fischer, M. H. Crawford, K. H. A. Bogart, and A. A. Allerman "Junction temperature measurements in deep-UV light-emitting diodes" in "GaN, AlN, InN and Their Alloys" edited by C. Wetzel, B. Gil, M. Kuzuhara, and M. Manfra, *Materials Research Society (MRS) Symposium Proceedings* **831**, E1.7 (MRS, Warrendale PA, January 2005)
210. S. Chhajed, Y. Xi, Y.-L. Li, T. Gessmann, and E. F. Schubert "Influence of junction temperature on luminous efficacy and color rendering properties of a trichromatic LED-based white light source" *Journal of Applied Physics* **97**, 054506 (February 2005)
211. (**Invited**) J. K. Kim, H. Luo, Y. Xi, J. M. Shah, T. Gessmann, and Schubert E. F. "Enhancement of light extraction in GaInN light-emitting diodes by diffuse omni-directional reflectors" *Proceedings of the Second Asia-Pacific Workshop on Wide-gap Semiconductors* (APWS-2005) Hsinchu Lakeshore Hotel, Hsinchu, Taiwan, March 7–9 (March 2005)
212. M. Furis, A. N. Cartwright, E. L. Waldron, and E. F. Schubert "Spectral and temporal resolution of recombination from multiple excitation states in modulation-doped AlGaN/GAN MQW heterostructures" *Applied Physics Letters* **86**, 162103 (April 2005)
213. (**Invited**) E. F. Schubert and J. K. Kim "Solid-state light sources getting smart" *Science* **308**, 1274 (May 2005)
214. J.-Q. Xi, M. Ojha, W. Chow, C. Wetzel, T. Gessmann, E. F. Schubert, J. L. Plawsky, and W. N. Gill "Omni-directional reflector using a low refractive index material" *Proceedings of the Conference on Lasers and Electrooptics* (CLEO), Baltimore MD, May 22-27 (May 2005)
215. J. K. Kim, H. Luo, E. F. Schubert, J. Cho, C. Sone, and Y. Park "Strongly enhanced phosphor efficiency in GaInN white light-emitting diodes using remote phosphor configuration and diffuse reflector cup" *Japanese Journal Applied Physics – Express Letter* **44**, L 649 (May 2005)
216. H. Luo, J. K. Kim, E. F. Schubert, J. Cho, C. Sone, and Y. Park "Analysis of high-power packages for phosphor-based white-light-emitting diodes" *Applied Physics Letters* **86**, 243505 (June 2005)
217. J.-Q. Xi, M. Ojha, W. Cho, J. L. Plawsky, W. N. Gill, T. Gessmann, and E. F. Schubert "Omnidirectional reflector using nanoporous SiO_2 as a low-refractive-index material" *Optics Letters* **30,** 1518 (June 2005)
218. J.-Q. Xi, J. K. Kim, and E. F. Schubert "Silica nanorod-array films with very low refractive indices" *Nano Letters* **5**, 1385 (July 2005)

219. (**Invited**) E. F. Schubert, J. K. Kim, and T. Gessmann "Light-emitting diodes" *Kirk-Othmer Encyclopedia of Chemical Technology*; on-line access at < www.mrw.interscience.wiley.com/kirk/ > (John Wiley and Sons and Wiley Inter-Science, New York NY, July 2005)
220. J.-Q. Xi, M. Ojha, J. L. Plawsky, W. N. Gill, J. K. Kim, and E. F. Schubert "Internal high-reflectivity omni-directional reflectors" *Applied Physics Letters* **87**, 031111 (July 2005)
221. (**Invited**) E. F. Schubert and T. Gessmann "Light-emitting diodes" published in "*Elsevier Encyclopedia of Condensed Matter Physics*" edited by F. Bassani, J. Liedl, and P. Wyder (Elsevier, Amsterdam, Netherlands, September 2005)
222. Y. Xi, T. Gessmann, J.-Q. Xi, J. K. Kim, J. M. Shah, E. F. Schubert, A. J. Fischer, M. H. Crawford, K. H. A. Bogart, A. A. Allerman "Junction temperature in ultraviolet light-emitting diodes" Special Issue on Ultraviolet Semiconductor Sources, *Japanese Journal of Applied Physics* **44**, 7260 (October 2005)
223. J.-Q. Xi, J. K. Kim, and E. F. Schubert "Low-refractive-index material with oblique-angle deposition" *LEOS Newsletter* Vol. **19** No. 6, page 10 (December 2005)
224. (**Invited**) E. F. Schubert, T. Gessmann, and J. K. Kim, "Inorganic semiconductors for light-emitting diodes" in *Organic Light-Emitting Devices, Synthesis, Properties, and Applications* edited by K. Müllen and U. Scherf, ISBN 3-527-31218-8 (Wiley VCH, New York, USA, 2006)
225. (**Invited**) E. F. Schubert, J. K. Kim, J.-Q. Xi, and H. Luo "Innovations in Light-emitting devices" in *The Physics of Semiconductor Devices* edited by V. Kumar, S. K. Agarwal, and S. N. Singh (Allied Publishers PVT. Limited, New Delhi, India, 2005)
226. J. K. Kim, J.-Q. Xi, H. Luo, J. Cho, C. Sone, Y. Park, and E. F. Schubert "Enhancement of light extraction in GaN light-emitting diodes by omnidirectional reflectors with ITO nanorod low-refractive-index layer" *Proceedings SPIE, Illumination Engineering, Fifth International Conference on Solid-State Lighting*, Vol. **5941**, page 5941 0K-1 – 6 (2005)

2006

227. J. K. Kim, T. Gessmann, E. F. Schubert, J.-Q. Xi, H. Luo, J. Cho, C. Sone, Y. Park "GaInN light-emitting diode with conductive omnidirectional reflector having a low-refractive index indium-tin oxide (ITO) layer" *Applied Physics Letters* **88**, 013501 (January 2006)
228. J. K. Kim, H. Luo, Y. Xi, J. M. Shah, T. Gessmann, and E. F. Schubert "Light extraction in GaInN light-emitting diodes using diffuse omnidirectional reflectors" *Journal of the Electrochemical Society* **153**, G105 (January 2006)
229. (**Invited**) J. K. Kim, J.-Q. Xi, E. F Schubert "Omni-directional reflectors for light-emitting diodes" *Light-Emitting Diodes: Research, Manufacturing, and Applications X, Proceedings of SPIE* **6134**, 61340D-1 (January 2006)
230. J. K. Kim, J.-Q. Xi, H. Luo, Jaehee Cho, Cheolsoo Sone, Yongjo Park, T. Gessmann, John M. Zavada, H. X. Jiang, and E. F Schubert, "GaN light-emitting triodes (LETs) for high-efficiency hole-injection and light emission" *Light-Emitting Diodes: Research, Manufacturing, and Applications X, Proceedings of SPIE* **6134**, 61340K-1 (January 2006)
231. J.-Q. Xi, J. K. Kim, E. F. Schubert, D. Ye, T.-M. Lu, S.-Y. Lin, and J. S. Juneja "Very low-refractive-index optical thin films consisting of an array of SiO_2 nanorods" *Optics Letters* **31**, 601 (March, 2006)
232. J. M. Shah, T. Gessmann, H. Luo, Y. Xi, K. Chen, J. K. Kim, and E. F. Schubert "Reduction of base access resistance in AlGaN/GaN heterojunction bipolar transistors using GaInN base cap layer and selective epitaxial growth" *Materials Research Society (MRS) Symposium Proceedings* Vol. **892**, page 0892-FF13-10.1 (March 2006)
233. F. Shahedipour-Sandvik, E. F. Schubert, B. K. Crone, H. Liu, Y-K. Su (editors) "Solid-State Lighting Materials and Devices" Symposium DD *Materials Research Society (MRS) Proceedings Volume 916* (May 2006)
234. C. W. Litton, D. Johnstone, S. Akarca-Biyikli, K. S. Ramaiah, I. Bhat, T. P. Chow, J. K. Kim, and E. F. Schubert "Effect of C/Si ratio on deep levels in epitaxial 4H–SiC" *Applied Physics Letters* **88**, 121914 (April 2006)
235. J. K. Kim, E. F. Schubert, Jaehee Cho, Cheolsoo Sone, J. Y. Lin, H. X. Jiang, and John M. Zavada "GaN light-emitting triode (LET) for high-efficiency hole injection" *Journal of The Electrochemical Society* **153**, G734 (June 2006)
236. (**Book**) E. F. Schubert "Light-emitting diodes, second edition" 422 pages, 255 line diagrams, 32 half-tones, 30 exercises, 287 figures, Hardback ISBN-13: 9780521865388 (Cambridge University Press, Cambridge UK, June 2006)
237. H. Luo, J. K. Kim, Y. A. Xi, E. F. Schubert, J. Cho, C. Sone, and Y. Park "Trapped whispering-gallery optical modes in white light-emitting diode lamps with remote phosphor" *Applied Physics Letters* **89**, 041125 (July 2006)

Patent Owner 138 East Ex. 2001
Page 096

238. Y. Andrew Xi, Xiaolu Li, J. K. Kim, F. Mont, T. Gessmann, Hong Luo, and E. F Schubert "Quantitative assessment of diffusivity and specularity of surface-textured reflectors for light extraction in light-emitting diodes" *Journal of Vacuum Science and Technology* **A 24**, 1627 (July 2006)
239. Y. A. Xi, K. X. Chen, F. Mont, J. K. Kim, C. Wetzel, E. F. Schubert, W. Liu, X. Li, and J. A. Smart "Very high quality AlN grown on (0001) sapphire by metal-organic vapor phase epitaxy" *Applied Physics Letters* **89**, 103106 (September 2006)
240. J. K. Kim, J.-Q. Xi, H. Luo, Schubert E. F., Jaehee Cho, Cheolsoo Sone and Yongjo Park "Enhanced light-extraction in GaInN near-ultraviolet light-emitting diode with Al-based omnidirectional reflector having NiZn/Ag microcontacts" *Applied Physics Letters* **89**, 141123 (October 2006)
241. J.-Q. Xi, Luo Hong, A.J. Pasquale, Jong Kyu Kim, and E. F Schubert "Enhanced light extraction in GaInN light-emitting diode with pyramid reflector" *IEEE Photonics Technology Letters* **18***,* 2347 (November 2006)
242. (**Invited**) E. F. Schubert, J. K. Kim, H. Luo, and J.-Q. Xi "Solid-state lighting – A benevolent technology" *Reports on Progress in Physics* **69**, 3069 (November 2006)

2007

243. Frank W. Mont, J. K. Kim, M. F. Schubert, H. Luo, E. F. Schubert, and R. W. Siegel "High refractive index nanoparticle-loaded encapsulants for light-emitting diodes" *Proceedings SPIE* **6486**, 64861C (February 2007)
244. F. W. Mont, H. Luo, M. F. Schubert, J. K. Kim, E. F. Schubert, and R. W. Siegel, "Nanoparticle-loaded encapsulation materials for light-emitting diode applications" *Materials Research Society Symposium Proceedings* **955**, I13-02 (January 2007)
245. J.-Q. Xi, Hong Luo, Jong Kyu Kim, and E. F. Schubert "High light-extraction efficiency in GaInN light-emitting diode with pyramid reflector" *SPIE Photonics West*, *Proceedings SPIE* **6486**, 648606, San Jose, CA, January 20 – 25 (January 2007)
246. Y. Andrew Xi, K. X. Chen, F. W. Mont, J. K. Kim, W. Lee, E. F. Schubert, W. Liu, X. Li, and J. A. Smart "Kinetic study of Al-mole fraction in $Al_xGa_{1-x}N$ grown on c-plane sapphire and AlN bulk substrates by metal-organic vapor-phase epitaxy" *Applied Physics Letters* **90**, 051104 (January 2007)
247. Y. Andrew Xi, K. X. Chen, F. Mont, J. K. Kim, E. F. Schubert, W. Liu, X. Li, J. A. Smart "Comparative study of n-type AlGaN grown on sapphire by using a superlattice layer and a low-temperature AlN interlayer" *Journal of Crystal Growth* **299**, 59–62 (January 2007)
248. J.-Q. Xi, Martin F. Schubert, J. K. Kim, E. Fred Schubert, Minfeng Chen, Shawn-Yu Lin, Wayne Liu, and Joe A. Smart "Optical thin-film materials with low refractive index for broadband elimination of Fresnel reflection" *Nature Photonics* **1**, 176 (March 2007)
249. Martin. F. Schubert, J.-Q. Xi, J. K. Kim, and E. F Schubert "Distributed Bragg reflector consisting of high- and low-refractive-index thin film layers made of the same material" *Applied Physics Letters* **90**, 141115 (April 2007)
250. Y. Andrew Xi, K. X. Chen, F. W. Mont, J. K. Kim, E. F. Schubert, C. Wetzel, W. Liu, X. Li, and J. A. Smart "Optimization of high-quality AlN epitaxially grown on (0001) sapphire by metal-organic vapor-phase epitaxy" *Journal of Electronic Materials* (Special Issue) **36**, 533 (DOI: 10.1007/s11664-007-0099-3) (May 2007)
251. Kaixuan X. Chen, Y. A. Xi, F. W. Mont, J. K. Kim, E. F. Schubert, W. Liu, X. Li, and J. A. Smart "Recombination dynamics in ultraviolet light-emitting diodes with Si-doped $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ multiple quantum well active regions" *Journal of Applied Physics* **101**, 113102 (June 2007)
252. Martin F. Schubert, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, and Jaehee Cho "Polarization of light emission by 460 nm GaInN/GaN light-emitting diodes grown on (0001) oriented sapphire substrates" *Applied Physics Letters* **91**, 051117 (August 2007)
253. Martin F. Schubert, Ahmed Noemaun, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, and Cheolsoo Sone "Encapsulation shape with non-rotational symmetry designed for extraction of polarized light from unpolarized sources" *Optics Express* **15***,* 10452 (August 2007)
254. (**Invited**) E. Fred Schubert and Jong Kyu Kim "Low-refractive index materials: A new class of optical thin-film materials" *Physica Status Solidi B* **244**, 3002 (DOI: 10.1002/pssb.200675603) (August 2007)
255. Kaixuan X. Chen, Q. Dai, W. Lee, J. K. Kim, E. F. Schubert, W. Liu, S. Wu, X. Li, and J. A. Smart "Parasitic sub-band-gap emission originating from compensating native defects in Si doped AlGaN" *Applied Physics Letters* **91**, 121110 (September 2007)
256. Martin F. Schubert, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, and Jaehee Cho "Linearly polarized emission from GaInN light-emitting diodes with polarization-enhancing reflector" *Optics Express* **15**, 11213 (September 2007)
257. (**Invited**) E. F. Schubert, J. K. Kim, and J.-Q. Xi "Light-emitting diodes hit the centenary milestone" *Compound Semiconductors* October issue, page 20–23 (October 2007)

Patent Owner 138 East Ex. 2001
Page 097

258. Min-Ho Kim, Martin F. Schubert, Qi Dai, Jong Kyu Kim, E. Fred Schubert, Joachim Piprek, and Yongjo Park "Origin of efficiency droop in GaN-based light-emitting diodes" *Applied Physics Letters* **91**, 183507 (October 2007)
259. Martin F. Schubert, Sameer Chhajed, Jong Kyu Kim, E. Fred Schubert, Daniel D. Koleske, Mary H. Crawford, Stephen R. Lee, Arthur J. Fischer, Gerald Thaler "Effect of dislocation density on efficiency droop in GaInN/GaN light-emitting diodes" *Applied Physics Letters* **91**, 231114 (December 2007)

2008

260. Jong Kyu Kim, S. Chhajed, M. F. Schubert, E. F. Schubert, A. J. Fischer, M. H. Crawford, J. Cho, H. Kim, and C. Sone "Light-extraction enhancement of GaInN light-emitting diodes by graded-refractive-index indium tin oxide anti-reflection contact" *Advanced Materials* **20**, 801 (March 2008)
261. Frank W. Mont, Jong Kyu Kim, Martin F. Schubert, E. Fred Schubert, and Richard W. Siegel "High-refractive-index TiO_2-nanoparticle-loaded encapsulants for light-emitting diodes" *Journal of Applied Physics* **103**, 083120 (April 2008)
262. Martin F. Schubert, Frank W. Mont, Sameer Chhajed, David J. Poxson, Jong Kyu Kim, and E. Fred Schubert "Design of multilayer antireflection coatings made from co-sputtered and low-refractive-index materials by genetic algorithm" *Optics Express* Vol. **16**, 5290 (April 2008)
263. Martin F. Schubert, Jiuru Xu, Jong Kyu Kim, E. Fred Schubert, Min Ho Kim, Sukho Yoon, Soo Min Lee, Cheolsoo Sone, Tan Sakong, and Yongjo Park "Polarization-matched GaInN/AlGaInN multi-quantum-well light-emitting diodes with reduced efficiency droop" *Applied Physics Letters* **93**, 041102 (July 2008)
264. David J. Poxson, Frank W. Mont, Martin F. Schubert, Jong Kyu Kim, and E. Fred Schubert "Quantification of porosity and deposition rate of nano-porous films grown by oblique-angle deposition" *Applied Physics Letters* **93**, 101914 (September 2008)
265. Mei-Ling Kuo, David J. Poxson, Yong Sung Kim, Frank W. Mont, Jong Kyu Kim, E. Fred Schubert, and Shawn-Yu Lin "Realization of a near-perfect antireflection coating for silicon solar energy utilization" *Optics Letters* **33**, 2527 (October 2008)
266. Jong Kyu Kim, Ahmed N. Noemaun, Frank W. Mont, David Meyaard, E. Fred Schubert, David J. Poxson, Hyunsoo Kim, Cheolsoo Sone, and Yongjo Park "Elimination of total internal reflection in GaInN light-emitting diodes by graded-refractive-index micropillars" *Applied Physics Letters* **93**, 221111 (November 2008)
267. Sameer Chhajed, Martin F. Schubert, Jong Kyu Kim, and E. Fred Schubert "Nanostructured multilayer graded-index antireflection coating for Si solar cells with broadband and omnidirectional characteristics" *Applied Physics Letters* **93**, 251108 (November 2008)
268. K. X. Chen, Q. Dai, W. Lee, J. K. Kim, E. F. Schubert, J. Grandusky, M. Mendrick, X. Li, and J. A. Smart "Effect of dislocations on electrical and optical properties of n-type $Al_{0.34}Ga_{0.66}N$" *Applied Physics Letters* **93**, 192108 (November 2008)
269. Jong Kyu Kim and E. Fred Schubert "Transcending the replacement paradigm of solid-state lighting" *Optics Express* **16**, 21835 (December 2008)

2009

270. Jiuru Xu, Martin F. Schubert, Ahmed N. Noemaun, Di Zhu, Jong Kyu Kim, E. Fred Schubert, Min Ho Kim, Hun Jae Chung, Sukho Yoon, Cheolsoo Sone, and Yongjo Park "Reduction in efficiency droop, forward voltage, ideality factor, and wavelength shift in polarization-matched GaInN/GaInN multi-quantum-well light-emitting diodes" *Applied Physics Letters* **94**, 011113 (January 2009)
271. Di Zhu, Jiuru Xu, Ahmed N. Noemaun, Jong Kyu Kim, E. Fred Schubert, Mary H. Crawford, and Daniel D. Koleske, "The origin of the high diode-ideality factors in GaInN/GaN multiple quantum well light-emitting diodes" *Applied Physics Letters* **94**, 081113 (February 2009)
272. Martin F. Schubert, Jiuru Xu, Qi Dai, Frank W. Mont, Jong Kyu Kim, and E. Fred Schubert "On resonant optical excitation and carrier escape in GaInN/GaN quantum wells" *Applied Physics Letters* **94**, 081114 (February 2009)
273. Qi Dai, M. F. Schubert, M. H. Kim, J. K. Kim, E. F. Schubert, D. D. Koleske, M. H. Crawford, S. R. Lee, A. J. Fischer, G. Thaler, and M. A. Banas "Internal quantum efficiency and nonradiative recombination coefficient of GaInN / GaN multiple quantum wells with different dislocation densities" *Applied Physics Letters* **94**, 111109 (March 2009)
274. David J. Poxson, Martin F. Schubert, Frank W. Mont, E. F. Schubert, and Jong Kyu Kim "Broadband omnidirectional antireflection coatings optimized by genetic algorithm" *Optics Letters* **34**, 728 (March 2009)
275. Roya Mirhosseini, Martin F. Schubert, Sameer Chhajed, Jaehee Cho, Jong Kyu Kim, and E. Fred Schubert "Improved color rendering and luminous efficacy in phosphor-converted white light-emitting diodes by use of dual-blue emitting active regions" *Optics Express* **17**, 10806 (June 2009)

Patent Owner 138 East Ex. 2001
Page 098

276. Martin F. Schubert, Qi Dai, Jiuru Xu, Jong Kyu Kim, and E. Fred Schubert "Electroluminescence induced by photoluminescence excitation in GaInN/GaN light-emitting diodes" *Applied Physics Letters* **95**, 191105 (November 2009)
277. Jong Kyu Kim and E. Fred Schubert "Enhancement in light-extraction efficiency of GaN-based light-emitting diodes" in *Advanced Semiconductor Materials and Devices Research: III-Nitrides and SiC*; edited by H-Y Cha (Transworld Research Network, Kerala, India, 2009)

2010

278. J. Cho, A. Mao, J. K. Kim, J. K. Son, Y. Park and E. F. Schubert "Analysis of reverse tunneling current in GaInN light-emitting diodes" *Electronics Letters* **46**, 156 (January 2010)
279. M. Ojha, A. Chatterjee, F. Mont, E. F. Schubert, P. C. Wayner Jr., and J. L. Plawsky "The role of solid surface structure on dropwise phase change processes" *International Journal of Heat and Mass Transfer* **53**, 910 (February 2010)
280. Wonseok Lee, Min-Ho Kim, Di Zhu, Ahmed N. Noemaun, Jong Kyu Kim, and E. F. Schubert "Growth and characteristics of GaInN/GaInN multiple quantum well light-emitting diodes" *Journal of Applied Physics* **107**, 063102 (March 2010)
281. Di Zhu, Ahmed N. Noemaun, Martin F. Schubert, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, and Daniel D. Koleske "Enhanced electron capture and symmetrized carrier distribution in GaInN light-emitting diodes having tailored barrier doping" *Applied Physics Letters* **96**, 121110 (March 2010)
282. Martin F. Schubert and E. Fred Schubert "Effect of heterointerface polarization charges and well width upon capture and dwell time for electrons and holes above GaInN/GaN quantum wells" *Applied Physics Letters* **96**, 131102 (March 2010)
283. Martin F. Schubert, David J. Poxson, Frank W. Mont, and E. Fred Schubert "Performance of anti-reflection coatings consisting of multiple discrete layers and comparison with continuously graded anti-reflection coatings" *Applied Physics Express* **3**, 082502 (August 2010)
284. Ming Ma, Frank W. Mont, David J. Poxson, Jaehee Cho, E. Fred Schubert, Roger E. Welser, and Ashok K. Sood "Enhancement of photovoltaic cell response due to high-refractive-index encapsulants" *Journal of Applied Physics* **108**, 043102 (August 2010)
285. Qi Dai, Qifeng Shan, Jing Wang, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, Daniel D. Koleske, Min-Ho Kim, and Yongjo Park "Carrier recombination mechanisms and efficiency droop in GaInN/GaN light-emitting diodes" *Applied Physics Letters* **97**, 133507 (September 2010)
286. David J. Poxson, Frank W. Mont, Martin F. Schubert, Jong Kyu Kim, Jaehee Cho, and E. Fred Schubert "Demonstration of optical interference filters utilizing tunable refractive index layers" *Optics Express* **18**, A594 (October 2010)
287. Qifeng Shan, Qi Dai, Sameer Chhajed, Jaehee Cho, and E. Fred Schubert "Analysis of thermal properties of GaInN light-emitting diodes and laser diodes" *Journal of Applied Physics* **108**, 084504 (October 2010)

2011

288. Ann Mao, Jaehee Cho, Qi Dai, and E. Fred Schubert, Joong Kon Son, and Yongjo Park "Characteristics of dot-like green satellite emission in GaInN light-emitting diodes" *Applied Physics Letters* **98**, 023503 (January 2011)
289. Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Jong Kyu Kim, Daniel D. Koleske, and Mary H. Crawford "Temperature-dependent light-output characteristics of GaInN light-emitting diodes with different dislocation densities" *Physica Status Solidi (A)* **208**, 947 (January 2011)
290. Qi Dai, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, Daniel D. Koleske, Min-Ho Kim, and Yongjo Park "On the symmetry of efficiency-versus-carrier-concentration curves in GaInN/GaN light-emitting diodes and relation to droop-causing mechanisms" *Applied Physics Letters* **98**, 033506 (January 2011)
291. Sameer Chhajed, Wonseok Lee, Jaehee Cho, E. Fred Schubert, and Jong Kyu Kim "Strong light-extraction enhancement in GaInN light-emitting diodes by using self-organized nanoscale patterning of p-type GaN" *Applied Physics Letters* **98**, 071102 (February 2011)
292. Roger E. Welser, Adam W. Sood, Ashok K. Sood, David J. Poxson, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Dennis L. Polla, and Nibir K. Dhar "Ultra-High Transmittance through Nanostructure-Coated Glass for Solar Cell Applications" *Proceedings of the SPIE* **8035**, 80350X (May 2011)
293. Xing Yan, Frank W. Mont, David J. Poxson, Jaehee Cho, E. Fred Schubert, Min-Ho Kim, and Cheolsoo Sone "Electrically conductive thin-film color filters made of single-material – indium-tin-oxide" *Journal of Applied Physics* **109**, 103113 (May 2011)

Patent Owner 138 East Ex. 2001
Page 099

294. Sameer Chhajed, David J. Poxson, Xing Yan, Jaehee Cho, E. Fred Schubert, Roger E. Welser, Ashok K. Sood, and Jong Kyu Kim "Nanostructured Multilayer Tailored-Refractive-Index Antireflection Coating for Glass with Broadband and Omnidirectional Characteristics" *Applied Physics Express* **4**, 052503 (May 2011)
295. David J. Poxson, Mei-Ling Kuo, Frank W. Mont, Y.-S. Kim, Xing Yan, Roger E. Welser, Ashok K. Sood, Jaehee Cho, Shawn-Yu Lin, and E. Fred Schubert "High-performance anti-reflection coatings utilizing nanoporous layers" *MRS Bulletin* **36**, 434 (June 2011)
296. Guan-Bo Lin, Martin F. Schubert, Jaehee Cho (SID Member), E. Fred Schubert, Hyungkun Kim "A complementary matching technique to reduce the variance of optical and electrical properties of light-emitting diodes" *Journal of the SID* **19/6**, 431 (June 2011)
297. David S. Meyaard, Qifeng Shan, Qi Dai, Jaehee Cho, E. Fred Schubert, Min-Ho Kim, and Cheolsoo Sone "On the temperature dependence of electron leakage from the active region of GaInN/GaN light-emitting diodes" *Applied Physics Letters* **99**, 041112 (July 2011)
298. Ahmed N. Noemaun, Frank W. Mont, Guan-Bo Lin, Jaehee Cho, E. Fred Schubert, Gi Bum Kim, Cheolsoo Sone, and Jong Kyu Kim "Optically functional surface composed of patterned graded-refractive-index coatings to enhance light-extraction of GaInN light-emitting diodes" *Journal of Applied Physics* **110**, 054510 (September 2011)
299. Roger E. Welser, Gopal G. Pethuraja, Ashok K. Sood, Oleg A. Laboutin, Mark Chaplin, Van Un, Wayne Johnson, Adam W. Sood, David J. Poxson, Jaehee Cho, E. Fred Schubert, Pradeep Haldar, Jennifer L. Harvey "High voltage quantum well waveguide solar cells" *Proceedings of the SPIE* Vol. **8111**, page 81110I-1 (September 2011)
300. David S. Meyaard, Guan-Bo Lin, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, Min-Ho Kim, and Cheolsoo Sone "Asymmetry of carrier transport leading to efficiency droop in GaInN based light-emitting diodes" *Applied Physics Letters* **99**, 251115 (December 2011)
301. Qifeng Shan, David S. Meyaard, Qi Dai, Jaehee Cho, E. Fred Schubert, Joong Kon Son, and Cheolsoo Sone "Transport-mechanism analysis of the reverse leakage current in GaInN light-emitting diodes" *Applied Physics Letters* **99**, 253506 (December 2011)

2012

302. Di Zhu, Martin F. Schubert, Jaehee Cho, E. Fred Schubert, Mary H. Crawford, Daniel D. Koleske, Hyunwook Shim, and Cheolsoo Sone "Genetic algorithm for innovative device designs in high-efficiency III–V nitride light-emitting diodes" *Applied Physics Express* **5**, 012102 (January 2012)
303. David S. Meyaard, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Sang-Heon Han, Min-Ho Kim, Cheolsoo Sone, Seung Jae Oh, and Jong Kyu Kim "Temperature dependent efficiency droop in GaInN light-emitting diodes with different current densities" *Applied Physics Letters* **100**, 081106 (February 2012)
304. Jong-In Shim, Dong-Pyo Han, Hyunsung Kim, Dong-Soo Shin, Guan-Bo Lin, David S. Meyaard, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, and Cheolsoo Sone "Efficiency droop in AlGaInP and GaInN light-emitting diodes" *Applied Physics Letters* **100**, 111106 (March 2012)
305. (**Invited**) Jaehee Cho and E. Fred Schubert "Light Emitting Diodes" in the *Encyclopedia of Optical Engineering* edited by R. G. Driggers and C. Hoffman (Taylor & Francis, New York, 2012)
306. Ashok K. Sood, Roger E. Welser, Adam W. Sood and Yash R. Puri, David Poxson, Jaehee Cho and E. Fred Schubert, Nibir K. Dhar, Martin B. Soprano, Raymond S. Balcerak "Development of nanostructure-based antireflection coatings for EO/IR sensors" *SPIE Photonics West Conference Proceedings*, Volume **8257**, paper 53 (April 2012)
307. Guan-Bo Lin, David Meyaard, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, and Cheolsoo Sone "Analytic model for the efficiency droop in semiconductors with asymmetric carrier-transport properties based on drift-induced reduction of injection efficiency" *Applied Physics Letters* **100**, 161106 (April 2012)
308. Adam W. Sood, David J. Poxson, Frank W. Mont, Sameer Chhajed, Jaehee Cho, E. Fred Schubert, Roger E. Welser, Nibir K. Dhar, and Ashok K. Sood "Experimental and theoretical study of the optical and electrical properties of nanostructured indium tin oxide fabricated by oblique-angle deposition" *Journal of Nanoscience and Nanotechnology* **12**, 3950 (July 2012)
309. Ming Ma, Ahmed N. Noemaun, Jaehee Cho, E. Fred Schubert, Gi Bum Kim, and Cheolsoo Sone "Emission pattern control and polarized light emission through patterned graded-refractive-index coatings on GaInN light-emitting diodes" *Optics Express* **20**, 16677 (July 2012)
310. Ming Ma, David S. Meyaard, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Gi Bum Kim, Min-Ho Kim, and Cheolsoo Sone "Polarized light emission from GaInN light-emitting diodes embedded with subwavelength aluminum wire-grid polarizers" *Applied Physics Letters* **101**, 061103 (August 2012)

311. Xing Yan, David J. Poxson, Jaehee Cho, Roger E. Welser, Ashok K. Sood, Jong Kyu Kim, and E. Fred Schubert "Enhanced omnidirectional photovoltaic performance of solar cells using multiple-discrete-layer tailored- and low-refractive index anti-reflection coatings" *Advanced Functional Materials* **2012**, 1 (September 2012)
312. Ming Ma, Jaehee Cho, E. Fred Schubert, Yongjo Park, Gi Bum Kim, and Cheolsoo Sone "Strong light-extraction enhancement in GaInN light-emitting diodes patterned with TiO_2 micro-pillars with tapered sidewalls" *Applied Physics Letters* **101**, 141105 (October 2012)

2013

313. Seung Jae Oh, Sameer Chhajed, David J. Poxson, Jaehee Cho, E. Fred Schubert, Sung Ju Tark, Donghwan Kim, and Jong Kyu Kim "Enhanced broadband and omni-directional performance of polycrystalline Si solar cells by using discrete multilayer antireflection coatings" *Optics Express* **21**, A157 (January 2013)
314. Jaehee Cho, E. Fred Schubert, and Jong Kyu Kim "Efficiency droop in light-emitting diodes: Challenges and countermeasures" *Laser and Photonics Reviews* 2012, **7**, 408 (January 2013)
315. David S. Meyaard, Guan-Bo Lin, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, Sang-Heon Han, Min-Ho Kim, Cheolsoo Sone, and Young Sun Kim "Identifying the cause of the efficiency droop in GaInN light-emitting diodes by correlating the onset of high injection with the onset of the efficiency droop" *Applied Physics Letters* **102**, 251114 (June 2013)
316. Roger E. Welser, Adam W. Sood, Jaehee Cho, E. Fred Schubert, Jennifer L. Harvey, Nibir K. Dhar, Ashok K. Sood "Nanostructured Transparent Conductive Oxides for Photovoltaic Applications" *Materials Research Society Symposium Proceedings* **1493**, 23 (July 2013)
317. Seung Cheol Han, Jae-Kwan Kim, Jun Young Kim, Dong Min Lee, Jae-Sik Yoon, Jong-Kyu Kim, E. F. Schubert, and Ji-Myon Lee "Ohmic contacts to N-face p-type GaN using Ni/Au for the fabrication of polarization inverted light-emitting diodes" *Journal of Nanoscience and Nanotechnology* **13**, 5715 (August 2013)
318. Jun Hyuk Park, Dong Yeong Kim, Sunyong Hwang, David Meyaard, E. Fred Schubert, Yu Dae Han, Joo Won Choi, Jaehee Cho, Jong Kyu Kim "Enhanced overall efficiency of GaInN-based light-emitting diodes with reduced efficiency droop by Al-composition-graded AlGaN/GaN superlattice electron blocking layer" *Applied Physics Letters* **103**, 061104 (August 2013)
319. Seung Jae Oh, Gyeongmin Go, Jong-Lam Lee, E. Fred Schubert, Jaehee Cho, Jong Kyu Kim "Enhanced phosphor conversion efficiency of GaN-based white light-emitting diodes having dichroic-filtering contacts" *Journal of Materials Chemistry C*, **1**, 5733 (August 2013)
320. Guan-Bo Lin, Dong-Yeong Kim, Qifeng Shan, Jaehee Cho, E. Fred Schubert, Hyunwook Shim, Cheolsoo Sone, and Jong Kyu Kim "Effect of Quantum Barrier Thickness in the Multiple-Quantum-Well Active Region of GaInN / GaN Light-Emitting Diodes" *IEEE Photonics Journal* **5**, 1600207 (August 2013)
321. David S. Meyaard, Jaehee Cho, E. Fred Schubert, Sang-Heon Han, Min-Ho Kim, and Cheolsoo Sone "Analysis of the temperature dependence of the forward voltage characteristics of GaInN light-emitting diodes" *Applied Physics Letters* **103**, 121103 (September 2013)
322. David S. Meyaard, Guan-Bo Lin, Ming Ma, Jaehee Cho, E. Fred Schubert, Sang-Heon Han, Min-Ho Kim, HyunWook Shim, and Young Sun Kim "GaInN light-emitting diodes using separate epitaxial growth for the p-type region to attain polarization-inverted electron-blocking layer, reduced electron leakage, and improved hole injection" *Applied Physics Letters* **103**, 201112 (November 2013)
323. Ming Ma, Jaehee Cho, E. Fred Schubert, Gi Bum Kim, and Cheolsoo Sone "Optically functional surface structures for GaN-based light-emitting diodes" *Journal of Materials Chemistry C*, **1**, 8134 (November 2013)
324. Hee-Dong Kim, Ho-Myoung An, Kyoung Heon Kim, Su Jin Kim, Chi Sun Kim, Jaehee Cho, E. Fred Schubert, and Tae Geun Kim "A universal method of producing transparent electrodes using wide-bandgap materials" *Advanced Functional Materials* DOI: 10.1002/adfm.201301697 (November 2013)

2014

325. Hyunah Kwon, Juyoung Ham, Dong Yeong Kim, Seung Jae Oh, Subin Lee, Sang Ho Oh, E. Fred Schubert, Kyung-Geun Lim, Tae-Woo Lee, Sungjun Kim, Jong-Lam Lee, and Jong Kyu Kim "Organic Solar Cells: Three-dimensional nanostructured indium-tin-oxide electrodes for enhanced performance of bulk heterojunction organic solar cells" *Advanced Energy Materials* 1301566 (January 2014)
326. David S. Meyaard, Ming Ma, E. Fred Schubert, Chel-Jong Choi, Jaehee Cho, and Morgan Evans "Mesa-free III-V nitride light-emitting diodes with flat surface" *ECS Solid-State Letters* **3**, Q17 (February 2014)
327. Ming Ma, E. Fred Schubert, Jaehee Cho, Morgan Evans, Gi Bum Kim and Cheolsoo Sone "Fabrication of tapered graded-refractive-index micropillars using ion-implanted-photoresist as an etch mask" *Journal of Vacuum Science and Technology* A **32**, 021305-1 (March 2014)

Patent Owner 138 East Ex. 2001
Page 101

328. Seung Hee Lee, Ho Jin, Dong-Yeong Kim, Kyung Song, Sang Ho Oh, Sungjee Kim, E. Fred Schubert, and Jong Kyu Kim "Enhanced power conversion efficiency of quantum dot sensitized solar cells with near single-crystalline TiO_2 nano-helixes used as photoanodes" *Optics Express* **22**, A868 (April 2014)
329. Seung Hee Lee, Jeong Kwon, Dong Yeong Kim, Kyung Song, Sang Ho Oh, Jaehee Cho, E. Fred Schubert, Jong Hyeok Park, Jong Kyu Kim "Enhanced power conversion efficiency of dye-sensitized solar cells with multifunctional photoanodes based on a three-dimensional TiO_2 nanohelix array" *Solar Energy Materials & Solar Cells* **132**, 47 (August 2014)
330. Michael E Coltrin, Andrew M Armstrong, Igal Brener, Weng W Chow, Mary H Crawford, Arthur J Fischer, David F Kelley, Daniel D Koleske, Lincoln J Lauhon, James E Martin, May D Nyman, E Fred Schubert, Lauren E Shea-Rohwer, Ganapathi S Subramania, Jeffrey Y Tsao, George T Wang, Jonathan J Wierer, Jr, Jeremy B Wright "The Energy Frontier Research Center for Solid-State Lighting Science: Exploring New Materials Architectures and Light Emission Phenomena" *The Journal of Physical Chemistry C* **118**, 13330 (April 2014)
331. Keith Goossen, Daniel Wolfe, E. Fred Schubert, Dan Kilper, and Ursula Keller "Negawatts – Optics, Photonics and Energy Savings" *Optics and Photonics News*, November issue, page 34, (November 2014)
332. Guan-Bo Lin, Qifeng Shan, Yaqi Wang, Ting Li, and E. Fred Schubert " "U-turn" feature in the efficiency-versus-current curve of GaInN / GaN light-emitting diodes" *Applied Physics Letters* **105**, 221116 (December 2014)

2015

333. Jaehee Cho, David S. Meyaard, Ming Ma, and E. Fred Schubert "GaInN-based light emitting diodes embedded with wire grid polarizers" *Japanese Journal of Applied Physics* **54**, 02BB02 (January 2015)
334. Dong Yeong Kim, Guan-Bo Lin, Sunyong Hwang, Jun Hyuk Park, David Meyaard, E. Fred Schubert, Han-Youl Ryu, and Jong Kyu Kim "Polarization-engineered high-efficiency GaInN light-emitting diodes optimized by genetic algorithm" *IEEE Photonics Journal* **7**, 1300209 (February 2015)
335. D. Y. Kim, J. H. Park, J. W. Lee, S. Y. Hwang, S. J. Oh, J. S. Kim, C. Sone, E. F. Schubert, and J. K. Kim (2015) "Overcoming the fundamental limitation in light-extraction efficiency of Deep-UV LEDs by utilizing transverse-magnetic-dominant emission" *Light: Science & Applications* **4***, e263;* doi:10.1038/lsa.2015.36 (May 2015)
336. Jun Hyuk Park, Guan-Bo Lin, Dong Yeong Kim, Jong Won Lee, Jaehee Cho, Jungsub Kim, Jinsub Lee, Yong-Il Kim, Youngsoo Park, E. Fred Schubert, and Jong Kyu Kim "Distinct U-shape efficiency-versus-current curves in AlGaN-based deep-ultraviolet light-emitting diodes" *Optics Express* **23**, 15398 (June 2015)
337. Ashok K. Sood, Gopal Pethuraja, Roger E. Welser and Yash R. Puri, Nibir K. Dhar, Priyalal S. Wijewarnasuriya, Jay Lewis, Harry Efstathiadis, Pradeep Haldar, and E. Fred Schubert "Development of large area nanostructured antireflection coatings for EO/IR sensor applications" *International Journal of NanoScience and Nanotechnology*, Volume **6**, Number 2, pp. 57-70 (August 2015)
338. Ashok K. Sood, Roger E. Welser, Gopal G. Pethuraja, Adam W. Sood, Yash R. Puri, E. Fred Schubert, Pradeep Haldar, Nibir K. Dhar, Dennis L. Polla, and Priyalal Wijewarnasuriya "Nanostructured anti-reflection (AR) coatings for optoelectronic applications" published in: *Comprehensive Guide for Nanocoatings Technology*, Volume **4**, Editor: Mahmood Aliofkhazraei, ISBN-13 978-1-63482-648-8 (Nova Science Publishers Inc., Hauppauge, New York, USA, November 2015)
339. E. Fred Schubert, Jaehee Cho, and Jong Kyu Kim "Light Emitting Diodes" published in: *Kirk-Othmer Encyclopedia of Chemical Technology*; on-line access at < http://onlinelibrary.wiley.com/book/10.1002/0471238961 > ISBN: 9780471238966 DOI: 10.1002/0471238961 (John Wiley and Sons and Wiley Inter-Science, New York NY, December 2015)
340. Guan-Bo Lin and E. Fred Schubert "Efficiency re-climbing in high-current droop regime for gallium-nitride-based light-emitting diodes" *International Journal of High-Speed Electronics and Systems*, *World Scientific Publishing Company* **24**, 1520008 (December 2015)
341. E. F. Schubert "Physical Foundations of Solid-State Devices" (author), eBook, 275 pages, 2015 Edition, ISBN-13: 978-0-9863826-2-8 (Google Books, Mountain View CA, 2015)

2016

342. E. Fred Schubert, Jaehee Cho, and Jong Kyu Kim "Light Emitting Diodes" published in: *Reference Module in Materials Science and Materials Engineering*, Section on Light Emitting Diodes, Materials Science and Materials Engineering, Edited by Saleem Hashmi (Elsevier Publishing Company, Amsterdam, 2016) < https://www.sciencedirect.com/science > (January 2016)
343. Kyurin Kim, Jun Hyuk Park, Hyunsoo Kim, Jong Kyu Kim, E. Fred Schubert, and Jaehee Cho "Energy bandgap variation in oblique angle-deposited indium tin oxide" *Applied Physics Letters* **108**, 041910 (January 2016)

344. Jun Hyuk Park, Jong Won Lee, Dong Yeong Kim, Jaehee Cho, E. Fred Schubert, Jungsub Kim, Jinsub Lee, Yong-Il Kim, Youngsoo Park, and Jong Kyu Kim "Variation of the external quantum efficiency with temperature and current density in red, blue, and deep ultraviolet light-emitting diodes" *Journal of Applied Physics* **119**, 023101 (January 2016)
345. JongWon Lee, Dong Yeong Kim, Jun Hyuk Park, E. Fred Schubert, Jungsub Kim, Jinsub Lee, Yong-Il Kim, Youngsoo Park, and Jong Kyu Kim "An elegant route to overcome fundamentally-limited light extraction in AlGaN deep-ultraviolet light-emitting diodes: Preferential outcoupling of strong in-plane emission" *Scientific Reports* **6**, 22537 (March 2016)

2017

346. Jaehee Cho, Jun Hyuk Park, Jong Kyu Kim, and E. Fred Schubert "White light-emitting diodes: History, progress, and future" *Laser and Photonics Review*, 1600147 (2017) / DOI 10.1002/lpor.201600147 (March 2017)
347. Jun Hyuk Park, Jaehee Cho, E. Fred Schubert, and Jong Kyu Kim "The effect of imbalanced carrier transport on the efficiency droop in GaInN-based blue and green light-emitting diodes" *Energies* **10**, 1277 (2017) DOI: 10.3390/en10091277 (August 2017)

2018

348. E. Fred Schubert "Light Emitting Diodes, 3rd Edition" Book, 672 pages, with hundreds of colored figures ISBN: 978-0-9 863826-6-6 (Google Books, Mountain View CA, 2018)
349. JH Park, DY Kim, EF Schubert, J Cho, JK Kim "Fundamental Limitations of Wide-Bandgap Semiconductors for Light-Emitting Diodes" *ACS Energy Letters* **3**, 655-662 (2018)

2020

350. Bhishma Pandit, E. Fred Schubert and Jaehee Cho "Dual-functional ultraviolet photodetector with graphene electrodes on AlGaN/GaN heterostructure" *Nature Research – Scientific Reports* **10**, 22059 (2020)

2022

351. E. F. Schubert "Physical Foundations of Solid-State Devices" (author), eBook, 318 pages, 2022 Edition, ISBN-13: 978-0-9863826-2-8 (Google Books, Mountain View CA, 2022)

2024

352. Yung Ryel Ryu, Sung Ki Hong, E Fred Schubert, Dong-Min Jeon, Dong-Soo Shin, Jong-In Shim, Sang-Mook Kim, Jong Hyeob Baek "A next-generation light-emitting device: ZOGAN LED with a heterogeneous p-layer composed of oxide and nitride semiconductors" *AIP Advances* (AIP Publishing), Volume **14**, Issue 4 (2024)