

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HANWHA SOLUTIONS CORPORATION,

Petitioner,

v.

MAXEON SOLAR PTE. LTD.,

Patent Owner.

Case No. IPR2024-01203

U.S. Patent No. 8,222,516

**DECLARATION OF DR. ZACHARY HOLMAN REGARDING
CLAIMS 1-12 OF U.S. PATENT NO. 8,222,516**

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I, Zachary Charles Holman, Ph.D., declare as follows:

I. INTRODUCTION

1. My name is Zachary Charles Holman.

2. I am making this declaration at the request of Hanwha Solutions Corporation (“HSC” or “Petitioner”) as an independent expert consultant in this proceeding before the United States Patent and Trademark Office and to provide testimony pertinent to Petitioner’s Petition for *Inter Partes* Review of U.S. Patent No. 8,222,516 (“’516 patent”). I understand that Petitioner is challenging the patentability of claims 1-12 of the ’516 patent (“Challenged Claims”).

II. QUALIFICATIONS AND EXPERIENCE

3. I have been involved in the field of solar cell technology for over 19 years. My qualifications for forming the opinions set forth in this declaration are summarized below. Attached as **Appendix A** is my curriculum vitae, which describes my education, experience, and professional activities and lists, among other things, my publications and patents.

4. I received a Bachelor of Arts in Physics from Reed College in 2005. While pursuing my undergraduate degree, I researched the movement of electrons in semiconductor materials used for solar cells. My research was summarized in my undergraduate thesis, which was titled *Electron Transport in Amorphous Silicon*. My thesis explained how “[m]any mechanisms reduce the output of a solar cell

including imperfect incident light absorption, recombination of charge carriers, and poor charge transport through the cells,” and it described research that I conducted using time-of-flight measurement techniques to characterize electron transport in hydrogenated amorphous silicon. *See* Ex.1010-Holman-Thesis, 2-4. My thesis revealed trapping of electrons in defect states in amorphous silicon, which inhibited their collection at metal contacts. *See generally*, Ex.1010-Holman-Thesis.

5. I received a Doctor of Philosophy (“Ph.D.”) in Mechanical Engineering from the University of Minnesota in 2010. I started my Ph.D. program in September 2005. For the entire duration of my Ph.D., my research focused on the design, manufacture, and characterization of materials and layers used in solar cells. My Ph.D. thesis was titled *Germanium Nanocrystal Solar Cells*, and it described the use of thin films of plasma-synthesized germanium and silicon nanocrystals and their use in novel solar cells.

6. I co-authored multiple academic papers in the fields of semiconductor materials and solar cell technology while I was working on my Ph.D., including: A. LaLonde, Z Holman, et al., “Metal Coatings on SiC Nanowires by Plasma-enhanced Chemical Vapor Deposition,” *Journal of Materials Research* **20**, 549 (2005) (describing method for coating silicon carbide nanowires with metal nanoparticles); R. Gresback, Z. Holman, and U. Kortshagen, “Plasma Synthesis of Highly

Monodisperse Ge Nanocrystals and Self-assembly of Dense Nanocrystal Layers,” *Materials Research Society Symposium Proceedings* 974 (2007) (describing synthesis method for germanium nanocrystals using low pressure, nonthermal plasma); Z. Holman, R. Gresback, and U. Kortshagen, “Nonthermal Plasma Synthesis of Conductive Germanium Nanocrystal Films for Photovoltaic Applications,” *ISPC-18 Proc.* (2007) (describing the nonthermal plasma synthesis of germanium nanocrystals and reporting on the current-voltage measurements of highly porous films of such nanocrystals); R. Gresback, Z. Holman, and U. Kortshagen, “Nonthermal Plasma Synthesis of Size-Controlled, Monodisperse, Freestanding Germanium Nanocrystals,” *Applied Physics Letters* **91**, 093119 (2007) (describing the synthesis of monodisperse germanium nanocrystals via a nonthermal plasma approach); U. Kortshagen, Z. Holman, et al., “Plasma synthesis of group IV quantum dots for luminescence and photovoltaic applications,” *Pure and Applied Chemistry* **80**, 1901 (2008) (describing the application of silicon and germanium nanocrystals in solar cells); C.Y. Liu, Z. Holman, and U. Kortshagen, “Hybrid solar cells from P3HT and silicon nanocrystals” *Nano Letters* **9**, 449 (2009) (describing a new solar cell comprised of silicon nanocrystals and poly-3(hexylthiophene) and reporting the properties of such cells); C.Y. Liu, Z. Holman, and U. Kortshagen, “Optimization of Si NC/P3HT hybrid solar cells,” *Advanced Functional Materials*

20, 2157 (2010), and X. Pi, Z. Holman, and U. Kortshagen, “Silicon and Germanium Nanocrystal Inks for Low Cost Solar Cells,” *4th International Conference on Energy Sustainability ASME Conf. Proc.* **2**, 471 (2010) (presenting method for forming silicon and germanium thin films using nanocrystals).

7. From 2010 to 2013, I was a postdoctoral researcher in the Photovoltaics and Thin-Film Electronics Laboratory at the Institute of Microengineering at Ecole Polytechnique Fédérale de Lausanne in Neuchâtel, Switzerland. I also served as a visiting professor with the Photovoltaics and Thin-Film Electronics Laboratory in 2014. While serving in these roles, I continued to research the design and manufacture of solar cells and their components.

8. While a postdoctoral researcher, I published extensively on silicon solar cells, including on passivation layers, transparent conductive oxide and metal contacts, contact resistance, parasitic absorption, and optimization of cell designs. Select peer-reviewed papers related to silicon solar cells that I co-authored while a postdoctoral researcher include: A. Descoeudres, Z. Holman, et al., “Improved amorphous/crystalline silicon interface passivation by hydrogen plasma treatment,” *Applied Physics Letters* **99**, 123506 (2011) (describing reducing recombination at silicon wafer surfaces with deposited amorphous silicon layers); Z. Holman, et al., “Current losses at the front of silicon heterojunction solar cells,” *IEEE Journal of*

Photovoltaics **2**, 7 (2012) (describing parasitic absorption in deposited emitters at the front of silicon solar cells); S. De Wolf, Z. Holman, et al., “High-efficiency silicon heterojunction solar cells: A review,” *Green* **2**, 7 (2012) (reviewing the status of silicon heterojunction solar cell science and technology); Z. Holman, et al., “Infrared light management in high-efficiency silicon heterojunction and rear-passivated solar cells,” *Journal of Applied Physics* **113**, 013107 (2013) (describing parasitic absorption in electrodes of silicon solar cells); and Z. Holman, et al., “Record infrared internal quantum efficiency in silicon heterojunction solar cells with dielectric/metal rear reflectors,” *IEEE Journal of Photovoltaics* **3**, 1243 (2013) (reporting a design for a silicon solar cell with record rear reflectance).

9. From 2013 to 2019, I was Assistant Professor in the School of Electrical, Computer and Energy Engineering at Arizona State University in Tempe, Arizona. In 2019, I became an Associate Professor, and, in 2023, I became a Professor, both again in the School of Electrical, Computer and Energy Engineering at Arizona State University. From 2019 to 2023, I also served as Director of Faculty Entrepreneurship in the Ira A. Fulton Schools of Engineering at Arizona State University. Since 2023, I have served as the Vice Dean for Research and Innovation of the Ira A. Fulton Schools of Engineering at Arizona State University.

10. My research interests as a professor include, among other things, contacts to solar cells, interconnection of solar cells, light management in silicon solar cells, and silicon-based tandem solar cells. While at Arizona State University, I have co-authored dozens of peer-reviewed articles in the field of solar cell technology, including: M. Boccard and Z. Holman, “Amorphous silicon carbide passivating layers for crystalline-silicon-based heterojunction solar cells,” *Journal of Applied Physics* **118**, 065704 (2015) (describing passivation layers for silicon solar cells); Y. Zhao, Z. Holman, et al., “Monocrystalline CdTe solar cells with open-circuit voltage over 1 V and efficiency of 17%,” *Nature Energy* **1**, 16067 (2016) (reporting the highest open-circuit voltage measured for a cadmium telluride solar cell, made by using an emitter from silicon solar technology); Z. Yu, M. Leilaoui, and Z. Holman, “Selecting tandem partners for silicon solar cells using spectral efficiency,” *Nature Energy* **1**, 16137 (2016) (describing a methodology for designing tandem solar cells); K. Bush, Z. Holman, et al., “23.6%-efficient monolithic perovskite/silicon tandem solar cells with improved stability,” *Nature Energy* **2**, 17009 (2017) (describing improved perovskite/silicon tandem solar cells); B. Hallam, Z. Holman, et al., “Pre-fabrication gettering and hydrogenation treatments for silicon heterojunction solar cells: A possible path to >700 mV open-circuit voltages using low-lifetime commercial-grade p-type Czochralski silicon,” *Solar*

RRL 1700221 (2018) (describing improvement of silicon solar cells through gettering and hydrogenation); Z. Ni, Z. Holman, et al., “Resolving Spatial and Energetic Distributions of Trap States in Metal Halide Perovskite Solar Cells,” *Science* **367**, 1352 (2020) (reporting on the spatial and energetic distributions of trap states in metal halide perovskite single-crystalline and polycrystalline solar cells.); J. Xu, Z. Holman, et al., “Triple-halide Wide-band Gap Perovskites with Suppressed Phase Segregation for Efficient Tandems,” *Science* **367**, 1097 (2020) (describing efficient wide-band gap perovskite top cells using triple-halide alloys); and K. Chen et al., “Self-aligned selective area front contacts on poly-Si/SiO_x passivating contact c-Si solar cells,” *IEEE Journal of Photovoltaics* **12**, 678 (2022) (describing a method to pattern polycrystalline silicon / silicon dioxide layers in silicon solar cells). Additional journal articles, book chapters, and conference papers are described in further detail in my CV (**Appendix A**).

11. I have received numerous awards for both my teaching and research. For my teaching, I have been honored with the ASU Fulton Schools of Engineering Top 5% Teaching Award in 2023, 2017, and 2015. For my research, I have received the IEEE Stuart R. Wenham Young Professionals Award in 2019 and the NSF CAREER Award in 2019 (an award given to photovoltaic researchers), among other honors, prizes, and awards. My awards and honors are listed in my CV. I have also

received numerous research grants, as detailed in my CV, including eighteen grants from the Department of Energy's Solar Energy Technologies Office. Two exemplary grants are "Development of new metallization pastes for front-side tunnel oxide passivated contact crystalline silicon solar cells" and "ASU-NREL joint silicon solar cell research: passivated contacts, metallization, and bulk defects."

12. Among the courses I teach at Arizona State University are "Electrical Engineering 465/591: Photovoltaic Energy Conversion," "Electrical Engineering: 498/591: Solar Energy," and "Electrical Engineering 565: Solar Cells." I have also taught innovation and venture development courses that combine academic learning with an applied business development approach. Other courses I have taught are listed in my CV.

13. I have advised numerous doctoral students and other researchers in training. Students whom I have advised have won numerous honors and awards, including many best-paper awards at top solar conferences. A full list of students I have advised and their awards are provided in my CV.

14. Some of my many professional activities include being editor of the *IEEE Journal of Photovoltaics* since 2022; serving as an organizing member for the IEEE Photovoltaic Specialists Conference, World Conference on Photovoltaic Energy Conversion, and International Workshop on Silicon Heterojunction Solar

Cells; serving as a member and chair of the ASU Solar Fabrication Core Facility Board since 2020; being a reviewer for journals including *Journal of Applied Physics*, *ACS Nano*, *Solar Energy Materials and Solar Cells*, *Thin Solid Films*, *Nanotechnology*, and *IEEE Journal of Photovoltaics*; being a reviewer for grant proposals for the Department of Energy and the National Science Foundation; and serving as a session chair for numerous symposia and conferences on solar science and technology. A full list of my professional and outreach activities is provided in my CV.

15. My research, engineering and entrepreneurial endeavors have been regularly recognized by the industry. For example, Arizona PBS has reported on one of my start-up companies, SunFlex Solar, which has developed an improved method for interconnecting back-contact solar cells into solar modules. See “New Solar Panel Technology,” *Arizona PBS* (Mar. 29, 2023), available at <https://azpbs.org/horizon/2023/03/new-solar-panel-technology>. Also, I worked with two United States-based solar cell manufacturers relating to an instrument that I developed to analyze recombination in solar cells; copies of the instrument are now used in their research and development facilities. As another example, my research demonstrating a manufacturing technique for high-efficiency perovskite-silicon tandem solar cell was covered in *PV Magazine*, a leading solar cell industry

publication. See Emilliano Bellini, “New Manufacturing Technique for 26%-efficient Tandem Perovskite Solar Cell,” *PV Magazine* (Apr. 20, 2020), available at <https://www.pv-magazine.com/2020/04/20/new-manufacturing-technique-for-26-efficient-tandem-perovskite-solar-cell>.

16. I am also an entrepreneur and have founded three companies to bring new solar technology to market. In 2021, I co-founded Beyond Silicon, Inc. (“Beyond Silicon”), which is developing perovskite/silicon tandem solar cells. Beyond Silicon was a finalist for the American-Made Perovskite Startup Prize. In 2020, I co-founded SunFlex Solar LLC (“SunFlex Solar”), which develops interconnected back-contact solar cells using aluminum foil for improved efficiency and durability. SunFlex Solar won the American-Made Solar Prize and has a partnership with a US solar panel manufacturer to commercialize its interconnection technology. In 2016, I co-founded Swift Coat, Inc. (“Swift Coat”), which has developed a transparent coating for solar panels that prevents dust buildup that would otherwise reduce solar panel efficiency. Swift Coat has also won a contract from NASA to deposit similar coatings—but modified to provide an anti-fogging functionality—on the inside of the helmet of NASA’s next generation xEMU space suit. In 2018, I received the Gordon and Betty Moore Foundation Inventor

Fellowship to support my efforts to accelerate the translation of my research to market.

17. I am being compensated for my work on this matter at my standard hourly consulting rate of \$500 per hour. My opinions are based on my own views and understanding of the prior art, the knowledge of a person of ordinary skill in the art, and the '516 patent. My compensation is not dependent on and in no way affects the substance of my statements, opinions, or conclusions in this declaration and it is also not dependent on any testimony I give or on the outcome of this proceeding.

18. I have no financial interest in Petitioner or Patent Owner. I similarly have no financial interest in the '516 patent, and I have had no contact with the named inventors of the '516 patent.

III. LEGAL PRINCIPLES

19. I am not an attorney. For the purposes of this declaration, I have been informed about certain aspects of the law that are relevant to my opinions. My understanding of the law was provided to me by Petitioner's attorneys.

A. Scope of Opinion

20. I have been informed and understand that the petitioner in an *inter partes* review may request cancellation of claims as unpatentable only on grounds that such claims are anticipated or would have been obvious to a person of ordinary skill in the art at the time of the purported invention, and only on the basis of prior

art consisting of patents and/or printed publications. My opinions in this matter address only such grounds.

B. Anticipation

21. I have been informed that a patent claim is anticipated and therefore unpatentable if every element of the claim is present in a single prior art reference.

C. Obviousness

22. I understand that a claim is unpatentable if, at the time the alleged invention was made, it would have been obvious to a person of ordinary skill in the art. I understand that a claim can be obvious based on the teachings or suggestions of either a single prior art reference or a combination of two or more prior art references. I understand that the obviousness analysis requires an understanding of the scope and content of the prior art, any differences between the prior art and the alleged invention, and the level of ordinary skill in evaluating the pertinent art.

23. I understand that in order to be considered for obviousness, prior art must be analogous to the patent at issue. I further understand that art is analogous if it either pertains to the same field of endeavor as the patent at issue or, alternatively, if it is reasonably related to the problem faced by the inventor(s) of the patent at issue.

24. I understand that a claim would have been obvious if it unites old elements with no change to their functions or alters prior art by mere substitution of

one element for another known in the field such that the combination yields predictable results. Also, I understand that obviousness does not require a physical combination or example, but rather is concerned with what the combined teachings would have taught or suggested to persons of ordinary skill in the art at the time of the alleged invention.

25. In connection with obviousness, I have been informed that there must have been some reason or motivation for a person of ordinary skill in the art to have combined or modified the relevant teachings in the prior art to obtain the claimed invention, and one of ordinary skill in the art must have had a reasonable expectation of success making the combination or modification.

26. I understand that a claim would have been obvious if a person of ordinary skill in the art would have had reason to combine multiple prior art references or add missing features to reproduce the alleged invention recited in the claims. I further understand that there is no rigid requirement of finding an express teaching, suggestion, or motivation to combine within the references, although such an express teaching or suggestion may be helpful in identifying a reason for the combination.

27. If a person of ordinary skill in the art can implement a predictable variation, that variation is likely unpatentable as obvious. For the same reason, if a

technique has been used to improve one device and a person of ordinary skill in the art would have recognized that it would improve similar devices in the same way, using the technique to make such an improvement would have been obvious.

28. I understand that when considering obviousness, it is important not to use the benefit of hindsight derived from the patent being considered. I also understand that one of ordinary skill in the art has ordinary creativity (i.e., is not a mindless automaton).

29. In sum, I understand that a determination of whether a claim would have been obvious is based upon the following non-exclusive considerations:

- whether prior art references teach or disclose known concepts combined in familiar ways, such that when combined they would yield predictable results;
- whether a person having ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- whether the claimed elements represent one of a limited number of known design choices, where those skilled in the art would have had a reasonable expectation of success in implementing that design choice;

- whether a person having ordinary skill would have been motivated based on the prior art to combine known elements in the manner described in the claim;
- whether there is a teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and
- whether the alleged invention applies a known technique that had been used to improve at least one similar device or method in a similar way.

30. I further understand that certain additional factors, commonly referred to as secondary considerations or objective indicia, may support or rebut the obviousness of a claim. I understand that secondary considerations include, among other things, commercial success of the patented invention, skepticism of those having ordinary skill in the art at the time of invention, unexpected results of the invention, any long-felt but unsolved need in the art that was satisfied by the alleged invention, the failure of others to make the alleged invention, praise of the alleged invention by those having ordinary skill in the art, copying of the alleged invention by others in the field, and contemporaneous and independent invention by others. I understand that there must be a nexus (i.e., a connection) between any such secondary considerations and the alleged invention. I also understand that secondary considerations cannot be used to overcome anticipation. I further understand that

contemporaneous and independent invention by others is a secondary consideration tending to show obviousness.

31. I reserve the right to respond to any allegations that Patent Owner may put forth in this proceeding suggesting that secondary considerations tend to rebut the obviousness of any claim of the '516 patent as discussed in this declaration.

D. Claim Dependency

32. I understand patents may include two types of claims: independent claims and dependent claims. An independent claim stands alone and simply recites the limitations it covers. In contrast, a dependent claim depends from either an independent claim or another dependent claim, and incorporates all the limitations recited in the claim or claims from which it depends along with the limitations it recites itself.

E. Written Description

33. I have been informed and understand that an application is required to describe the claim limitations contained in the application. I understand this requirement is called the “written description requirement.” I have been informed and understand that to satisfy the written description requirement, the patent’s specification must describe the claimed invention with enough detail for a person of ordinary skill in the art to reasonably conclude that the inventor had possession of the claimed invention at the time of filing.

* * *

34. The analysis that follows in this declaration is in accordance with the above-stated legal principles.

IV. MATERIALS CONSIDERED

35. In forming my opinions, in addition to my knowledge and experience, I have considered the materials cited herein and listed in **Appendix B**.

V. PRIORITY DATE

36. I have been informed that the priority date of the '516 patent is February 20, 2008. I have formed my opinions in reference to this priority date. Should Patent Owner suggest a different priority date, I reserve the right to revise my opinions accordingly.

VI. LEVEL OF ORDINARY SKILL IN THE ART

37. I understand that when considering the claims of the '516 patent and the prior art, I must do so from the perspective of one of ordinary skill in the art as of the patent's effective priority date.

38. I have been informed and I understand the factors to be considered in determining who would be a person of ordinary skill in the art include: (1) the types of problems encountered in the art; (2) the prior art solutions to those problems; (3) the rapidity with which innovations are made; (4) the sophistication of the technology; and (5) the educational level of active workers in the field.

39. Based on these factors as well as my experience and expertise, a person of ordinary skill in the art as of the claimed priority date of the '516 patent (also called, a "POSITA") would have had (1) an advanced degree in applied physics, chemistry, electrical engineering, materials science, mechanical engineering, or a related discipline and (2) at least one year of experience designing, developing, or researching the design and/or manufacture of solar cells or related technologies. Alternatively, a person of ordinary skill in the art would have had (1) a bachelor's degree in one of the aforementioned disciplines and (2) at least two years of experience designing, developing, or researching the design and/or manufacture of solar cells or related technologies. Additional work experience may compensate for less formal education, and vice versa.

40. My analysis and opinions herein regarding the '516 patent have been based on the perspective of a person of ordinary skill in the art as of the priority date for the '516 patent (i.e., February 20, 2008).

41. I have the qualifications and experience necessary to assess the '516 patent based on the perspective of a person of ordinary skill in the art, including as of the priority date for the '516 patent. *See* Section II (Qualifications and Experience). For example, by 2008, I had a degree in physics. I also had over three years of experience designing, developing, or researching the design and/or

manufacture of solar cells, as my research for my Ph.D. and undergraduate thesis was focused on the design and manufacture of components used in solar cells. *See* Section II (Qualifications and Experience).

VII. TECHNOLOGY BACKGROUND

A. Overview of Solar Cells

42. A solar cell is a solid-state electrical device that absorbs solar radiation (sunlight) and converts that solar radiation to electricity. An individual solar cell generates electricity when it is exposed to solar radiation by directing excited electrons around an external circuit. Ex.1016-Komp, 2-4; Ex.1010-Holman-Thesis, 1-2. To generate a usable amount of energy, a single solar cell is typically not used in isolation; instead, multiple solar cells are electrically connected to each other to form a solar module. Ex.1016-Komp, 49-51. An example solar module is below, which is the BP MSX-120 Solar Module that was available before 2008 and includes “72 multicrystalline silicon solar cells” that are electrically connected to each other.



Ex.1017-BP-MSX-120, 1. Multiple solar modules are connected together in a solar array to generate larger amounts of electricity. Ex.1016-Komp, 34-36, 49-53.

43. The design and manufacture of solar cells have been studied for several decades. A solar cell is typically made of a slab of silicon, called a “wafer,” and thin layers added to each side of the wafer. Ex.1016-Komp, 13-14, 20-21, 30-34. The thin layers can be made of many materials, including silicon. Silicon can come in different forms depending on how its atoms are organized. Ex.1016-Komp, 25-29, 37-39. For example, silicon can be “monocrystalline” if its atoms are all arranged in a perfectly periodic structure—a crystal. Ex.1016-Komp, 27-29; Ex.1018-Nelson, 179 (“Materials can be prepared as single crystals (monocrystalline) or as polycrystalline or multicrystalline wafers.”); *see also* Ex.1010-Holman-Thesis, 19-

20. Silicon can also be “polycrystalline” silicon (also called “polysilicon”), which means that it has multiple crystalline regions or “grains,” but they are not aligned with each other, resulting in “grain boundaries” at their interfaces. Ex.1016-Komp, 37-38; Ex.1018-Nelson, 179. A third type of silicon, amorphous silicon, is also utilized by some solar cells and has a non-crystalline structure—a somewhat randomized arrangement of atoms. Ex.1016-Komp, 40-47; Ex.1010-Holman-Thesis, 20-22. These three types of silicon have long been used in solar cells and were well-established in the art prior to 2008. Ex.1016-Komp, 25.

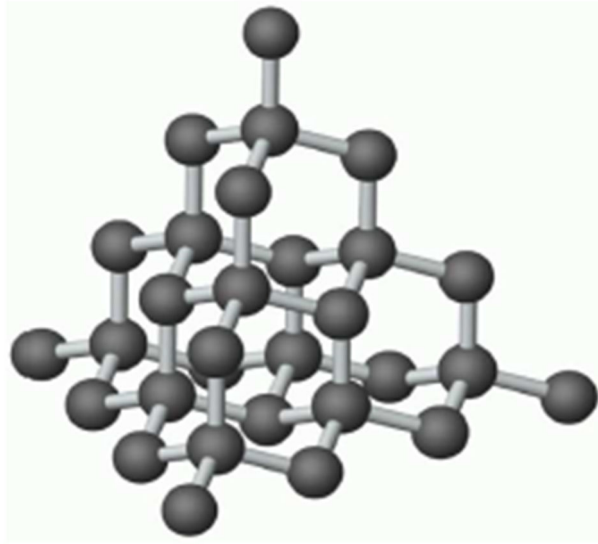
44. Prior to 2008, it was well known that solar cells had wafers or layers that were doped with phosphorus or boron to create PN junctions, solar cells included metal contacts to connect the cells to each other, and the front side of solar cells were textured and had anti-reflective coatings. The following sections briefly discuss these concepts.

1. Doping

45. In typical solar cells, chemical elements are introduced into silicon wafers or silicon layers to change the material properties of the silicon in the region where the elements are present. Ex.1010-Holman-Thesis, 23-24. The process for introducing these chemical elements, which are typically boron or phosphorus, is known as doping. *E.g.*, Ex.1018-Nelson, 181-182. As explained below, doping

introduces extra “electrons” or “holes,” which can alter the behavior of electrons that are excited in the solar cell when it is illuminated. Ex.1016-Komp, 7-9; Ex.1010-Holman-Thesis, 23-25.

46. An electron is a negatively charged particle and is part of an atom. Ex.1016-Komp, 7-9. An atom has one or more “valence” electrons, which are electrons on the outermost shell of an atom. Ex.1016-Komp, 7-9. Silicon has four valence electrons, and its outermost shell can hold up to eight. Ex.1033-Pierret, 26; Ex.1010-Holman-Thesis, 20. In a crystalline silicon solid, silicon atoms bond with four neighboring silicon atoms in a periodic arrangement or “lattice.” *See* Ex.1010-Holman-Thesis, 19-20 (showing two-dimensional crystalline lattice); Ex.1033-Pierret, 26. The silicon atoms share their valence electrons with the atoms to which they are bonded, resulting in each silicon atom perceiving that it has a filled valence shell of eight atoms. Ex.1018-Nelson, 44; Ex.1033-Pierret, 26. A simplified diagram of a silicon lattice is the following:



Ex.1010-Holman-Thesis, 20; *see also* Ex.1045-Green-1995, 5; Ex.1033-Pierret, 9-10.

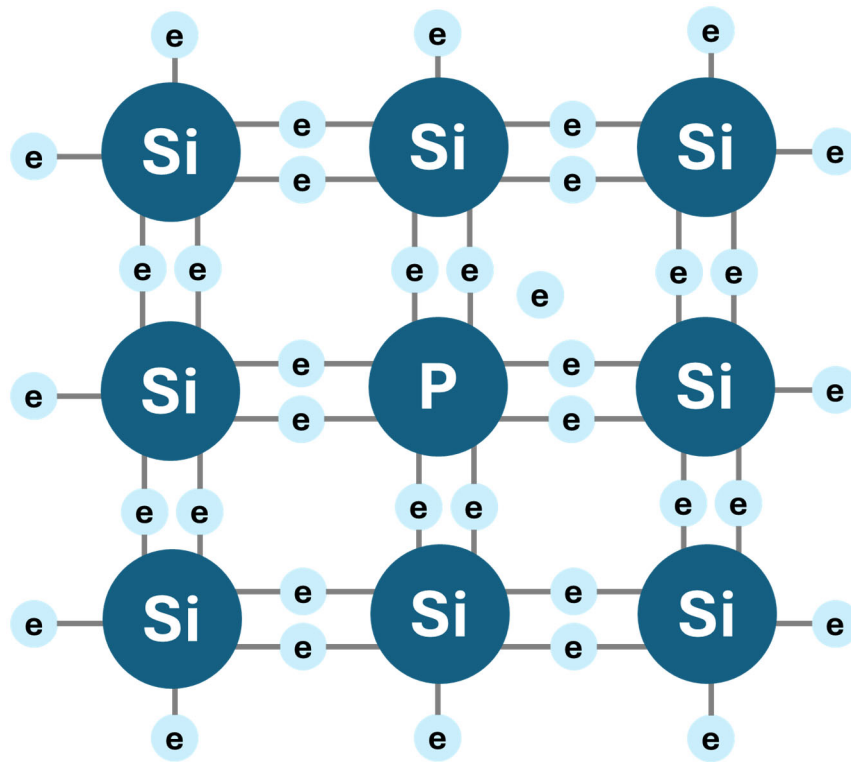
47. Once silicon atoms are bonded together in a solid, their valence electrons no longer reside in the individual shells of the isolated atoms, but instead populate a “valence band.” *See* Ex.1016-Komp, 13-18; Ex.1033-Pierret, 26-29; Ex.1010-Holman-Thesis, 6. The valence band is normally mostly full of electrons. Ex.1033-Pierret, 26-29. Silicon also has another band that is important to the function of solar cells, the “conduction band.” Ex.1033-Pierret, 29-32; Ex.1010-Holman-Thesis, 6. The conduction band is at a higher energy than the valence band and is thus normally mostly empty of electrons, but it may become (partially) populated either by the introduction of dopant atoms into the silicon crystal or by excitation of an electron from the valence band. Ex.1033-Pierret, 29-32. The

energetic distance between the top of the valence band and the bottom of the conduction band is the “bandgap energy.” Ex.1033-Pierret, 29-32; Ex.1010-Holman-Thesis, 6.

48. Introducing atoms with one more valence electron than silicon into the silicon crystal creates an extra electron that does not fit in the valence band. Ex.1033-Pierret, 35-39. Instead, at the temperatures at which solar cells normally operate, the extra electron resides in the conduction band. Ex.1033-Pierret, 35-39. The extra electron does not participate in bonding and is free to move around in the solid. Introducing such atoms is called doping, and in particular, n-type doping when extra electrons are introduced. Ex.1018-Nelson, 181-82; Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 23-24. In solar cells, n-type doping is used to create extra electrons in certain regions of the silicon wafer or layers of the solar cell. Ex.1018-Nelson, 181-82; *see also* Ex.1010-Holman-Thesis, 23-25.

49. It was well known prior to 2008 that phosphorous was commonly used as a dopant to create n-type regions or layers. As shown in the simplified diagram below, because phosphorus has five valence electrons (one more than silicon), an extra electron is introduced in the conduction band that can move through the lattice structure. Ex.1033-Pierret, 35-39; Ex.1016-Komp, 12-13 (“[I]f a small amount of phosphorus is added to the silicon crystal, the atoms of phosphorus (which have 5

valence electrons) will contribute 4 electrons and 4 levels to the valence band, and the extra electron will occupy a level near the bottom of the conduction band...It takes very little energy for the extra electron to jump to the conduction band from this donor level, so-called because it can donate conduction electrons to the system.”).



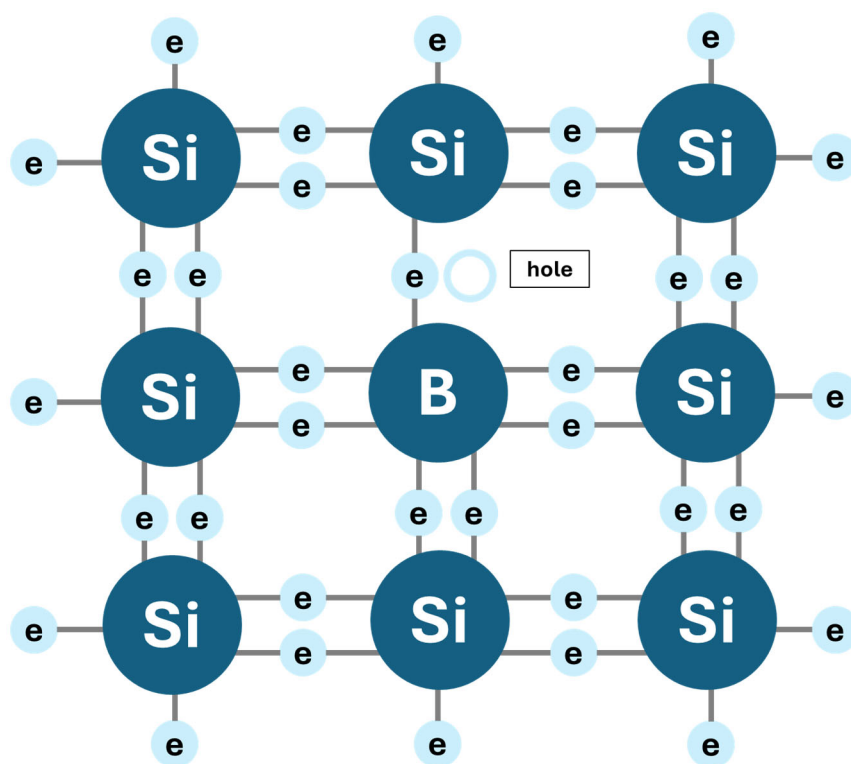
See Ex.1010-Holman-Thesis, 25; *see also* Ex.1033-Pierret, 36.

50. On the other hand, introducing atoms with one fewer valence electron than silicon into the silicon crystal creates a “hole” in the valence band. Ex.1033-Pierret, 35-39. A hole is not a physical object, like an electron, but rather a mathematical concept that represents an absence of an electron in the valence band.

Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 8. A hole in the valence band is mobile, much like an electron in the conduction band. Ex.1010-Holman-Thesis, 8. A hole does not physically move like an electron does, but because electrons move by filling holes, the science considers that holes also move, figuratively. Ex.1033-Pierret, 35-39; Ex.1010-Holman-Thesis, 8. A moving electron carries a negative charge, and a moving hole carries a positive charge. Ex.1010-Holman-Thesis, 8. Thus, in the solar cell field, electrons and holes are both called “charge carriers” or simply “carriers” (of electricity). Ex.1016-Komp, 7-11.

51. Introducing atoms with one fewer valence electron than silicon is called p-type doping. Ex.1033-Pierret, 35-39; Ex.1018-Nelson, 181-182; Ex.1010-Holman-Thesis, 23-24. In solar cells, p-type doping is used to create extra holes in certain regions of the silicon wafer or layers of the solar cell. It was well known prior to 2008 that boron was commonly used as a dopant to create p-type regions or layers. Ex.1018-Nelson, 181-182. As shown in the simplified diagram below, because boron has three valence electrons (one fewer than silicon), a hole is introduced in the valence band that can move through the lattice structure. *See* Ex.1016-Komp, 11 (“[I]f an atom of boron (which has a valence of 3) is added to the crystal, it will contribute only 3 electrons to the system. It will also contribute 3 valence levels, plus 1 level which will be created in the band gap slightly above the

top of the valence band...These extra levels, called acceptor levels, are capable of accepting an electron from the valence band. Since the acceptor level is associated with a particular impurity atom, the electron that occupies it is trapped and cannot move. However, the hole created when the electron leaves the valence band can move.”).



See Ex.1010-Holman-Thesis, 25; *see also* Ex.1033-Pierret, 36.

52. Techniques for doping solar cell layers with phosphorous or boron were well-established by 2008. Ex.1016-Komp, 11 (“The process of deliberately adding a known impurity to a pure semiconductor is called doping.”). Silicon wafers were commonly purchased by solar cell manufacturers already uniformly doped (i.e., with

spatially uniform “background” dopant concentration). A wafer with uniform n-type doping was referred to as an “n-type wafer;” a wafer with uniform p-type doping was referred to as a “p-type wafer.” *See* Ex.1033-Pierret, 40; Ex.1010-Holman-Thesis, 22-23.

53. A common doping technique used in solar cell fabrication, called “diffusion,” involved driving dopant atoms from a dopant source—a gas, a liquid, or a solid containing dopant atoms—into a silicon wafer or a polysilicon layer at high temperatures in a furnace. Ex.1030-Benick, Abstract (“Emitter formation by in-line deposition of a PECVD PSG and subsequent diffusion in an in-line belt furnace”); Ex.1004-Froitzheim, [0011] (“diffusion from a p-type dopant from a liquid that is applied to the rear side”); Ex.1007-Smith (depositing boron-doped silicon dioxide (“BSG”) and phosphorus-doped silicon dioxide and diffusing dopants into a wafer). Diffusion was commonly used during solar cell fabrication to dope the region(s) near a surface of a wafer n-type or p-type, which either further enhanced the background doping of the wafer (if the diffused region had the same polarity as the wafer) or converted the polarity of the surface region of the wafer (if the diffused region had the opposite polarity as the wafer).

54. One well-known technique for diffusing phosphorus into a silicon wafer or polysilicon layer was known as phosphosilicate glass (PSG) diffusion. The

PSG diffusion technique involved forming a layer of PSG on the surface of the wafer (or a polysilicon layer on the wafer). One method to do this involved vaporizing phosphorus-containing liquid such as phosphorus oxychloride (POCl_3) into a furnace containing silicon wafers, where it reacted with the silicon atoms to form the PSG. Applying heat then drove the phosphorus from the PSG into the silicon or polysilicon via diffusion. *See, e.g.*, Ex.1018-Nelson, 187 (“Phosphorus may be deposited either from the vapour phase by exposure to nitrogen gas bearing POCl_3 ; from solid phase, for example by chemical vapour deposition of phosphorus oxide; or directly by ion implantation.”); Ex.1007-Smith, 3:56-57 (“atmosphere containing phosphorus oxychloride”); Ex.1004-Froitzheim, [0044] (“diffusion of Phosphorous from the gas phase”); Ex.1019-Krygowski, 1 (“ POCl_3 diffusion step is used to co-diffuse the emitter and pre-alloyed BSF”); Ex.1030-Benick (explaining POCl_3 diffusion).

55. Another known technique for diffusing boron into a silicon wafer or polysilicon layer was known as borosilicate glass (BSG) diffusion. This technique involved forming a layer of BSG on the surface of the wafer (or a polysilicon layer on the wafer) to form BSG. Ex.1007-Smith, 2:44-4:2; Ex.1004-Froitzheim, [0040]-[0041]. One method to do this involved vaporizing boron-containing liquid such as boron tribromide (BBr_3) into a furnace containing silicon wafers, where it reacted

with the silicon atoms to form the BSG. Ex.1043-Kerr, 153-155. Applying heat then drove the boron from the BSG into the silicon or polysilicon via diffusion. Ex.1007-Smith, 2:44-4:2; Ex.1004-Froitzheim, [0040]-[0041].

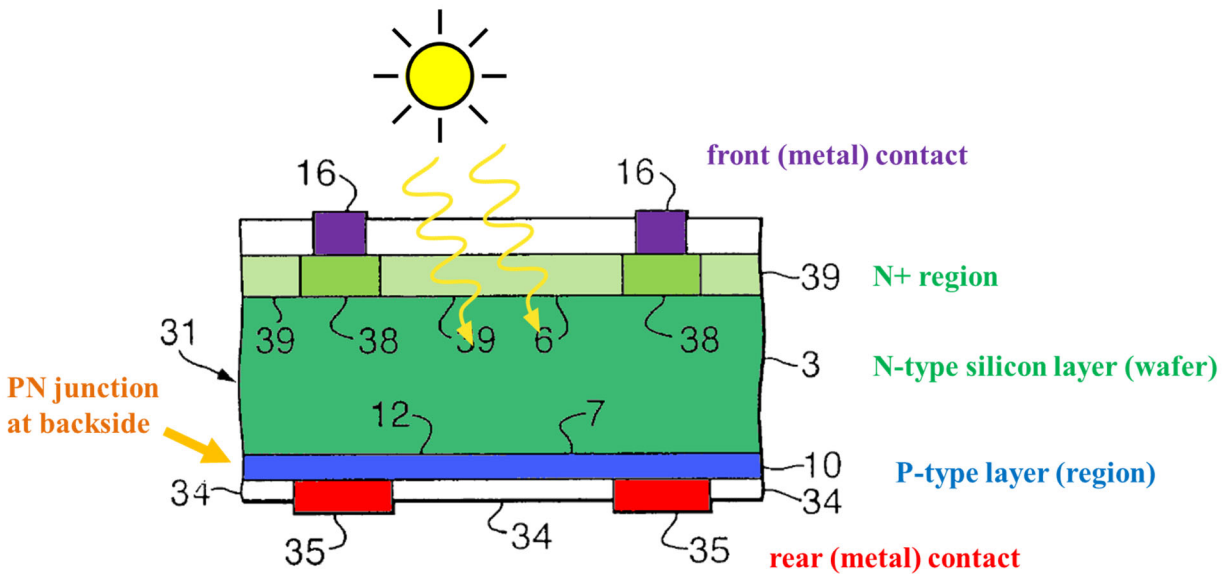
2. PN Junction

56. In a typical solar cell, an interface between n-type and p-type regions in a silicon wafer, or between an n-type wafer and a p-type layer added to that wafer (alternatively, a p-type wafer and an n-type layer added to it), is formed and is commonly known as the “PN junction.” Ex.1016-Komp, 5-18; Ex.1050-Tarr, 655-57. At the center of a PN junction is established an “electric field.” An electric field exerts a force on charge carriers that pushes them in the direction of the electric field or opposite the direction of the electric field, depending on the polarity of the charge carriers. Ex.1033-Pierret, 75-79. The PN junction—because of its built-in electric field—acts as the driving force to create electrical current when the solar cell is illuminated. Ex.1033-Pierret, 101; Ex.1010-Holman-Thesis, 26 (“The internal electric field separates the charges and pulls them towards the appropriate contacts. They flow through an external circuit, and—voilà!—electricity.”).

57. When solar radiation reaches a solar cell, and when the energy of the photons is greater than the bandgap energy of the silicon wafer, electrons in the valence band may be excited to the conduction band, absorbing the photons’ energy

to make the transition. *See* Ex.1016-Komp, 5-18, 10 (“The electron might be thermally excited by...a photon of light of sufficient energy might be absorbed by the crystal and cause the electron to jump. Once the electron is in the upper conduction band, it is free to move and can act as a carrier of electricity.”); Ex.1010-Holman-Thesis, 14-15. Each “photoexcited” electron leaves behind a hole in the valence band; light absorption creates an “electron-hole pair.” *See* Ex.1016-Komp, 5-18, 182 (defining “band gap energy” as “[t]he energy needed to raise an electron from the top of the valence band to the bottom of the conduction band”); Ex.1010-Holman-Thesis, 14-15. As discussed herein, the photoexcited electrons are mobile in the conduction band, and the photoexcited holes are mobile in the valence band. Ex.1010-Holman-Thesis, 14-15. A solar cell produces electricity when the photoexcited electrons are conveyed to one metal contact and the photoexcited holes are conveyed to a separate metal contact. Ex.1010-Holman-Thesis, 16. The PN junction facilitates this separation of the charge carriers. In particular, photoexcited electrons that encounter the PN junction are swept to the n-type region or layer by the PN junction’s electric field, and photoexcited holes that encounter the PN junction are swept to the p-type region or layer. *See* Ex.1016-Komp, 2-18; *see also* Ex.1010-Holman-Thesis, 24-25.

58. As an example, the below solar cell shown includes an **n-type silicon layer (wafer)** containing n-type dopants such as phosphorous. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. The wafer is often called a “substrate” because it is the base upon which other layers of the solar cell are built. It is also the thickest layer in the solar cell, commonly being 100-300 μm thick. The backside (also called a rear side in literature) of the solar cell below includes a **p-type layer (region)**, made by diffusing p-type dopants such as boron into the substrate’s backside. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. Diffused regions are thin relative to the wafer’s thickness, commonly extending 0.3-3 μm into the wafer’s surface. Ex.1004-Froitzheim, [0026]. At the interface of the n-type substrate and p-type region, the “PN junction” is formed. Ex.1004-Froitzheim, [0010], [0022], [0025]. Because the diffused region is thin and the wafer is thick, the PN junction is much closer to the backside of the solar cell than its middle or front. The p-type layer, in this case, as it is oppositely doped from the substrate, is called an “emitter.” In the field of solar cell technology, “emitter” usually refers to the region or layer that is oppositely doped from the substrate.



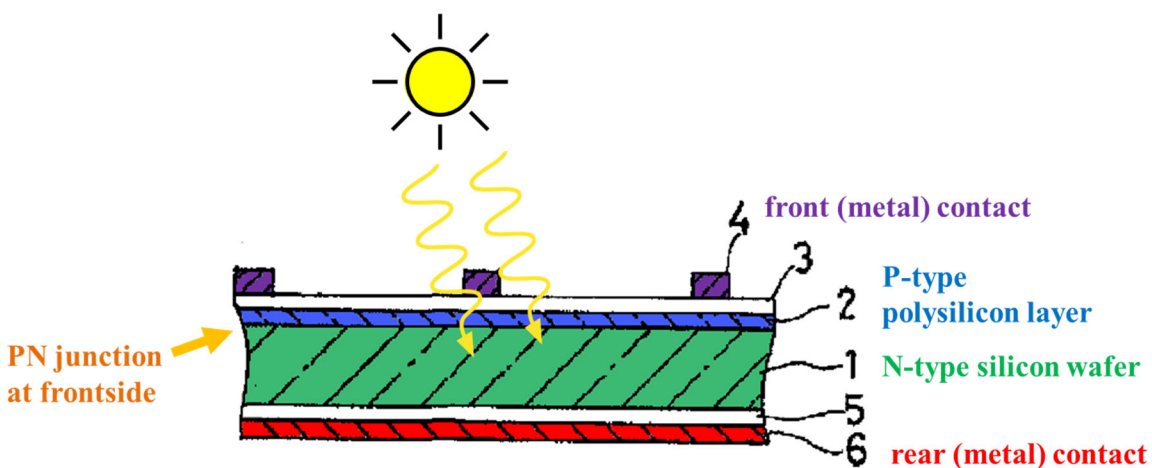
Ex.1004-Froitzheim, Fig.3.¹

59. Throughout the history of solar cells, many different arrangements of solar cell components have been developed. The placement of the PN junction, whether at the “backside” of the solar cell (formed by, e.g., a diffusion into the back of the wafer) or at the “frontside” of the solar cell (formed by, e.g., a diffusion into the front of the wafer), was one of the well-known arrangement options. *Compare* Ex.1018-Nelson, 188 (Fig. 7.7, frontside configuration); Ex.1004-Froitzheim, Fig.3 (backside configuration). In a “back-junction” (also called “backside junction”)

¹ All annotations and emphasis in figures and text throughout this Declaration are added unless otherwise noted.

configuration, in which the junction is at the solar cell's backside (as shown in Froitzheim above), the uniformly doped "bulk" of the wafer is closer to the sun than the oppositely doped emitter region or layer, and the sunlight hits the former first. *E.g.*, Ex.1004-Froitzheim, Fig.3. The PN junction is thus formed at the backside of the substrate, at the interface between the wafer bulk (n-type in the above figure) and the emitter (p-type in the above figure). Ex.1004-Froitzheim, Fig.1, Fig.3; Ex.1008-Li, Fig.1; Ex.1022-Meier, Fig.2, 4:27-65.

60. Alternatively, in a "front-junction" (also called "frontside junction") configuration, the emitter region or layer is located closer to the sun than the wafer bulk, and the sunlight hits the emitter first. *E.g.*, Ex.1031-Okayasu, Fig.1. The PN junction is formed at the frontside of the substrate, at the interface between the emitter (p-type in the below figure) and the wafer bulk (n-type in the below figure):



Ex.1031-Okayasu,² Fig.1.

61. A second method to form an emitter, in addition to dopant diffusion into a region near a surface of the wafer, as in Froitzheim above, is to “deposit” a layer onto the wafer surface that has the opposite doping polarity of the wafer. Deposition refers to a process to add such a layer, which is commonly built up atom by atom. Known processes include chemical vapor deposition and physical vapor deposition. Amorphous silicon and polycrystalline silicon emitter layers were well known by 2008. *E.g.*, Ex.1008-Li, Fig.1; Ex.1031-Okayasu, Fig.1. Okayasu above shows a polycrystalline silicon emitter.

62. It was well known that back-junctions were advantageous, especially for solar cells with high-quality silicon wafers (i.e., those with low rates of bulk recombination, as described below). For example, it was known that locating the emitter at the front of the solar cell can reduce solar cell efficiency because (i) diffused emitters can have high doping concentrations that can induce unwanted recombination if there is considerable absorption (i.e., parasitic absorption) within the emitter and (ii) most absorption in a solar cell occurs near the front of the solar cell. I explain recombination below in Section VII.B (Overview of Cell Efficiency).

² See 1032-Okayasu-Decl. (translator declaration for Okayasu translation).

Back-junction solar cells do not suffer from such parasitic absorption because locating the emitter at the rear of the solar cell ensures that most light is beneficially absorbed in the wafer before reaching the emitter. *See* Ex.1004-Froitzheim, [0025]-[0026] (“At the rear side 7, a p-doped layer 10 is arranged suitably such as discussed further below, and a p/n-junction 12 with the body layer is formed. The doping level of the p-region can be higher than what one would use at a front contact, since at the rear side that is away from the light-receiving front side there most of the light has already been absorbed and there is less risk for recombination.”).

63. Deposited silicon emitters were similarly known by 2008 to have higher absorption when they were located on the front side of a solar cell. For example, it was reported that a p-type amorphous silicon emitter deposited on an n-type wafer “act[ed] mainly as a ‘dead layer’ in which almost all the absorbed light [did] not generate photocurrent.” Ex.1061-Centurioni, 1818-1819. Similarly, it was reported that an n-type polycrystalline silicon emitter deposited on a p-type wafer caused a decrease in generated current due to optical losses (i.e., absorption) in the emitter. Ex.1062-Farrokh-Baroughi, 5-6.

64. Because polycrystalline silicon is a material that has optical properties very close to that of a monocrystalline or multicrystalline silicon wafer, it absorbs light of the same wavelengths as a wafer. Ex.1059-Lubberts, 6877 (explaining

absorption coefficient of doped polysilicon as a function of wavelength). Consequently, a polysilicon emitter at the front side absorbed light that would otherwise go to the substrate. *See* Ex.1062-Farrokh-Baroughi, 5-6; *see also* Ex.1060-Bordogna, 2:32-34 (“The use of Polysilicon leads to an intrinsic parasitic absorption of light that involves a consequent loss of a portion of the optical signal before it reaches the sensor”).

65. The manufacturing processes for front- and back-junction solar cells were functionally similar. For instance, they both involved a doped silicon wafer, diffusing dopants into the surface of the wafer or into polycrystalline silicon layers deposited on the wafer to form a PN junction, adding an anti-reflection coating, and adding metal contacts, among other standard manufacturing steps. *E.g., compare* Ex.1004-Froitzheim, [0038]-[0051] *with* Ex.1031-Okayasu, [0044].

3. Metal Contacts

66. Solar cells have metal contacts (also called electrodes) at which photogenerated electrons and holes are collected and passed to external circuits. Ex.1016-Komp, 154-55. For example, the solar cells shown above (Froitzheim and Okayasu) each include at least one **front metal contact** (i.e., metal contact on the front side of the solar cell) and one **rear metal contact** (i.e., metal contact on the rear side of the solar cell). Ex.1004-Froitzheim, Fig.3; Ex.1031-Okayasu, Fig.1.

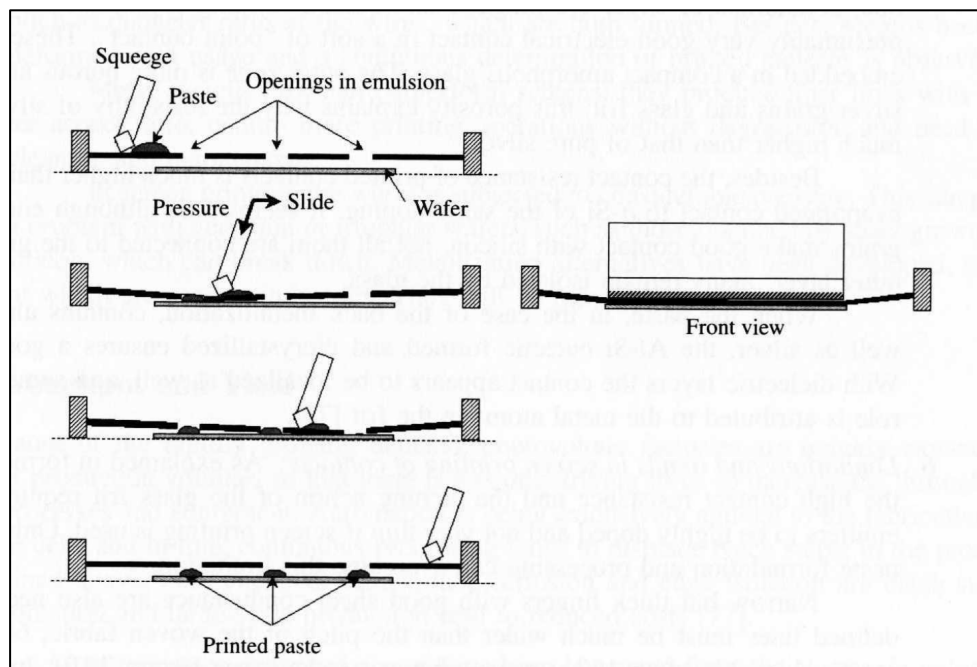
These metal contacts connect the solar cells to one another in solar modules, and the resulting “strings” of interconnected solar cells are connected to external circuits. Ex.1016-Komp, 13-14 (“The back contact and the top fingers shown are used to connect the solar cell to the external circuit”).

67. Basic physics dictates that the polarity of the metal contact must match that of the solar cell region or layer to which it is connected. Ex.1016-Komp, 14-18. Simply stated, because an n-type region or layer accumulates negatively charged electrons when the solar cell is illuminated, the metal contact connected to it is the negative electrode. Similarly, because a p-type region or layer accumulates positively charged holes, the metal contact connected to it is the positive electrode. Ex.1016-Komp, 14-18. This was well understood by 2008. Ex.1016-Komp, 14-18.

68. One well-known way to manufacture metal contacts was screen printing. Ex.1045-Green-1995, Chapter 11.2 (discussing “screen-printed” solar cells); Ex.1004-Froitzheim, [0020], [0049]. For instance, a 2001 publication described screen printing as being part of “[t]he most common fabrication approach” to reduce cell costs. Ex.1021-Gordon, 324. Screen-printed front and rear contacts were made from metal paste. Ex.1004-Froitzheim, [0020], [0049]; Ex.1045-Green-1995, 234-39; Ex.1018-Nelson, 188 (“In large scale production, AR coat, front and back contacts are usually deposited by screen printing and then fired.”). Screen-

printed contacts were made of silver and/or aluminum. Ex.1004-Froitzheim, [0020], [0049]; Ex.1045-Green-1995, 234-39 (“addition of aluminum to the silver paste”), Ex.1022-Meier, 7:10-16 (“FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating. By way of example, a silver layer is screen-printed onto the n^+ layer 216, covering about 7% of the front surface in a grid pattern. Silver may be deposited by screen-printing to a thickness that is generally between about 5 μm and about 20 μm and preferably about 10 μm .”). Screen printing was favored in many applications because it was cheaper than other options. Ex.1018-Nelson, 188.

69. The basic steps of a typical screen-printing process are shown in the following illustrations:



Ex.1020-Luque, Fig.7.9, 277-78. As shown, first, a paste containing metal particles is deposited on a screen, which has openings where the contacts are desired to be formed on the underlaying solar cell. Second, a squeegee is moved across the screen, dragging the paste with it. Ex.1020-Luque, Fig.7.9, 277-78. Once the paste reaches an opening in the screen, the squeegee's pressure deposits the paste through the opening onto the solar cell. Ex.1020-Luque, Fig.7.9, 277-78. After the paste is thus "printed" on the wafers, the structure is "fired." Ex.1020-Luque, Fig.7.9, 277-78. The firing process entails heating the structure under certain conditions. Ex.1020-Luque, Fig.7.9, 277-78. This solidifies the paste into the final contacts and makes electrical contact between the paste and an n-type or p-type region or layer (e.g., the emitter). Ex.1020-Luque, Fig.7.9, 277-78. In many cases, the paste was designed to "fire through" an anti-reflection coating located between the wafer and the paste. Ex.1020-Luque, 278 ("Higher temperatures are needed if an AR coating must be penetrated...."). Firing through refers to the paste etching (i.e., locally dissolving) the coating so that metal particles make contact to the underlying doped region or layer. Ex.1020-Luque, Fig.7.6, 278; Ex.1022-Meier, 7:10-12 ("FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating."), Fig.3D.

4. Texturing and Anti-reflection Coating

70. It was well known by 2008 that the addition of texture and anti-reflection coatings to the front side of solar wafers would help maximize the amount of sunlight that a solar cell absorbs. Ex.1016-Komp, 20 (“To decrease reflection loss, most manufacturers etch the surface of the cell to roughen or ‘texturize’ it and apply antireflection coatings.”).

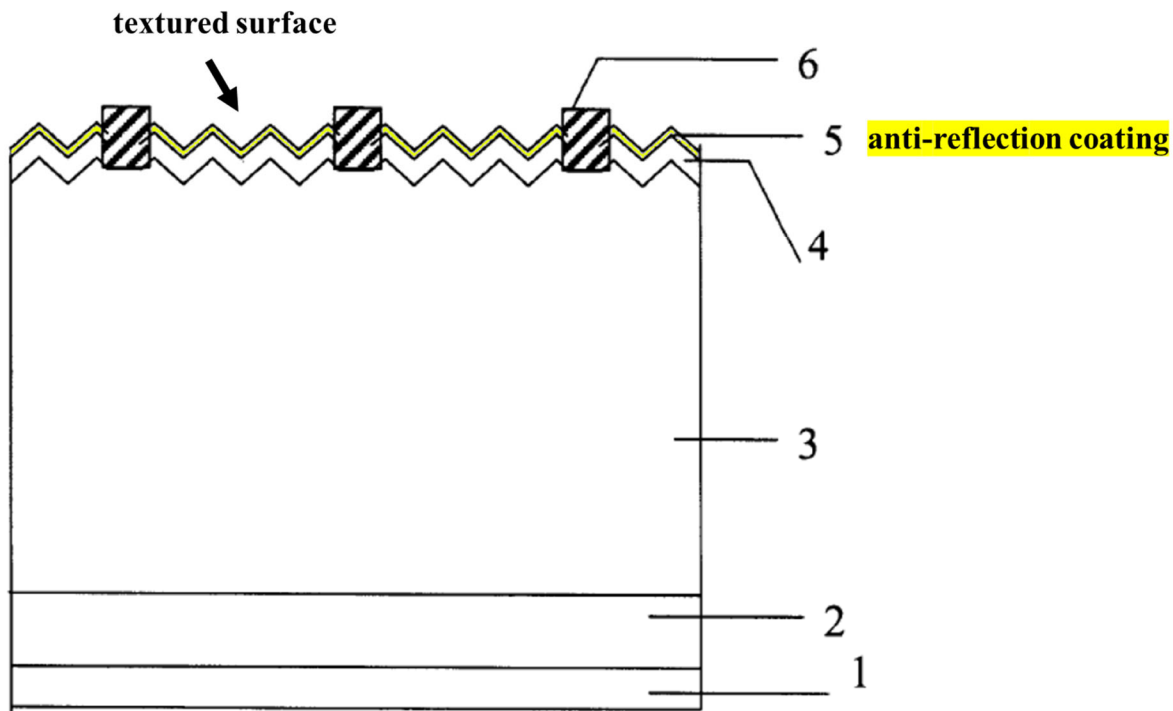
71. By 2008, texturing the surface of silicon had long been studied and implemented to increase a solar cell’s efficiency. Ex.1023-Yablonovitch, 2:49-55 (“front surface texturing...is essential for optical enhancement (light trapping)”); Ex.1045-Green-1995, 282 (“In the historical development of silicon cells...texturing accounted for the more than 10% relative performance advantage of black cells over violet cells.”). Texturing the surface of silicon increases a solar cell’s efficiency because some of the sunlight that reflects off the planar surface can be recaptured with a textured surface. Ex.1023-Yablonovitch, 1:60-62 (“The front of the cell may be textured to help trap the light internally and to reduce reflection losses.”); Ex.1018-Nelson, 188 (“textured to reduce reflectivity”). One well-known way to texture a surface was to etch the surface with chemicals. Ex.1004-Froitzheim, [0039] (“[E]tching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection.”), [0023], [0056] (“After etch

removal, texture etching was applied to the [n-type] wafers.”), [0087]; Ex.1006-Borden-575, [0029] (discussing front surface textured solar cells); Ex.1024-Borden-578, [0023] (“[I]n step S302, the front surface of the n-type substrate is textured. This may be accomplished using conventional etching, such as isopropyl alcohol and KOH.”), Fig.3; Ex.1016-Komp, 20 (“To decrease reflection loss, most manufacturers etch the surface of the cell to roughen or ‘texturize’ it and apply antireflection coatings.”).

72. By 2008, anti-reflective coatings were also routinely applied to solar cells to increase their efficiency. Anti-reflection coatings, applied over the textured surface, minimize the amount of light that is reflected away from the cell and were well known. Ex.1004-Froitzheim, [0050] (“[A]ntireflection coating can be applied using known methods.”); Ex.1022-Meier, 1:30-35 (“Commercial embodiments of conventional solar cells typically include an optional anti reflective coating”), 4:45-47; Ex.1025-Sah, 3:52-55 (“front surface 12 ...[includes] antireflection coating”), Fig.1a (showing prior art); Ex.1023-Yablonovitch, 2:49-55 (“[A]n anti-reflection coating is desirable, and is assisted by the front surface texturing which is essential for optical enhancement (light trapping) in any case.”); Ex.1016-Komp, 20; Ex.1018-Nelson, 188.

73. One common material used for anti-reflection coating was silicon nitride. Ex.1004-Froitzheim, [0030], [0019], [0023], claim 7; Ex.1022-Meier, 6:20-25 (“An anti-reflective coating 214 may then be deposited on top of n^+ layer 216, as shown in Fig. 3B. By way of example, plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride...is carried out to form anti-reflective coating 214.”); Ex.1018-Nelson, 188 (“Suitable materials for silicon [AR coating include]...silicon nitride (Si_3N_4)”).

74. Li (below) provides one example of a solar cell with a textured front surface and anti-reflection coating. In two-dimensional images, such as Li, it was common to show surface texturing by depicting the surface of the solar cell as having jagged edges.



Ex.1008-Li, Fig.1. Froitzheim teaches another example of a solar cell with a textured front surface and anti-reflection coating. Although Froitzheim's figures do not depict a textured front surface, Froitzheim explains that the front surface is textured via etching. Ex.1004-Froitzheim, [0039] ("a short, alkaline crystal-oriented etching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection").

B. Overview of Solar Cell Efficiency

75. As discussed above, solar cells generate electricity when incident light excites electron-hole pairs that are separated and reach metal contacts connected to an external circuit. Solar cell efficiency is the ratio of power output from the cell to

the power input from the sun under specific conditions, and solar cell efficiency is referred to as “power conversion efficiency.” Ex.1018-Nelson, 289. In other words, power conversion efficiency is a measure of the amount of electrical power extracted from the solar cell per amount of radiation power incident on the solar cell under particular conditions. For terrestrial solar cells, the conditions for evaluating efficiency are Air Mass 1.5 Global spectrum, 1000 W/cm^2 , and 25°C . Ex.1018-Nelson, 289.

76. Since the first modern solar cell was created in 1954 by Bell Laboratories (Ex.1026-Chapin), skilled artisans have worked continuously to improve cell efficiency. When the modern solar cell was initially created, the efficiency was about 6%. Ex.1026-Chapin. In 1961, a groundbreaking paper discussing the limit of solar cell efficiency was published by William Shockley and Hans Queisser. Ex1027-Shockley. It noted that a “theoretically justifiable upper limit” of efficiency exists in solar cells based on the laws of physics. Since then, the Shockley-Queisser limit for silicon-based solar cell (bandgap energy of 1.12eV) efficiency has been known to be about 30%. Ex1027-Shockley, 510. Because of the physical limit on a cell’s efficiency, even small efficiency gains were desirable. Ex.1025-Sah, 1:15-20 (patent filed in 1986 noting that “[s]ince about 1956, silicon solar cell conversion efficiency has been improved from about 5% to more than

16%”); Ex.1028-Metz (claiming 18.5% efficiency); Ex.1029-De-Ceuster (claiming 22% efficiency); Ex.1030-Benick (claiming 17.5% efficiency).

77. As I explained above, a solar cell generates electricity through the separation of photogenerated electrons and holes. One important goal of solar cell design is to maximize the number of electron-hole pairs that contribute to generating electricity by exiting through their respective metal contacts (i.e., electrodes). This is because the created electricity becomes usable only when it powers an external circuit. Ex.1016-Komp, 3-4, 121, 154-57.

78. A major factor decreasing solar cell efficiency is a phenomenon called “recombination.” Ex.1016-Komp, 19-20; Ex.1051-Swanson-1986, 86 (“It has long been recognized that an important path to improved efficiency is through reducing carrier recombination.”). Recombination was well studied by 2008 and occurs when electrons and holes “recombine” with each other before exiting the cell. Ex.1016-Komp, 19-20. When an electron that has been excited to the conduction band (via the absorption of light) encounters a hole in the valence band, there is a possibility that the electron will return to the valence band and fill the hole—i.e., “recombine.” Ex.1010-Holman-Thesis, 15-16. While physics dictates that some types of recombination are inevitable, so-called “non-radiative recombination” is undesirable for cell efficiency because electrons and holes that recombine no longer contribute

to the generated power of the solar cell. Ex.1016-Komp, 19-20; Ex.1018-Nelson, 81; Ex.1010-Holman-Thesis, 15-16.

79. By 2008, it was well known that (i) recombination occurs at several locations in a solar cell and (ii) non-radiative recombination should be reduced at such locations to achieve better efficiency. Ex.1045-Green-1995, 223 (“To obtain high cell performance, recombination throughout the cell has to be kept to a minimum.”), Ex.1051-Swanson-1986, 92 (“Carrier recombination can occur in four regions of the [point-contact solar cell]: (1) the bulk silicon (which is largely mediated through defects and impurities), (2) the surfaces of the silicon on the front and between the contact diffusions on the back (passivation with SiO₂ reduces this component), (3) the diffused junction regions and (4) the metal-silicon contacts. Research into improving the recombination related parameters of solar cells [] has resulted in cells where the recombination is dominated entirely by the diffused junction regions.”).

80. For example, it was well known that non-radiative recombination occurs in bulk regions (i.e., the silicon wafer) at defects in the crystalline lattice such as structural defects (e.g., grain boundaries), unintentional impurities (e.g., metal atoms), and intentional impurities (e.g., dopant atoms). Ex.1045-Green-1995, 223 (“Recombination in bulk regions can be minimized by choosing as high a quality

starting material as possible”). It was also well known that recombination occurs at the surfaces of the wafer, where “surface” was commonly understood to mean the interface of the wafer with any other material, and surfaces were recognized to be extended crystalline defects. For example, it was well known that recombination occurs at the wafer interface with metal contacts. Ex.1045-Green-1995, 226 (“The regions where metal contact to the cell is made are regions of potentially very high recombination.”); Ex.1006-Borden-575, [0003].

81. Because recombination was an important factor in design considerations, ways to measure recombination were known in the art. This was beneficial because it allowed skilled artisans to compare whether different solar cell materials and configurations had decreased non-radiative recombination. A known way to evaluate recombination was to measure the emitter saturation current density (J_o). *See* Ex.1043-Kerr, 18-19. The emitter saturation current density represents the sum of the different recombination mechanisms that may incur inside of the emitter. *See* Ex.1043-Kerr, 81-84 (“[R]ecombination due to the heavily doped emitter regions is characterised by a saturation current density....”). Lower emitter saturation current density indicates less recombination and thus the likelihood of a more efficient solar cell. *See* Ex.1043-Kerr, 18-19, 81-84.

82. Prior to 2008, different techniques to reduce non-radiative recombination were known. For example, it was well known that surfaces could be “passivated” to reduce recombination, i.e., reduce the density of electrons available to recombine with holes (or vice versa) or reduce the number of interfacial defect sites that facilitate such recombination. Ex.1043-Kerr, Abstract (“Surface recombination processes in silicon solar cells are becoming progressively more important as industry drives towards thinner substrates and higher cell efficiencies. The surface recombination properties of well-passivating SiN films on p-type and n-type silicon have been comprehensively studied, with S_{eff} values as low as 1cm/s being unambiguously determined.”); Ex.1004-Froitzheim, [0019] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”). One well-known surface passivation method was to heavily dope the surface region of a wafer—or a layer deposited on the wafer surface—so that there was primarily only one carrier type (i.e., electrons or holes) near the wafer surface. Ex.1049-Green-1986, 129 (“The heavily doped P^+ region at the rear of the cell blocks minority carrier flows, making the PP^+ junction plane an effective low recombination-velocity surface.”). As recombination requires both an electron and a hole, having primarily only one carrier type reduces

recombination. Ex.1049-Green-1986, 129, 151. An emitter, being doped and in the vicinity of a wafer surface, could provide such passivation.

83. Another well-known surface passivation method was to deposit a “passivation layer” on the wafer surface. A passivation layer either (i) removed defects at the wafer surface (“chemical passivation”) by advantageously bonding with the atoms on the silicon surface or (ii) contained immobile charge that repelled one carrier type (“field-effect passivation”). Ex.1004-Froitzheim, [0019] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”). Suitable passivation layers were known to include silicon nitride (which also commonly served as an anti-reflection coating, as I have described) and silicon oxide. Ex.1045-Green-1995, 224-226 (“Recombination in non-contacted areas of the surface can be minimized by the growth of a high-quality thermal oxide. Conditions for producing low interface state densities have been well documented for microelectronics”).

84. Numerous references throughout the history of solar cells taught passivating the surface of a silicon wafer by placing a very thin silicon oxide layer between the wafer surface and a deposited layer, including a deposited emitter layer. In this case, the oxide layer is sandwiched in the PN junction and advantageously bonds with the atoms on the silicon surface to reduce recombination. For example,

in the 1980s, Yablonovitch and Kwark taught the concept of a tunnel oxide layer. Ex.1036-Yablonovitch-1985, 1212-13 (discussing “tunneling” and a “thin [interfacial] oxide layer”); Ex.1023-Yablonovitch, 3:61-64 (“The interface 18 between the silicon ribbon 14 and the n⁺-SIPOS heterocontact contains a 20-40 Å interfacial layer of silicon dioxide which is so thin as to be permeable to electrons”); Ex.1046-Kwark, 1125 (“[b]oth poly-silicon and SIPOS emitters [can improve] performance through incorporating a thin, tunnelable interfacial oxide”). In 1990, Gan published a study on a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245. In 2008, Borden-575 taught a “tunnel oxide” that “provides passivation between the substrate and the polysilicon [emitter].” Ex.1006-Borden-575, [0022]; *see also* Ex.1016-Komp, 23 (“Current carriers pass through this insulator by a quantum mechanical process called tunneling. ... If the insulating layer is one of the proper thickness, around 20 Å, the open-circuit voltage of a cell can be increased without any significant loss in short-circuit current.”).

85. The teachings of oxide layers sandwiched in the PN junction also came from microelectronics technologies such as transistors. Ex.1034-Rahim, 2506 (“A considerable amount of work has been published in the literature on the effects of the interfacial oxide on the base current [] and emitter resistance [] of polysilicon

emitter contacts”); Ex.1035-Parekh, 3167 (“a simple method for modifying the interfacial oxide thickness in a polysilicon emitter technology incorporated in a BiCMOS process [] allows an increase in the bipolar npn transistor current gain without adversely impacting other device parameters.”); Ex.1047-Wolstenholme, 232 (“there is a strong correlation between the high gain of polysilicon emitter bipolar transistors and the existence of a continuous, thin, interfacial oxide layer between the single-crystal silicon and the polysilicon.”). Since silicon-based solar cells and transistors are closely related in structure (e.g., both rely on PN junctions) and manufacturing, skilled artisans in solar cells frequently learned from and adopted transistor technologies. Ex.1045-Green-1995, 218 (“To achieve design objectives in [surface passivation,] full advantage had to be taken of developments in microelectronics”), 224 (stating that recombination and the usage of thermal oxide have been “well documented for microelectronics”).

86. In addition to recombination, skilled artisans also addressed contact resistance to increase solar cell efficiency. Contact resistance (ρ_c) is present in every solar cell and is the resistance between the interface of two materials, or the resistance between the multiple interfaces of more than two materials. *See* Ex.1045-Green, 181-182 (“Metallic contacts to the cell are required to transfer the generated current to an external load. At the interface with silicon, it is known from experiment

that metals induce a barrier to majority carriers.”); Ex.1020-Luque, 258, 263-264, 274-275 (“The requirements for the front metallization are low contact resistance to silicon.”). In the latter case of multiple interfaces, the resistance was sometimes called the “lumped contact resistance.” It was well known that contact resistance represents an opposition to current flow. *See* Ex.1045-Green, 182 (“The energy barrier to majority carrier flow gives rise to an undesirable contact resistance.”). Thus, it was well known that if an interface or a series of interfaces has higher resistance (i.e., there is higher contact resistance), it will be harder for current to flow and the power output of the solar cell would be lower. Ex.1045-Green, 182. As a result, skilled artisans sought to design for lower contact resistance because doing so would create a more efficient solar cell. Ex.1045-Green, 182; Ex.1005-Gan, 249.

87. It was well known that surface recombination and contact resistance were closely related, and that there were tradeoffs in achieving good (lower) surface recombination and good (lower) contact resistance. *E.g.*, Ex.1005-Gan, 248 (explaining that a decrease in contact resistance increases recombination in certain cases). As a result, skilled artisans were familiar with techniques to balance recombination and contact resistance to improve overall efficiency. *E.g.*, Ex.1005-Gan, 249 (explaining that with polysilicon emitters, both low recombination and contact resistance are achievable with a very small fraction of interfacial oxide

breakup because of “tunneling” through oxide resistance); Ex.1058-Swanson-1990, 473 (“In short, the criteria outlined above for an optimized single-diffusion front-side phosphorus emitter [include]...Surface dopant concentration $\leq 10^{20} \text{ cm}^{-3}$ to obtain low emitter saturation currents for the passivated emitter regions [and] Surface dopant concentration $\geq 10^{19} \text{ cm}^{-3}$ to insure good contact resistance.”).

VIII. OVERVIEW OF THE '516 PATENT

A. Summary of the '516 Patent

88. The '516 patent describes a structure for a solar cell, which the '516 patent acknowledges was a “well known device[] for converting solar radiation to electrical energy.” Ex.1001-USP516, Abstract, 1:15-22, 1:46-48. As depicted in Figure 1 below, the '516 patent's solar cell has an **N-type substrate 101 (green)** that includes “N-type doped regions 105 and 106 formed in the **substrate.**” Ex.1001-USP516, 2:28-49. The **N-type substrate 101** forms a “backside junction” with a **P-type emitter 108 (blue)** because the **P-type emitter** is on the back side of the cell (i.e., the side facing away from the sun).³ Ex.1001-USP516, 2:28-36 (“In

³ As described below, I understand that the applicant of the '516 patent represented to the Patent Office on multiple occasions that an emitter is oppositely doped from the substrate. Section VIII.C (Prosecution History of Related Patent).

the example of FIG. 1, the solar cell 100 includes a backside junction formed by a P-type doped polysilicon emitter 108 serving as a P-type diffusion region and an N-type silicon substrate 101 serving as an N-type diffusion region.”), 1:22-23 (“A solar cell includes P-type and N-type diffusion regions that form a junction.”). The front side of the **N-type substrate** may be textured (113) and include an anti-reflective coating 103. Ex.1001-USP516, 2:35-38, 2:50-52.

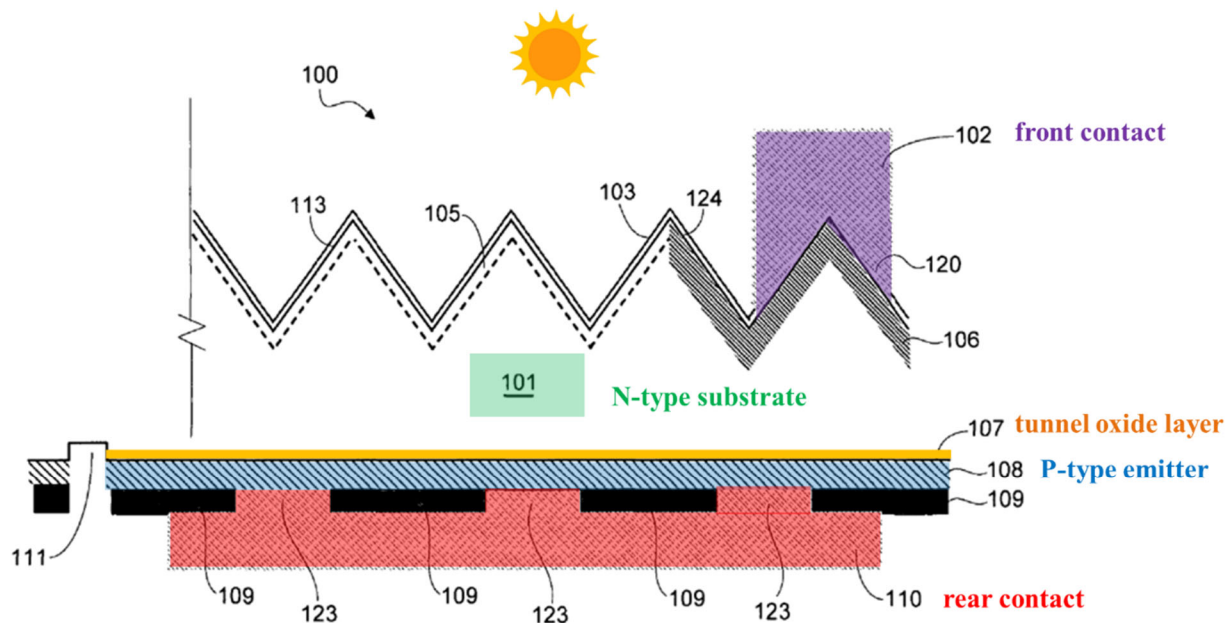


FIG. 1

Ex.1001-USP516, Fig.1.

89. The '516 patent's solar cell is structured to have front and back metal contacts, which allows “an external electrical circuit to be coupled to and be powered by the solar cell.” Ex.1001-USP516, 1:26-30, 2:66-3:21. As shown in Figure 1, a **metal contact 102 (purple)** is electrically connected to the **N-type substrate** (via

“N-type doped region[]...formed in the [front of the] **substrate**”), and a **metal contact 110 (red)** is electrically connected to the **P-type emitter**. Ex.1001-USP516, 2:66-3:21. The “**metal contact 110** electrically connects to the polysilicon emitter 108 through contact holes 123 formed through a dielectric comprising a silicon dioxide layer 109.” Ex.1001-USP516, 2:66-3:2.

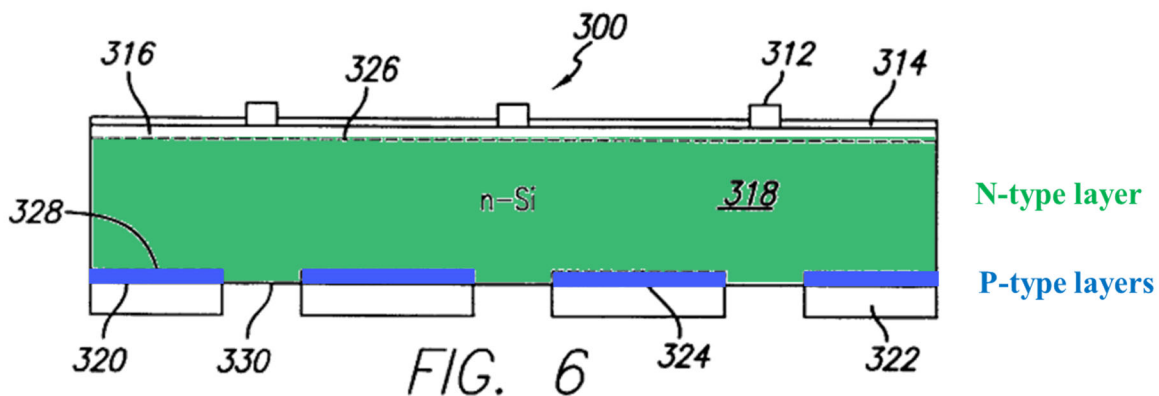
90. The '516 patent explains that a **tunnel oxide layer 107 (orange)** may be formed between the N-type substrate and P-type emitter. Ex.1001-USP516, 2:57-66. The '516 patent does not identify or discuss the purpose or function of the **tunnel oxide layer**. *See generally* Ex.1001-USP516.

B. Prosecution History

91. I have reviewed the prosecution history for the '516 patent. Based on my review, I understand that Application No. 12/070,742 issued as the '516 patent on July 17, 2012. I understand that the '516 patent was filed on February 20, 2008, and the '516 patent does not claim priority to any prior application. Ex.1001-USP516, Cover.

92. I understand that the applicant had to amend its claims several times during prosecution, and the amendments made by the applicant adjusted the scope of what the applicant claimed to have invented. For instance, I understand that the original claims of the '516 patent recited a “backside junction” but not an “oxide

layer” between the substrate and the emitter layer. Ex.1002-FH516, 16-19. The claims were twice rejected over two primary references, Meier (Ex.1022) and Sah (Ex.1025). Ex.1002-FH516, 74-84 (December 24, 2009 rejection), 116-129 (May 26, 2010 rejection). As shown below, Meier and Sah teach a substrate and an oppositely doped emitter layer at the back of the solar cell (i.e., a backside junction). Specifically, Figure 6 of Meier (below) teaches a solar cell that includes “a base layer 318 of n-type conductivity” and “p-type layer[s]” 320 to form a backside junction. Ex.1022-Meier, 7:66-8:8; Ex.1002-FH516, 118-119.



Ex.1022-Meier, Fig.6. Similarly, Figure 4a of Sah (below) teaches a solar cell that includes an n-type base 20” and p-type layer 22” to form a backside junction. Ex.1025-Sah, 7:31-36; Ex.1002-FH516, 120-121.



FIG. 4a

93. To overcome these rejections, I understand the applicant amended the independent claims to recite “an oxide layer formed between the back surface of the substrate and the emitter layer.” Ex.1002-FH516, 135-137. The applicant argued the cited prior art references did not disclose this element. Ex.1002-FH516, 138-141. In particular, the applicant argued that the prior art references’ emitter layers were formed by diffusing dopants into the substrate. Ex.1002-FH516, 139 (“In any event, regardless of the material of the substrate in Jordan or Meier, an oxide layer cannot be formed between the emitter and the substrate in Jordan or Meier.”), 140 (“In any event, Sah does not disclose an oxide layer formed between a P-type polysilicon emitter and an N-type silicon substrate. As explained above, neither does Jordan.”). According to the applicant, because the emitter of the cited prior art was

diffused into the substrate, an oxide layer did not and could not exist between the substrate and oppositely doped emitter. Ex.1002-FH516, 139-140.

94. I understand the Examiner allowed the claims following this amendment. Ex.1002-FH516, 147-153. The Examiner explained that the claims were allowed because the prior art reviewed by the Examiner “lack[ed] an oxide layer formed between an emitter and an oppositely doped substrate and a metal contact making an electrical connection to the substrate on the front light incident side of the solar cell.” Ex.1002-FH516, 152.

95. I understand that the references on which I rely in this declaration, including Froitzheim, Gan, Borden-575, and Li, were not disclosed or considered by the Examiner during prosecution. *See* Ex.1001-USP516, Cover. As I explain in more detail below in Section XI (Grounds), Gan and Borden-575 teach the oxide layer the Examiner identified as missing from the “prior art of record.” Ex.1002-FH516, 152.

C. Prosecution History of Related Applications

96. I understand that the applicant of the '516 patent filed two applications that claim priority to the '516 patent. I have reviewed both applications. I understand that the first application is Application No. 13/495,577, which was filed on June 13, 2012, issued as U.S. Patent No. 8,878,053 (“’053 patent”), claims

priority to the '516 patent, and shares the same specification and figures as the '516 patent. *See generally* Ex.1037-USP053; Ex.1001-USP516. I understand that the second application is Application No. 14/504,771 (“’771 Application”), which was filed on October 2, 2014 and ultimately abandoned by the applicant. Ex.1039-771FH, 28-33, 465-466. Similar to the '053 patent, the '771 Application claims priority to the '516 patent and shares the same specification and figures as the '516 patent. Ex.1039-771FH, 3-25, 28-33; Ex.1001-USP516. I understand that the applicant of the '516 patent represented to the Patent Office during prosecution of the '053 patent and '771 Application that an emitter is the layer that is oppositely doped from the substrate.

97. For example, I understand that during prosecution of the '053 patent, the pending claim 21 (which issued as claim 9) recited the following:

A method of fabricating a solar cell comprising:
forming a layer of polysilicon over a back surface of a silicon substrate;
forming a first dopant source layer over the layer of polysilicon;
diffusing dopants from the first dopant source layer to the layer of polysilicon to form a backside junction with the silicon substrate;
diffusing dopants into a front surface of the silicon substrate, the front surface of the silicon substrate facing the sun during normal operation; and
forming a metal contact on the front surface of the silicon substrate, wherein the metal contact is electrically coupled to the silicon substrate.

Ex.1038-FH053, 148-156 (February 3, 2014 amendment). The claims were subsequently rejected, and in response to this rejection, the applicant did not amend the claims and instead argued the claims were patentable over the prior art. Ex.1038-FH053, 161-172 (February 26, 2014 rejection), 216-220 (April 16, 2014 response). In particular, the applicant explained that the pending claims recited “that the layer of polysilicon forms a backside junction with the silicon substrate.” Ex.1038-FH053, 217-218. The applicant argued that the cited prior art “discloses a solar cell with a polysilicon back surface field (BSF), and “[a]s is well known, a BSF has the same dopant type as the substrate, but at a higher concentration to keep minority charge carriers away from the back surface.” Ex.1038-FH053, 217-218. Because the back surface field was the same dopant type as the substrate (i.e., the back surface field was not an emitter), the applicant argued that the cited prior art did not disclose the recited backside junction. Ex.1038-FH053, 217-218. Thus, the applicant of the ’516 patent represented to the Patent Office during prosecution of the ’053 patent that an emitter is a layer that is oppositely doped from the substrate. *See also* Ex.1038-FH053, 231-237 (applicant’s appeal brief arguing that an emitter is the layer that is oppositely doped from the substrate).

98. Similarly, I understand that during prosecution of the ’771 Application, pending claim 1 recited the following:

A solar cell, comprising:
a substrate having a front surface that faces the sun to collect solar radiation during normal operation and a back surface opposite the front surface;
an oxide layer disposed on the front surface of the substrate;
an anti-reflective coating on the oxide layer;
a tunnel dielectric disposed over the back surface of the substrate;
an emitter disposed over the tunnel dielectric, the emitter forming a backside junction with the substrate;
a doped diffusion region in the substrate;
a front electrode that is coupled to the doped diffusion region on the front surface of the substrate; and
a back electrode that is coupled to the emitter on the back surface of the substrate.

Ex.1039-771FH, 408-421. In a brief to the Patent Trial and Appeal Board, the applicant argued that the cited prior art “discloses a manufacturing method for a [back surface field (BSF)] type solar cell,” and “[a]s is well known, a BSF layer is a backside layer that has the same polarity as the substrate.” Ex.1039-771FH, 416. The applicant emphasized that “a BSF layer cannot form a backside junction with the substrate because it has the same polarity as the substrate.” Ex.1039-771FH, 416. Thus, the applicant of the ’516 patent represented to the Patent Office during prosecution of the ’771 Application that an emitter is a layer that is oppositely doped from the substrate. *See also* Ex.1039-771FH, 262-268 (applicant response arguing that an emitter is a layer that is oppositely doped from the substrate), 279-282 (applicant pre-appeal brief arguing the same), 312-317 (applicant pre-appeal brief arguing the same), 387-392 (applicant’s response arguing the same).

IX. CLAIM CONSTRUCTION

99. I was informed and I understand that I should give claim terms their ordinary and customary meaning as understood by a person of ordinary skill in the art at the time of the invention. I was informed and I understand that the words used in the patent's claims and the context in which the words are used in the claims are highly relevant to determine a word's meaning. I also understand that the words of a claim are to be interpreted in the context of the entire patent. This includes the patent's claims, its specification, and its figures.

100. I have been further instructed that a patent's prosecution history (also called the file history) may provide helpful evidence about how the U.S. Patent and Trademark Office and the applicant understood the patent and its claims. Therefore, I have been instructed that claims should also be interpreted with the patent's prosecution history in mind.

101. I have also been instructed that "extrinsic evidence" (such as pertinent scientific or technical references or dictionaries) may also help inform how a person of ordinary skill in the art would have understood a claim term. I have been instructed that extrinsic evidence must always be considered with intrinsic evidence.

102. I have applied these instructions in this declaration. I give the claim terms their plain and ordinary meaning, including as would have been understood

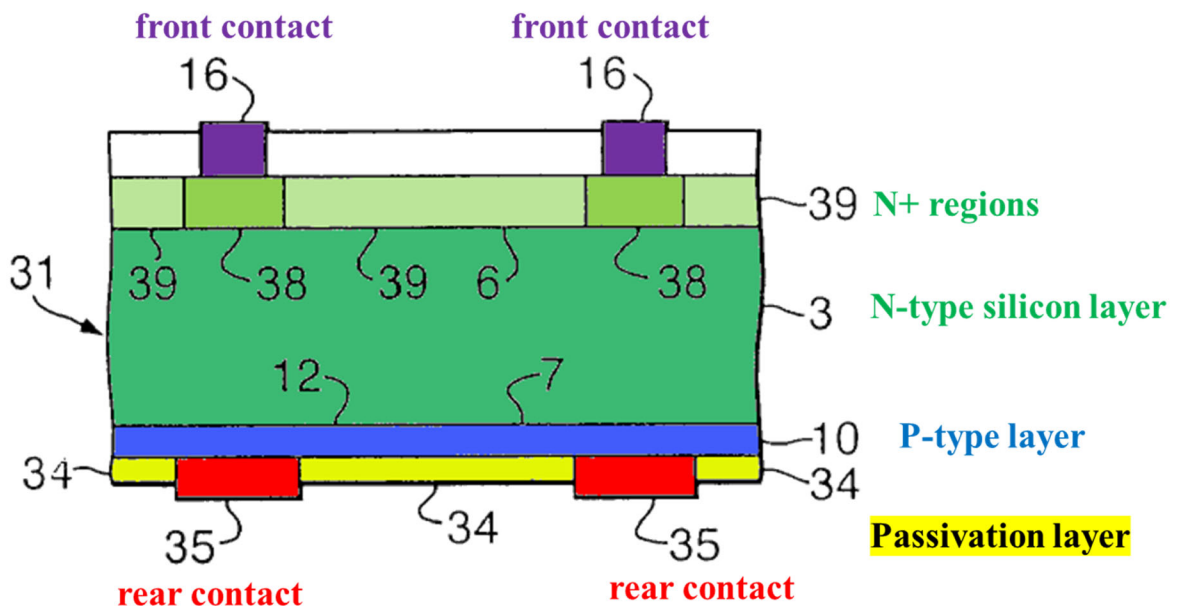
by a person of ordinary skill in the art. However, if Patent Owner proposes an express claim construction in this proceeding or in another proceeding involving the patent, I reserve the right to respond to that construction. I also reserve the right to propose an express construction consistent with the term's plain and ordinary meaning, if one is needed.

X. OVERVIEW OF THE PRIOR ART

A. Froitzheim

103. I understand that EP 1,732,142A1 to Froitzheim ("Froitzheim," Ex.1004) was published on December 13, 2006, i.e., before the '516 patent was filed on February 20, 2008. Ex.1004-Froitzheim, Cover; Ex.1001-USP516, Cover. Froitzheim teaches a rear junction (i.e., back-junction) solar cell. Froitzheim's solar cell (shown below) includes a **silicon body layer 3 (green)** with a front side that faces the sun and a rear side that faces away from the sun. Ex.1004-Froitzheim, [0010]-[0011]. The **silicon body layer** includes **n+ doped regions 38 and 39 (light green)**. Ex.1004-Froitzheim, [0034]. The rear side of Froitzheim's solar cell has a diffused **p-type layer (blue)**. The diffused **p-type layer** forms a PN junction with the substrate's backside, i.e., a back-junction. Ex.1004-Froitzheim, [0010] ("a non-alloyed p-type doped region at the rear side of the body layer and forming a p/n-junction therewith"), [0011].

104. Froitzheim teaches that its solar cell further has a **passivation layer 34** (yellow) on the back side of the cell. Ex.1004-Froitzheim, [0019]. Froitzheim explains that the **passivation layer 34** “minimize[s] recombination losses” and is an oxide such as silicon oxide (SiO_2). Ex.1004-Froitzheim, [0019]. As also shown below, Froitzheim’s solar cell also includes **front contacts 16** (purple) that are electrically coupled to the **silicon body layer** (via the **n+ doped region 38**) and **rear contacts 35** (red) that are electrically coupled to the **p-type layer**. Ex.1004-Froitzheim, [0033].



Ex.1004-Froitzheim, Fig.3,⁴ [0024]-[0032], Fig.1.

105. In addition, Froitzheim describes that “etching can be used to texture the surface in order to improve the geometry of incidence of light in order to prevent reflection.” Ex.1004-Froitzheim, [0039]. Froitzheim further explains that an “antireflection coating can be applied using known methods.” Ex.1004-Froitzheim, [0050].

B. Gan

106. I understand that Gan is an article that was published in 1990, i.e., before the '516 patent was filed on February 20, 2008. Ex.1005-Gan, 246; Ex.1001-USP516, Cover. Gan explains that solar “cell performance can be improved if [a] diffused-emitter is replaced with [a] polysilicon emitter....” Ex.1005-Gan, 245. Gan notes that “a very thin oxide (interfacial oxide)” “always exists” between the “polysilicon [emitter] and the substrate.” Ex.1005-Gan, 245. This oxide “can be as

⁴ Froitzheim’s Figure 1 is similar to its Figure 3, but Figure 3 also contains other layers and contacts as compared to Figure 1. Ex.1004-Froitzheim, [0033]-[0034]. Froitzheim teaches that the top layer in Figure 1 is also a passivation layer. Ex.1004-Froitzheim, [0030]. As a result, a person of ordinary skill in the art would have understood that the top layer in Figure 3 is a **passivation layer**.

a by-product of the cleaning process or is grown intentionally.” Ex.1005-Gan, 245. Gan analyzes and evaluates a solar cell test structure with a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245-246. One polysilicon emitter evaluated by Gan is a p-type emitter, and Gan’s grown oxide layer has a thickness below 20 Angstroms. Ex.1005-Gan, 245, 246, 249, Figs.4-5.

107. Gan teaches that two important factors for cell efficiency, lower recombination (J_o) and contact resistance (ρ_c), are improved when a solar cell has a polysilicon emitter and also a thin oxide layer between the polysilicon emitter and substrate. Ex.1005-Gan, 245. Gan specifically discusses two metrics: (i) J_o , which is the emitter saturation current density, and (ii) ρ_c , which is the contact resistivity. *See* Ex.1005-Gan, 249. It was well known that lower J_o indicates less recombination, and lower ρ_c indicates less contact resistance. Lower J_o and ρ_c values therefore provide for a solar cell to have higher efficiency. Ex.1005-Gan, 245; Ex.1043-Kerr, 18-19, 81-84; Ex.1020-Luque, 274-275.

108. Gan determined J_o and ρ_c measurements for the solar cell test structures it was evaluating, and it observed “that the J_o of the p-type polysilicon emitter” with a “thermal oxide layer as the interfacial layer” “appeared to be much lower than [was] previously reported.” Ex.1005-Gan, 248. Based on these measurements, Gan

also observed that a polysilicon emitter with thin interfacial oxide layer had lower J_o and ρ_c , relative to diffused emitters. Ex.1005-Gan, 249 (“First, most of J_o are below 5×10^{-14} A/cm² which is about one order magnitude lower than that of diffused emitters. Second, most of ρ_c are also lower than 5×10^{-5} Ω -cm²”).

109. In view of these observations, Gan concludes that polysilicon emitters with interfacial oxide layers are “quite useful for silicon concentrator solar cells.” Ex.1005-Gan, 249.⁵ Gan further determined “more than one absolute percent of the cell efficiency is obtained for a **backside contact solar cell** with polysilicon emitters with characteristics shown here.” Ex.1005-Gan, 249 (“It is interesting to see how much of the cell efficiency can be improved with polysilicon emitters of characteristics given here.”). By 2008, it was well known that “backside contact” solar cells included PN junctions on the rear side of the cell. See Ex.1015-Swanson-485, 1:20-26 (“In a back side contact solar cell, **the p-type and n-type regions are coupled to metal contacts on the back side of the solar cell** to allow an external

⁵ Concentrator solar cells are a category of solar cells that use lenses, mirrors, etc. to focus (i.e., concentrate) sunlight onto the cell. Ex.1016-Komp, 56-58. Non-concentrator solar cells are solar cells that do not have these features (i.e., sunlight is not focused onto the cell). Ex.1016-Komp, 56-58.

electrical circuit or device to be coupled to and be powered by the solar cell.”); Ex.1051-Swanson-1986, 85 (“In this [interdigitated back-contact] cell both the n- and p-type diffusions are interleaved **on the back surface** and contacted with two interdigitated comb-shaped metal bus systems.”).

C. Borden-575

1. Borden-575 is Supported by its Provisional Application

110. I understand that International Pub. 2009/094575 to Borden (Ex.1006-Borden-575) claims priority to U.S. Provisional App. 61/023,354 (“Borden-575 Provisional”) that was filed on January 24, 2008, i.e., before the ’516 patent was filed on February 20, 2008. Ex.1006-Borden-575, Cover; Ex.1001-USP516, Cover. I have been informed and understand that a patent publication qualifies as prior art as of the filing date of its priority provisional application if the provisional application (i) includes the relevant subject matter of the patent publication that is relied upon and (ii) supports at least one claim in the patent publication. In my opinion, the Borden-575 Provisional meets each of these requirements because (1) the Borden-575 Provisional includes the subject matter of Borden-575 that I rely on in this Declaration and (2) the Borden-575 Provisional provides support for at least claim 1 of Borden-575.

111. As demonstrated in the below chart, the subject matter of Borden-575 that I rely on in this Declaration is described in the Borden-575 Provisional.

Borden-575 (Ex.1006-Borden-575)	Borden-575 Provisional (Ex.1011-Borden-575-Provisional)
Abstract	[0013], [0006]
[0002]	[0001]
[0003]	[0002]
[0004]	[0003]
[0005]	[0004]
[0006]	[0005]
[0007]	[0006]
[0008]	[0013], [0016]-[0017]
[0016]	[0013]
[0017]	[0014]
[0018]	[0015]
[0019]	[0016]
[0020]	[0016], Fig.2
[0021]	[0017]
[0022]	[0018]
[0023]	[0019]
[0024]	[0020]
[0025]	[0021]
[0026]	[0022]
[0027]	[0022]

Borden-575 (Ex.1006-Borden-575)	Borden-575 Provisional (Ex.1011-Borden-575-Provisional)
[0028]	[0023]
[0029]	[0024]
[0030]	[0025]
[0031]	[0026]
[0032]	[0027]
[0033]	[0028]
Fig.2	Fig.2
Fig.3	Fig.3
Fig.4	Fig.4

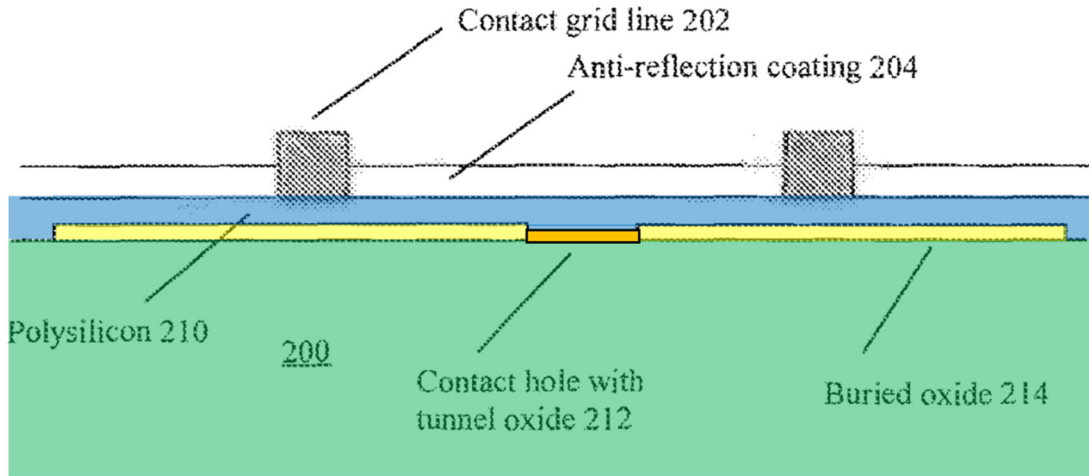
112. Moreover, as demonstrated in the below chart, the Borden-575 Provisional supports at least claim 1 of Borden-575.

Borden-575, Claim 1 (Ex.1006-Borden-575)	Borden-575 Provisional (Ex.1011-Borden-575-Provisional)
A solar cell comprising:	Abstract, [0006], Fig.2, claim 1
an emitter layer formed on a semiconductor substrate; and	Abstract, [0006], [0013], [0016]-[0018], Fig.2, claims 1-2

Borden-575, Claim 1 (Ex.1006-Borden-575)	Borden-575 Provisional (Ex.1011-Borden-575-Provisional)
an insulating layer between the emitter layer and a surface of the substrate, the insulating layer being patterned to include contact holes that allow current flow therethrough.	Abstract, [0006], [0013], [0016]-[0018], Fig.2, claims 1-2, 7

2. Overview of Borden-575

113. Borden-575 discusses solar cells with polysilicon emitters. Borden-575's goal is to create "high efficiency in silicon solar cells...[by] eliminat[ing] surface recombination [which] comes from both unpassivated surfaces and from metal contacts." Ex.1006-Borden-575, [0003]. Borden-575 teaches including a **tunnel oxide 212 (orange)** that "provides passivation between the **substrate [200 (green)]** and the **polysilicon [emitter 210 (blue)]**." Ex.1006-Borden-575, [0022]. In addition to the **tunnel oxide 212**, Borden-575 teaches **"buried oxide" layers 214 (yellow)**. Ex.1006-Borden-575, [0007]. Borden explains that the **substrate 200** is n-type or p-type, and that the **polysilicon emitter** is oppositely doped from the substrate (i.e., for an n-type substrate, the emitter is p-type polysilicon) to form a PN junction. Ex.1006-Borden-575, [0020], [0027]. These layers are shown in Figure 2 of Borden-575, reproduced below.



Ex.1006-Borden-575, Fig.2.

114. Borden-575 explains that its polysilicon emitter and tunnel oxide layer can be used in a solar cell with the PN junction on the rear side. Borden-575 teaches its structure may be “formed on the back of the cell.” Ex.1006-Borden-575, [0029]. Borden-575 explains that configuring the PN junction on the rear side of the cell “is advantageous if the front of the cell has a texture.” Ex.1006-Borden-575, [0029].

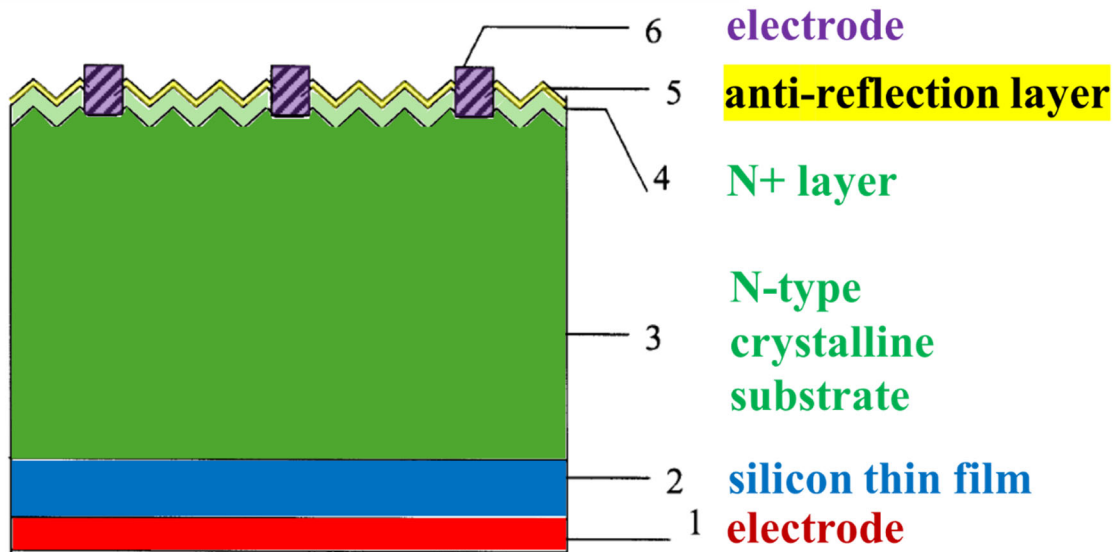
D. Li

115. I understand that CN 1949545A to Li (“Li,” Ex.1008)⁶ was published on April 18, 2007, i.e., before the ’516 patent was filed on February 20, 2008. Ex.1008-Li, Cover; Ex.1001-USP516, Cover. Li teaches a crystalline silicon solar

⁶See 1009-Li-Decl. (translator declaration for Li translation).

cell with a thin-film silicon emitting region (i.e., emitter) on its back surface.

Ex.1008-Li, 2. Specifically, Li teaches a solar cell (shown below) that includes a back **electrode 1 (red)**; a **silicon thin film 2 (blue)**; an **N-type crystalline silicon substrate 3 (darker green)**; a **highly doped N+ layer 4 (lighter green)**; an **anti-reflection layer 5 (yellow)**; and a **positive electrode 6 (purple)**. Ex.1008-Li, Abstract, 3.



Ex.1008-Li, Fig.1.⁷

⁷ Li only includes one figure. *See generally* Ex.1008-Li. For simplicity, I refer to this Figure as “Figure 1.”

116. Li explains the **silicon thin film 2** (P-type emitter) is prepared by a deposition method. Ex.1008-Li, 3. It can be made of a material such as amorphous silicon, microcrystalline silicon, or nanocrystalline silicon. Ex.1008-Li, 2. The cell also has **anti-reflection layer 5**, which can be a material such as SiN (silicon nitride) or SiO₂ (silicon oxide). Ex.1008-Li, 4. The solar cell implements a **highly doped N+ layer 4**, used “for passivating the front surface of a cell by using changes in doping concentration and for providing good ohmic contact to a front surface electrode.” Ex.1008-Li, 4.

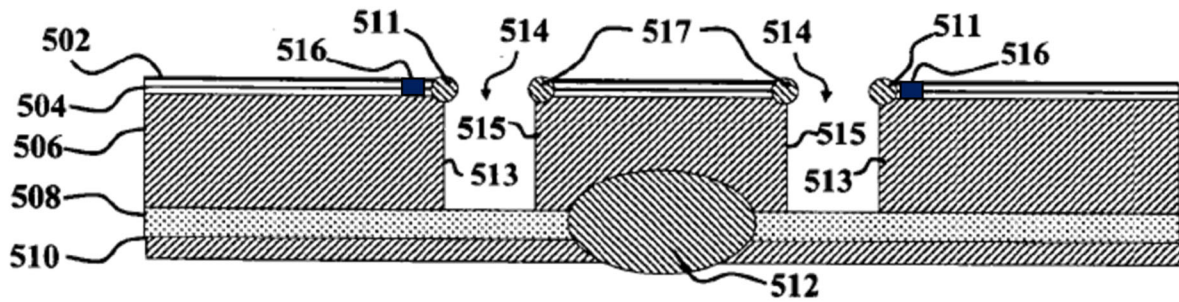
117. Li states that the front **electrode** is “positive,” and the back **electrode** is “negative”; however, this is a clear typographical error. Ex.1008-Li, 4. A person of ordinary skill in the art would have known Li’s use of “positive” and “negative” to be clearly inadvertently switched. Ex.1016-Komp, 14-18. Fundamental and elementary physics dictates the polarity of the electrode necessarily matches that of the solar cell layer to which it is connected, meaning that the “N” connects to “N” and the “P” connects to “P.” Ex.1016-Komp, 14-18. Li’s N-type front substrate connected to a positive electrode (“N” connected to “P”) and P-type back emitter connected to a negative electrode (“P” connected to “N”) would not function as intended; the “positive” electrode would become negatively charged and the “negative” electrode would become positively charged when the solar cell was

illuminated. Ex.1016-Komp, 14-18. A person of ordinary skill in the art would have simply corrected the error to make Li's solar cell work. Ex.1016-Komp, 14-18.

118. Li explains that its solar cell is constructed such that it "avoids light loss caused by the amorphous silicon layer and the transparent conductive thin film on the front surface, such that the cell efficiency can be improved by 10% or above," compared to "an amorphous silicon/crystalline silicon heterojunction solar ['HIT'] cell." Ex.1008-Li, 4. In addition, Li explains that the "improvement of the cell efficiency and simplification of processes can make up for adverse influence caused by increase of material costs" to implement Li's design. Ex.1008-Li, 3-4.

E. Sheats

119. I understand that U.S. Patent Pub. No. 2006/0157103 to Sheats ("Sheats," Ex.1012), was published on July 20, 2006, i.e., before the '516 patent was filed on February 20, 2008. Ex.1012-Sheats, Cover; Ex.1001-USP516, Cover. As the Examiner found during prosecution, Sheats teaches a solar cell that includes "**an isolation trench 516** [that] is formed through the transparent conductive layer and the active layer to the bottom electrode 506 as shown in Fig. 5D" below. Ex.1012-Sheats, [0003]-[0004], [0058]-[0059]; Ex.1002-USP516FH, 81-82.



Ex.1012-Sheats, Fig.5D. Sheats explains that “[t]he isolation trench 516 surrounds the closed-loop trench 514 and electrically isolates the short circuits 511 on the outside wall 513 of the trench from the rest of the structure 500.” Ex.1012-Sheats, [0059]. Sheats also explains that “[a] laser scribing process may [be used to] form the isolation trench 516.” Ex.1012-Sheats, [0059].

XI. GROUNDS FOR FINDING THE CHALLENGED CLAIMS INVALID

120. It is my opinion that the Challenged Claims are unpatentable on the following grounds.

- **Ground I:** Claims 1-4 and 6-12 are invalid as obvious over Froitzheim and Gan.
- **Ground II:** Claim 5 is invalid as obvious over Froitzheim, Gan, and Sheats
- **Ground III:** Claims 1-4 and 6-12 are invalid as obvious over Froitzheim and Borden-575
- **Ground IV:** Claim 5 is invalid as obvious over Froitzheim, Borden-575, and Sheats
- **Ground V:** Claims 1-2 and 8-11 are invalid as obvious over Li and Gan.

The below discussion demonstrates in detail that claims 1-12 of the '516 patent are unpatentable as obvious. A copy of the Challenged Claims is attached as **Appendix C**.

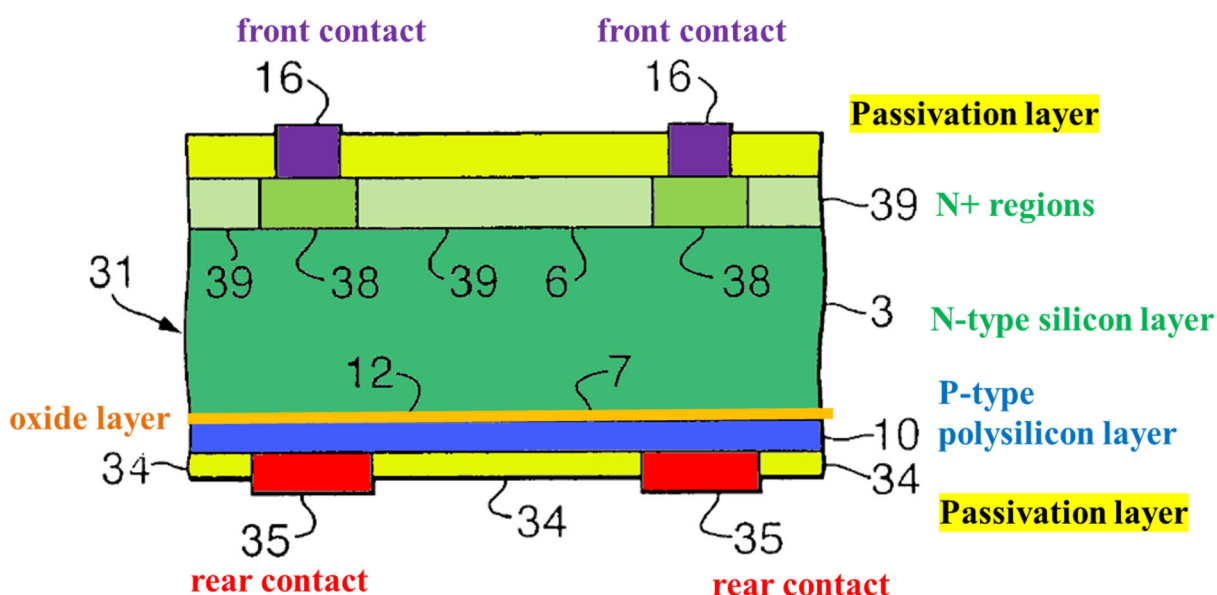
A. Ground I: Claims 1-4 and 6-12 Are Invalid as Obvious over Froitzheim and Gan

1. Motivation to Combine

121. I understand that for a patent to be obvious in view of multiple references, the references must be analogous to the claims being challenged. *See* Section III (Legal Principles). In addition, I understand that a person of ordinary skill in the art must have been motivated to combine the references with a reasonable expectation of success. *See* Section III (Legal Principles). It is my opinion that each requirement is met for the combination of Froitzheim and Gan.

122. The combination of Froitzheim's back-junction solar cell and Gan's polysilicon emitter and oxide layer structure simply amounts to using a known structural feature—polysilicon emitter and oxide layer on a silicon wafer as taught by Gan—to improve a similar apparatus—Froitzheim's back-junction solar cell. The combination of Froitzheim and Gan achieves goals common to both references and the industry—increasing a solar cell's efficiency to thereby increase its power output. The combination of Froitzheim's back-junction solar cell and Gan's polysilicon emitter and oxide layer structure would have also been a simple

modification because it would have simply involved implementing Gan's oxide layer and polysilicon emitter on the backside of Froitzheim's n-type silicon layer. The implementation of Gan's oxide layer and polysilicon emitter into Froitzheim's back-junction solar cell is shown in the below figure, which depicts the oxide layer implemented on the backside of Froitzheim's n-type silicon layer and the polysilicon emitter implemented on the backside of the oxide layer to form a PN junction on the backside of the solar cell.



Ex.1004-Froitzheim, Fig.3; Ex.1005-Gan, 245, 249.

123. **First**, Froitzheim and Gan are in the same field as the Challenged Claims—solar cells. Both references are focused on increasing efficiency, one of the main problems addressed in the Challenged Claims. Both references also offer the same types of solutions for increasing efficiency—optimized solar cell

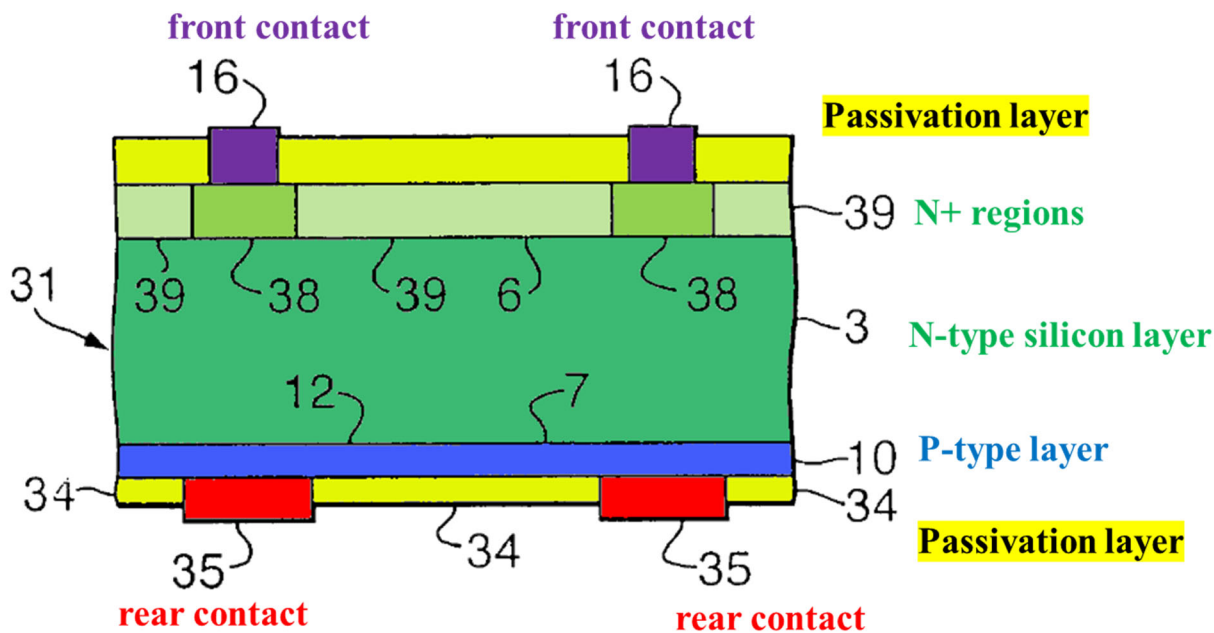
configurations. Ex.1004-Froitzheim, [0001]-[0009] (“It is an object of the present invention to provide a new type of Si solar cell that shows improved stability and good efficiency.”); Ex.1005-Gan, 245-49 (“more than one absolute percent of the cell efficiency is obtained for a backside contact solar cell with polysilicon emitters with characteristics shown here”). Therefore, Froitzheim and Gan are analogous art to the Challenged Claims.

124. **Second**, a person of ordinary skill would have been motivated to implement Gan’s oxide layer and polysilicon emitter in Froitzheim’s back-junction solar cell to create a more efficient solar cell that would result in greater power output.

125. Froitzheim and Gan each teach solar cell structures that are intended to improve a solar cell’s efficiency, meaning that they can convert more sunlight to usable energy. Froitzheim teaches a solar cell that has multiple features that are directed to improving a cell’s efficiency. Froitzheim teaches that its solar cell is a rear (back) junction solar cell. Ex.1004-Froitzheim, [0010]-[0011], Fig.3. Specifically, Froitzheim teaches a “rear junction solar cell” (i.e., back-junction solar cell) with an **n-type silicon layer** and **p-type emitter**. Ex.1004-Froitzheim, [0022], [0024] (“The solar cell 1 comprises a silicon body layer 3 of n-type bulk doping having a front side 6 and a rear side 7.”), [0027] (“At the rear side 7, a p-doped layer

10 is arranged suitably such as discussed further below, and a p/n-junction 12 with the body layer is formed”), Fig.1, Fig.3. The **n-type silicon layer** and **p-type emitter** form a PN junction on the cell’s back side, as shown below. Ex.1004-Froitzheim, [0022], [0027]. As I explained in Section VII.A.2 (Overview of Solar Cells – PN Junction), Froitzheim explains that this configuration is advantageous because it minimizes the amount of light absorbed by the emitter before it reaches the substrate. Ex.1004-Froitzheim, [0013] (“The placement of the p/n-junction at the rear side of the cell has the further advantage that the photocurrent maximised since light cannot be unproductively absorbed in a front-side emitter, in particular in the so-called dead zone of such an emitter.”).

126. Froitzheim’s solar cell also teaches and implements **passivation layers** to minimize recombination at the silicon wafer surfaces. In particular, Froitzheim explains that its solar cell includes **passivation layers** at the front and back sides of its cell. Ex.1004-Froitzheim, [0010]-[0011], [0017]-[0021] (“The solar cell further suitably comprises a passivation layer at the front side, in order to minimize recombination losses at the front surface.”), [0033] (“Between the fingers a passivation layer 34 is arranged, for which the same type of layers can be used as for the front side.”).



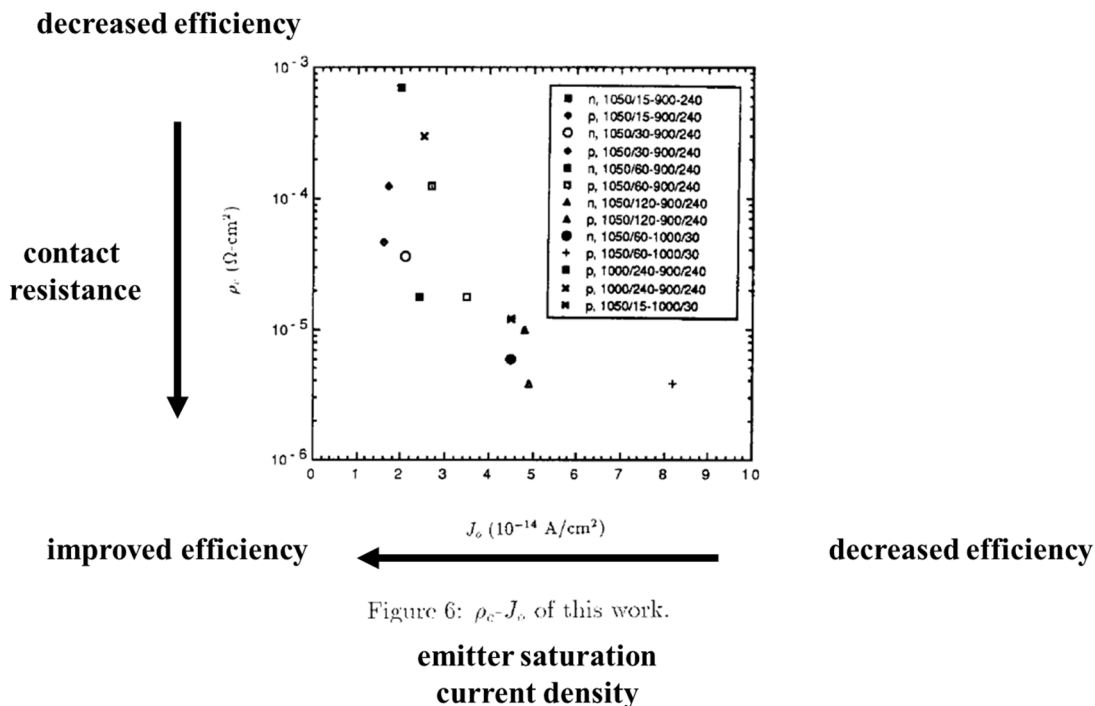
Ex.1004-Froitzheim, Fig.3. After studying this configuration, Froitzheim found it had “improved stability and good efficiency.” Ex.1004-Froitzheim, [0009].

127. Gan similarly focuses on solar cell efficiency, and a person of ordinary skill in the art would have been motivated to improve the efficiency of Froitzheim's back-junction solar cell by implementing a polysilicon emitter and oxide layer to form the PN junction, as taught by Gan. As detailed below, Gan teaches that replacing a diffused emitter with a polysilicon emitter and an oxide layer placed between the polysilicon emitter and silicon substrate would result in improved performance. Ex.1005-Gan, 245-246.

128. As I explained in Section X.B (Overview of the Prior Art – Gan), Gan studies a solar cell that has a **p-type polysilicon emitter** and an **oxide layer** between

the polysilicon emitter and silicon substrate. Ex.1005-Gan, 245. Gan specifically teaches the emitter saturation current density (J_o) and contact resistance (ρ_c) of this emitter design. As I explained in Section VII.B (Overview of Solar Cell Efficiency), emitter saturation current density (J_o) indicates the amount of recombination that is occurring within the emitter, and lower emitter saturation current density (J_o) indicates lower recombination and the potential for a more efficient solar cell. As I also explained in Section VII.B (Overview of Solar Cell Efficiency), contact resistance (ρ_c) indicates how much power is lost at one or more interfaces between the wafer and metal contacts, and lower contact resistance (ρ_c) indicates less power loss and thus the potential for a more efficient solar cell. Thus, all else being equal, these two metrics are indicative of solar cell efficiency, and as these two metrics decrease, solar cell efficiency increases.

129. The emitter saturation current density (J_o) and contact resistance (ρ_c) for Gan's analyzed solar cell test structures are reported in Figure 6. As shown in Figure 6 below, the contact resistance (ρ_c) is on the vertical axis and the emitter saturation current density (J_o) is on the horizontal axis.



Ex.1005-Gan, 245. Gan found that its analyzed **p-type polysilicon emitter** and **oxide layer** structure demonstrated improved performance over prior emitters. Specifically, Gan found “that the J_o of the p-type polysilicon emitter” with a “thermal oxide layer as the interfacial layer” was “much lower than [was] previously reported.” Ex.1005-Gan, 248. Gan noted that this combination—**polysilicon emitter** and **oxide layer** on the wafer surface—had less recombination and lower contact resistance as compared to that of diffused emitters. Ex.1005-Gan, 249 (“[M]ost of J_o [in Figure 6] are...about one order magnitude lower than that of diffused emitters [and] most of ρ_c [in Figure 6] are also lower”). Based on this data, Gan concludes that a polysilicon emitter and oxide layer structure is “quite useful

for silicon solar cells,” and teaches that “cell performance can be improved if the diffused-emitter is replaced with the polysilicon emitter.” Ex.1005-Gan, 245, 249 (“To conclude, we showed that polysilicon emitters with low [emitter saturation current density (J_o) and contact resistance (ρ_c)] can be obtained with a very small fraction of interfacial oxide breakup.”).

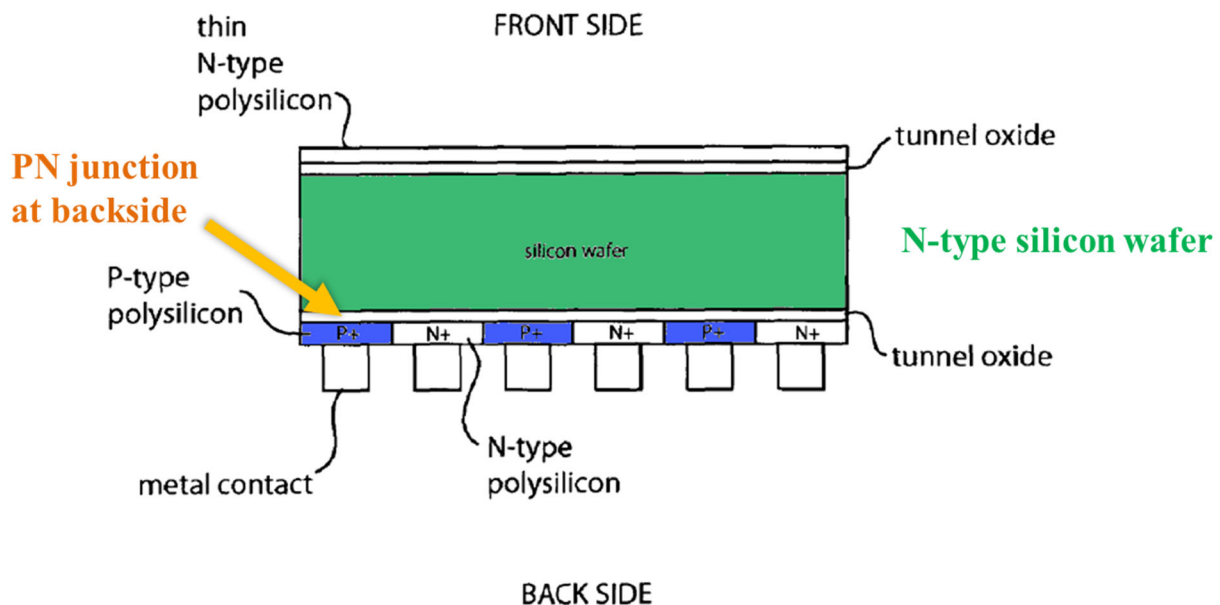
130. A person of ordinary skill in the art would have been motivated to apply Gan’s teachings to Froitzheim’s solar cell to improve the efficiency of Froitzheim’s solar cell. A person of ordinary skill in the art would have understood that Gan’s teachings are directly applicable to Froitzheim. As discussed above, Froitzheim teaches a diffused emitter, and Gan specifically teaches replacing a diffused emitter with a polysilicon emitter and oxide layer structure to improve the efficiency of a solar cell. *See* Ex.1005-Gan, 245, 249. Significantly, Gan explains that its overall structure is beneficial to p-type emitters and silicon substrates, and Froitzheim teaches a p-type emitter and a silicon substrate. *E.g.*, Ex.1004-Froitzheim, [0010]-[0011]. Thus, a person of ordinary skill in the art would have understood that Froitzheim’s solar cell would obtain Gan’s benefits by implementing Gan’s disclosed structure.

131. Moreover, although Gan references a concentrator solar cell—a category of solar cells that uses lenses, mirrors, and other components to focus (i.e.,

concentrate) sunlight on a cell (Ex.1016-Komp, 56-58)—a person of ordinary skill in the art would have understood that Gan’s teachings are equally applicable to non-concentrator solar cells. Importantly, Gan explains that its disclosed polysilicon emitter and oxide layer structure is “useful for silicon solar cells” generally and does not state that its teachings are limited to concentrator solar cells. Ex.1005-Gan, 249. As a result, a person of ordinary skill in the art would have understood that Gan’s teachings are equally relevant for non-concentrator cells, even if Froitzheim does not expressly teach light concentration structures (such as a lens) for use with its solar cell. Persons of ordinary skill in the art frequently looked at various solar cell designs and related technologies when evaluating how to improve a solar cell’s efficiency, which is exactly what Gan did when evaluating how to improve a cell’s design. *E.g.*, Ex.1005-Gan (explaining that “[p]olysilicon emitters, because of their important applications in high speed bipolar transistors, have been widely studied” and applying those learnings to solar cells).

132. Additionally, Gan teaches that its structure is useful for solar cells that have PN junctions on the backside of the solar cell, as in Froitzheim. Gan specifically estimates that this structure on “backside contact solar cells” would achieve an improvement of “more than one absolute percent of the cell efficiency.” Ex.1005-Gan, 249. As I explained in Section X.B (Overview of the Prior Art – Gan),

it was well known prior to 2008 that “backside contact” solar cells (i.e., solar cells with the metal contacts just on the backside) included PN junctions on the back side of the cell—they are a type of back-junction solar cells. For example, Swanson-458 (patent filed in 2005) explained that “[i]n a back side contact solar cell, **the p-type and n-type regions are coupled to metal contacts on the back side of the solar cell** to allow an external electrical circuit or device to be coupled to and be powered by the solar cell.” Ex.1015-Swanson-485, 1:20-26. This is shown in Figure 1 of Swanson (below), where the PN junction is on the rear side of the cell.



Ex.1015-Swanson, Fig.1. As a result, a person of ordinary skill in the art would have understood that Gan’s teachings were applicable to Froitzheim because Gan’s teachings were directly applicable to solar cells that had PN junctions on the back side of the cell. In other words, a person of ordinary skill in the art would have

understood that implementing a polysilicon emitter and oxide layer, as taught by Gan, in Froitzheim's back-junction solar cell was merely applying a known technique (Gan) to a similar device (Froitzheim) that is ready for improvement to yield predictable results (a more efficient solar cell) and was a predictable variation of the prior art.

133. A person of ordinary skill in the art would have also been motivated to implement a polysilicon emitter, as taught by Gan, on the back side of Froitzheim's solar cell. For example, Froitzheim specifically teaches that a backside emitter is beneficial. As I explained in VII.A.2 (Overview of Solar Cells – PN Junction), absorption within a heavily doped region—such as an emitter—reduces the amount of electricity generated by a solar cell. Froitzheim explains that a backside emitter is beneficial because it optimally reduces the amount of sunlight that could be parasitically absorbed by the emitter since light is instead absorbed by the wafer before reaching the emitter at its backside. Ex.1004-Froitzheim, [0013] (“The placement of the p/n-junction at the rear side of the cell has the further advantage that the photocurrent maximised since light cannot be unproductively absorbed in a front-side emitter, in particular in the so-called dead zone of such an emitter. This maximises in particular the contribution of short wavelength light to the

photocurrent, because such light is predominantly absorbed close to the front side, whereas longer wavelength light penetrates deeper into the cell.”).

134. Significantly, it was known that if a polysilicon emitter is placed on the front side of the cell, the polysilicon emitter would absorb light that otherwise would have gone to the active region of the solar cell (i.e., the region where usable electron-hole pairs are generated), thereby decreasing the amount of electricity that could be produced by the cell. *See* Section VII.A (Overview of Solar Cells); Ex.1062-Farrokh-Baroughi, 5-6; Ex.1059-Lubberts, 6877. As a result, a person of ordinary skill in the art would have understood implementing Gan’s polysilicon emitter in Froitzheim’s back-junction solar cell would improve the efficiency of the cell (as taught by Gan) while also accounting for the potential drawbacks of polysilicon emitters (parasitic absorption). In other words, implementing a polysilicon emitter in Froitzheim’s back-junction solar cell would improve the cell’s efficiency and ensure sunlight would not be absorbed by the polysilicon emitter before reaching the active region (i.e., wafer).

135. A person of ordinary skill in the art would have also been motivated to modify Froitzheim’s back-junction solar cell to incorporate a polysilicon emitter and oxide layer structure, as taught by Gan, because each reference teaches similar and compatible solar cell structures. Froitzheim and Gan each teach solar cells that have

the same basic configuration of a silicon wafer substrate, p-type emitter, and metal contacts. Ex.1004-Froitzheim, Abstract, [0010]-[0013], Fig.1, Fig.3; Ex.1005-Gan, 245-249. Froitzheim and Gan also teach solar cell structures that are made with similar manufacturing processes. In particular, each teach common manufacturing processes, such as diffusion from a dopant source to form the emitter, including overlapping temperature ranges for said diffusion. Ex.1004-Froitzheim, [0042] (teaching a temperature range between 900-1200 °C); Ex.1005-Gan, 246 (teaching a temperature range between 900-1000°C). Thus, a person of ordinary skill in the art would have understood that Froitzheim's solar cell and Gan's solar cell have compatible manufacturing processes, especially because new equipment—e.g., a furnace for diffusion—would have been unnecessary.

136. A person of ordinary skill in the art would have known how to add oxide layers to silicon surfaces, as doing so was well-known and routine by 2008. *E.g.*, Ex.1005-Gan, 246; Ex.1006-Borden-575, [0026]; Ex.1004-Froitzheim, [0030]; Ex.1015-Swanson, 1:50-2:61; *see also* Section VII.B (Overview of Solar Cell Efficiency). A person of ordinary skill in the art would have also readily understood how to manufacture a polysilicon emitter. Manufacturing polysilicon emitters was well-known and routine by 2008. Ex.1050-Tarr, 655 (“It has been known for over a decade that polysilicon emitter contacts can reduce the back-injection current and

thereby improve the performance of bipolar transistors[[]]. It is, therefore, somewhat surprising that[, as of 1985,] consideration has only recently been given to the use of polysilicon contacts in the production of high-efficiency solar cells.”). Moreover, the ’516 patent itself assumes (correctly) that a person of ordinary skill in the art would have understood how to manufacture solar cell layers. The ’516 patent generically describes manufacturing an oxide layer and doped polysilicon layer but does not provide specific implementation details. *See generally* Ex.1001-USP516. Thus, a person of ordinary skill in the art would have been motivated to modify Froitzheim to include a polysilicon emitter and oxide layer because doing so would simply involve substituting one known element (diffused emitter) for another (polysilicon emitter and oxide layer) to obtain predictable results (a more efficient solar cell).

137. Also, a person of ordinary skill in that art would have understood that adding Gan’s configuration to Froitzheim’s solar cell was a simple design choice. Because efficiency is an important design consideration, a person of ordinary skill in the art would have been motivated to seek a more efficient solar cell even if doing so resulted in additional manufacturing steps or components. In fact, as I explained in Section VII.B (Overview of Solar Cell Efficiency), over the past 50 years, solar cell designers have continued to prioritize gains in efficiency when evaluating

potential designs. Thus, even if implementing Gan's configuration to Froitzheim's solar cell resulted in additional costs due to manufacturing steps or components, a person of ordinary skill in that art would have nevertheless been motivated to make such a design change to achieve a more efficient solar cell.

138. Finally, a person of ordinary skill in the art would have been aware of the plethora of teachings explaining the use and benefits of polysilicon emitters, including with interfacial oxide layers and including for solar cells and transistors. Section VII.B (Overview of Solar Cell Efficiency). For example, Foglietti disclosed forming an interfacial oxide between a substrate and polysilicon emitter. Ex.1042-Foglietti, [0046] ("the wafer has the single crystal substrate 250 and an interfacial oxide 260 formed thereon in accordance with the present invention and a polysilicon layer 262 lies thereover"). Also, I understand that during prosecution of the '771 Application, which claims priority to the '516 patent, the Board affirmed that Foglietti teaches an interfacial oxide and that "it would have been obvious to one of ordinary skill in the art to modify the interface between the doped polysilicon regions and the monocrystalline substrate by adding an interfacial oxide as disclosed by Foglietti and Gan to allow for optimal growth of the polysilicon region and result in recombination occurring primarily at the oxide interface." Ex.1039-FH771, 462-463. Thus, the Board affirmed that Foglietti teaches an interfacial oxide between a

substrate and polysilicon emitter and that a person of ordinary skill in the art would be motivated to implement these features in a solar cell.

139. As explained in Sections VII.B (Overview of Solar Cell Efficiency), X.C.2 (Overview of the Prior Art – Borden-575), and XI.C.1 (Ground III, Motivation to Combine), Borden-575 is another example of a reference that teaches an interfacial oxide between a polysilicon emitter and silicon substrate without inhibiting current flow. Ex.1006-Borden-575, [0022] (“This oxide – typically 8 to 15 Å thick – provides passivation between the substrate and the polysilicon, while allowing for tunnel current flow”). Other publications such as Kwark and Yablonovitch also contain similar teachings. Ex.1046-Kwark, 1125 (“poly-silicon contacts and SIPOS contacts...both obtain their improved performance through incorporating a thin, tunnelable interfacial oxide that impedes the flow of holes”); Ex.1023-Yablonovitch, 3:61-64 (“The interface 18 between the silicon ribbon 14 and the n⁺-SIPOS heterocontact contains a 20-40 Å interfacial layer of silicon dioxide which is so thin as to be permeable to electrons”).

140. It was also well-known in transistor art to use an interfacial oxide between a polysilicon emitter and substrate. For example, Rahim taught that a “well controlled interfacial oxide [] gives low values of emitter resistance” and there was “a considerable amount of work...published in the literature on the effects of the

interfacial oxide on the base current [] and emitter resistance [] of polysilicon emitter contacts.” Ex.1034-Rahim, 2506. Gan also explains that polysilicon emitters and oxide layers were previously implemented on transistors and such improvements were applicable to solar cells. Ex.1005-Gan, 245 (“Polysilicon emitters, because of their important applications in high speed bipolar transistors, have been widely studied. It was [previously] found that...[an interfacial oxide] can be...grown intentionally[.]”). The underlying physics for transistors and solar cells are similar (both rely on current flow at PN junctions), and therefore persons of skill in the art developing new solar cells often looked to teachings from transistors and often had success porting over transistor technology into solar cells. Ex.1023-Yablonvitch, 1:27-44, 2:10-12 (teaching implementing a material known for transistors into a solar cell). A person of ordinary skill in the art would have thus been motivated to combine Froitzheim and Gan because the combination would have merely involved the use of known techniques (polysilicon emitter and oxide layer) to improve similar devices (solar cells) in the same way (applying the learnings from transistors to solar cells).

141. Accordingly, a person of ordinary skill in the art would have been motivated to replace Froitzheim’s diffused emitter with Gan’s polysilicon emitter and oxide layer.

142. **Third**, a person of ordinary skill in the art would have had a reasonable expectation of success in implementing Gan's polysilicon emitter and oxide layer in Froitzheim's back-junction solar cell. Including a polysilicon emitter and oxide layer was well known in the art, and Gan specifically describes steps for implementing a polysilicon emitter and oxide layer on a silicon substrate. Ex.1005-Gan, 246; Ex.1006-Borden-575, [0022]; Ex.1046-Kwark, Abstract, 1121. Therefore, a person of ordinary skill in the art would have known that modifying Froitzheim so that it had Gan's polysilicon emitter and oxide layer was simply substituting one known structural feature (i.e., Gan's polysilicon emitter and oxide layer) for another structural feature (i.e., Froitzheim's diffused emitter) to obtain the predictable result of a more efficient solar cell.

143. Furthermore, as I discussed above, a person of ordinary skill in the art would have appreciated that the references have compatible structures and manufacturing steps. For example, each reference teaches thermal diffusion processes to drive dopants into the emitter, and they disclose overlapping temperature ranges. Ex.1004-Froitzheim, [0042]; Ex.1005-Gan, 246. Thus, as I explained above, a person of ordinary skill in the art would have understood that Froitzheim's solar cell and Gan's solar cell have compatible manufacturing processes, especially because new equipment—e.g., a furnace for diffusion—would

not be needed. That is, a person of ordinary skill in the art would have had a reasonable expectation of success at implementing an oxide layer and polysilicon emitter in Froitzheim, as taught by Gan, because doing so would be a simple substitution of one element for another.

144. As I also discussed above, a person of ordinary skill in the art would also have easily been able to replace a diffused emitter with a polysilicon emitter and oxide layer. Manufacturing techniques for solar cells were well-known by 2008, including manufacturing polysilicon emitters and oxide layers. *E.g.*, Ex.1005-Gan (polysilicon emitter, oxide layer); Ex.1006-Borden-575 (polysilicon emitter, oxide layer); Ex.1046-Kwark (polysilicon emitter, oxide layer); Ex.1023-Yablonovitch (oxide layer); Ex.1031-Okayasu (polysilicon emitter); Ex.1050-Tarr (polysilicon emitter). In fact, the '516 patent itself assumes (correctly) that a person of ordinary skill in the art would have understood how to manufacture a solar cell. The '516 patent generically describes manufacturing an oxide layer and doped polysilicon layer but does not provide specific implementation details. *See generally* Ex.1001-USP516. Thus, a person of ordinary skill in the art would have readily understood that replacing Froitzheim's back side emitter, which Froitzheim teaches is made by diffusing boron into the back side of the substrate, with Gan's deposited polysilicon emitter would easily be accomplished, especially since Gan teaches the well-known

manufacturing steps to do so. *See* Ex.1005-Gan, 246 (describing manufacturing steps). In other words, a person of ordinary skill in the art would have understood that replacing Froitzheim's back side emitter with Gan's polysilicon emitter and oxide layer would have simply involved using Gan's known technique of a polysilicon emitter and oxide layer with Froitzheim's known solar cell to improve Froitzheim's solar cell in a similar way.

145. Finally, as discussed, a person of ordinary skill in the art would have reasonably expected success because tunnel oxide layers and polysilicon emitters had been successfully implemented in multiple instances, including for transistors and solar cells. Ex.1005-Gan, 246; Ex.1006-Borden-575, [0022]; Ex.1046-Kwark, Abstract, 1121. As a result, a person of ordinary skill in the art would have expected that Gan's known technique of a polysilicon emitter and oxide layer was a known, successful technique for solar cells and transistors, and would expect that this known technique would be successful when applied to Froitzheim's back-junction solar cell. Accordingly, it is my opinion that a person of ordinary skill in the art would have been motivated to modify Froitzheim's back-junction solar cell to implement a polysilicon emitter and oxide layer, as taught by Gan, with a reasonable expectation of success.

2. **Claim 9**

- a. **Element 9[pre]: a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side**

146. Froitzheim teaches *a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side*.⁸

147. Froitzheim teaches a solar cell with opposite sides. Ex.1004-Froitzheim, Abstract, [0024] (“The solar cell 1 comprises a silicon body layer 3...having a front side 6 and a rear side 7.”), [0032]-[0033], Fig.1, Fig.3, claim 1. When the solar cell is used under ordinary operating conditions, the *front side* faces the sun and receives sunlight (i.e., *solar radiation*). The solar cell also has a rear (i.e., *back*) side that is *opposite the front side* and thus faces away from the sun during ordinary operating conditions. Ex.1004-Froitzheim, [0032] (“During normal operation of the solar cell 1 the front side 6 faces the sun and light is received through the area of the front surface that is not covered by the front contact 16.”).

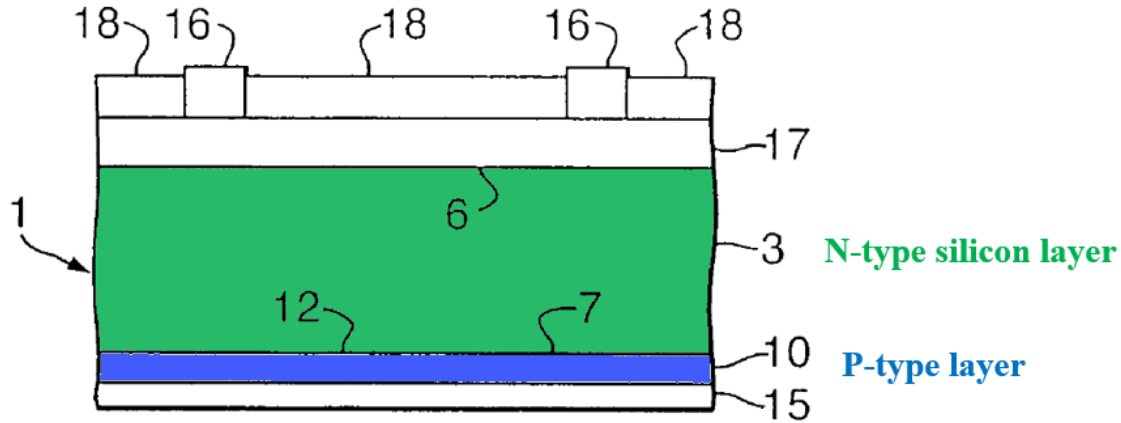
- b. **Element 9[a]: a substrate having a textured front surface**

148. Froitzheim teaches *a substrate having a textured front surface*.

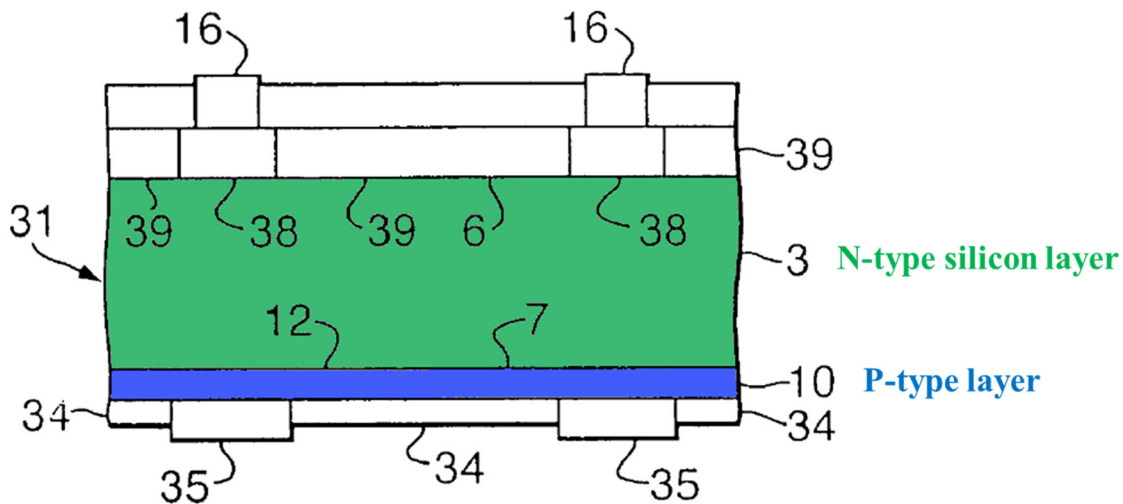
⁸ Italicized text is used to indicate claim language unless otherwise noted.

149. Froitzheim teaches that its solar cell includes “a **silicon body layer 3** of n-type bulk doping.” Ex.1004-Froitzheim, [0024], Abstract, [0010]-[0013], claim

1. This **silicon body layer 3** is shown in Figures 1 and 3:



Ex.1004-Froitzheim, Fig.1.



Ex.1004-Froitzheim, Fig.3.

150. A person of ordinary skill in the art would have understood that the **n-type silicon layer** is the substrate. Froitzheim explains that this **silicon body layer**

3 is made from a crystalline silicon wafer, which was a common substrate material. Ex.1004-Froitzheim, Abstract, [0024], [0039]. Froitzheim further explains that by placing the **n-type silicon layer** above the **p-type layer**, “a p/n-junction” is formed. Ex.1004-Froitzheim, Abstract, [0024]-[0026], claim 1. Thus, it was well known that a PN junction is formed by placing a substrate (**n-type layer**) next to an emitter (**p-type layer**), as shown in Figures 1 and 3.

151. Froitzheim’s explanations and figures show what was commonly understood as a “substrate,” which was a routine solar cell component. Section VII.A (Overview of Solar Cells). Moreover, Froitzheim’s explanations and figures are consistent with the ’516 patent’s description of a substrate. For instance, the ’516 patent explains that a substrate is a “N-type silicon wafer.” Ex.1001-USP516, 2:28-49. The ’516 explains that the N-type silicon substrate and the P-type emitter form a “junction,” due to their opposite polarities. Ex.1001-USP516, 2:28-49.

152. As I discussed above, it was well known by 2008 that solar cells had textured front surfaces to increase absorption and thus solar cell efficiency. Section VII.A.4 (Overview of Solar Cells – Texturing and Anti-reflection Coating). Froitzheim also teaches this common feature of solar cells. Froitzheim’s explanation of using “etching...to **texture the surface [of the n-type silicon layer]** in order to improve the geometry of incidence of light in order to prevent reflection,” was a

common practice to texture solar cells to increase absorption. Ex.1004-Froitzheim, [0039], [0023], [0056] (“After etch removal, texture etching was applied to the [n-type] wafers.”), [0087]. That is, Froitzheim teaches the well-known concept of texturing the front side of the solar cell to reduce the amount of light reflected away from the cell and increase the amount of light that enters the cell to generate electricity. As a result, a person of ordinary skill the art would have understood that Froitzheim teaches a solar cell having an **n-type silicon layer** (i.e., *substrate*) with a *textured front surface*.

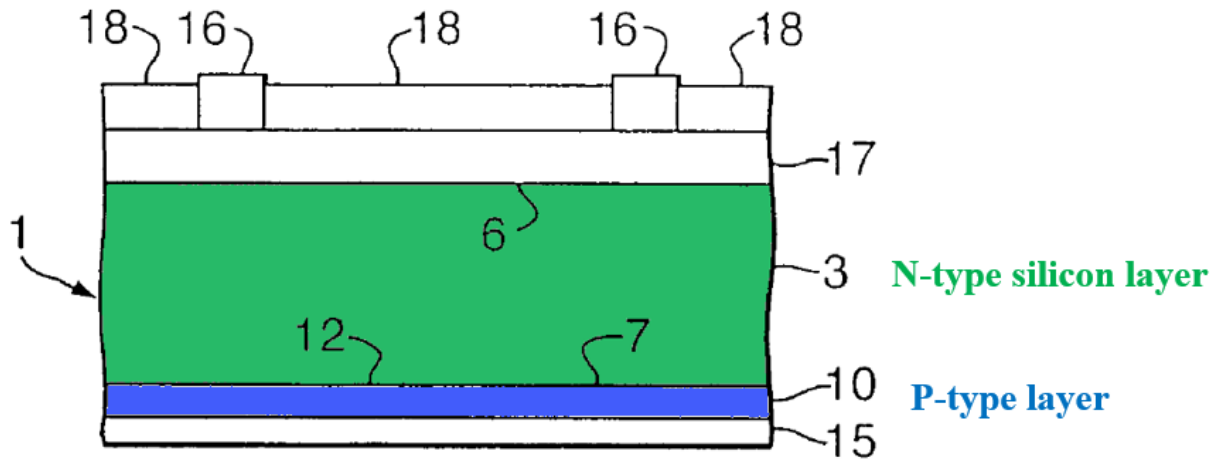
c. Element 9[b]: an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate.

153. The combination of Froitzheim and Gan teaches *an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate*.

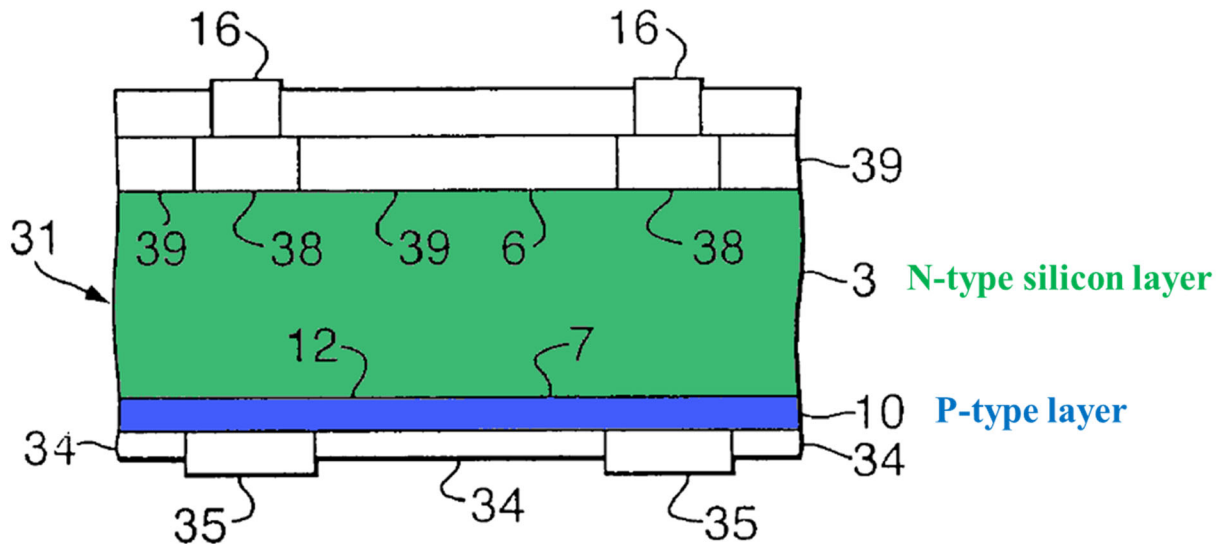
154. Froitzheim specifically teaches *an emitter layer formed on the back of the substrate, the emitter layer forming a backside junction with the substrate*. As discussed in Section XI.A.2.b (Ground I, Element 9[a]), Froitzheim teaches that its solar cell includes a “**p-doped layer 10**” that is on the rear side of the cell. Ex.1004-Froitzheim, [0025]; *see also* Abstract, [0010]-[0013], [0024], Fig.1, Fig.3. Froitzheim also teaches that the “**p-doped layer 10**” forms a “p/n *junction*” with the

n-type silicon layer 3. *E.g.*, Ex.1004-Froitzheim, [0025]. Thus, a person of ordinary skill in the art would have understood that the “**p-doped layer 10**” in Froitzheim is an *emitter layer* because it forms “a p/n *junction*” with an oppositely doped **n-type silicon layer 3**, which is the substrate. Ex.1004-Froitzheim, Abstract, [0024]-[0026], claim 1.

155. Froitzheim’s “p/n junction” is a *backside junction* because the p/n junction is on the rear side of the wafer, just like the configuration the ’516 patent describes as a “backside junction.” In the ’516 patent, a “backside junction” is described as an emitter being located on the backside of the solar cell (*i.e.*, the side opposite of the side facing the sun), and an emitter has the opposite doping of the substrate. Ex.1001-USP516, 1:46-48 (“A bipolar solar cell includes a backside junction formed by an N-type silicon substrate and a P-type polysilicon emitter formed on the backside of the solar cell.”). Thus, as shown in Figures 1 and 3 below, Froitzheim teaches a *backside junction* because it teaches a **P-type layer 10** on the backside of an **n-type silicon layer 3** to create a rear “p/n” junction.



Ex.1004-Froitzheim, Fig.1.

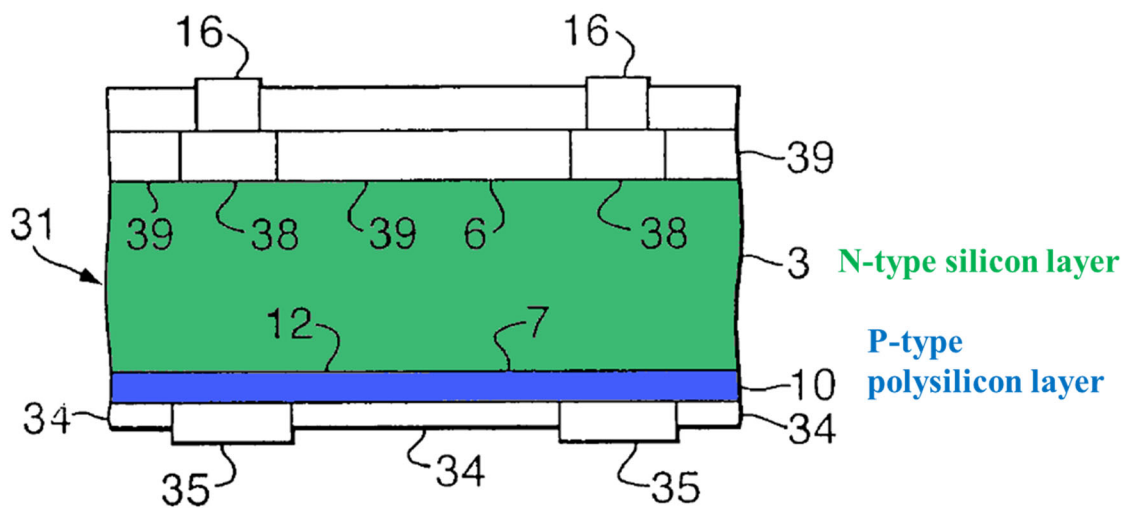


Ex.1004-Froitzheim, Fig.3., Abstract, [0010]-[0013], [0024], [0025].

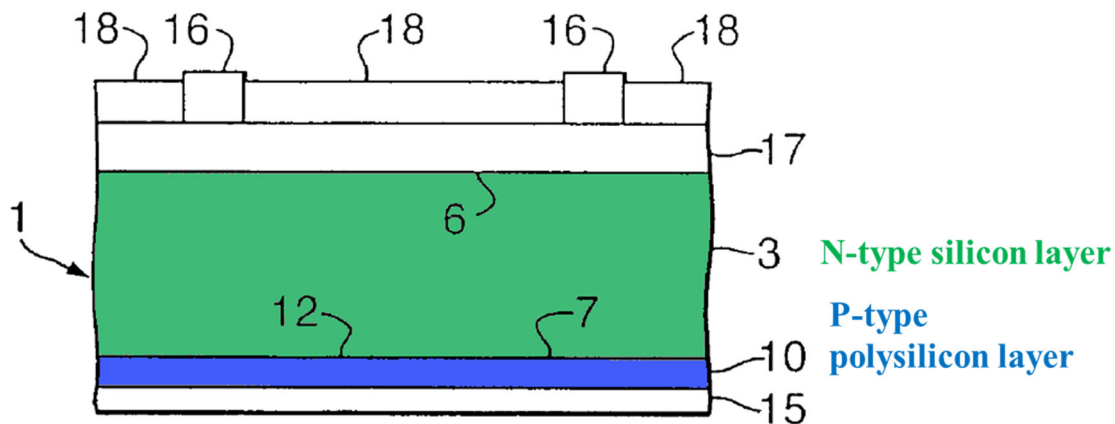
156. Gan teaches forming a PN junction by depositing a **P-type polysilicon emitter** on a **silicon substrate**. Ex.1005-Gan, 245-246. In other words, Gan teaches forming a polysilicon emitter layer over a surface of a silicon substrate. Gan describes that a polysilicon emitter can replace a diffused emitter to achieve various

performance benefits, as I described in Section X.B (Overview of the Prior Art – Gan). Ex.1005-Gan, 245 (discussing and analyzing “both n- and **p-type polysilicon emitters**”), 245 (explaining that “cell performance can be improved if **the diffused-emitter is replaced with the polysilicon emitter**”).

157. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s solar cell in view of Gan and would have had a reasonable expectation of success in doing so. The combination of Froitzheim and Gan would have entailed implementing a **P-type polysilicon emitter** as taught by Gan in Froitzheim’s solar cell such that the **P-type polysilicon emitter** (i.e., *emitter layer*) is formed over the *back surface of the n-type silicon layer* (i.e., *substrate*), as shown in the following modified version of Froitzheim’s Figure 3.



Ex.1004-Froitzheim, Fig.3. It also would have been well within a person skilled in the art's ability to likewise implement Gan's **P-type polysilicon emitter** into the solar cell of Froitzheim's Figure 1, which has a differently shaped backside metal contact than Figure 3,⁹ as the shape of the metal contact does not depend on this implementation of Gan:



Ex.1004-Froitzheim, Fig.1. As a result, the combination of Froitzheim and Gan teaches a *backside junction* formed from an *emitter layer* formed over a back surface of the substrate.

⁹ The metal contacts are labeled 35 in Figure 3, and the metal contact is labeled 15 in Figure 1. Ex.1004-Froitzheim, [0027], [0033].

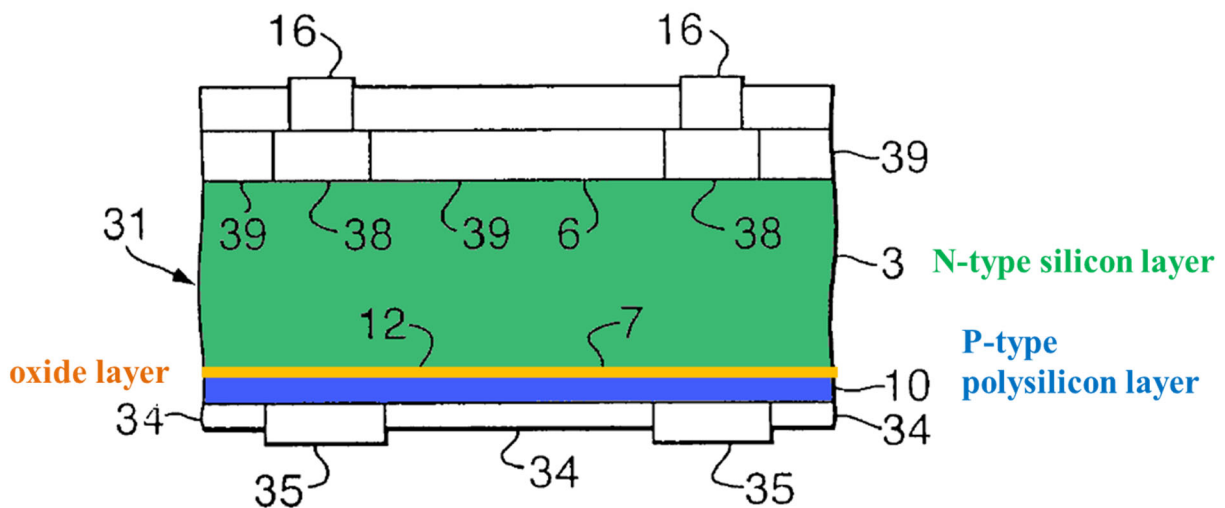
d. Element 9[c]: an oxide layer formed between the back surface of the substrate and the emitter layer

158. The combination of Froitzheim and Gan teaches *an oxide layer formed between the back surface of the substrate and the emitter layer*.

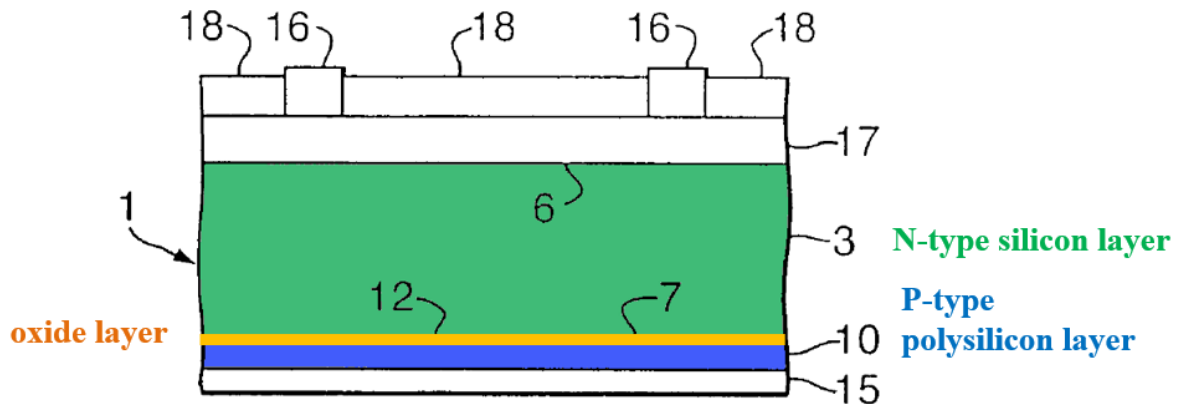
159. As I explained in Section VII.B (Overview of Solar Cell Efficiency), interfacial oxide layers placed between an emitter and a substrate were well known by 2008 and described and studied in multiple publications and patents. Gan specifically teaches an oxide layer placed between a polysilicon emitter and substrate. Gan studies a solar cell having a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245-246. By describing the oxide as being “interfacial,” a person of ordinary skill in the art would have understood that Gan teaches that the oxide layer is formed between a substrate and emitter layer—i.e., at their interface. As discussed in Section X.B (Overview of the Prior Art – Gan), Gan is a paper about controlling the oxide layer between a p-type polysilicon emitter and a silicon substrate to ultimately improve solar cell efficiency. Ex.1005-Gan, 249 (“[C]ell efficiency can be improved with polysilicon emitters of characteristics given here.”).

160. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s structure (with a reasonable expectation of success) to implement a **P-type**

polysilicon emitter and **oxide layer** formed between the back surface of the **substrate** and the **emitter** layer as taught by Gan. Implementing a **P-type polysilicon emitter** and **oxide layer** in Froitzheim is shown in the following image, which is a modified version of Froitzheim's Figure 3 and shows where the oxide layer and polysilicon emitter of Gan would be placed in Froitzheim's solar cell:



Ex.1004-Froitzheim, Fig.3. As discussed in Section XI.A.1 (Ground I, Motivation to Combine), it also would have been well within a person skilled in the art's ability to likewise implement Gan's polysilicon emitter and oxide layer into the solar cell of Froitzheim's Figure 1, as shown below:



Ex.1004-Froitzheim, Fig.1. Thus, the combination of Froitzheim and Gan teaches this claim element, i.e., *an oxide layer* formed between the PN junction (i.e., backside junction comprising the *substrate and emitter layer*) on the backside of the solar cell.

- e. **Elements 9[d]-9[e]: a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell.**

161. Froitzheim teaches *a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell.*

162. As I explained above, it was well known and ubiquitous that solar cells had metal contacts. Section VII.A.3 (Overview of Solar Cells – Metal Contacts). It

was also widely known that metal contacts were used to make an electrical connection to other solar cells or external circuits so electricity produced could be used for various applications. Section VII.A.3 (Overview of Solar Cells – Metal Contacts). These claim elements simply describe a well-known contact configuration where there are metal contacts on the front and back of the solar cell. Section VII.A (Overview of Solar Cells).

163. Froitzheim’s solar cells include this well-known feature. Froitzheim explains that it uses “screen printing” to fabricate “**front side contacts 16** [that are] in **electrical connection** with the **n-type silicon body layer**.” Ex.1004-Froitzheim, [0028], Abstract, [0049], [0010], [0033]-[0034], [0049] (“The front side contact is also suitably produced by screen printing and firing.”), [0060], Fig.1, Fig.3. A person of ordinary skill in the art would have understood that the **frontside contacts** (as in solar cells typically at the time) were electrically connected to the **n-type silicon body layer** (i.e., *substrate*) because this is taught by Froitzheim and shown in Figures 1 and 3 (below).

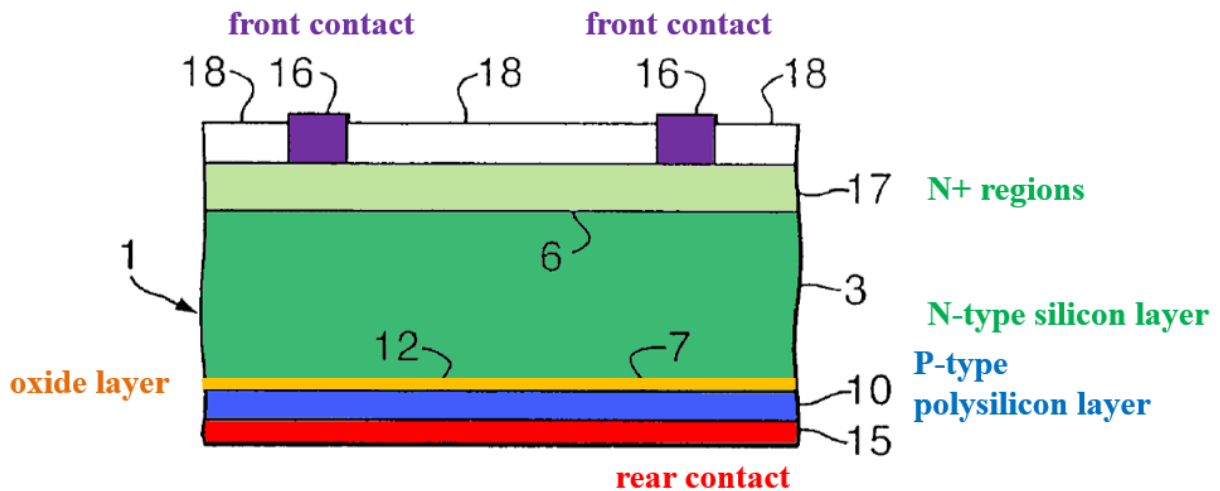
164. Froitzheim also describes the **frontside contacts** in relation to the **n+ doped layers** (38 and 39) in Figure 3. Froitzheim explains that these are formed by “diffus[ing] [] Phosphorous” into the **n-type silicon body layer**. Ex.1004-Froitzheim, [0044]. That is, the **n+ doped layers** are part of the substrate. Their

purpose is to ensure “*a better electrical connection*” between the **frontside contacts** and **n-type silicon body layer** (i.e., *substrate*). Ex.1004-Froitzheim, [0016], [0022]. Because the **n+ doped layers** were to facilitate the electrical connection, a person skilled in the art would have understood the **frontside contacts** (i.e., *first metal contacts*) were electrically connected to the **n-type silicon body layer** via the **n+ doped layers** that are at the front of the substrate (i.e., *on the front side of the solar cell*).

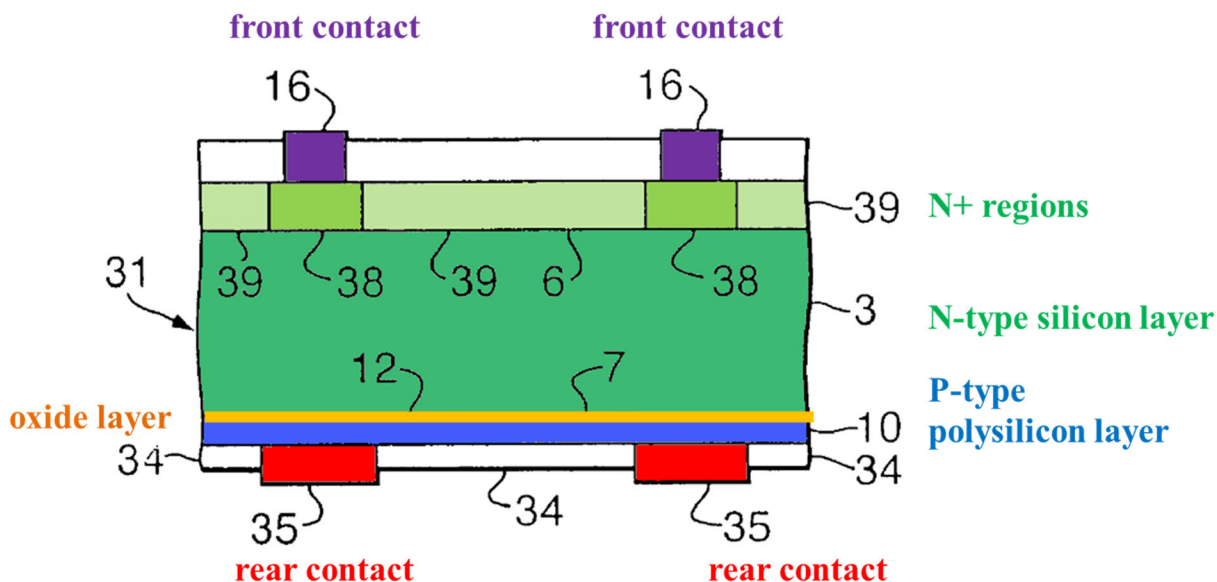
165. Froitzheim’s solar cell also includes a screen-printed “**rear side contacts 35**” “arranged in electrical connection with the **p-doped layer 10**.” Ex.1004-Froitzheim, [0027], [0033] (explaining that the “rear contacts 35” shown in Figure 3 are similar to the rear contact in Figure 1), Abstract, [0010], [0034], [0048]-[0049], [0060], Fig.1, Fig.3. That is, a person of ordinary skill in the art would have understood that the **rear side contact** (as in solar cells typically at the time) was electrically connected to the **p-doped layer 10** (i.e., *emitter*) because this is taught by Froitzheim and shown in Figures 1 and 3 (below).

166. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine) and Section XI.A.2.d (Ground I, Element 9[c]), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s structure (with a reasonable expectation of success) to implement a **p-type polysilicon emitter** and **oxide layer**

formed between the back surface of the **substrate** and the **emitter** layer, as taught by Gan. Implementing a **P-type polysilicon emitter** and **oxide layer** in Froitzheim is shown in the following image, which shows a modified version of Froitzheim's Figure 3 and shows where Gan's oxide layer and polysilicon emitter would be placed in Froitzheim's solar cell. Because Froitzheim's **rear side contact** would be in contact with the **p-type polysilicon emitter** taught by Gan, a person of ordinary skill in the art would have understood that the **rear side contact** (i.e., *second metal contact*) would be electrically connected to the **p-type polysilicon emitter**, which is over the back of the substrate (i.e., *on the backside of the solar cell*).



Ex.1004-Froitzheim, Fig.1.



Ex.1004-Froitzheim, Fig.3.

167. A person of ordinary skill in the art would have further understood that Froitzheim’s screen-printed **frontside contacts** and **rear side contact** were *metal* contacts. Froitzheim explains that the paste for screen-printed **frontside contacts** and **rear side contact** included silver and aluminum. Ex.1004-Froitzheim, [0020], [0049] (“The squeegee paste for rear side contacts can contain silver particles....and also an amount of Aluminum”). It was also well-known that screen-printed metal contacts were typically made from metal paste, as Froitzheim explains. Ex.1045-Green-1995, 234-39. Thus, a person of ordinary skill in the art would have understood that Froitzheim’s screen-printed **frontside contacts** and **rear side contact** were *metal* contacts.

f. Element 9[f] the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell.

168. Froitzheim teaches *the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell*.

169. This claim element simply recites the basic function of any solar cell. As I explained above, the function of solar cells is to generate solar energy for use in any number of applications (e.g., to power a business, house, etc.). By 2008, it was well known that this was done by configuring metal contacts to allow an *external* electrical circuit to be powered by the solar cell. Ex.1016-Komp, 14 (contacts “are used to connect the solar cell to the external circuit”), 154-55. Otherwise, the energy would simply remain in the solar cell and dissipate as heat, without any practical use.

170. Given this, it is unsurprising that Froitzheim teaches this basic function of a solar cell. Froitzheim’s “[f]ront and rear side contacts are arranged that are in electrical connection with the n-doped layer and the p-doped base layer, respectively, to **withdraw a photocurrent from both sides of the p/n-junction**” and thus power an external electrical circuit. Ex.1004-Froitzheim, [0002]. Froitzheim also explains that instruments had been connected to its solar cell, which

were used to test characteristics of the cell such as efficiency. Ex.1004-Froitzheim, [0061]-[0093] (measuring the open circuit voltage, which is a measurement related to the efficiency of a solar cell). Froitzheim's disclosures regarding withdrawing a photocurrent and connecting instruments to the solar cell demonstrates that Froitzheim's solar cell and its metal contacts were used to generate and transfer electrical current to external circuits.

171. Moreover, the '516 patent itself acknowledges that metal contacts "allow[ed] an external electrical circuit to be coupled to and be powered by the solar cell." Ex.1001-USP516, 1:25-29. As a result, a person of ordinary skill in the art would have readily understood that metal contacts were *configured to allow an external electrical circuit to be powered by the solar cell*.

172. Accordingly, claim 9 is obvious over the combination of Froitzheim and Gan.

3. **Claim 10: The solar cell of claim 9 further comprising an antireflective layer over the textured front surface of the substrate.**

173. Claim 10 depends from claim 9. Therefore, I incorporate by reference my discussion of Claim 9 in Section XI.A.2 (Ground I, Claim 9).

174. In addition, the combination of Froitzheim and Gan teaches *an antireflective layer over the textured front surface of the substrate*. As I discussed

in Section XI.A.2 (Ground I, Claim 9), Froitzheim teaches a solar cell with an **n-type silicon layer** (i.e., substrate) that has a textured front surface (i.e., *textured front surface of the substrate*).

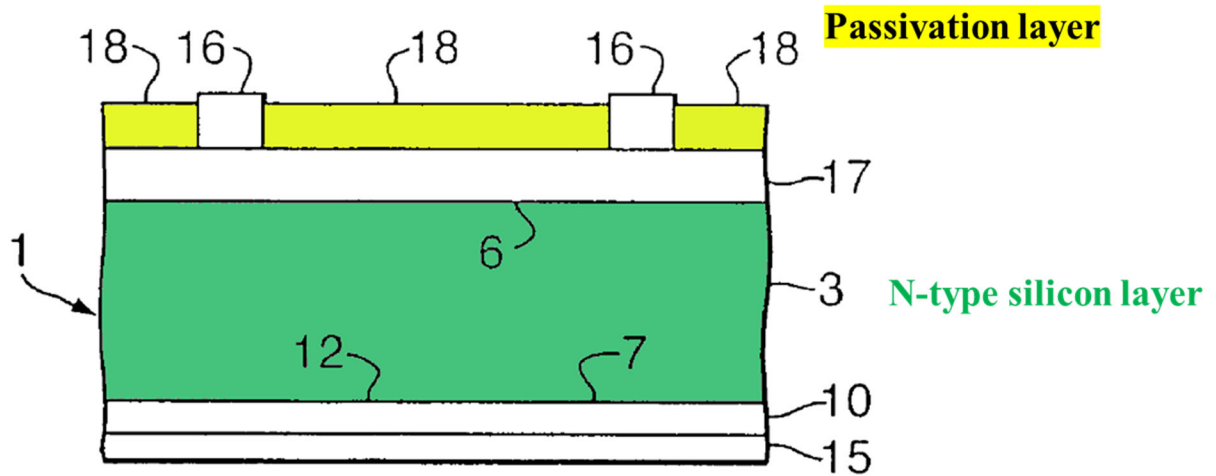
175. As I discussed in Section VII.A.4 (Overview of Solar Cells – Texturing and Anti-reflection Coating), it was routine and well-known to include antireflective layers over textured front surfaces by 2008. Antireflective layers (also often called anti-reflection coatings or AR coatings) had been extensively studied and implemented because they were known to increase solar cell efficiency by increasing the amount of sunlight entering the solar cell.

176. Froitzheim’s solar cells also have this well-known feature, as is explained by Froitzheim’s discussion of using “an anti-reflective coating...**as known in the art.**” Ex.1004-Froitzheim, [0030]-[0031], [0060]. Froitzheim also provides additional details on its antireflective coating. Froitzheim’s solar cell includes a **passivation layer** formed from silicon nitride (SiN). Ex.1004-Froitzheim, [0030], [0019], [0023], claim 7. Froitzheim explains that, in addition to performing passivation functions (i.e., decreasing recombination), silicon nitride is used for “**antireflection** as well.” As I discussed above, silicon nitride was commonly used as an antireflective layer. Ex.1016-Komp, 34 (“[S]ilicon nitride antireflection coatings are used on commercial solar cells.”); Ex.1018-Nelson, 188

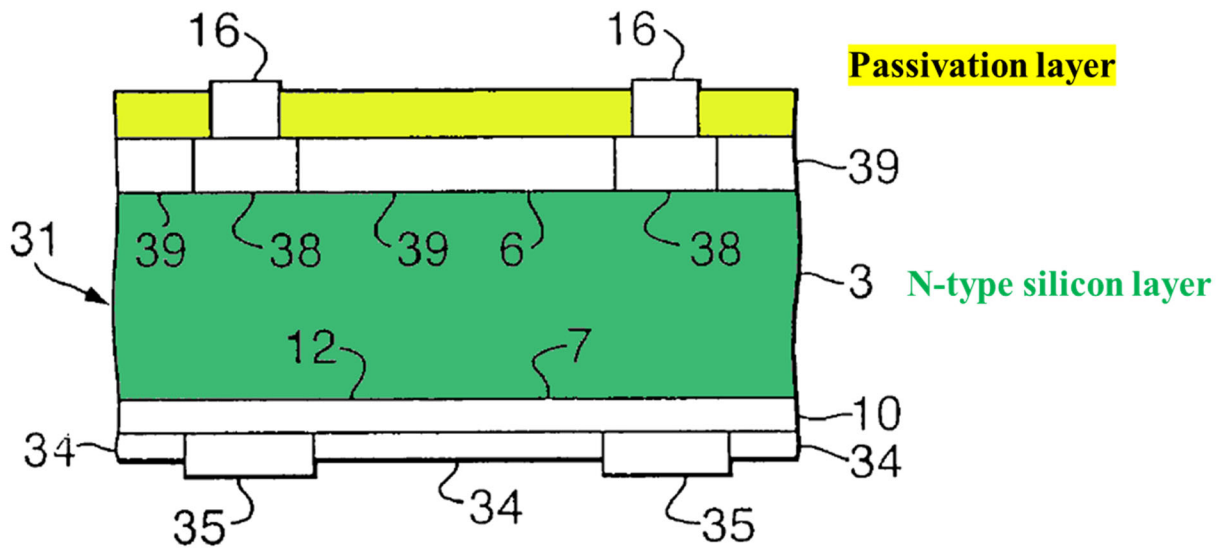
(“Suitable materials for silicon [AR coating include]...silicon nitride (Si_3Ni_4)”). As such, a person of ordinary skill in the art would have understood that the silicon nitride layer in Froitzheim’s solar cell was an *antireflective layer*.

177. Froitzheim’s Figures 1 and 3 below show that the antireflective silicon nitride layer (i.e., **passivation layer**) is placed *over* (i.e., closer to the sun) the *textured n-type silicon layer*.¹⁰ Ex.1004-Froitzheim, [0024], [0039]. Figure 3 of Froitzheim contains additional layers and contacts as compared to Figure 1 but is otherwise identical. Ex.1004-Froitzheim, [0033]-[0034].

¹⁰ As I discussed in Section XI.A.2 (Ground I, Claim 9), Froitzheim teaches that the **n-type silicon layer** has a textured front surface. Although Froitzheim teaches the **n-type silicon layers** are textured, the textured front surfaces are not depicted in Figures 1 and 3.



Ex.1004-Froitzheim, Fig.1,



Ex.1004-Froitzheim, Fig.3. Thus, a person of ordinary skill in the art would have understood that Figures 1 and 3 of Froitzheim depict the *antireflective* silicon nitride layer over the textured **n-type silicon layer**.

178. Froitzheim also teaches that during the manufacturing process for its disclosed solar cell, the antireflective silicon nitride layer is applied over the **n-type silicon layer** after the **n-type silicon layer** is textured. Ex.1004-Froitzheim, [0038]-[0039], [0050]. The sequence of steps makes sense because it would be unnecessarily complex (and not consistent with standard manufacturing techniques) to place the antireflective layer underneath a separate layer of textured silicon. A person of ordinary skill in the art therefore would have understood that Froitzheim teaches *an antireflective layer* (in this case, a silicon nitride **passivation layer**) *over the textured front surface of the substrate*. Thus, the combination of Froitzheim and Gan renders claim 10 obvious.

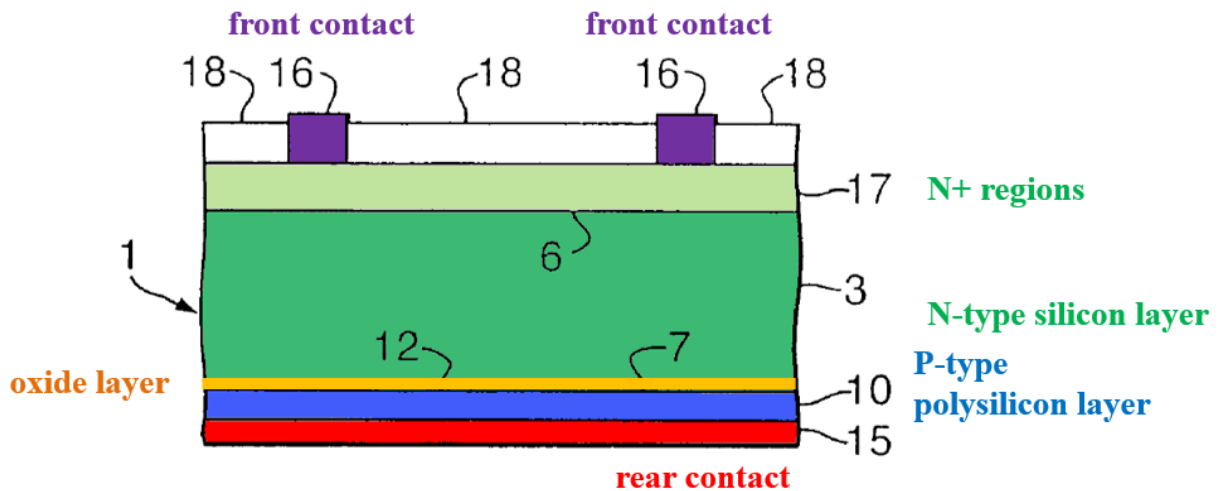
4. **Claim 11: The solar cell of claim 9 wherein the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon.**

179. Claim 11 depends from claim 9. Therefore, I incorporate by reference Section XI.A.2 (Ground I, Claim 9).

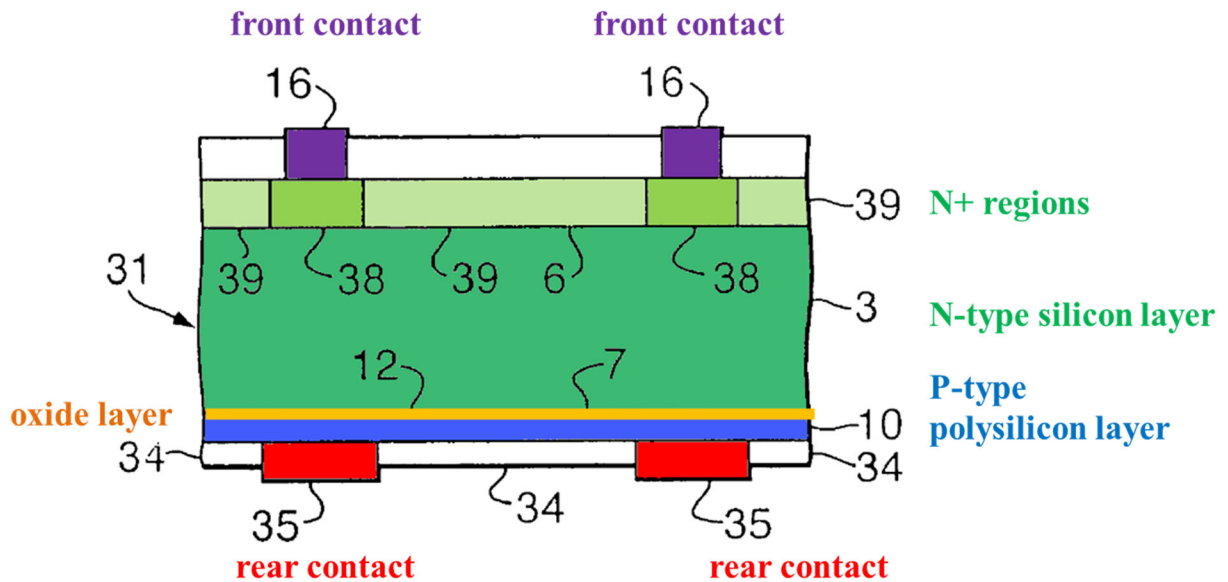
180. The combination of Froitzheim and Gan also teaches *the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon*. As I discussed in Section XI.A.2 (Ground I, Claim 9), Froitzheim's solar cell has an **n-type silicon layer** (thus, an N-type silicon substrate as claimed) and a "**p-doped layer 10**" (thus, a P-type emitter as claimed). Ex.1004-

Froitzheim, [0025]. As I also discussed in Section XI.A.2 (Ground I, Claim 9), Gan teaches a solar cell that uses a **P-type doped polysilicon emitter**. Ex.1005-Gan, 245, 249.

181. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim's solar cell (with a reasonable expectation of success) to implement a **P-type polysilicon emitter**, as taught by Gan. The resulting solar cell is shown in the following two modified Froitzheim figures, which implement Gan's **polysilicon emitter** and **oxide layer**:



Ex.1004-Froitzheim, Fig.1.



Ex.1004-Froitzheim, Fig.3. As a result, the combination of Froitzheim and Gan teach *the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon.*

5. **Claim 12: The solar cell of claim 9 wherein the second metal contact comprises silver formed over a layer of silicon dioxide.**

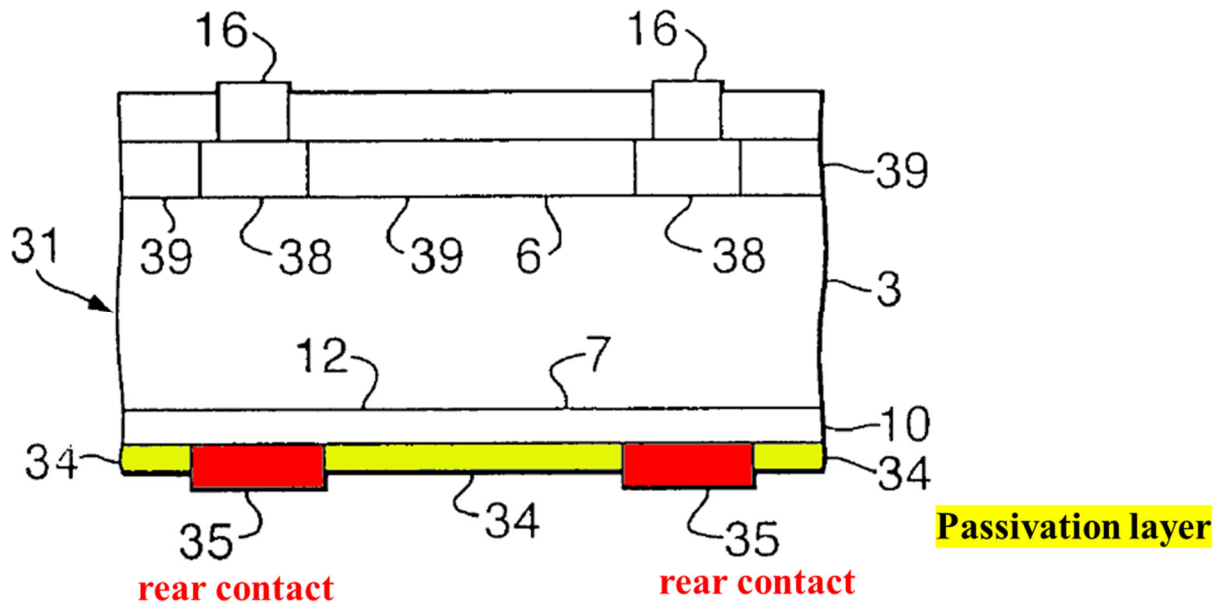
182. Claim 12 depends from claim 9. Therefore, I incorporate by reference Section XI.A.2 (Ground I, Claim 9).

183. The combination of Froitzheim and Gan also teaches *the second metal contact comprises silver formed over a layer of silicon dioxide.* As I explained in Sections XI.A.2.e (Ground I, Elements 9[d]-9[e]), Froitzheim teaches that its screen-printed metal contacts (e.g., **rear contact**) contain silver particles and aluminum.

Ex.1004-Froitzheim, [0020] (“less material such as Ag or Al is required for the contacts”), [0049] (“rear side contacts can contain silver particles...and also an amount of Aluminum”). A person of ordinary skill in the art would have also understood that it was common and routine to make screen-printed contacts from metal paste that included silver. *E.g.*, Ex.1045-Green-1995, 234-39 (“addition of aluminum to the silver paste”); Ex.1022-Meier, 7:10-16 (“FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating. By way of example, a silver layer is screen-printed onto the n^+ layer 216, covering about 7% of the front surface in a grid pattern. Silver may be deposited by screen-printing to a thickness that is generally between about 5 μm and about 20 μm and preferably about 10 μm .”).

184. Froitzheim further teaches that a **“passivation layer 34”** is created over the **p-doped layer 10**, and that the **passivation layer 34** is made of silicon dioxide (SiO_2). Ex.1004-Froitzheim, [0019], [0030], [0033]. Froitzheim specifically teaches that this **passivation layer 34** can be applied **before** contact formation, as it teaches that the “[p]assivation and antireflection coating **can be applied** using known methods, **before** or after contact formation.” Ex.1004-Froitzheim, [0050]. Because the rear contacts are applied **after** the passivation layer, a person of ordinary skill in the art would have understood that Froitzheim teaches that the **rear contact**

35 includes silver and is formed over a layer of silicon dioxide (e.g., **passivation layer 34**).



Ex.1004-Froitzheim, Fig.3. That is, Froitzheim teaches *the second metal contact* (e.g., **rear contact 35**) *comprises silver formed over a layer of silicon dioxide* (e.g., **passivation layer 34**).

6. Claim 1

185. Claim 1 is not as broad as claim 9 because it includes additional limitations, including (1) the manner in which the substrate and emitter are doped; (2) the polarity of the metal contacts that are on the rear and front sides of the cell; and (3) an antireflective layer, which is recited in dependent claim 10 (which depends from claim 9). As I discuss below, each of these elements is obvious in view of the combination of Froitzheim and Gan.

- a. Element 1[pre]: A solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising:**

186. As I described in Section XI.A.2.a (Ground I, Element 9[pre]), which I incorporate by reference, Froitzheim teaches *a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side.*

- b. Element 1[a]: an N-type silicon substrate**

187. As I described in Section XI.A.2.b (Ground I, Element 9[a]), which I incorporate by reference, Froitzheim teaches *an N-type silicon substrate.*

- c. Element 1[b]: a textured surface on the N-type silicon substrate on the front side of the solar cell**

188. As I described in Section XI.A.2.b (Ground I, Element 9[a]), which I incorporate by reference, Froitzheim teaches *a textured surface on the N-type silicon substrate on the front side of the solar cell.*

- d. Element 1[c]: an antireflective layer over the textured surface of the N-type silicon substrate**

189. As I described in Section XI.A.3 (Ground 1, Claim 10), which I incorporate by reference, Froitzheim teaches *an antireflective layer over the textured surface of the N-type silicon substrate.*

e. Element 1[d]: a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate

190. The combination of Froitzheim and Gan teaches a *P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate*. As I described in Section XI.A.2.c (Ground I, Element 9[b]), which I incorporate by reference, Froitzheim teaches a **P-type layer** (i.e., P-type emitter) on the backside of an **n-type silicon layer** (i.e., N-type silicon substrate) to form a backside junction. As I described in Section XI.A.1 (Ground I, Motivation to Combine), which I incorporate by reference, a person of ordinary skill in the art would have been motivated to modify Froitzheim's solar cell (with a reasonable expectation of success) to implement a **P-type polysilicon emitter**, as taught by Gan, over the **n-type silicon layer**. As a result, the combination of Froitzheim and Gan teaches *a P-type polysilicon emitter formed over an N-type silicon substrate to form a backside junction*.

f. Element 1[e]: an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate

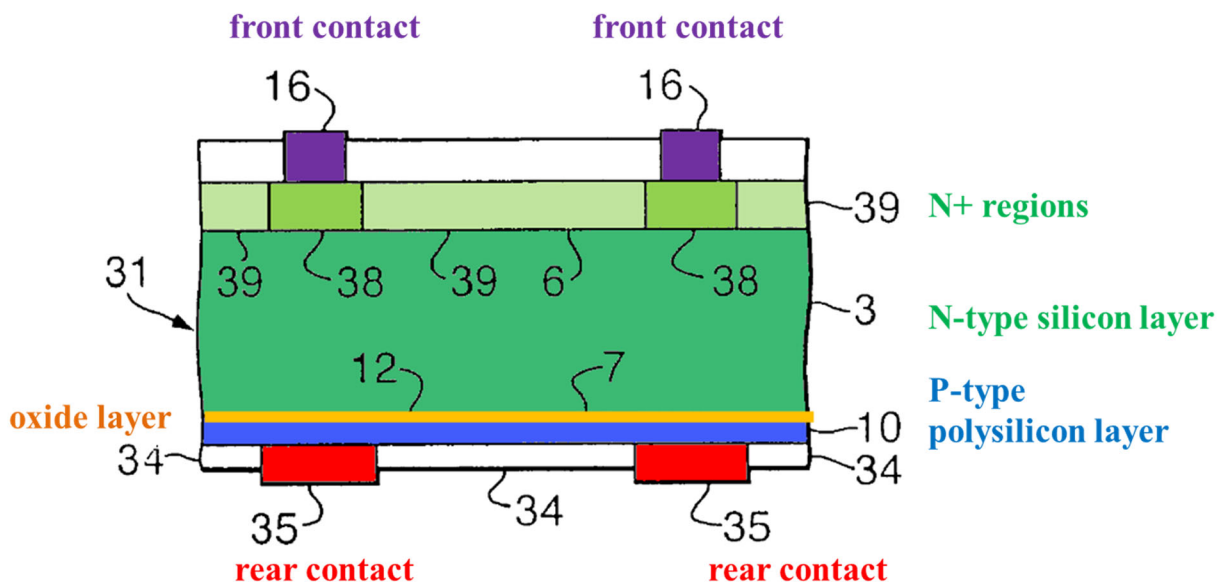
191. The combination of Froitzheim and Gan teaches *an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate*. As I described in Section XI.A.2.d (Ground I, Element 9[c]), which I incorporate by reference, Gan teaches an **oxide layer** between a p-type emitter and silicon substrate.

As I described in Section XI.A.1 (Ground I, Motivation to Combine), which I incorporate by reference, a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a reasonable expectation of success) to incorporate Gan's **P-type polysilicon emitter** and **oxide layer** *formed between the back surface of Froitzheim's n-type silicon substrate and the emitter layer*. Thus, the combination of Froitzheim and Gan teaches *an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate*.

- g. Elements 1[f]–1[g]: a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell and a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell.**

192. The Froitzheim and Gan combination teaches *a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell and a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell*. As I described in Section XI.A.2.e (Ground I, Elements 9[d]-9[e]), which I incorporate by reference, Froitzheim teaches **frontside contacts** on the front of the solar cell that are electrically connected to the **n-type silicon body layer** (i.e., *substrate*), a **rear side contact** on the back of the solar cell that is electrically connected to the **p-doped layer 10** (i.e., *emitter*), and that the contacts are metal contacts. As I described in

Section XI.A.1 (Ground I, Motivation to Combine), which I incorporate by reference, a person of ordinary skill in the art would have been motivated to modify Froitzheim's solar cell (with a reasonable expectation of success) to implement a **P-type polysilicon emitter** as taught by Gan. Thus, Froitzheim's **rear side contact** would be arranged in electrical connection with the **P-type polysilicon emitter**, as shown below.



Ex.1004-Froitzheim, Fig.3.

193. A person of ordinary skill in the art also would have known that Froitzheim's **frontside contacts** were a *negative polarity metal contact* and Froitzheim's **rear side contact** was a *positive polarity metal contact*. As discussed in Section VII.A.1 (Overview of Solar Cells – Doping), it was well understood that the p-type layer in the PN junction of a solar cell developed positive polarity when

the cell was illuminated, due to the additional “holes that accumulated in that layer,” and the n-type layer developed negative polarity when the cell was illuminated, due to the additional electrons that accumulated in that layer. *See* Ex.1016-Komp, 14-18 (explaining the fundamentals of solar cell operation and polarity). Furthermore, it well known that a metal contact in electrical connection with the n-type layer in a PN junction had a negative polarity and a metal contact in electrical connection with the p-type layer in a PN junction had a positive polarity, because otherwise the solar cell would not work. As a result, a person of ordinary skill in the art would have known that if a solar cell had a backside junction with a p-type emitter—e.g., Froitzheim’s p-type emitter—the front contact would have had a negative polarity because it was in contact with the n-type layer (“N” connected to “N”) and the rear contact would have a positive polarity because it was in contact with the p-type layer (“P” connected to “P”).

194. Accordingly, claim 1 is obvious over the combination of Froitzheim and Gan.

7. **Claim 2: The solar cell of claim 1 wherein the antireflective layer comprises a layer of silicon nitride.**

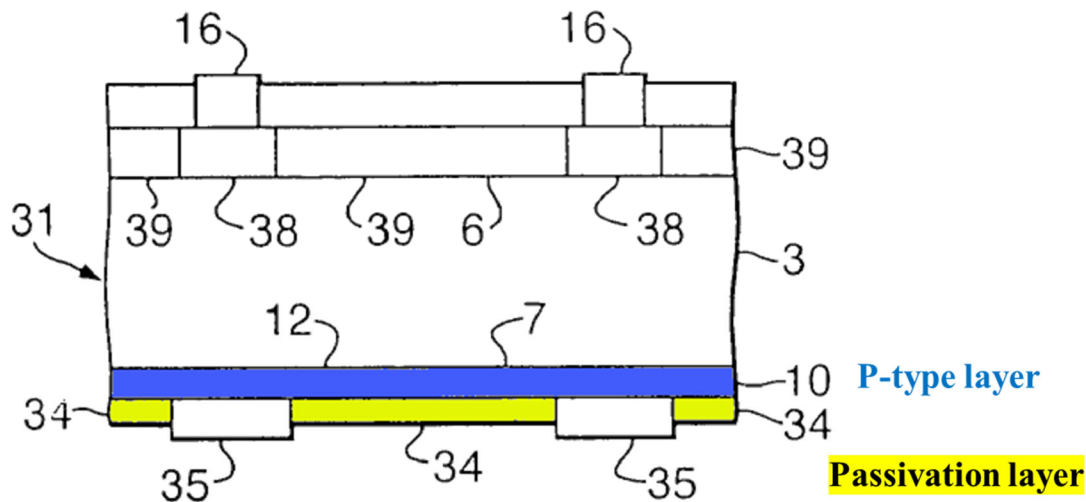
195. Claim 2 depends from claim 1. Therefore, I incorporate Section XI.A.6 (Ground I, Claim 1) by reference.

196. As I described in Section XI.A.3 (Ground I, Claim 10), which I incorporate by reference, the combination of Froitzheim and Gan also teaches *the antireflective layer comprises a layer of silicon nitride*.

8. **Claim 3: The solar cell of claim 1 further comprising a dielectric layer over the P-type polysilicon emitter.**

197. Claim 3 depends from claim 1. Therefore, I incorporate Section XI.A.6 (Ground I, Claim 1) by reference.

198. The Froitzheim and Gan combination further teaches *a dielectric layer over the P-type polysilicon emitter*. As shown in Figure 3 of Froitzheim, Froitheim's solar cell includes a "**passivation layer 34**" that is placed over the **p-doped layer 10**. Ex.1004-Froitzheim, [0033].

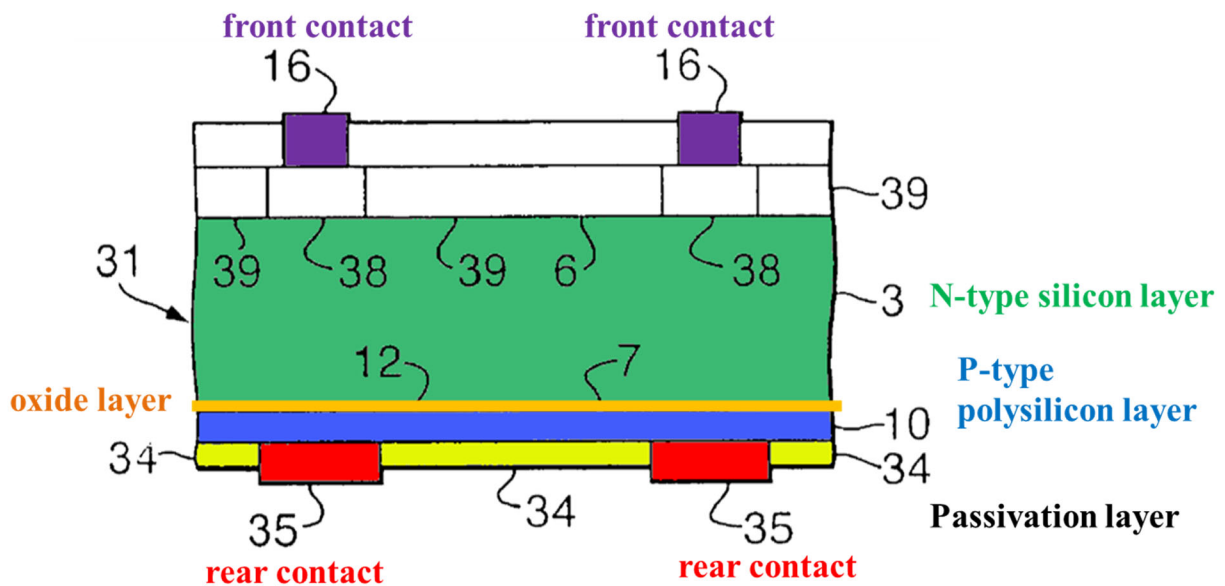


Ex.1004-Froitzheim, Fig.3. Froitzheim teaches that the rear **passivation layer 34** is made of the same materials used from the front side passivation layer. Ex.1004-

Froitzheim, [0030] (“The passivation layer can...be an oxide such as SiO₂.”), [0033] (“[A] passivation layer 34 is arranged, for which the same type of layers can be used as for the front side.”). Therefore, Froitzheim teaches that its rear **passivation layer 34** is made of silicon dioxide (SiO₂). A person of ordinary skill in the art would have understood that it was well known that silicon dioxide is a dielectric material and was commonly used for dielectric layers. *E.g.*, Ex.1054-Gee, 9:13-22 (“dielectric materials, such as SiO₂,...for surface passivation”); Ex.1056-Agostinelli (forming a dielectric layer with silicon dioxide to provide surface passivation). A person of ordinary skill in the art therefore would have known that Froitzheim teaches a *dielectric layer over the p-doped layer*. Moreover, the ’516 patent (correctly) acknowledges that silicon dioxide is used for dielectric layers. Ex.1001-USP516, 3:2 (“dielectric comprising a silicon dioxide”). The ’516 patent’s silicon dioxide disclosure thus confirms my opinion that a person of ordinary skill in the art would have known that Froitzheim teaches a *dielectric layer over the p-doped layer*.

199. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s solar cell (with a reasonable expectation of success) to implement a **P-type polysilicon emitter** as taught by Gan. A person of ordinary skill in the art would have been motivated to retain Froitzheim’s backside **passivation layer 34** including

because Froitzheim teaches that its **rear side contacts 35** are screen printed by firing through the **passivation layer 34**, which as I explained in Section VII.A.3 (Overview of Solar Cells – Metal Contacts) was a common manufacturing technique. Ex.1004-Froitzheim, [0033], [0048]-[0049]. As shown in the below modified Figure 3 of Froitzheim, the resulting solar cell includes a **passivation layer** (i.e., *dielectric layer*) over the **P-type polysilicon emitter**. Thus, the combination of Froitzheim and Gan teaches *a dielectric layer over the P-type polysilicon emitter*.



9. **Claim 4: The solar cell of claim 3 wherein the dielectric layer comprises silicon dioxide.**

200. Claim 4 depends from claim 3. Therefore, I incorporate Section XI.A.8 (Ground I, Claim 3) by reference. As I discussed in Section XI.A.8 (Ground I, Claim 3), Froitzheim teaches that its **passivation layer 34** (i.e., *dielectric layer*) is made

from silicon dioxide. Therefore, the combination of Froitzheim and Gan teaches that the *dielectric layer comprises silicon dioxide*.

10. Claim 6: The solar cell of claim 1 wherein the positive polarity metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer.

201. Claim 6 depends from claim 1. Therefore, I incorporate Section XI.A.6 (Ground I, Claim 1) by reference.

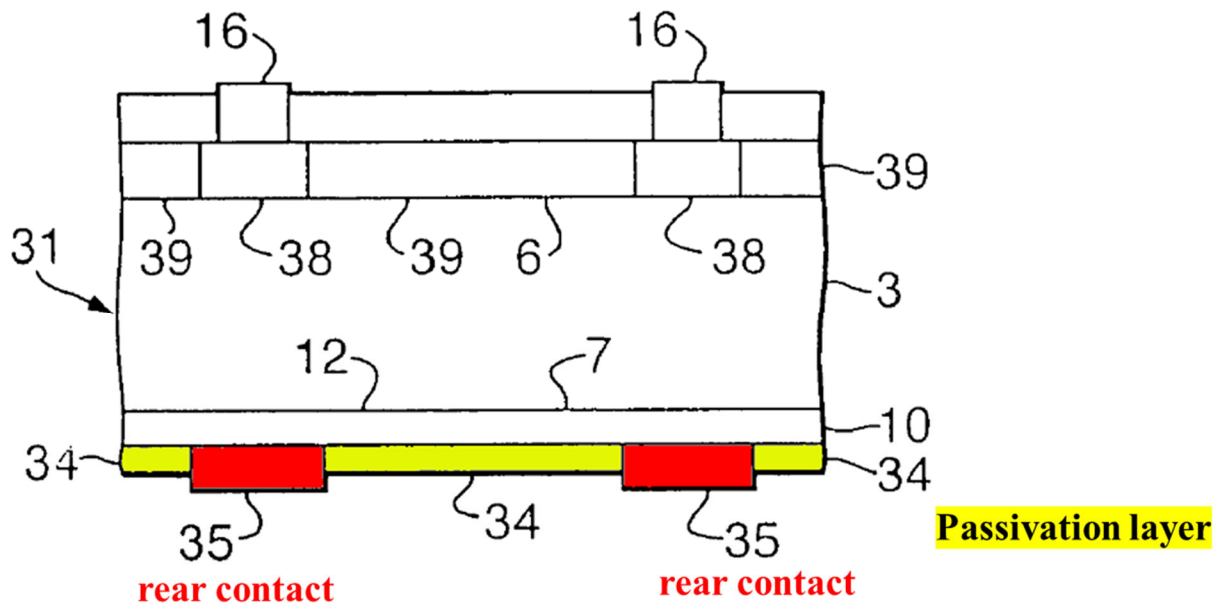
202. The combination of Froitzheim and Gan further teaches *the positive polarity metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer*. As shown in Figure 3 of Froitzheim (below), the **rear contacts** cover a portion of the backside of the solar cell. Ex.1004-Froitzhiem, Fig.3, [0033] (“[R]ear contacts 35 are arranged in a finger structure covering only part of the rear side....A typical coverage is in the range of 10-40% of the rear surface.”). As explained in Sections XI.A.2.e-f (Ground I, Elements 9[d]-9[f]), Froitzheim teaches that its screen-printed **rear contacts** contained silver particles and aluminum and a person of ordinary skill in the art would have known the **rear contacts** had positive polarity. Ex.1004-Froitzheim, [0020], [0049]. It was well known that screen-printed contacts were made from metal paste that included silver and/or aluminum. Ex.1045-Green-1995, 234-39 (“addition of aluminum to the silver paste”).

203. A person of ordinary skill in the art would have understood that Froitzheim's **rear contacts** reflected infrared light. In particular, a person of ordinary skill in the art would have understood that visible sunlight incident on the front side of the solar cell will be completely absorbed within the wafer within one pass through the wafer's thickness, but infrared light is weakly absorbed in silicon and will not be entirely absorbed. As a result, some infrared sunlight will reach the back of the solar cell where it will be reflected off the rear metal contact and back into the silicon, which increases energy absorption. Ex.1016-Komp, 1-2; Ex.1045-Green-1995, 92-93 ("[T]o obtain the best possible photovoltaic performance from silicon, every possible advantage must be taken of the light absorbing capabilities of a given cell volume. This means taking advantage of schemes which trap the light into the cell so that, if not absorbed during its first passage through the cell volume, light will have additional opportunities for absorption."); Ex.1051-Swanson-1986, 88 ("Silicon is only weakly absorbing at energies just above the bandgap so photons in this region have a significant chance of reaching the back of the cell. In cells with alloyed aluminum back contacts most of these photons will be parasitically absorbed there. By making the back reflective (preferably highly reflective) many of these photons will be reflected toward the front and have an additional chance to produce electron-hole pairs."), 92-93.

204. In other words, a person of ordinary skill in the art would have also understood that metal contacts (e.g., made from silver or aluminum) would reflect infrared light. *See* Ex.1045-Green-1995, 167 (discussing “longer wavelengths,” which includes infrared), 234-39 (discussing aluminum and silver); Ex.1049-Green-1986, 167 (discussing “longer wavelengths,” which a person of ordinary skill in the art would know includes infrared); Ex.1004-Froitzheim, [0064] (discussing “red (long wavelength) response”); Ex.1020-Luque, 547 (“Usually, silver is used as the reflective layer for research cells because of its high reflectivity, whereas aluminum is used in production because of difficulties with production yield for silver.”). A person of ordinary skill in the art would have thus understood that Froitzheim’s metal **rear contacts** that are configured as “fingers” would reflect light back into a solar cell. That is, because the rear contact is a reflective material, a person of ordinary skill in the art would have understood that the contact reflects infrared light back into the cell.

205. Froitzheim further teaches that a **“passivation layer 34”** (i.e., *dielectric layer*) is disposed over the **p-doped layer 10**, and the passivation layer is made of silicon dioxide (SiO₂). Ex.1004-Froitzheim, [0019], [0030], [0033]; *see also* Sections XI.A.5 (Ground I, Claim 12) and XI.A.8 (Ground I, Claim 3). Froitzheim also teaches that the metal **rear contacts** are manufactured by screen printing after

the **passivation layer** is disposed. Ex.1004-Froitzheim, [0048]-[0049]; *see also* Ex.1049-Green-1986, 167 (“The back contact to the cell can be designed to be reflective to give the longer wavelengths a second chance at being absorbed. Such back surface reflectors (BSR) can give quite a boost to the performance of thin cells, as well as helping to maintain low operating temperature.”). Thus, because the **metal contacts** reflect infrared light and are disposed next to the **passivation layer** (i.e., *dielectric layer* and as shown in Figure 3 below), Froitzheim teaches that *the metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer*.



Ex.1004-Froitzheim, Fig.3.

206. Finally, the '516 patent assumes that a person of ordinary skill in the art would have understood that the combination of metal contacts and a passivation layer (made of silicon dioxide) reflects infrared light, as it generically describes that “[t]he metal contact 110 may comprise silver [or aluminum], which, together with the silicon dioxide layer 109, makes an excellent backside infrared reflector” without further explanation. Ex.1001-USP516, 5:52-55. Thus, because Froitzheim teaches rear metal contacts and a rear passivation layer (made of silicon dioxide), a person of ordinary skill in the art would have understood that Froitzheim teaches that *the positive polarity metal contact* (e.g., **rear contacts 35**) *comprises a metal* (e.g., silver and/or aluminum) and *forms an infrared reflecting layer with a dielectric layer* (e.g., **passivation layer 34**).

11. **Claim 7: The solar cell of claim 1 wherein the positive polarity metal contact comprises silver forming an infrared reflecting layer with a dielectric layer comprising silicon dioxide.**

207. Claim 7 depends from claim 1. Therefore, I incorporate Section XI.A.6 (Ground I, Claim 1) by reference. The combination of Froitzheim and Gan further teaches *the positive polarity metal contact comprises silver forming an infrared reflecting layer with a dielectric layer comprising silicon dioxide*. As I discussed in Section XI.A.10 (Ground I, Claim 6), Froitzheim teaches that *the positive polarity metal contact comprises silver and forms an infrared reflecting layer with a*

dielectric layer. As I discussed in Section XI.A.9 (Ground I, Claim 4), Froitzheim teaches the *dielectric layer comprises silicon dioxide*.

12. Claim 8: The solar cell of claim 1 wherein the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate.

208. Claim 8 depends from claim 1. Therefore, I incorporate Section XI.A.6 (Ground I, Claim 1) by reference.

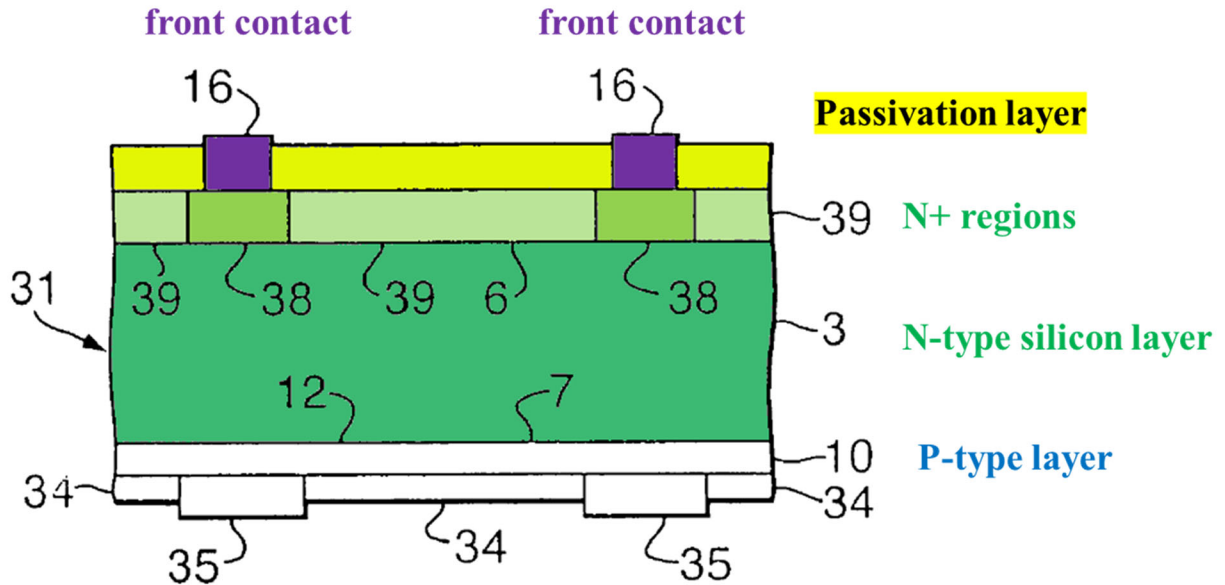
209. The Froitzheim and Gan combination also teaches *the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate*. As I discussed in Section XI.A.2.e (Ground I, Elements 9[d]-9[e]), a person of ordinary skill in the art would have understood that Froitzheim's solar cell includes **n+ doped layers** that are formed on the front side of the **n-type silicon layer**. As discussed in Section XI.A.3 (Ground I, Claim 10), Froitzheim's solar cell also includes a **passivation layer** that is on the front side of the cell.

210. Froitzheim also teaches that its solar cell includes screen-printed **frontside contacts**, which are "in electrical connection with the n-type body layer." Ex.1004-Froitzheim, [0028]. As explained in Section XI.A.2.e (Ground I, Elements 9[d]-[e]), the **frontside contacts** are in "electrical connection [with the **n-type silicon layer**] via [the] shallow n+ doped layer 16 on the front side 6." Ex.1004-

Froitzheim, [0028]. As explained in Section XI.A.6.g (Ground I, Elements 1[f]-[g]), the frontside contacts are *negative polarity metal* contacts.

211. Froitzheim further teaches a manufacturing process for its solar cell, and it explains that the **frontside contacts** are screen printed after the **passivation layer** is deposited. Ex.1004-Froitzheim, [0050]. As I explained in Section VII.A.3 (Overview of Solar Cells – Metal Contacts), screen printing, which Froitzheim implements, was a common process to make metal contacts, which involved the paste “firing through” (i.e., locally dissolving) a surface coating so that metal particles could connect to the underlying doped region or layer. A person of ordinary skill in the art would have understood that it was necessary and common to create holes in passivation layers on the front side of a solar cell during the screen printing process to ensure that the front contacts are electrically connected to the substrate. Ex.1006-Borden-575, [0020], Fig.2; Ex.1022-Meier, 8:12-14 (“Metal contacts 312 are illustrated as being deposited through anti-reflective (AR) coating 314.”), 7:10-12 (“FIG. 3D shows the structure resulting after depositing metal contacts and firing through the optional anti-reflective coating.”), Fig.3D, Fig.6. Indeed, as shown in Figure 3 below and consistent with what was known in the art, the **frontside contacts** are screen printed such that *holes* are created in the passivation layer to ensure that the **frontside contacts** contact the silicon layer (i.e., *N-type silicon*

substrate). Ex.1004-Froitzheim, [0050], Fig.1, Fig.3. In other words, the passivation layer includes *holes* that allow the **frontside contacts** to remain electrically connected to the **n-type silicon layer**.



Ex.1004-Froitzheim, Fig.1. Thus, a person of ordinary skill in the art would have understood that Froitzheim teaches that its **frontside contacts** (i.e., *negative polarity metal contact*) are *formed in a contact hole to the N-type silicon substrate*.

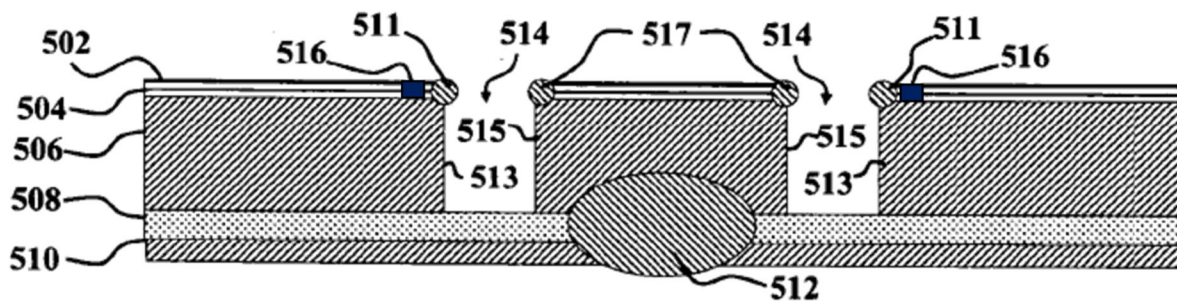
B. Ground II: Claim 5 is Invalid as Obvious over Froitzheim, Gan, and Sheats

212. It is my opinion that claim 5 would have been obvious over the combination of Froitzheim, Gan, and Sheats.

213. Claim 5 recites *the solar cell of claim 3 further comprising a trench cutting through the dielectric layer and the P-type polysilicon emitter and into a*

portion of the N-type silicon substrate on the backside of the solar cell. Because claim 5 depends from claim 3, I incorporate Sections XI.A.1 (Ground I, Motivation to Combine) and XI.A.8 (Ground I, Claim 3). In those sections, I explain (among other things) how the combination of Froitzheim and Gan teaches a dielectric layer, a backside P-type polysilicon emitter, and an N-type silicon substrate.

214. As I explained in Section X.E (Overview of the Prior Art – Sheats), and as shown in Figure 5D below, Sheats teaches a solar cell that includes “an **isolation trench 516**.” Sheats explains that the **isolation trench 516** “is formed through the transparent conductive layer and the active layer to the bottom electrode 506.” Ex.1012-Sheats, [0003]-[0004], [0059].

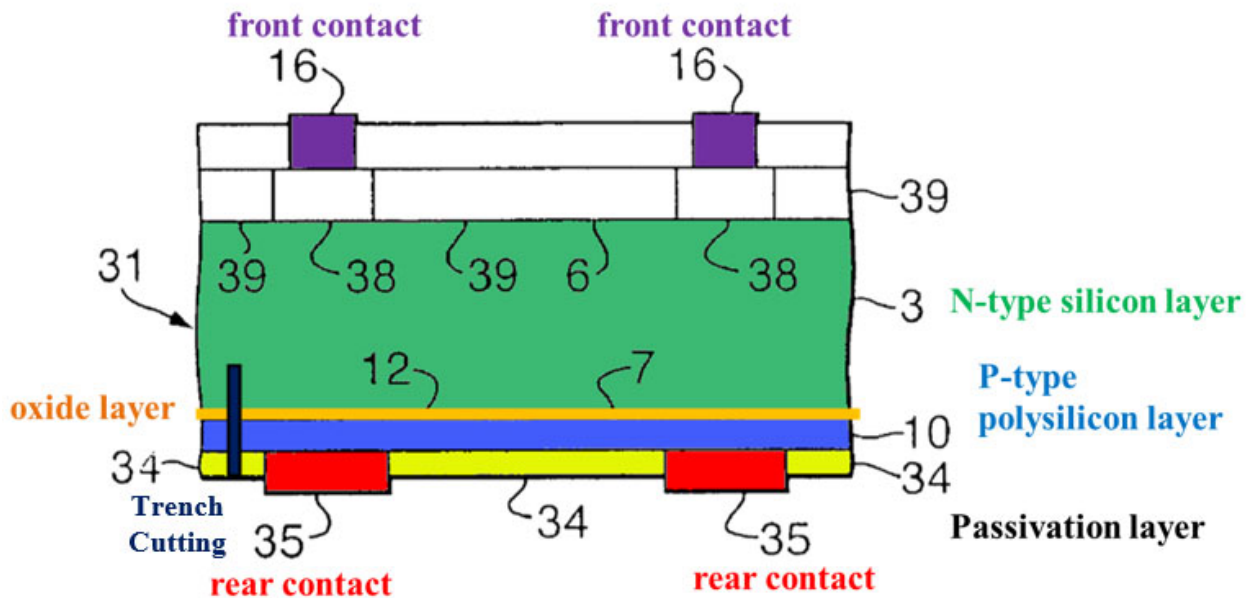


Ex.1012-Sheats, Fig.5D.

215. I understand that during prosecution of the '516 patent, the applicant did not dispute that Sheats teaches claim 5. In particular, on December 24, 2009, the Examiner found that Sheats teaches a solar cell having an **isolation trench 516**, which creates “edge isolation which prevents short circuits on the outside walls of

the device.” Ex. 1002-USP516FH, 81-82. I also understand that the applicant’s response on March 19, 2010 was silent regarding Sheats’ disclosure. Ex. 1002-USP516FH, 112.

216. A person of ordinary skill in the art would have incorporated an **isolation trench** to the combined structure of Froitzheim (back-junction solar cell) and Gan (polysilicon emitter and oxide layer), as shown in the modified Figure 3 of Froitzheim below. The figure below shows an **isolation trench** in the combined structure of Froitzheim and Gan such that the **isolation trench** is *through the dielectric layer and the P-type polysilicon emitter and into a portion of the N-type silicon substrate on the backside of the solar cell*.



217. It is my opinion that each requirement for obviousness is met for the combination of Froitzheim, Gan, and Sheats. **First**, Froitzheim, Gan, and Sheats are analogous art to the Challenged Claims. Froitzheim, Gan, and Sheats each relate to solar cells and are thus in the same field as the Challenged Claims. These references also relate to solving the problems of the Challenged Claims, namely improved efficiency obtained by controlling the flow of electrons. The references and the Challenged Claims all are directed to the same types of solutions, namely, optimized solar cell configurations, including through the use of structural features that prevent electrons from moving along unintended paths. *See* Section XI.A.1 (Ground I, Motivation to Combine) (discussing Froitzheim and Gan); Ex.1012-Sheats, [0007], [0041], [0055] (addressing the efficiency loss in prior art and proposing patterning metal traces to improve efficiency).

218. **Second**, a person of ordinary skill in the art would have been motivated to add an **isolation trench** (or edge isolation) to the combined structure of Froitzheim and Gan. In fact, it was well known in the art before 2008 that certain manufacturing steps, such as POCl₃ diffusion (which Froitzheim uses), can cause a solar cell to short circuit (“shunt”) and become unusable due to opposite-polarity layers making unintended contact with each other (e.g., after diffusion) by wrapping around the edges of the wafer. Ex.1063-Houser, 1739 (“After most emitter diffusion

techniques, especially the POCl_3 diffusion, the front contact is connected with the back contact through the emitter around the edge of the solar cell.”).

219. Edge isolation was therefore used by the industry to prevent a solar cell from short-circuiting, typically achieved by adding trenches, sometimes with insulating materials, near the edge of a solar cell. *E.g.*, Ex.1065-Mason, 6:11-7:16 (“the undesired electrically conductive deposits of nickel and copper on the edges were removed by cutting a groove to a depth of 100-150 μm into the silicon surface on the rear of the wafer and around the perimeter at a distance of 1 mm from the wafer edge.”); *see also* Ex.1066-Wenham, 7:23-40 (“Edge isolation”); Ex.1020-Luque, 290 (“Edge isolation by laser”). Sheats is another example that used this well-known edge isolation technique for its thin film structure. Ex.1012-Sheats, [0059] (“electrically isolate undesirable short circuits 511 formed on an outside wall 513”). As a result, a person of ordinary skill in the art would have been motivated to add a trench to the combination of Froitzheim and Gan to isolate the edge of the modified cell and prevent short circuits. Indeed, adding a trench to prevent short circuits was well known and Sheats expressly teaches that adding a trench prevents short circuits. Ex.1012-Sheats, [0059], Fig.5D.

220. **Third**, a person of ordinary skill in the art would have had a reasonable expectation of success in incorporating an **isolation trench** to the combined

structure of Froitzheim and Gan. Sheats explains using “laser scribing,” a well-known and routine manufacturing process by 2008, to form its **isolation trench**. Ex.1012-Sheats, [0059]; *see also* Ex.1065-Mason, 4:16-24 (“edge isolation (laser scribing and cleaving the edges)”); Ex.1066-Wenham, 7:23-40 (describing edge isolation by laser scribing); Ex.1020-Luque, 290 (“Edge isolation by laser”). As Sheats did, a person of ordinary skill in the art would have also easily been able to add the **isolation trench** to the Froitzheim and Gan combination, particularly because adding trenches to solar cells was a common technique in 2008. The ’516 patent itself assumes (correctly) that a person of ordinary skill in the art would have known how to add a trench to a solar cell particularly because the ’516 patent does not describe anything more than that a trench is simply added. *See* Ex.1001-USP516, 3:22-25, 4:20-27. That is because references before Sheats, such as Mason, Wenham, Houser, and Luque show that implementing an **isolation trench** to a solar cell was simply using a known technique (as Sheats did) to improve a solar cell in a similar way.

221. Thus, the combination of Froitzheim, Gan, and Sheats renders obvious *a trench cutting through the dielectric layer and the P-type polysilicon emitter and into a portion of the N-type silicon substrate on the backside of the solar cell.*

C. Ground III: Claims 1-4 and 6-12 Are Invalid as Obvious over Froitzheim and Borden-575

222. It is also my opinion that claims 1-4 and 6-12 would have been obvious over the combination of Froitzheim and Borden-575. In Grounds III and IV (which addresses claim 5 below), I rely on Borden-575 instead of Gan for the teachings of a polysilicon emitter and oxide layer.

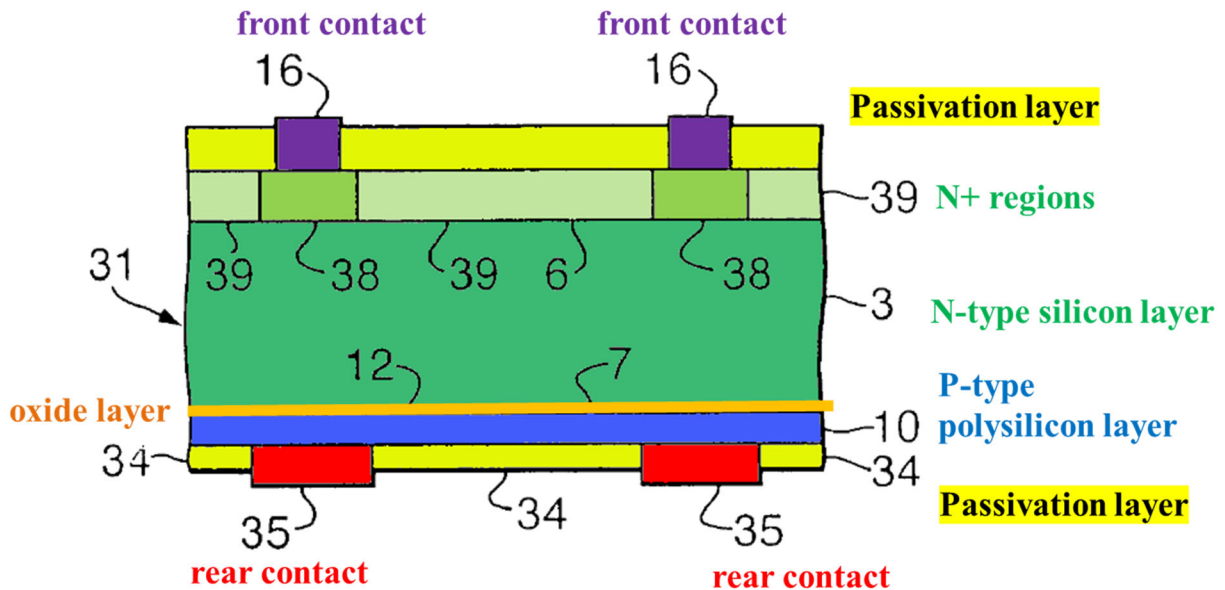
1. Motivation to Combine

223. It is my opinion that each requirement for obviousness is met for the combination of Froitzheim and Borden-575. **First**, like Froitzheim, Borden-575 is analogous art. Borden-575 teaches solar cells, and Borden-575 is thus in the same field as the Challenged Claims. Borden-575 is also reasonably related to solving the problems addressed in the Challenged Claims, namely, increasing efficiency. Borden-575 further uses the same types of solutions as the Challenged Claims, namely, optimizing solar cell configuration. Ex.1006-Borden-575, Abstract [0002]-[0008], [0016]-[0033]; Section XI.A.1 (Ground I, Motivation to Combine).

224. **Second**, a person of ordinary skill in the art would have been motivated to modify Froitzheim to incorporate a polysilicon emitter and tunnel oxide layer as taught by Borden-575 with a reasonable expectation of success. Similar to Ground I (Section XI.A), the combination of Froitzheim's back-junction solar cell and a polysilicon emitter and oxide layer as taught by Borden-575 simply amounts to using

a known structural feature—Borden-575’s polysilicon emitter and tunnel oxide layer between the PN junction—to improve a similar device—Froitzheim’s back junction cell. The combination of Froitzheim and Borden-575 achieves goals common to both references and the industry—increasing a solar cell’s efficiency to thereby increase its power output.

225. The combination of Froitzheim’s back-junction solar cell and Borden-575’s polysilicon emitter and tunnel oxide layer structure would have also been a simple modification because it would have simply involved implementing Borden-575’s tunnel oxide layer and polysilicon emitter on the backside of Froitzheim’s n-type silicon layer. The implementation of Borden-575’s tunnel oxide layer and polysilicon emitter to Froitzheim is shown in the below figures, which depicts the tunnel oxide layer implemented on the backside of Froitzheim’s n-type silicon layer and the polysilicon emitter implemented on the backside of the tunnel oxide layer to form a PN junction on the backside of the solar cell.



Ex.1004-Froitzheim, Fig.3; Ex.1006, Borden-575, [0016]-[0031], Figs.2-4.

226. In particular, a person of ordinary skill in the art would have been motivated to combine Froitzheim and Borden-575 with a reasonable expectation of success for the reasons discussed in Section XI.A.1 (Ground I, Motivation to Combine). Therefore, I incorporate my discussion in Section XI.A.1 (Ground 1, Motivation to Combine) by reference here.

227. As discussed in Section XI.A.1 (Ground I, Motivation to Combine), Gan and other references teach the benefits of incorporating a polysilicon emitter and oxide layer. For example, as discussed in Section XI.A.1 (Ground I, Motivation to Combine), Gan teaches that a polysilicon emitter and oxide layer structure improves the efficiency of a solar cell. *See* Ex.1005-Gan, 245, 249. As a result, a person of ordinary skill in the art would have been motivated to obtain these benefits

in Froitzheim's solar cell, and would have understood that such benefits (i.e., improved efficiency) would be obtained by implementing a polysilicon emitter and tunnel oxide layer, as taught by Borden-575, in Froitzheim's backside configuration. Section XI.A.1 (Ground 1, Motivation to Combine). Moreover, as I explained in Section XI.A.1 (Ground 1, Motivation to Combine), a person of ordinary skill in the art would have understood how to implement a polysilicon emitter and tunnel oxide layer in a back-junction solar cell like Froitzheim, and the prior art specifically explained how to implement a polysilicon emitter and tunnel oxide layer and why it would be beneficial to do so. Thus, a person of ordinary skill in the art would also have had a reasonable expectation of success at implementing a polysilicon emitter and tunnel oxide layer, as taught by Borden-575, in Froitzheim's solar cell. Section XI.A.1 (Ground 1, Motivation to Combine).

228. In addition to the reasons I discussed in Section XI.A.1 (Ground 1, Motivation to Combine), Borden-575 itself also provides teachings that a person of ordinary skill in the art would have considered. For example, Borden-575 teaches that adding a tunnel oxide layer between a substrate and polysilicon emitter “provides **passivation** between the substrate and the polysilicon, while allowing for tunnel current flow.” Ex.1006-Borden-575, [0022] (“This [tunnel] oxide – typically 8 to 15Å thick – provides passivation between the substrate and the polysilicon,

while allowing for tunnel current flow.”). As I discussed in Section VII.B (Overview of Cell Efficiency), passivation refers to reducing recombination, and therefore a person of ordinary skill in the art would have understood that Borden-575 teaches that recombination can be reduced by utilizing an oxide layer and polysilicon emitter.

229. Moreover, a person of ordinary skill in the art would have understood that Borden-575’s teaching that the tunnel oxide layer “allow[s]...current flow” refers to low contact resistance between the substrate and polysilicon emitter. As discussed in Section VII.B (Overview of Cell Efficiency), contact resistance reduces the amount of current that passes between two or more layers, and thus, Borden-575’s teaching that the oxide layer “allow[s]...current flow” indicates low contact resistance. As also discussed in Section VII.B (Overview of Cell Efficiency), lower recombination and lower contact resistance result in a more efficient solar cell, and lower recombination and lower contact resistance are also the same benefits taught by Gan (*see* Section XI.A.1 (Ground I, Motivation to Combine). A person of ordinary skill in the art would have thus understood that implementing Borden-575’s design would increase the efficiency of Froitzheim’s solar cell because the oxide layer would provide passivation (i.e., reducing recombination) while still allowing

current to pass (i.e., having low contact resistance) from the substrate to the polysilicon emitter.

230. Furthermore, Borden-575 teaches that its polysilicon emitter and tunnel oxide layer can be implemented into a back-junction solar cell (i.e., Froitzheim's configuration). For instance, Borden-575 teaches that its structure may be "formed on the back of the cell." Ex.1006-Borden-575, [0029] ("The described structure may be formed on the front of the cell. In an alternate embodiment, it is formed on the back of the cell."). As also discussed in Section XI.A.1, a person of ordinary skill in the art would have been motivated to retain Froitzheim's back-junction, including because a person of ordinary skill in the art would have understood that implementing a polysilicon emitter, as taught by Borden-575, in Froitzheim's back-junction solar cell would improve the cell's efficiency and ensure sunlight would not be absorbed by the polysilicon emitter before reaching the active region (i.e., wafer).

231. A person of ordinary skill in the art would have also been motivated to modify Froitzheim's back-junction solar cell to incorporate a polysilicon emitter and tunnel oxide layer, as taught by Borden-575, because each reference teaches similar and compatible solar cell structures. Froitzheim and Borden-575 each teach solar cells that have the same basic configuration of a silicon wafer substrate, p-type emitter, and metal contacts. Ex.1004-Froitzheim, Abstract, [0010]-[0013], Fig.1,

Fig.3; Ex.1006-Borden-575, [0017]-[0025], [0029]-[0032], Fig.2. As a result, a person of ordinary skill in the art would have understood that Froitzheim's solar cell and Borden-575's solar cell would have similar manufacturing steps, and thus, new equipment—e.g., a furnace for diffusion—to manufacture the combination of Froitzheim and Borden-575 would have been unnecessary. Accordingly, a person of ordinary skill in the art would have been motivated to apply Borden-575's teaching to Froitzheim's solar cell and would have had reasonable expectation of success in combining the features from Froitzheim and Borden-575.

2. Claim 9

a. Elements 9[pre]-9[a], 9[f]

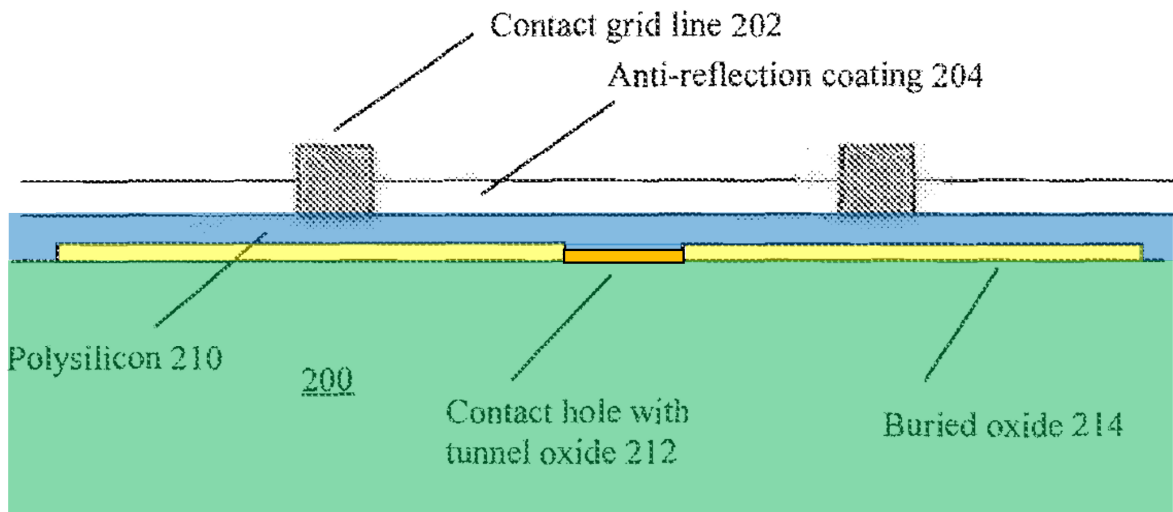
232. These elements of claim 9 are obvious for the same reasons as I explained in Ground I. Therefore, I incorporate by reference the sections from Ground I here. Sections XI.A.2.a-b and XI.A.2.f (Ground I, Elements 9[pre]-9[a], 9[f]).

b. Element 9[b]: an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate

233. The combination of Froitzheim and Borden-575 teaches *an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate.*

234. As described in Section XI.A.2.c (Ground, Element 9[b]) Froitzheim teaches *an emitter layer formed on the back of the substrate, the emitter layer forming a backside junction with the substrate.*

235. As shown in Figure 2 below, Borden-575 teaches a solar cell that includes an **n-type silicon substrate 200** and a **p-type polysilicon emitter 210** formed over the **substrate**. Ex.1006-Borden-575, [0019]-[0020], [0022], [0031] (“[I]f the poly layer is p-type and the substrate is n-type, then the poly layer is positive with respect to the substrate.”).

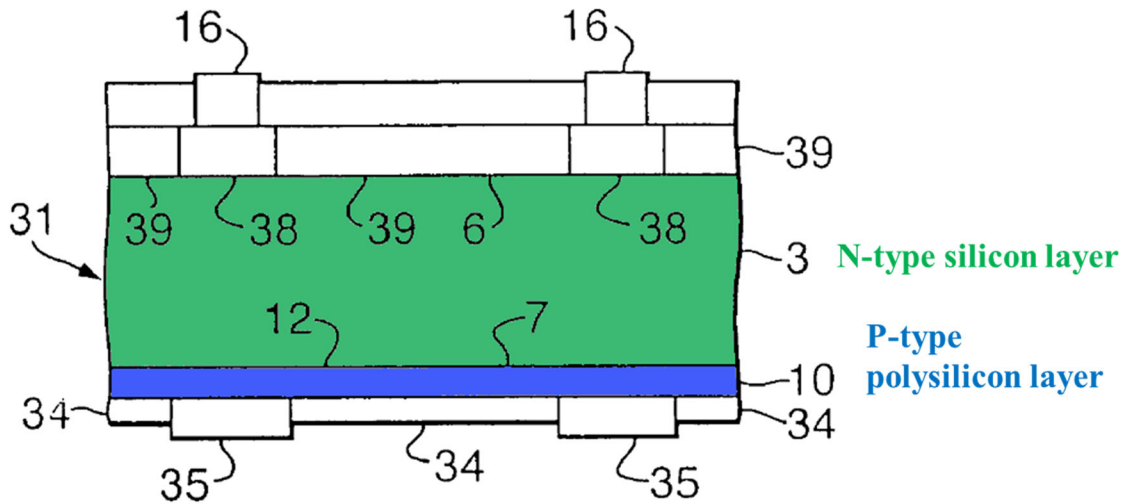


Ex.1006-Borden-575, Fig.2.

236. As discussed in Section VII.A.2 (Overview of Solar Cells – PN Junction), a PN junction is formed between two oppositely doped layers, and therefore, Figure 2 of Borden-575 depicts a junction between the **p-type polysilicon**

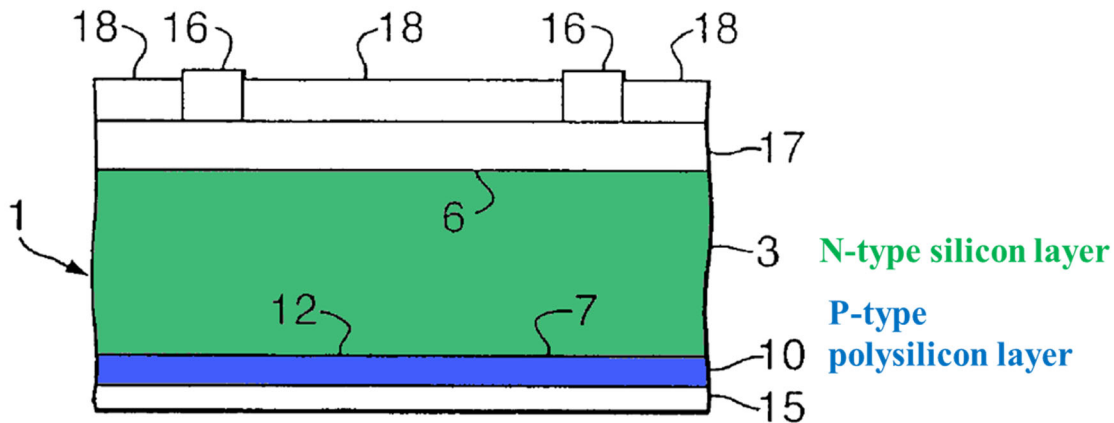
emitter 210 and **n-type silicon substrate 200**. Borden-575 also teaches that its disclosed configuration can be implemented on the backside of the cell. In particular, Borden-575 explains that its **polysilicon emitter** and **tunnel oxide layer** may be implemented in a solar cell with the PN junction on the rear side, as it teaches that its structure may be “formed on the back of the cell.” Ex.1006-Borden-575, [0029].

237. As I discussed in Section XI.A.1 (Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim’s solar cell in view of Borden-575 and would have had a reasonable expectation of success in doing so. The combination of Froitzheim and Borden-575 would have entailed implementing a **P-type polysilicon emitter** as taught by Borden-575 in Froitzheim’s solar cell such that the **P-type polysilicon emitter** (i.e., *emitter layer*) is formed over the *back surface of the* **n-type silicon layer** (i.e., *substrate*), as shown in the following modified version of Froitzheim’s Figure 3.



Ex.1004-Froitzheim, Fig.3. It also would have been well within a person skilled in the art's ability to implement Borden-575's **P-type polysilicon emitter** into the solar cell of Froitzheim's Figure 1, which has a differently shaped backside metal contact than Figure 3,¹¹ as the shape of the metal contact does not depend on this implementation of Borden-575:

¹¹ The metal contacts are labeled 35 in Figure 3, and the metal contact is labeled 15 in Figure 1. Ex.1004-Froitzheim, [0027], [0033].

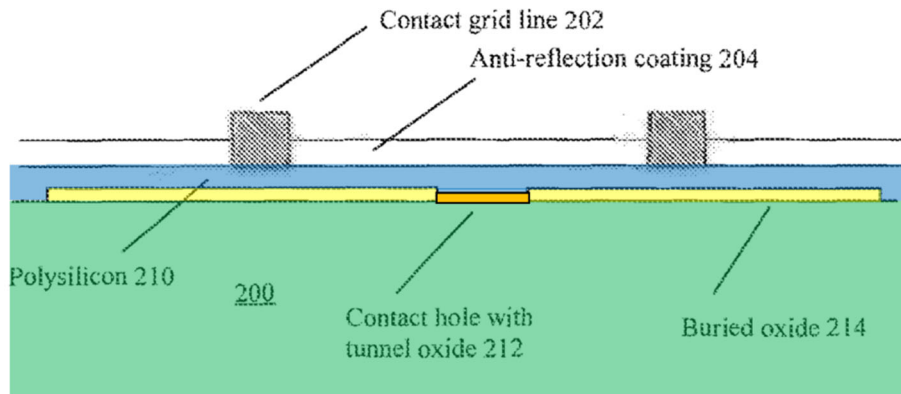


Ex.1004-Froitzheim, Fig.1. As a result, the combination of Froitzheim and Borden-575 teaches *an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate.*

c. Element 9[c]: an oxide layer formed between the back surface of the substrate and the emitter layer

238. The combination of Froitzheim and Borden-575 teaches *an oxide layer formed between the back surface of the substrate and the emitter layer.*

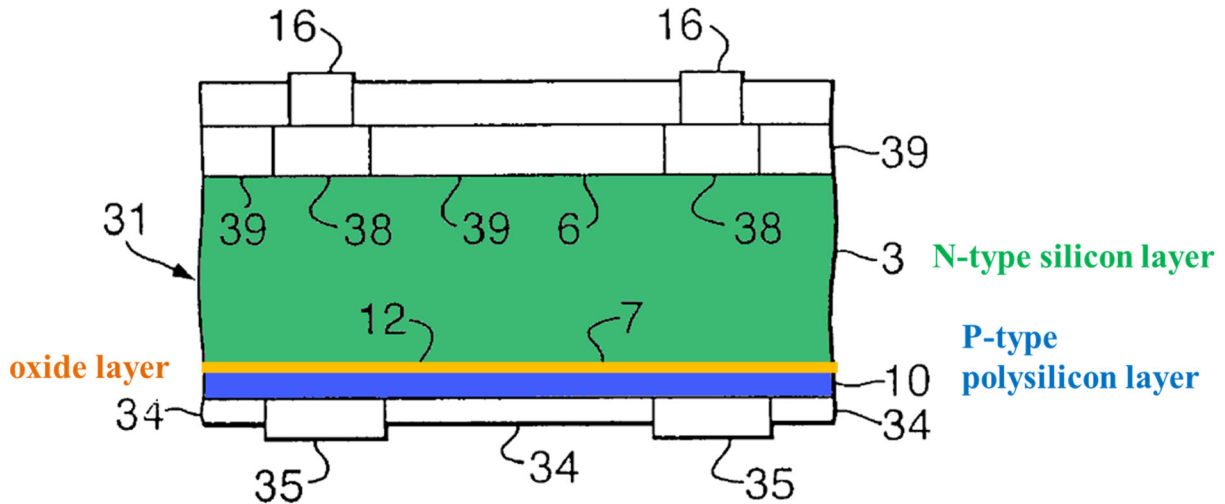
239. As discussed in Section XI.C.2.b (Ground III, Element 9[b]), Borden-575 teaches a **polysilicon emitter** and **substrate**. As shown in Figure 2, below, Borden-575 explains that a **tunnel oxide 212** layer is grown between the **polysilicon emitter** and **substrate** in the contact holes, and that the **tunnel oxide 212** layer “provides passivation between the **substrate** and the **polysilicon**” (i.e., the **tunnel oxide** is between the **polysilicon emitter** and *surface* of the **substrate**). Ex.1006-Borden-575, [0022].



Ex.1006-Borden-575, Fig.2.¹²

240. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated (with a reasonable expectation of success) to modify Froitzheim to incorporate a **P-type polysilicon emitter** and **oxide layer**, as taught by Borden-575, *formed between the back surface of the substrate and the emitter layer* as shown in modified Figure 3 of Froitzheim (below).

¹² Borden-575 also teaches placing “a **buried oxide** under the emitter of a polysilicon emitter solar cell” between the **polysilicon emitter** and **substrate**. Ex.1006-Borden-575, [0007]. In particular, the “**buried oxide 214**” is disposed between the **polysilicon emitter** and **substrate**. Ex.1006-Borden-575, [0019]-[0020].



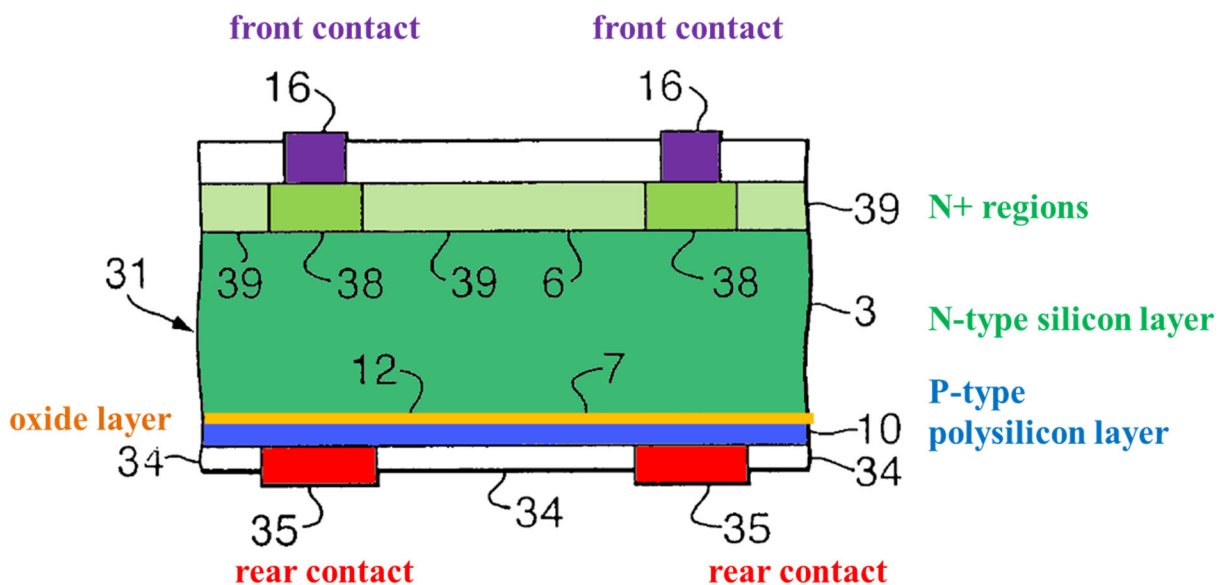
Thus, the combination of Froitzheim and Borden-575 teaches *an oxide layer formed between the back surface of the substrate and the emitter layer.*

- d. Elements 9[d]-9[e]: a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell**

241. As described in Section XI.A.2.e (Ground I, Elements 9[d]-9[e]), Froitzheim teaches *a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell.*

242. The combination of Froitzheim and Borden-575 also teaches *a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell.* As discussed in Section X.A.1

(Ground I, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a reasonable expectation of success) to implement a **P-type polysilicon emitter**, as taught by Borden-575. Thus, as shown in modified Figure 3 of Froitzheim below, the **rear side contacts** (i.e., second metal contacts) would be electrically connected to the **P-type polysilicon emitter**.



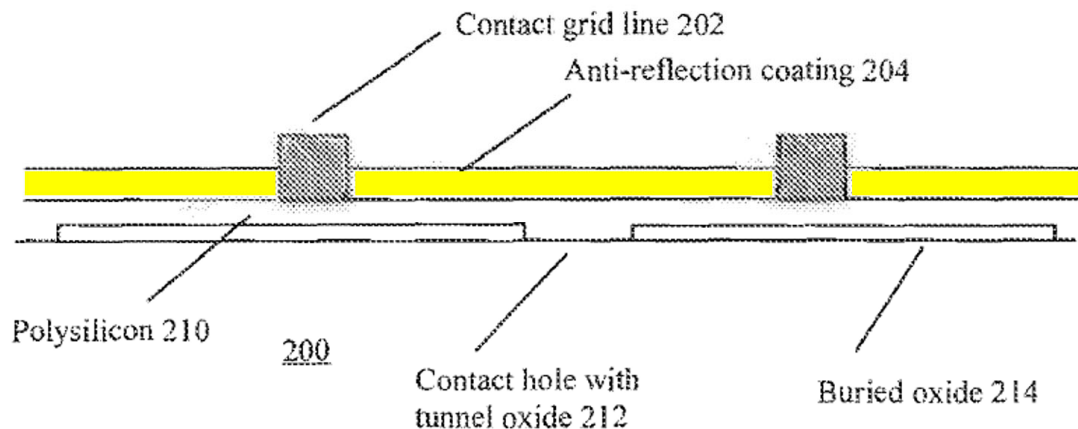
243. Accordingly, the combination of Froitzheim and Borden-575 renders claim 9 obvious.

3. **Claim 10: The solar cell of claim 9 further comprising an antireflective layer over the textured front surface of the substrate.**

244. Claim 10 depends from claim 9. Therefore, I incorporate by reference my discussion of Claim 9 in Section XI.C.2 (Ground III, Claim 9).

245. The combination of Froitzheim and Borden-575 further teaches *an antireflective layer over the textured front surface of the substrate*. As discussed in Section XI.A.3 (Ground I, Glaim 10), Froitzheim teaches that its solar cell includes an antireflective silicon nitride layer that is disposed over the textured surface of the **n-type silicon layer**. Thus, Froitzheim teaches *an antireflective layer over the textured front surface of the substrate*.

246. Like Froitzheim, Borden-575 also teaches a textured front surface of the substrate and an **anti-reflection coating 204** (i.e., *antireflective layer*, below). A person of ordinary skill in the art would have understood that the anti-reflection coating would be on top of the textured surface of the substrate because the purpose of the “coating” was to cover the front surface of the solar cell and anti-reflection coatings were well-known. Ex.1006-Borden-575, [0029]; Section VII.A.4 (Overview of Solar Cells – Texturing and Anti-reflective Coatings).

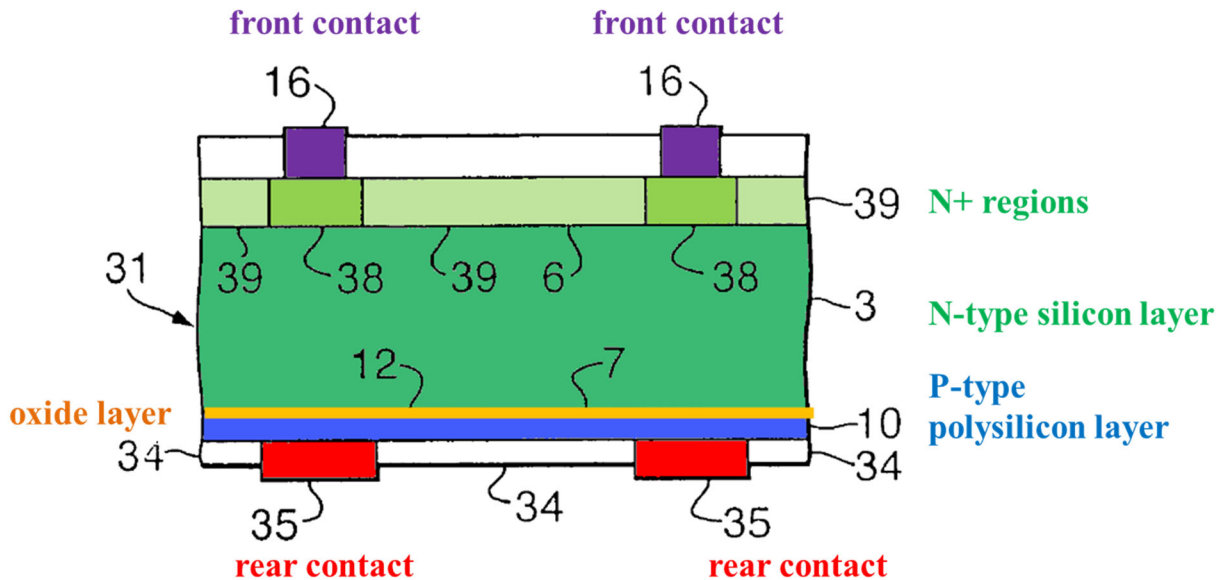


Ex.1006-Borden-575, Fig.2.

4. **Claim 11: The solar cell of claim 9 wherein the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon.**

247. Claim 11 depends from claim 9. Therefore, I incorporate by reference Section XI.C.2 (Ground III, Claim 9).

248. The combination of Froitzheim and Borden-575 also teaches *the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon*. As I discussed in Section XI.A.4 (Ground I, Claim 11), Froitzheim teaches an **n-type silicon layer** (i.e., *N-type silicon substrate*) and a “**p-doped layer 10**” on the rear side of the **n-type silicon layer**. Ex.1004-Froitzheim, [0025]. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a reasonably expectation of success) to implement a **P-type polysilicon emitter** (i.e., *P-type doped polysilicon emitter*), as taught by Borden-575, as shown below. Thus, the combination of Froitzheim and Borden-575 teaches an **n-type silicon layer** (i.e., *N-type silicon substrate*) and a **P-type polysilicon emitter** (i.e., *P-type doped polysilicon emitter*).



5. **Claim 12: The solar cell of claim 9 wherein the second metal contact comprises silver formed over a layer of silicon dioxide.**

249. Claim 12 depends from claim 9. Therefore, I incorporate by reference Section XI.C.2 (Ground III, Claim 9).

250. The combination of Froitzheim and Borden-575 further teaches *the second metal contact comprises silver formed over a layer of silicon dioxide*. As I explained in Section XI.A.5 (Ground I, Claim 12), a person of ordinary skill in the art would have understood that Froitzheim's **rear contacts** (i.e., second metal contact) included *silver* and were *formed over a layer of silicon dioxide*.

6. **Claim 1**

a. **Elements 1[pre]-1[c] and 1[f]-1[g]**

251. Element 1[pre] recites *a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side*, Element 1[a] recites *an N-type silicon substrate*, Element 1[b] recites *a textured surface on the N-type silicon substrate on the front side of the solar cell*, Element 1[c] recites *an antireflective layer over the textured surface of the N-type silicon substrate*, and Elements 1[f]-1[g] *a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell and a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell*. These claim elements are obvious for the same reasons discussed for claim 9. Therefore, I incorporate by reference Sections XI.A.2 and XI.C.2 (Grounds I and III, Claim 9).

b. **Element 1[d]: a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate**

252. The combination of Froitzheim and Borden-575 teaches *a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate*. As I explained in Section XI.A.2.c (Ground I, Element 9[b]), Froitzheim teaches a *backside junction* because it teaches a **P-type layer** formed on the back side (i.e., opposite the sun facing side) of an **n-**

type silicon layer. As explained in Section XI.C.2.b (Ground III, Element 9[b]), Borden-575 teaches a solar cell structure that includes an **n-type silicon substrate** and a **p-type polysilicon emitter** formed over the substrate. As explained in Section XI.C.2.b (Ground III, Element 9[b]), Borden-575 also explains that its structure can be in a backside junction configuration. Ex.1006-Borden-575, [0029]. As discussed in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a reasonable expectation of success) to implement a **p-type polysilicon emitter** as taught by Borden-575. Thus, the combination of Froitzheim and Borden-575 teaches *a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate.*

c. Element 1[e]: an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate

253. The combination of Froitzheim and Borden-575 teaches *an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate.* As I explained in Section XI.C.2.c (Ground III, Element 9[c]), Borden-575 teaches a **tunnel oxide layer** formed between a **polysilicon emitter** and **substrate**. As I explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a

reasonable expectation of success) to implement a **tunnel oxide layer** formed between the **P-type polysilicon emitter** and the **N-type silicon substrate** as taught by Borden-575.

7. **Claim 2: The solar cell of claim 1 wherein the antireflective layer comprises a layer of silicon nitride.**

254. Claim 2 depends from claim 1. Therefore, I incorporate Section XI.C.6 (Ground III, Claim 1) by reference.

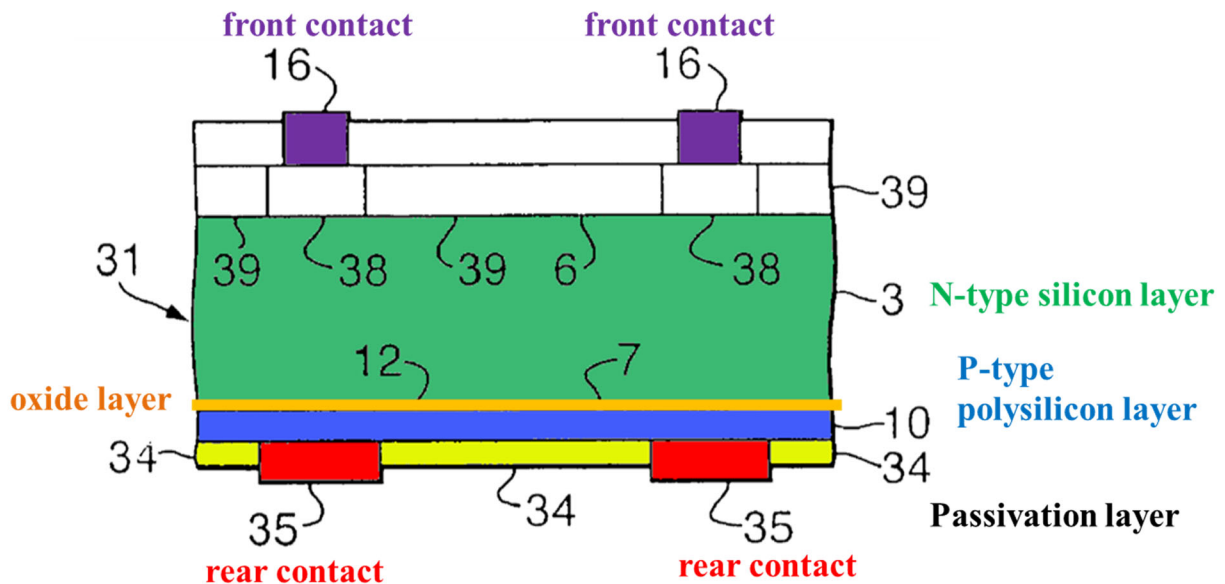
255. The combination of Froitzheim and Borden-575 further teaches *the antireflective layer comprises a layer of silicon nitride*. As I discussed in Section XI.C.3 (Ground III, Claim 10), Froitzheim teaches that its *antireflective layer* is made from *silicon nitride*. Borden-575 also teaches its anti-reflection coating is a “layer of silicon nitride.” Ex.1006-Borden-575, [0027].

8. **Claim 3: The solar cell of claim 1 further comprising a dielectric layer over the P-type polysilicon emitter.**

256. Claim 3 depends from claim 1. Therefore, I incorporate Section XI.C.6 (Ground III, Claim 1) by reference.

257. The combination of Froitzheim and Borden-575 further teaches *a dielectric layer over the P-type polysilicon emitter*. As discussed in Section XI.A.8 (Ground I, Claim 3), Froitzheim teaches a *dielectric layer* over the **p-doped layer**. As explained in Section XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Froitzheim (with a

reasonable expectation of success) to implement a **P-type polysilicon emitter** as taught by Borden-575. As explained in Section XI.A.8, a person of ordinary skill in the art would have been motivated to retain Froitzheim's backside **passivation layer 34**, including because Froitzheim teaches that its **rear side contacts 35** are screen printed by firing through the **passivation layer 34**, which as I explained in Section VII.A.3 (Overview of Solar Cells – Metal Contacts), was a common manufacturing technique. Ex.1004-Froitzheim, [0033], [0048]-[0049]. Thus, as shown in the below modified Figure 3 of Froitzheim, the **passivation layer** (i.e., *dielectric layer*) is over the **P-type polysilicon emitter**.



9. **Claim 4: The solar cell of claim 3 wherein the dielectric layer comprises silicon dioxide.**

258. Claim 4 depends from claim 3. Therefore, I incorporate Section XI.C.8 (Ground III, Claim 3) by reference.

259. The combination of Froitzheim and Borden-575 further teaches *the dielectric layer comprises silicon dioxide*. As explained in Section XI.A.8 (Ground I, Claim 3) Froitzheim teaches that its **passivation layer 34** (i.e., *dielectric layer*) is made from silicon dioxide.

10. **Claim 6: The solar cell of claim 1 wherein the positive polarity metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer.**

260. Claim 6 depends from claim 1. Therefore, I incorporate Section XI.C.6 by reference.

261. The Froitzheim and Borden-575 combination further teaches *the positive polarity metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer*. As I discussed in Section XI.A.10 (Ground I, Claim 6), a person of ordinary skill in the art would have understood that Froitzheim teaches that *the positive polarity metal contact* (e.g., **rear contacts**) *comprises a metal* (e.g., silver and/or aluminum) and *forms an infrared reflecting layer with a dielectric layer* (e.g., **passivation layer 34**).

11. **Claim 7: The solar cell of claim 1 wherein the positive polarity metal contact comprises silver forming an infrared reflecting layer with a dielectric layer comprising silicon dioxide.**

262. Claim 7 depends from claim 1. Therefore, I incorporate Section XI.C.6 (Ground III, Claim 1) by reference. The combination of Froitzheim and Borden-575 further teaches *the positive polarity metal contact comprises silver forming an infrared reflecting layer with a dielectric layer comprising silicon dioxide*. As discussed in Section XI.A.11 (Ground I, Claim 7), Froitzheim teaches that the **rear contacts** are made of *silver and form an infrared reflecting layer with a dielectric layer that comprises silicon dioxide*.

12. **Claim 8: The solar cell of claim 1 wherein the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate.**

263. Claim 8 depends from claim 1. Therefore, I incorporate Section XI.C.6 (Ground III, Claim 1) by reference.

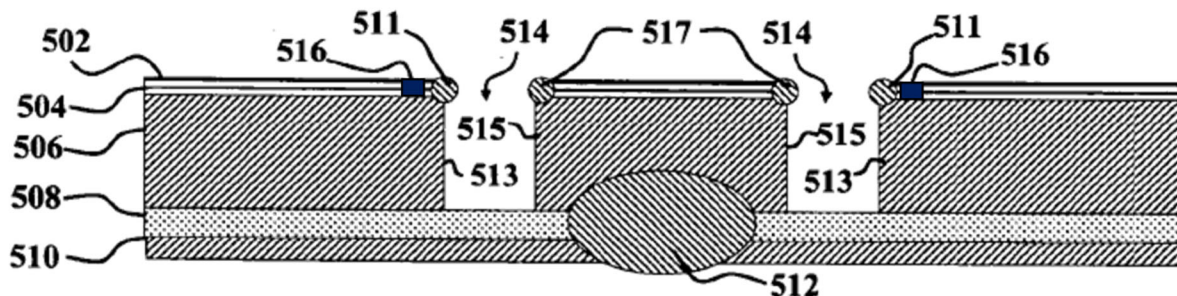
264. The combination of Froitzheim and Borden-575 further teaches *the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate*. As discussed in Section XI.A.12 (Ground I, Claim 8), Froitzheim teaches that its **frontside contacts** (*i.e., negative polarity metal contact*) are *formed in a contact hole to the N-type silicon substrate*.

D. Ground IV: Claim 5 is Invalid as Obvious over Froitzheim, Borden-575, and Sheats

265. It is my opinion that claim 5 would have been obvious over the combination of Froitzheim, Borden-575, and Sheats.

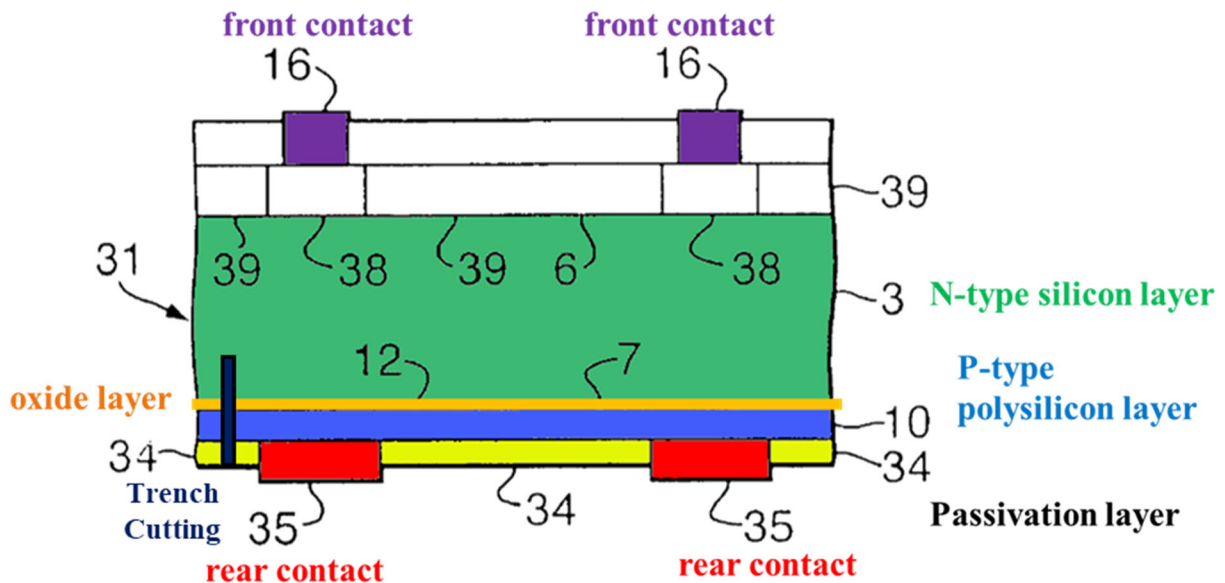
266. Claim 5 recites *the solar cell of claim 3 further comprising a trench cutting through the dielectric layer and the P-type polysilicon emitter and into a portion of the N-type silicon substrate on the backside of the solar cell*. Because claim 5 depends from claim 3, I incorporate Sections XI.C.1 (Ground III, Motivation to Combine) and XI.C.8 (Ground III, Claim 3). In those sections, I explain (among other things) how the combination of Froitzheim and Borden-575 teaches a dielectric layer, a backside P-type polysilicon emitter, and an N-type silicon substrate.

267. As I explained in Sections X.E (Overview of the Prior Art – Sheats) and XI.B (Ground II), and as shown in Figure 5D below, Sheats teaches a solar cell that includes “an **isolation trench 516**.” Ex.1012-Sheats, [0003]-[0004], [0059].



Ex.1012-Sheats, Fig.5D.

268. For the reasons I discussed in Section XI.B (Ground II) and incorporate here, a person of ordinary skill in the art would have been motivated to modify the combined structure of Froitzheim and Borden-575 (with a reasonable expectation of success) to implement an **isolation trench**, a well-known feature before 2008, also taught by at least Mason, Wenham, Houser, and Luque, to prevent solar cells from short-circuiting and becoming unusable after certain manufacturing steps, such as POCl_3 diffusion (which Froitzheim uses). The modified solar cell reflecting the combination of Froitzheim, Borden-575, and Sheats is below.



Thus, the combination of Froitzheim, Borden-575, and Sheats renders obvious *a trench cutting through the dielectric layer and the P-type polysilicon emitter and into a portion of the N-type silicon substrate on the backside of the solar cell.*

E. Ground V: Claims 1-2 and 8-11 Are Invalid as Obvious over Li and Gan

269. It is my opinion that claims 1-2 and 8-11 would have been obvious over the combination of Li and Gan. Ground V relies on Li as the primary reference instead of Froitzheim. Li is similar to Froitzheim in that both Li and Froitzheim teach solar cells having a backside PN junction, among other features. Li teaches depositing an emitter over the rear surface of a substrate rather than creating a diffused emitter like Froitzheim. Gan also teaches a deposited emitter. As explained below, the combination of Li and Gan renders claims 1-2 and 8-11 obvious.

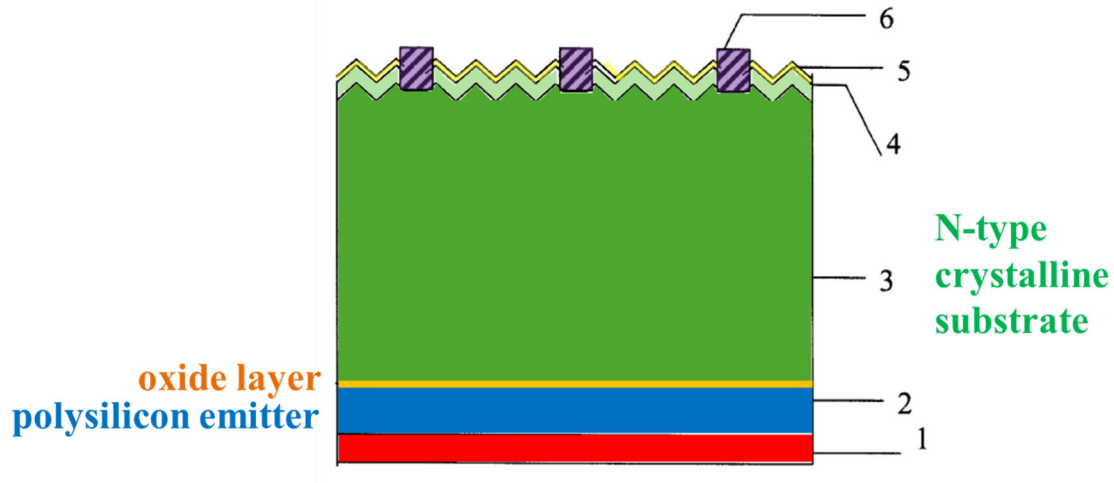
1. Motivation to Combine

270. It is my opinion that each requirement for obviousness is met for the combination of Li and Gan. **First**, like Gan, Li is analogous art to the Challenged Claims. Li teaches solar cells, and Li is thus in the same field as the Challenged Claims. Li is also reasonably related to solving the problems addressed in the Challenged Claims, namely, increasing efficiency. Li further uses the same types of solutions as the Challenged Claims, namely, optimizing solar cell configuration. Ex.1008-Li, 1-4; Section XI.A.1 (Ground I, Motivation to Combine).

271. **Second**, a person of ordinary skill in the art would have been motivated to modify Li to incorporate a polysilicon emitter and tunnel oxide layer, as taught by Gan, with a reasonable expectation of success. Similar to Section XI.A (Ground I),

the combination of Li's back-junction solar cell and Gan's polysilicon emitter and oxide layer simply amounts to using a known structural feature—Gan's polysilicon emitter and tunnel oxide layer between the PN junction—to improve a similar device—Li's back-junction cell. The combination of Li and Gan achieves goals common to both references and the industry—increasing a solar cell's efficiency to thereby increase its power output.

272. The combination of Li's back-junction solar cell and Gan's polysilicon emitter and tunnel oxide layer structure would have also been a simple modification because it would have simply involved replacing Li's deposited silicon thin film with Gan's deposited **polysilicon emitter** and implementing an oxide layer between Li's **N-type crystalline substrate** and the deposited **polysilicon emitter**. The implementation of Gan's tunnel oxide layer and polysilicon emitter to Li is shown in the below figure, which depicts the **oxide layer** implemented on the backside of Li's **N-type crystalline substrate** and the P-type **polysilicon emitter** implemented over the **oxide layer** to form a PN junction with the **N-type crystalline substrate** on the backside of the solar cell.



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245, 249.

273. In particular, a person of ordinary skill in the art would have been motivated to combine Li and Gan with a reasonable expectation of success for the reasons discussed in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine), which are incorporated by reference here.

274. For example and as described in Section X.D (Overview of the Prior Art – Li), similar to Froitzheim, Li teaches a solar cell that includes an n-type substrate and p-type emitter on the rear side of the substrate to form a backside PN junction. Ex.1008-Li, 2, Fig.2. Li teaches that this configuration improves a solar cell's efficiency. Ex.1008-Li, 2-4 (explaining that its solar cell is constructed such that it "avoids light loss caused by the amorphous silicon layer and the transparent conductive thin film on the front surface, such that the cell efficiency can be improved by 10% or above," compared to "an amorphous silicon/crystalline silicon

heterojunction solar [‘HIT’] cell”). As I described in Sections VII.B (Overview of Solar Cell Efficiency), Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine), multiple references, including Gan and Borden-575, taught the benefits of using a polysilicon emitter and oxide layer. As I also described in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have understood that these teachings regarding the benefits of using a polysilicon emitter and oxide layer were applicable to backside junction solar cells, and applying these features to a backside junction solar cell would improve the efficiency of the cell. Gan specifically teaches that its polysilicon emitter and oxide layer were applicable to p-type emitters and backside junctions, just like the emitter and backside junction taught by Li. Ex.1005-Gan, 245-249; Ex.1008-Li, 4, Fig.1.

275. Additionally, similar to the motivations explained in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine) regarding the Froitzheim and Gan and Froitzheim and Borden-575 combinations, a person of ordinary skill in the art would also have been motivated to retain a backside PN junction, as taught by Li, when implementing a polysilicon emitter and oxide layer. As discussed in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art

would have understood that implementing the polysilicon emitter on the rear side of the cell would allow the cell to obtain the benefits of a polysilicon emitter and oxide layer, as taught by Gan, while avoiding the potential absorption drawback of a polysilicon emitter on the front side of the cell.

276. A person of ordinary skill in the art would have also been motivated to modify Li's back-junction solar cell to incorporate Gan's polysilicon emitter and oxide layer because each reference teaches similar and compatible solar cell structures. Li and Gan each teach solar cell structures that have the same basic configuration of a silicon wafer substrate, p-type emitter, and metal contacts. Ex.1008-Li, Abstract, 4, Fig.1; Ex.1005-Gan, 245-249. Indeed, Li and Gan both teach solar cell structures that have deposited emitters over a silicon substrate. Ex.1008-Li, 4, Fig.1; Ex.1005-Gan, 245-246. As a result, a person of ordinary skill in the art would have understood that Li and Gan's deposited emitters were easily interchangeable without needing additional equipment—e.g., a furnace for diffusion—to manufacture the modified solar cell.

277. Accordingly, for the reasons explained here and in Sections XI.A.1 (Ground I, Motivation to Combine) and XI.C.1 (Ground III, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify

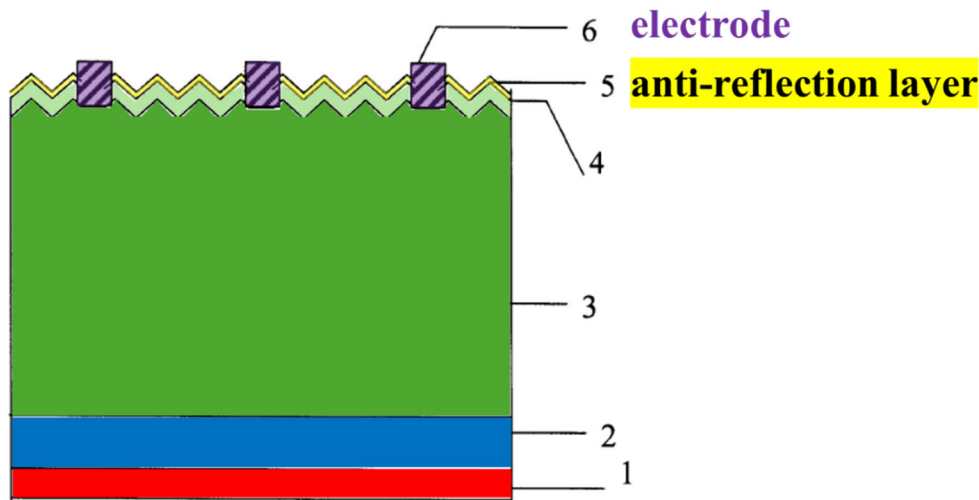
Li's backside PN junction (with a reasonable expectation of success) to incorporate a polysilicon emitter and oxide layer as taught by Gan.

2. Claim 9

- a. Element 9[pre]: a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side**

278. Li teaches *a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side.*

279. As shown in Figure 1 of Li below, Li teaches a solar cell that includes a “front surface” and a “back surface.” Ex.1008-Li, Abstract, 4, Fig., claims 1-3. A person of ordinary skill in the art would have known that the “front surface” faced the sun to collect solar radiation during normal operation. A person of ordinary skill in the art would have known that the front surface was opposite to the back surface, as solar cells typically were configured. Furthermore, Li's figure confirms that its “front surface” is the sun-facing side because it has a textured surface (jagged edges), an **anti-reflection layer 5**, and a front **electrode 6** that does not cover the entire surface, all of which were designed for the solar cell to receive more sunlight. Ex.1008-Li, 4, Fig.1.



Ex.1008-Li, Fig.1.

b. Element 9[a]: a substrate having a textured front surface

280. Li teaches *a substrate having a textured front surface*. As I explained in Section VII.A.4 (Overview of Solar Cells – Texturing and Anti-reflective Coating), texturing the front surface of the substrate was a routine and typical process applied to solar cells. Li likewise teaches this well-known and common feature.

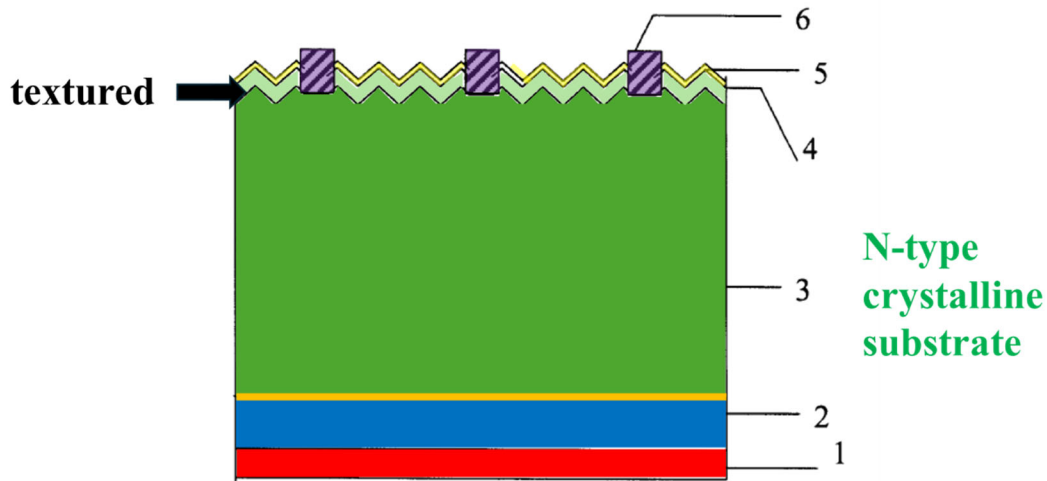
281. Li teaches that the surfaces of the **N-type crystalline [substrate] 3** are “*textured* by a standard industrial process.” Ex.1008- Li, 4, claim 2 (“[T]he solar

cell is structurally a positive electrode^[13]/anti-reflection layer/*surface textured N-type crystalline silicon*/silicon thin film/back electrode.”). Li explains the “*texturing treatment*” is used “to reduce light reflection and improve a light trapping effect, which is conducive to improving the photoelectric conversion efficiency of the cell.”

Ex.1008- Li, 4.

282. In addition to the text description, the textured surface is also shown in Li’s modified figure (Li and Gan combined), below, by the jagged edges on the front side of the solar cell, as was commonly done to graphically depict texturing. *E.g.*, Ex.1018-Nelson, 188; Ex.1024-Borden-578, Fig.1A; Ex.1007-Smith, Fig.7; *see also* Ex.1001-USP516, Fig.1. Thus, Li teaches *a substrate having a textured front surface*.

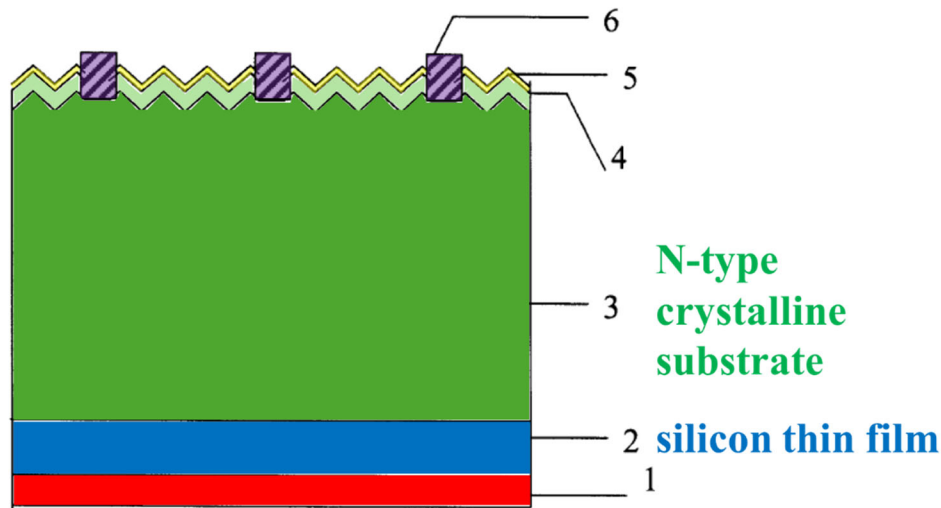
¹³ As discussed in Section X.D (Overview of the Prior Art – Li), a person of ordinary skill in the art would have understood that Li’s reference to “positive electrode” was a typographical error, as a person of ordinary skill in the art would have understood that Li’s “positive electrode” was a “negative electrode.”



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245, 249.

- c. **Element 9[b]: an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate**

283. Li teaches *an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate*. Li teaches “[a] **layer of silicon thin film [2]** is deposited on a back surface of **N-type crystalline silicon** to form an emitting region” (i.e., the **silicon thin film** is *formed over a back surface of the substrate*). Ex.1008-Li, 4, Abstract, claims 1, 3 and 5, Fig.1. Li teaches that **the layer of silicon thin film 2** is “P-type.” Ex.1008-Li, 4, claim 6.



Ex.1008-Li, Fig.1.

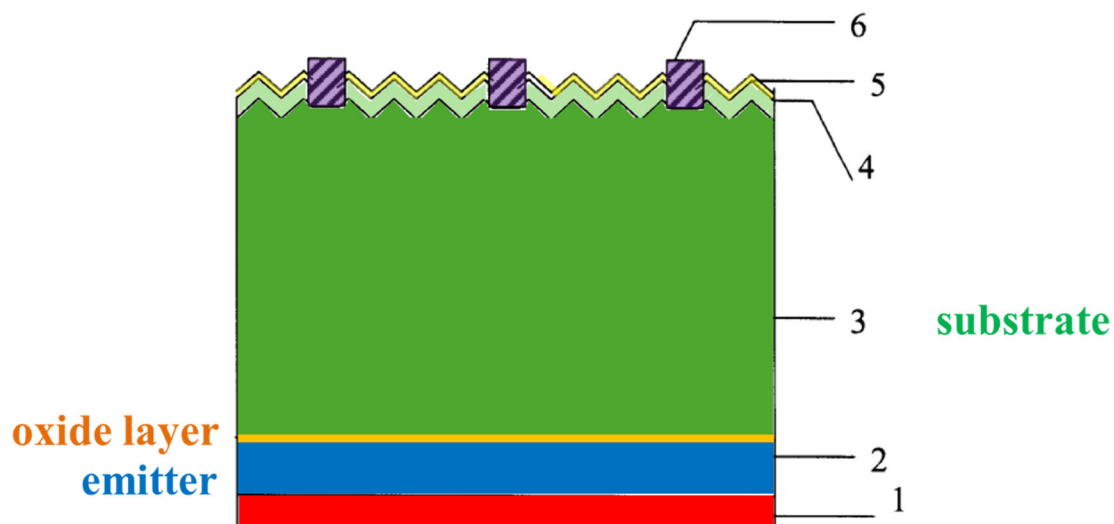
284. A person of ordinary skill in the art would understand that depositing the emitter region on the “back surface” forms a *backside junction* with the N-type silicon substrate because the emitter is located on the backside of the solar cell and is oppositely doped from the substrate. Ex.1008-Li, 3 (“[A] PN junction is placed on the back surface of the cell.”); *see also* Ex.1001-USP516, 1:46-48 (“backside junction” exists when an emitter is located on the backside of the solar cell and has an opposite dopant than the substrate). Li teaches this element.

d. Element 9[c]: an oxide layer formed between the back surface of the substrate and the emitter layer

285. The Li and Gan combination teaches *an oxide layer formed between the back surface of the substrate and the emitter layer*.

286. As discussed in Section XI.A.2.d (Ground I, Element 9[c]), Gan teaches a solar cell test structure that includes a “polysilicon emitter with a thermally grown interfacial oxide” over a silicon substrate. Ex.1005-Gan, 245. Gan teaches that this oxide layer between a p-type polysilicon emitter and a silicon substrate would improve cell efficiency. Ex.1005-Gan, 249.

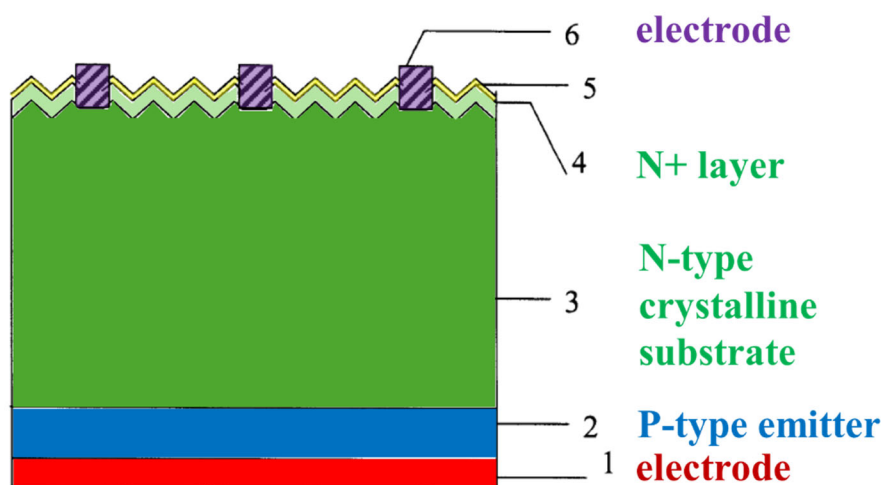
287. As I explained in Section XI.E.1 (Ground V, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to incorporate Gan’s *oxide layer formed between the back surface of the substrate and the emitter layer*, and would have had a reasonable expectation of success in making this modification. As shown in the following modified Li Figure, the modification would have been a simple exchange of Li’s deposited emitter with Gan’s oxide layer and polysilicon emitter (also a deposited emitter):



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245, 249. Thus, the combination of Li and Gan teaches *an oxide layer formed between the back surface of the substrate and the emitter layer* on the back side of the solar cell.

- e. **Elements 9[d]-9[e]: a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell**

288. Li teaches *a first metal contact making an electrical connection to the substrate on the front side of the solar cell and a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell*. Li's solar cell includes a front "**electrode**." Ex.1008-Li, 4. A person of ordinary skill in the art would have understood, as shown in Li's Figure, that the **electrode** is electrically connected to the **N-type crystalline silicon substrate 3** (i.e., *substrate*) via the highly doped **N+ layer 4**. Ex.1008-Li, 4, Fig.1. Li's solar cell also includes a rear **electrode 1 (red)** on the back of a **silicon thin film 2** (i.e., *emitter layer*). Ex.1008-Li, 4, Fig.1. As discussed in Section X.D (Overview of the Prior Art – Li), Li's emitter is a P-type emitter. Thus, as shown below, the rear **electrode 1 (red)** would be electrically connected to the **P-type emitter**.



Ex.1008-Li, Fig.1.

289. A person of ordinary skill in the art would have understood that Li's "electrodes" were *metal contacts*. For instance, Li explains that "a *metal electrode* layer [1] on the back surface can re-reflect light that penetrates the cell back into the cell." Ex.1008-Li, 4; *see also* 3 (discussing the "front surface structure" of background art as having "a metal grid"). A person of ordinary skill in the art would have known that metal electrodes were common in solar cells at the time because electrodes of conductive materials like metal are required for a solar cell to function. Gan also teaches forming metal contacts. Ex.1005-Gan, 246 ("Metal finger definition").

f. Element 9[f]: the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell

290. Li teaches *the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell.*

291. It was well known that metal contacts on solar cells were used to transfer the generated electrical current to external circuits. Ex.1016-Komp, 14, 154-55. Li's solar cells likewise implement this basic feature of practically any solar cell. Li explains that its solar cell pertains to "solar energy applications." Ex.1008-Li, 3. Li's design sought to improve "efficiency" over other cells, and is disclosed as reaching an efficiency of "20% or above." Ex.1008-Li, Abstract, 2-4. Efficiency is an indicator of how much power a solar cell can deliver to an external electrical circuit. Moreover, the '516 patent itself acknowledges that metal contacts "allow[ed] an external electrical circuit to be coupled to and be powered by the solar cell." Ex.1001-USP516, 1:25-29. As a result, a person of ordinary skill in the art would have readily understood that Li teaches a solar cell (with the contacts) *configured to allow an external electrical circuit to be powered by the solar cell*, as otherwise the solar cell's efficiency would be irrelevant as its generated energy could not be put to use.

292. The combination of Li and Gan renders claim 9 obvious, as I discussed above.

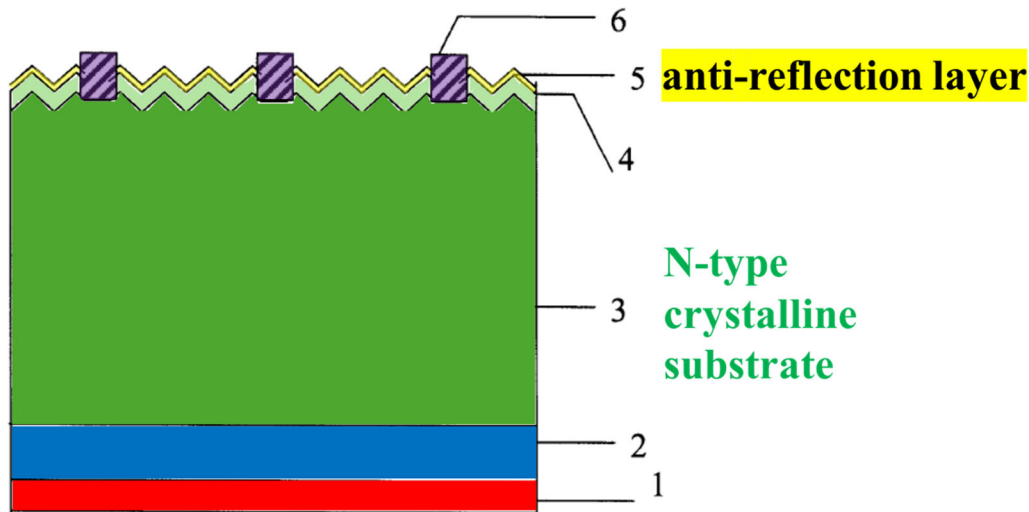
3. **Claim 10: The solar cell of claim 9 further comprising an antireflective layer over the textured front surface of the substrate**

293. Claim 10 depends from claim 9. Therefore, I incorporate by reference my discussion of Claim 9 in Section XI.E.2 (Ground V, Claim 9).

294. As I have discussed, an antireflective layer over the textured front surface of a substrate was a standard solar cell feature by 2008. *See* Section VII.A.4 (Overview of Solar Cells – Texturing and Anti-reflection Coating). As such, Li also teaches this routine structure.

295. Li teaches *an antireflective layer over the textured front surface of the substrate*. As I discussed in Section XI.E.2.b (Ground V, Element 9[a]), Li teaches that the **N-type crystalline silicon substrate 3** has a *textured front surface*. Moreover, Li teaches “[a]n *anti-reflection film* can be prepared on the texturing surface to further improve the photoelectric conversion efficiency of the cell.” Ex.1008-Li, 4, claim 2. Li’s figure, below, shows a solar cell with an **anti-reflection layer 5** over the textured front surface. The **anti-reflection layer 5** can be a material such as SiN or SiO₂. Ex.1008-Li, 2. A person of ordinary skill in the art would have understood that SiN or SiO₂ were commonly used as an antireflective layer. *E.g.*,

Ex.1018-Nelson, 188 (“Suitable materials for silicon [AR coating include]...silicon nitride (Si_3Ni_4)”).



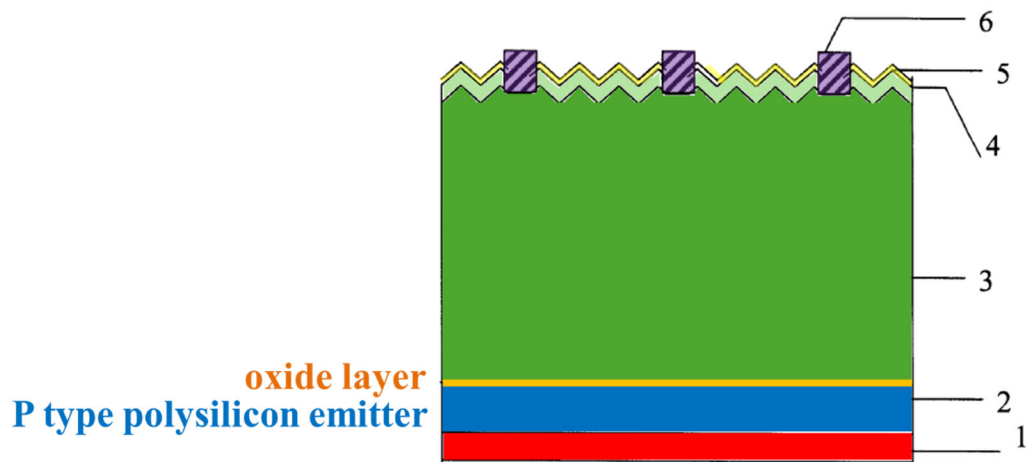
Ex.1008-Li, Fig.1.

4. **Claim 11: The solar cell of claim 9 wherein the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon.**

296. Claim 11 depends from claim 9. Therefore, I incorporate by reference Section XI.E.2 (Ground V, Claim 9)

297. The combination of Li and Gan further teaches the substrate comprises an N-type *silicon substrate* and the emitter layer comprises a *P-type doped polysilicon*. As explained in Section XI.E.2.c (Ground V, Element 9[b]), Li teaches “[a] **layer of silicon thin film [2]** is deposited on a back surface of N-type monocrystalline silicon to form an emitting region.” Ex.1008-Li, 4, Abstract, claims 1, 3 and 5, Fig.1. Li explains that **the layer of silicon thin film 2** (i.e. *emitter layer*)

is “P-type.” Ex.1008-Li, 4, claim 6. As explained in Section XI.A.2 (Ground I, Claim 9), Gan teaches *the emitter layer comprises a P-type doped polysilicon*. A person of ordinary skill in the art would have been motivated to implement Gan’s **P-type doped polysilicon emitter** as shown in the modified Li Figure:



Ex.1008-Li, Fig.1; Ex.1005-Gan, 245, 249.

5. Claim 1

a. Elements 1[pre]-1[d]

298. As discussed in Sections XI.E.2.a-c (Ground V, Elements 9[pre]-9[b]) and XI.E.3 (Ground V, Claim 10), the combination of Li and Gan teach and render obvious *a solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising: an N-type silicon substrate; a textured surface on the N-type silicon substrate on the front side of the solar cell; an antireflective layer over the textured*

surface of the N-type silicon substrate; a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate. Therefore, I incorporate by reference Sections XI.E.2.a-c (Ground V, Elements 9[pre]-9[b]) and XI.E.3 (Ground V, Claim 10).

b. Element 1[e]: an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate

299. The combination of Li and Gan teaches *an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate.* As described in Section XI.A.6.f (Ground I, Element 1[e]), Gan teaches an *oxide layer* between a p-type polysilicon emitter and n-type substrate. As discussed in Section XI.E.2.c (Ground V, Element 9[b]), Li teaches a P-type emitter and N-type silicon substrate.

300. As discussed in Section XI.E.1 (Ground V, Motivation to Combine), a person of ordinary skill in the art would have been motivated to modify Li to incorporate Gan, specifically by adding an *oxide layer on the back surface of Li's N-type substrate* and replacing Li's *P-type emitter* with a *P-type polysilicon emitter*. A person of ordinary skill in the art would have had a reasonable expectation of successfully implementing such a change. See Section XI.E.1 (Ground V, Motivation to Combine). Thus, the combination of Li and Gan teaches this element.

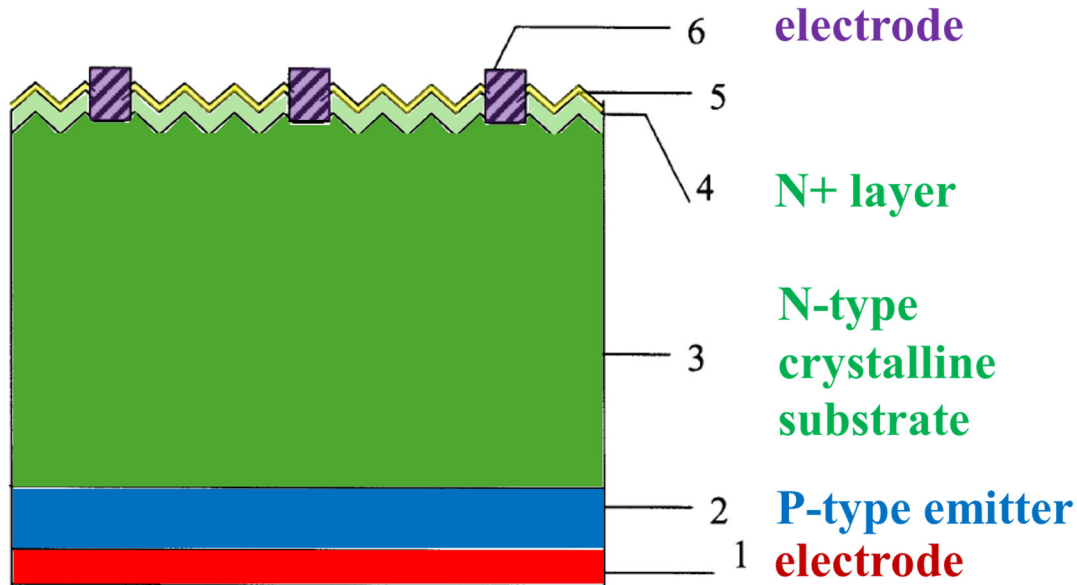
- c. **Elements 1[f]–1[g]: a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell and a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell.**

301. Li teaches *a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell and a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell.*

302. As discussed in Section XI.E.2.e (Ground V, Elements 9[d]-[e]), Li teaches an **electrode** that is electrically connected to the **N-type crystalline silicon substrate 3** on the solar cell's front side. Ex.1008-Li, 4. Li's solar cell also includes an **electrode 1 (red)** on the back of a **silicon thin film 2** (i.e., *emitter*) at the solar cell's backside. As discussed in Section VII.A.3 (Overview of Solar Cells – Metal Contacts), a person of ordinary skill in the art would have understood “electrode” to mean metal contact. As discussed in Section XI.A.2.c (Ground I, Element 9[b]), Gan's emitter is a P-type polysilicon emitter.

303. Moreover, a person of ordinary skill in the art would have understood that Li's front **electrode** is a *negative polarity metal contact*, and Li's back **electrode** is a *positive polarity metal contact*. Although Li states that the front **electrode** is “positive” and the back **electrode** is “negative,” a person of ordinary skill in the art

would have understood “positive” and “negative” to be inadvertently switched in Li as I explained in Section X.D (Overview of the Prior Art – Li). *See* Section X.D; Ex.1008-Li, 4. Basic physics dictates the polarity of the electrode necessarily matches that of the solar cell layer to which it is connected, meaning that the “N” connects to “N” and the “P” connects to “P.” Ex.1016-Komp, 14-18. Li’s N-type front substrate connected to a positive electrode (“N” connected to “P”) and P-type back emitter connected to a negative electrode (“P” connected to “N”) would not function as intended because the “positive” electrode would become negatively charged and the “negative” electrode would become positively charged when the solar cell was illuminated. Ex.1016-Komp, 14-18. However, a person of ordinary skill in the art would have noticed this typographical error in Li and would have simply made the correction. *See* Section VII.A.3 (Overview of Solar Cells – Metal Contacts).



304. Accordingly, claim 1 is obvious over the combination of Li and Gan.

6. **Claim 2: The solar cell of claim 1 wherein the antireflective layer comprises a layer of silicon nitride.**

305. Claim 2 depends from claim 1. Therefore, I incorporate Section XI.E.5 (Ground V, Claim 1) by reference.

306. The combination of Li and Gan further teaches *the antireflective layer comprises a layer of silicon nitride*. As I discussed in Section XI.E.3 (Ground V, Claim 10), Li teaches that its *anti-reflection layer* is made from *silicon nitride*.

7. **Claim 8: The solar cell of claim 1 wherein the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate.**

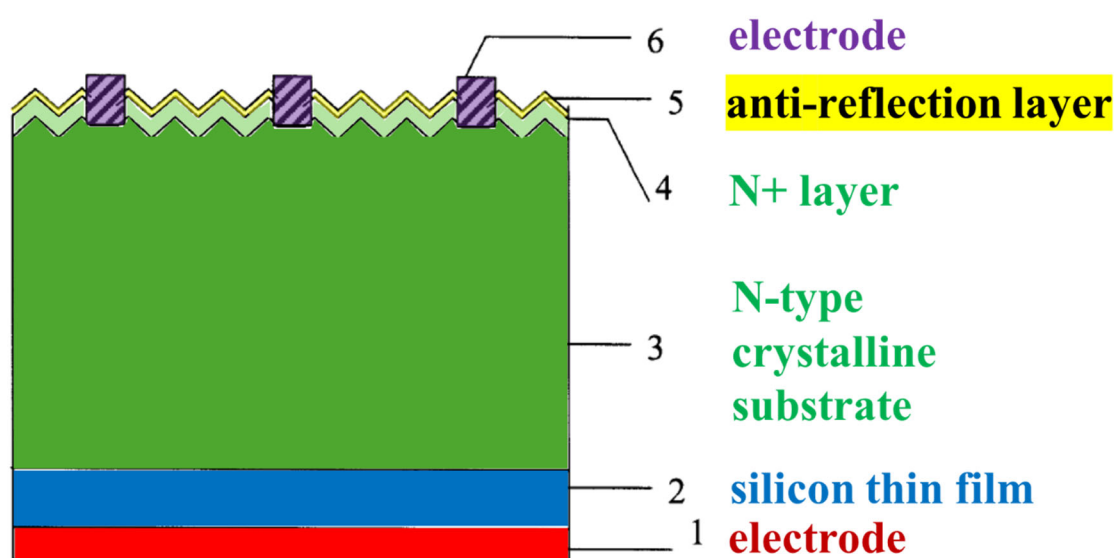
307. Claim 8 depends from claim 1. Therefore, I incorporate Section XI.E.5 (Ground V, Claim 1) by reference.

308. The combination of Li and Gan further teaches that *the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate*. Li teaches a solar cell with a **highly doped N+ layer 4** that is formed on the front side of the **N-type crystalline silicon substrate 3**. Ex.1008-Li, 4, Fig.1. Li's **highly doped N+ layer 4** is used "for passivating the front surface of a cell by using changes in doping concentration and for providing good ohmic contact to a front surface electrode." Ex.1008-Li, 4. A person of ordinary skill in the art would have known and understood that the front **electrode** makes an electrical connection with the **N-type crystalline silicon substrate 3** through the **highly doped N+ layer 4** because the **highly doped N+ layer 4** is "first diffused on the front surface" of the **N-type crystalline silicon substrate 3**, meaning, the **highly doped N+ layer 4** is part of the **N-type crystalline silicon substrate 3**. Ex.1008-Li, 4. Without such an electrical connection, the solar cell would not generate usable electricity.

309. Li also teaches that **anti-reflection layer 5**, which may be made of an electrically insulating dielectric such as SiN or SiO₂, is deposited or grown on the **highly doped N+ layer 4**. Ex.1008-Li, 4. Then, the front **electrode 6** is "prepared on" the **anti-reflection layer 5**. Ex.1008-Li, 4. Because the **anti-reflection layer 5** is first deposited and then the **electrode 6** is added, a person of ordinary skill in

the art would have known that a *contact hole* has to be present in the **anti-reflection layer 5** in order for the **electrode 6** to make contact with the **highly doped N+ layer 4** (and thus with the **N-type crystalline silicon substrate 3**). That is, the **electrode 6** must go through the electrically insulating anti-reflection coating. As I explained in Section VII.A.3 (Overview of Solar Cells – Metal Contacts), the most common way to achieve the contact was to make the electrode by screen printing of metal paste and then “firing through” the anti-reflection coating. *E.g.*, Ex.1045-Green-1995, Chapter 11.2; Ex.1020-Luque, 277-278; Ex.1022-Meier, 7:10-12; Ex.1018-Nelson, 188; *see also* Section VII.A.3 (Overview of Solar Cells – Metal Contacts).

310. A person of ordinary skill in the art would have therefore known that Li teaches that its front **electrode 6** (i.e., *negative polarity metal contact*) is formed in a *contact hole* (in the **anti-reflection layer 5**) to the **N-type silicon substrate 3**.



XII. SECONDARY CONSIDERATIONS

311. As I explained in Section III (Legal Principles), I understand that secondary considerations may support or rebut the obviousness of a claim. I am not aware of any secondary considerations that support that the claims of the '516 patent are nonobvious. To the extent Patent Owner argues that secondary considerations are relevant here, I reserve the right to respond.

XIII. AVAILABILITY FOR CROSS-EXAMINATION

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

XIV. RIGHT TO SUPPLEMENT

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

XV. JURAT

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

Dated: August 8, 2024

/s/  _____
Zachary C. Holman, Ph.D

Declaration of Dr. Zachary Holman
Appendix A (Curriculum Vitae)

APPENDIX A

ZACHARY CHARLES HOLMAN

Professor and Vice Dean

School of Electrical, Computer, and Energy Engineering
Arizona State University
Tempe, AZ 85287-5706

Phone: (480) 965-9959
Fax: (480) 965-3837
zachary.holman@asu.edu

APPOINTMENTS

08/2023–	Vice Dean for Research and Innovation Ira A. Fulton Schools of Engineering, Arizona State University (Tempe, Arizona)
08/2023–	Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
08/2019–07/2023	Associate Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
08/2019–06/2023	Director of Faculty Entrepreneurship Ira A. Fulton Schools of Engineering, Arizona State University (Tempe, Arizona)
06/2021–	Cofounder Beyond Silicon, Inc. (Chandler, Arizona)
03/2020–	Cofounder Sunflex Solar LLC (Phoenix, Arizona)
07/2016–	Cofounder and Chief Technology Officer Swift Coat, Inc. (Tempe, Arizona)
03/2013–07/2019	Assistant Professor School of Electrical, Computer, and Energy Engineering, Arizona State University (Tempe, Arizona)
07/2014–08/2014	Visiting Professor Photovoltaics and Thin-Film Electronics Laboratory, Institute of Microengineering, Ecole Polytechnique Fédérale de Lausanne (Neuchâtel, Switzerland)
10/2010–03/2013	Postdoctoral Researcher Photovoltaics and Thin-Film Electronics Laboratory, Institute of Microengineering, Ecole Polytechnique Fédérale de Lausanne (Neuchâtel, Switzerland)

EDUCATION

10/2010	Doctor of Philosophy Mechanical Engineering; Nanoparticle Science and Engineering (minor), University of Minnesota (Minneapolis, Minnesota) Dissertation: <i>Germanium nanocrystal solar cells</i> ; Advisor: Prof. Uwe Kortshagen
05/2005	Bachelor of Arts Physics, Reed College (Portland, Oregon) Thesis: <i>Electron transport in amorphous silicon</i> ; Advisor: Prof. John Essick

RESEARCH INTERESTS

Broad research interests span the fields of solar cells, coatings, nanotechnology, semiconductors, plasmas, and aerosols. Specific interests include silicon-based tandem solar cells, contacts to solar cells, light management

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

in solar cells, novel uses of nanoparticles in devices, semiconductor nanoparticles, optical and electronic properties of nanoscale materials, plasma synthesis of powders, and deposition of powders and thin films.

AWARDS & HONORS

2023	ASU Fulton Schools of Engineering Top 5% Teaching Award
2022	Hopkins Professorship
2021	American-Made Perovskite Startup Prize Winner
2020	American-Made Solar Prize Winner
2019	IEEE Stuart R. Wenham Young Professional Award
2019	NSF CAREER Award
2018	Gordon and Betty Moore Foundation Inventor Fellowship
2018	Fulton Entrepreneurial Professorship
2017	ASU Fulton Schools of Engineering Top 5% Teaching Award
2016	Trustees of ASU Professorship
2016	Joseph C. Palais Distinguished Faculty Scholar Award
2016	Fulton Outstanding Assistant Professor Award
2015	ASU Fulton Schools of Engineering Top 5% Teaching Award
2014	ASU Senior Sustainability Scientist
2013	3 rd International Conference on Crystalline Silicon Photovoltaics top 5% of papers
2010	NSF EAPSI Fellowship at the Tokyo Institute of Technology
2010	University of Minnesota Doctoral Dissertation Fellowship
2008	Particle Society of Minnesota Scholarship
2007	18 th International Symposium on Plasma Chemistry Best Paper Award
2005	NSF IGERT Fellowship at the University of Minnesota

AWARDS WON BY STUDENTS AND POSTDOCS

2023	Bernard Henry AIMCAL-SVC Scholarship (Zach Leuty)
2022	ARCS (Achievement Awards for College Scientists) Award (David Quispe)
2022	Hool Coury Law Tech Venture Challenge Winner (Wahab Alasfour, Zach Leuty, David Quispe)
2021	ASU Presidential Graduate Assistantship (Vidya Krishnan)
2021	NSF Graduate Research Fellowship (David Quispe)
2021	American-Made Perovskite Startup Prize Winner (Jason Yu, Wahab Alasfour, Zach Leuty, David Quispe)
2020	American-Made Solar Prize Winner (Kate Fisher, Jason Yu, Barry Hartweg)
2020	ASU Dean's Fellowship (Mason Mahaffey)
2020	NSF Graduate Research Fellowship (Justin Huxel)
2020	QESST Best Paper Award (Zachary Leuty)
2019	SiliconPV Best Poster Award (William Weigand and Jason Yu)
2018	ASU Dean's Fellowship (Barry Hartweg)
2018	Palais' Outstanding Doctoral Student Award (Jason Yu)
2018	Venture Madness Hardware Tech Winner (Peter Firth)

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

2017	European PV Solar Energy Conference and Exhibition Student Award (Jason Yu)
2017	IEEE Photovoltaic Specialists Conference Most Outstanding Technical Contribution (Jason Yu)
2017	MRS Graduate Student Silver Award (Jason Yu)
2017	Rice Business Plan Competition Department of Energy Cleantech University Prize (Peter Firth and Jonathan Bryan)
2017	ASU Innovation Open SRP Innovation Award (Peter Firth)
2017	SiliconPV Award (Jason Yu)
2017	SiliconPV Award (Mathieu Boccard)
2017	ASU Graduate and Professional Student Association Research Award (Jason Yu)
2017	ThinkSwiss Research Scholarship (Nathan Rodkey)
2017	ARCS (Achievement Awards for College Scientists) Award (Peter Firth)
2017	Zero Mass Water Materials Award (Peter Firth)
2017	DOE Science Undergraduate Laboratory Internship at NREL (Nathan Rodkey)
2017	Rhodes Scholarship (Ngoni Mugwisi)
2016	Palais Senior Design Prize (Heliovation senior design team)
2016	Arizona Student Energy Conference Distinguished Poster Award (Jason Yu)
2016	IEEE Photovoltaic Specialists Conference Best Paper Award (Mathieu Boccard)
2016	IEEE Photovoltaic Specialists Conference Best Poster Award (Mathieu Boccard)
2016	ASU Dean's Fellowship (Will Weigand)
2016	ASU Dean's Fellowship (Jonathan Bryan)
2016	ASU New Venture Challenge Winner (Peter Firth)
2016	ARCS (Achievement Awards for College Scientists) Award (Peter Firth)
2016	Micron Technology Team Prize (Hall Effect senior design team)
2015	IEEE Photovoltaic Specialists Conference Best Poster Award (Jason Yu)
2015	Harold and Lucille Dunn Memorial Engineering Scholarship (Jason Yu)
2015	Barrett Electronic Materials Fellowship (Peter Firth)
2015	ASU Dean's Fellowship (Peter Firth)
2015	Arizona Student Energy Conference Distinguished Poster Award (Priyaranga Koswatta)
2015	NSF Graduate Research Fellowship (Joe Carpenter)
2014	NSF Integrative Graduate Education and Research Traineeship (Michael Bernstein)
2014	NSF Integrative Graduate Education and Research Traineeship (Joe Carpenter)
2014	University Graduate Fellowship (Salman Manzoor)

PROFESSIONAL ACTIVITIES & OUTREACH

- Editor of the IEEE Journal of Photovoltaics (2022–)
- Member of the Industry Liaison Committee for the World Conference on Photovoltaic Energy Conversion (2022)
- Member of the Program Committee for the IEEE Photovoltaic Specialists Conference (2020)
- Member of the Organizing Committee for the International Workshop on Silicon Heterojunction Solar Cells (2019, 2020)
- Symposium Organizer for the E-MRS Spring Meeting (2017)
- Symposium Organizer for the IEEE Photovoltaic Specialists Conference (2016, 2017, 2018, 2021)
- Symposium Organizer or Lead Symposium Organizer for the MRS Spring Meeting (2015, 2016, 2018)

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

- Session Chair for IEEE Photovoltaic Specialists Conference, MRS Spring Meeting, SiliconPV (2013–)
- Member of the Fulton Schools of Engineering Dean’s Research Committee (2017–2019)
- Member of the Fulton Schools of Engineering Master Mentors (2019–)
- Co-leader of Thrust 2 of the Quantum Energy and Sustainable Solar Technology ERC (2015–2020)
- Member of the ASU Goldwater Materials Science Facility Steering Committee (2014–2016)
- Member of the ASU Leadership Academy Materials Team (2015–2016)
- Member of the ASU University Undergraduates Standards Committee (2015–2017)
- Member of the ASU Instrument Design and Fabrication Board (2016–2019; 2020–)
- Member and Chair of the ASU Advanced Electronics and Photonics Core Facility Board (2020–)
- Member of the ASU Solar Fabrication Core Facility Board (2021–)
- Member of the ASU Eyring Materials Center Board (2017–2021)
- Member or Chair of an ASU ECEE Faculty Search Committee (2015, 2018, 2020, 2021, 2022)
- Member of the ASU ECEE Website Design Committee (2015, 2019)
- Member of the ASU Faculty Working Group for the MS degree in Innovation and Venture Development
- Designer and instructor of a new course entitled *EEE 598: Manuscript Writing for Engineers*
- Reviewer for funding bodies, including NSF and DOE, and journals, including *Journal of Applied Physics*, *ACS Nano*, *Solar Energy Materials and Solar Cells*, *Thin Solid Films*, *Nanotechnology*, *IEEE Journal of Photovoltaics*
- Volunteer Scientist for ASU’s Night of The Open Door, ASU’s Summer Transportation Institute, Cesar Chavez High School, Minnesota FIRST LEGO League, and the Science Museum of Minnesota

FUNDING

11/2023–10/2028	NSTXL Microelectronics Commons, “Southwest Advanced Prototyping (SWAP) Hub,” (Co-PI)
10/2023–05/2027	DOE SETO, “TEAMUP: Tandems for efficient and advanced modules using ultrastable perovskites,” (Co-PI)
07/2023–04/2024	DOE BES SBIR, “Development of new metallization pastes for front-side tunnel oxide passivated contact crystalline silicon solar cells,” (Co-PI)
07/2023–06/2024	TSMC, confidential project, (PI)
04/2023–03/2024	Applied Materials, confidential project, (PI)
10/2022–10/2023	DOE SETO, “PV Foundry: Increasing manufacturing innovation and capabilities in the US,” (PI)
09/2022–08/2024	US Department of State, “GIST Innovates the Balkans,” (Co-PI)
11/2021–10/2026	USAID, “Center of Excellence for Energy,” (Co-PI)
11/2021–10/2022	AZ New Economy Initiative, “Suns-ERE: A characterization tool to accelerate the learning cycle of thin-film photovoltaics,” (PI)
10/2021–09/2024	EDA Build to Scale, “Arizona semiconductor industry startup entrepreneurial development project,” (Co-PI)
10/2021–11/2025	DOE SETO, “Manufacturing 27%-efficient perovskite/silicon tandem photovoltaic cells using slot die coating at >5000 wafers per hour,” (Co-PI)
04/2021–03/2024	DOE SETO, “The role of hydrogen in the performance and long-term stability of high-efficiency silicon cells and modules,” (Co-PI)

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

01/2021–12/2022	Sunflex Solar, “Scaling Sunfoil solar modules,” (PI)
08/2020–08/2020	Corporate gift (PI)
04/2020–03/2023	DOE SETO, “Sonic Wafering™ of III-V substrates for high efficiency cells: A path to <\$0.50/W,” (Co-PI)
10/2019–09/2020	US Government, “Flexible and advanced solar panel technologies,” (PI)
08/2019–07/2021	NSF, “Center to center (C2C) international collaboration on advanced photovoltaics: Electrode manufacturing and indoor power applications,” (Co-PI)
08/2019–07/2022	DOE SETO, “Scalable manufacturing of efficient perovskite/silicon tandem modules,” (Co-PI)
03/2019–02/2024	NSF CAREER, “CAREER: Transparent, passivating, and carrier-selective heterojunction contacts for silicon and cadmium telluride solar cells,” (PI)
01/2019–12/2021	DOE SETO, “Diagnosing and overcoming recombination and resistive losses in non-silicon solar cells using a silicon-inspired characterization platform,” (PI)
01/2019–12/2021	DOE SETO, “Bringing high-efficiency silicon solar cells with heterojunction contacts to market with a new, versatile deposition technique,” (PI)
01/2019–06/2020	DOE SETO, “Wide-bandgap polycrystalline III-Vs as transparent, carrier-selective heterojunction contacts for silicon photovoltaics,” (Co-PI)
01/2019–12/2020	NREL, “ASU-NREL joint silicon solar cell research: passivated contacts, metallization, and bulk defects,” (PI)
01/2019–12/2021	ARPA-E DAYS, “Solid state thermal battery,” (Co-PI)
01/2019–12/2019	FSE/CLAS/AMI Seed, “MRSEC planning and preliminary data collection,” (Co-PI)
10/2018–09/2020	Fulton Entrepreneurial Professors Program, “Aerosol impaction-driven assembly of functional nanomaterial coatings,” (PI)
10/2018–09/2021	Moore Foundation Inventor Fellowship, “Aerosol impaction-driven assembly of functional nanomaterial coatings,” (PI)
10/2018–09/2019	FSE/CLAS/AMI Seed, “Diamond and III-nitride integration for ultra-gap devices,” (PI)
06/2018–05/2019	NSF SBIR, “Non-thermal plasma source for functional metal-oxide nanoparticle coatings,” (Co-PI)
02/2018–09/2018	NREL, “PERC and SHJ silicon solar modules with high infrared reflectance,” (Co-PI)
01/2018–01/2021	ARENA, “Hydrogenated and hybrid heterojunction p-type silicon PV cells R&D project,” (Co-PI)
10/2017–09/2020	DOE PVRD-II, “Perovskite-on-silicon tandem solar cells,” (Co-PI)
10/2017–05/2020	DOE DuraMAT, “Silicon IBC modules with copper foil electrodes: Failure mechanisms of electrically conductive adhesive bonds between cells and foil,” (PI)
10/2017–09/2018	BAPVC, “Low capex solar manufacturing enabled by perovskite semiconductors,” (Co-PI)
08/2017–01/2019	ACAP, “P-type hybrid heterojunction solar cells,” (Co-PI)
05/2017–04/2019	NSF EAGER, “Collaborative research: 30%-efficient, stable perovskite/silicon monolithic tandem solar cells,” (PI)

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

02/2017–04/2017	NSF SBIR, “The aerosol-spray deposition of photoluminescent quantum-dot coatings on substrates,” (Co-PI)
01/2017–12/2019	ARPA-E SHIELD, “Single-pane windows with insulating sprayed particulate coatings,” (PI)
12/2016–11/2017	NSF SBIR, “Low damage sputter magnetron for silicon heterojunction PV production,” (Co-PI)
11/2016–10/2018	DOE NextGen-III, “Developing efficient silicon cells for perovskite/silicon tandem devices,” (Co-PI)
09/2016–08/2017	American Jobs Project, “Arizona’s advanced energy landscape,” (PI)
08/2016–07/2019	DOE PVRD, “Monolithic silicon module manufacturing at < 0.40 \$/W,” (PI)
08/2016–07/2018	DOE PVRD, “15%-efficiency (Mg,Zn)CdTe solar cells with 1.7 eV bandgap for tandem applications,” (PI)
08/2016–07/2017	SolarReserve, “Hybrid heliostat development,” (PI)
07/2016–01/2017	FSE Technology Innovation Laboratory, “Advanced manufacturing of nanoparticle-based coatings,” (PI)
06/2016–05/2017	DOE PVRD SIPS, “A new class of tandems: Optically coupled III-V/silicon module with outdoor efficiency exceeding 30%,” (PI)
05/2016–11/2016	FSE Technology Innovation Laboratory, “Hybrid heliostat for combined photovoltaic and solar thermal power plants,” (PI)
04/2016–03/2019	NSF REU Site, “Solar energy research for the Terawatt Challenge,” (PI)
01/2016–12/2018	DOE SuNLaMP, “Overcoming bottlenecks to low-cost, high-efficiency Si PV and industrially relevant, ion implanted interdigitated back passivated contact cell development,” (Co-PI)
09/2015–08/2018	NSF Energy for Sustainability, “Collaborative research: 30%-efficient III-V/silicon tandem solar cells,” (PI)
08/2015–07/2020	NSF ERC, “Nano-Enabled Water Treatment: NEWT,” (Co-PI)
06/2015–05/2020	USAID, “U.S.-Pakistan Centers for Advanced Studies in Energy,” (Co-PI)
05/2015–04/2016	ARPA-E I-Corps Supplement, “PVMirror: Cost competitive solar with storage,” (PI)
02/2015–01/2017	RCSA Scialog, “Scalable tandem architecture for solar water splitting,” (PI)
06/2014–05/2017	ARPA-E FOCUS, “PVMirror: A solar concentrator mirror incorporating PV cells,” (PI)
09/2013–08/2016	DOE FPACE-II, “Thin silicon solar cells: A path to 35% Shockley-Queisser limits,” (Co-PI)
08/2011–07/2021	NSF/DOE ERC, “Quantum Energy and Sustainable Solar Technologies: QESST,” (Co-PI)
06/2010–08/2010	NSF EAPSI, “Novel solar cells using silicon nanocrystals synthesized in an atmospheric-pressure plasma,” (PI)

STUDENTS, POSTDOCS, AND STAFF ADVISED

• Ph.D.:	Ashling Leilaoui (2013–2018)	Jianwei Shi (2013–2018)
	Jason Yu (2014–2018)	Salman Manzoor (2014–2019)
	Joe Carpenter (2014–2020)	Peter Firth (2015–)

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

- | | | |
|---------------------|---|--|
| | Jonathan Bryan (2016–2021) | William Weigand (2016–2023) |
| | Barry Hartweg (2018–2023) | Warda Mushtaq (2018–) |
| | Zachary Leuty (2019–) | Abdulwahab Alasfour (2019–) |
| | David Quispe (2019–) | Mark Li (2019–) |
| | Alan Wu (2019–2021) | Mason Mahaffey (2020–) |
| | Vidya Krishnan (2021–) | Maria Garcia (2021–) |
| | Jason Ro (2022–) | |
| • M.S.: | Salman Manzoor (2013–2014) | Prateek Garg (2013–2015) |
| | Priyaranga Koswatta (2013–2016) | Peter Firth (2014–2015) |
| | Michael Bernstein (2014–2016) | Alec Jackson (2014–2016) |
| | Trent Hoffman (2016–2017) | Sujyot Mony (2018–2019; MORE) |
| | Sagnik Dasgupta (2019–2020) | |
| • Undergraduate: | Claire Block (2017–2018) | Joe Carpenter (2013–2014; FURI) |
| | Christopher Chen (2017–2019) | Angelo Delluomo (2015–2016; FURI) |
| | Angelica Guzman (2018–2019; FURI) | Justin Huxel (2017–2019; FURI) |
| | Sanketh Kamath (2013–2015; FURI) | Mark Kapron (2017–2018; FURI) |
| | Ngoni Mugwisi (2016–2017; Barrett) | Corbin Ott (2017–2018; FURI) |
| | Marcial Rodarte (2016–2017) | Nathan Rodkey (2015–2018; FURI, Barr.) |
| | Kari Sanford (2015–2017; FURI, Barrett) | Nicholas Scheenstra (2015–2016; FURI) |
| | Daniel Sinclair (2017–2018; FURI) | Marshall Styers (2015–2016) |
| | Brian Wu (2018–2019; FURI) | John Hsu (2021–2021; SURI) |
| • Postdoc: | Mathieu Boccard (2014–2016) | Drew Swanson (2016–2017) |
| | Martyn Fisher (2016–2018) | Arthur Onno (2017–2020) |
| | Shaline Kavadiya (2018–2020) | Shannon Poges (2018–2020) |
| | Salman Manzoor (2019–2020) | Joe Carpenter (2020–2020) |
| | Thomas Fiducia (2021–2023) | |
| • Staff: | Kathryn Fisher (2014–) | Nathan Rodkey (2018–2019) |
| | Albert Victoria (2019–) | Mark George (2020–) |
| | Juan Venegas (2021–2022) | John Hsu (2021–) |
| • Research faculty: | Jason Yu (2018–) | Arthur Onno (2020–2022) |
| • REU visitor: | Emily Dafflon (2013) | Ethan Bendau (2015) |
| | Juan Asencio (2018) | William Firth (2015) |
| | Culver McWhirter (2016) | Amine El Mahati (2016) |
| | Jones Ou (2016) | Matthew Warner (2016) |
| | Jakob Häusele (2017) | Noemi Mundhaas (2017) |
| | Stefan Mercado (2017) | Syeda Mohsin (2017) |
| | Tien Ngo (2017) | Yuji Okamoto (2017) |
| | David Quispe (2017) | Mateo Estrada (2018) |
| | Jewel Haik (2018) | Richelle Javier (2018) |
| | Xingyi Wang (2019) | Alexa Cetta (2019) |
| | Jorge Almeida (2019) | Maria Garcia (2019) |
| • PCASE visitor: | Saleem Ahmed (2016) | Asad Ali (2016) |
| | Asghar Ali (2016) | Waqar Ali (2016) |
| | Farah Qazi (2016) | Ijaz Husnain (2016) |
| | Mahmood Jamil (2016) | Mehwish Javed (2016) |
| | Syeda Qudsia (2016) | Warda Mushtaq (2016) |
| | Maham Akhlaq (2017) | Kamran Alam (2017) |
| | Maoz (2017) | Asma Shamim (2017) |

ZACHARY CHARLES HOLMAN

(480) 965-9959 • zachary.holman@asu.edu

Hira Rehman (2017)
Maria Kanwal (2018)
Fazal Subhan (2018)
Qandeel Rehman (2019)
Muneeza Ahmad (2019)

Shah Naveed (2017)
Sundas Khan (2018)
Mudasar Rashid (2019)
Kashan Ahmad (2019)
Saddam Hussain (2019)

COURSES TAUGHT

- EEE 352: Properties of Electronic Materials (F15, F16, F17, F18)
- EEE 436/591: Fundamentals of Solid State Devices (F13, F14, S16)
- EEE 465/591: Photovoltaic Energy Conversion (S15)
- EEE 498/591: Solar Energy (S14)
- EEE 536: Semiconductor Characterization (S17)
- EEE 565: Solar Cells (F22)
- EEE 598: Manuscript Writing for Engineers (F14, F15, F17, F18, F19, F20, F21, F22)
- ASU 101: The ASU Experience (F14)
- IVD 561: Innovation Studio II: Problem Reframing (F21)
- IVD 562: Innovation Studio III: Explore, Fail, Solve (S21, S22)

PEER-REVIEWED PUBLICATIONS

(ASU students in **red**; ASU postdocs and staff in **orange**)

111. **Z. Leuty**, **M. George**, **M. Garcia**, **Z. Yu**, and **Z. Holman**, “High mobility soft sputtered ITO coatings by dual gas-flow sputtering,” (submitted).
110. **Z. Leuty**, **W. Weigand**, **J. Ochoa**, **J. Carpenter**, **Z. Yu**, M. Bertoni, and **Z. Holman**, “Ultra-high throughput inline deposition of silicon oxide for polycrystalline silicon passivating contacts,” (submitted).
109. G. Yang, **Z. Yu**, M. Wang, Z. Shi, Z. Ni, H. Jiao, C. Fei, A. Wood, **A. Alasfour**, B. Chen, **Z. Holman**, and J. Huang, “Shunt mitigation toward efficient large-area perovskite-silicon tandem solar cells,” *Cell Reports Phys. Sci.* **4**, 101628 (2023).
108. **M. Mahaffey**, **A. Onno**, C. Reich, A. Danielson, W. Sampath, and **Z. Holman**, “Measuring the absorber doping concentration of Si, CdSeTe, and perovskite solar cells using injection-dependent quasi-steady-state photoluminescence,” *IEEE J. Photovoltaics* **13**, 800–807 (2023).
107. **B. Hartweg**, **K. Fisher**, **J. Ro**, and **Z. Holman**, “Qualification of laser-weld interconnection of aluminum foil to back-contact silicon solar cells,” *Sol. Energy Mater. Sol. Cells* **266**, 112647 (2023).
106. **D. Quispe**, B. Eng, M. Kim, **A. Onno**, **B. Coppa**, **Z. Yu**, M. Lee, and **Z. Holman**, “Optical constants of polycrystalline $\text{Al}_{0.25}\text{Ga}_{0.75}\text{P}$ and $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}$ determined by variable-angle spectroscopic ellipsometry,” *J. Appl. Phys.* **134**, 073104 (2023).
105. **J. Levi**, S. Guo, **S. Kavadiya**, **Y. Luo**, **C.-S. Lee**, H. Jacobs, **Z. Holman**, M. Wong, S. Garcia-Segura, C. Zhou, b. Rittmann, and P. Westerhoff, “Comparing methods to deposit Pd-In catalysts on hydrogen-permeable hollow-fiber membranes for nitrate reduction,” *Water Res.* **235**, 119877 (2023).
104. G. Yang, M. Wang, C. Fei, H. Gu, **Z. Yu**, **A. Alasfour**, **Z. Holman**, and J. Huang, “Recycling silicon bottom cells from end-of-life perovskite–silicon tandem solar cells,” *ACS Energy Lett.* **8**, 1639–1644 (2023).

103. A. Bothwell, C. Reich, A. Danielson, [A. Onno](#), [Z. Holman](#), W. Sampath, and D. Kuciauskas, “Charge carrier lifetime determination in graded absorber solar cells using time-resolved photoluminescence simulations and measurements,” *Solar RRL*, 2201029 (2023).
102. A. Danielson, C. Reich, R. Pandey, A. Munshi, [A. Onno](#), [W. Weigand](#), D. Kuciauskas, S. Li, A. Bothwell, J. Guo, M. Murugeson, J. McCloy, R. Klie, [Z. Holman](#), and W. Sampath, “Electro-optical characterization of arsenic-doped CdSeTe and CdTe solar cell absorbers doped in-situ during close space sublimation,” *Sol. Energy Mater. Sol. Cells* **251**, 112110 (2023).
101. [B. Hartweg](#), [K. Fisher](#), [S. Niverty](#), N. Chawla, and [Z. Holman](#), “Analysis of electrically conductive adhesives in shingled solar modules by X-ray imaging techniques,” *Microelectron. Reliab.* **136**, 114627 (2022).
100. B. Chen, Z. Yu, [A. Onno](#), [Z. Yu](#), S. Chen, J. Wang, [Z. Holman](#), and J. Huang, “Bifacial all-perovskite tandem solar cells,” *Sci. Adv.* **8**, eadd0377 (2022).
99. G. Yang, Z. Ni, [Z. Yu](#), Z. Yu, B. Larson, B. Chen, [A. Alasfour](#), X. Xiao, J. Luther, [Z. Holman](#), and J. Huang, “Defect engineering in wide bandgap perovskites for efficient perovskite-silicon tandem solar cells,” *Nature Photonics* **16**, 588–594 (2022).
98. H. Bauser, M. Foley, M. Phelan, [W. Weigand](#), D. Needell, [Z. Holman](#), and H. Atwater, “Amorphous silicon carbide high contrast gratings as highly efficient spectrally selective visible reflectors,” *Opt. Express* **30**, 26787–26793 (2022).
97. [A. Onno](#), C. Reich, S. Li, A. Danielson, [W. Weigand](#), A. Bothwell, S. Grover, J. Bailey, G. Xiong, D. Kuciauskas, W. Sampath, and [Z. Holman](#), “Understanding what limits the voltage of polycrystalline CdSeTe solar cells,” *Nature Energy*, **7**, 400–408 (2022).
96. K. Chen, [B. Hartweg](#), M. Woodhouse, H. Guthrey, W. Nemeth, S. Theingi, M. Page, [Z. Holman](#), P. Stradins, S. Agarwal, and D. Young, “Self-aligned selective area front contacts on poly-Si/SiO_x passivating contact c-Si solar cells,” *IEEE J. Photovoltaics* **12**, 678–689 (2022).
95. N. Liew, [Z. Yu](#), [Z. Holman](#), and H.-J. Lee, “Parametric study about performances of a solar photovoltaic/thermal hybrid using a spectral beam splitting technique,” *J. Renew. Sustain. Energy* **14**, 013701 (2022).
94. [J. Ding](#), [C. Campbell](#), [J. Becker](#), [C.-Y. Tsai](#), [S. Schaefer](#), [T. McCarthy](#), [M. Boccard](#), [Z. Holman](#), and Y.-H. Zhang, “Monocrystalline 1.7-eV MgCdTe solar cells,” *J. Appl. Phys.* **131**, 023107 (2022). [[Editor’s Pick](#)].
93. K. Liu, B. Chen, [Z. Yu](#), Y. Wu, Z. Huang, X. Jia, C. Li, D. Spronk, Z. Wang, Z. Wang, S. Qu, [Z. Holman](#), and J. Huang, “Reducing sputter induced stress and damage for efficient perovskite/silicon tandem solar cells,” *J. Mater. Chem. A* **10**, 1343–1349 (2022).
92. D. Kuciauskas, S. Li, J. Moseley, D. Albin, C. Lee, [A Onno](#), and [Z. Holman](#), “Voltage loss comparison in CdSe/CdTe solar cells and polycrystalline CdSeTe heterostructures,” *IEEE J. Photovoltaics* **12**, 6–10 (2022).
91. [J. Bryan](#), T. Silverman, M. Deceglie, [M. Mahaffey](#), [P. Firth](#), and [Z. Holman](#), “Systematic operating temperature differences between Al-BSF, PERC, and PERT-with-optimized-rear-reflector solar mini-modules due to rear reflectance,” *IEEE J. Photovoltaics* **12**, 293–300 (2022).
90. N. Liew, [Z. Yu](#), [Z. Holman](#), and H.-J. Lee, “Application of spectral beam splitting using wavelength-selective filters for photovoltaic/concentrated solar power hybrid plants,” *Appl. Thermal Eng.* **201**, 117823 (2022).

89. G. Yeung, C. Reich, **A. Onno**, A. Bothwell, A. Danielson, Z. Holman, W. Sampath, and C. Wolden, “Robust passivation of CdSeTe based solar cells using reactively sputtered magnesium zinc oxide,” *Sol. Energy Mater. Sol. Cells* **233**, 111388 (2021).
88. M. Wright, B. Vicari Stefani, A. Soeriyadi, B. Hallam, Z. Holman, **Z. Yu**, **W. Weigand**, D. Macdonald, R. Basnet, and C. Sun, “Progress with defect engineering in silicon heterojunction solar cells,” *Phys. Status Solidi RRL* **15**, 2100170 (2021).
87. **S. Kavadiya**, **A. Onno**, C. Boyd, **X. Wang**, **A. Cetta**, M. McGehee, and Z. Holman, “Investigation of the selectivity of carrier transport layers in wide-bandgap perovskite solar cells,” *Solar RRL* **5**, 2100107 (2021).
86. **J. Bryan**, T. Silverman, M. Deceglie, and Z. Holman, “Thermal model to quantify the impact of sub-bandgap reflectance on operating temperature of fielded PV modules,” *Solar Energy* **220**, 246–250 (2021).
85. **J. Bryan**, **J. Carpenter**, **Z. Yu**, **A. Leilaouioun**, **J. Shi**, **W. Weigand**, **K. Fisher**, and Z. Holman, “Aluminum-silicon interdiffusion in silicon heterojunction solar cells with a-Si:H(i)/a-Si:H(n/p)/Al rear contacts,” *J. Phys. D* **54**, 134002 (2021).
84. **A. Alasfour**, **Z. Yu**, **W. Weigand**, **D. Quispe**, and Z. Holman, “Sub-micrometer random-pyramid texturing of silicon solar wafers with excellent surface passivation and low reflectance,” *Sol. Energy Mater. Sol. Cells* **218**, 110761 (2020).
83. **Z. Yu**, **Z. Yang**, **Z. Ni**, **Y. Shao**, **B. Chen**, **Y. Lin**, **H. Wei**, **Z. Yu**, Z. Holman, and **J. Huang**, “Simplified interconnection structure based on $\text{C}_{60}/\text{SnO}_{2-x}$ for all-perovskite tandem solar cells,” *Nature Energy* **5**, 657–665 (2020).
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APPENDIX B

Appendix B: Materials Considered

No.	Description
1001	U.S. Patent No. 8,222,516 B2 (“USP516”)
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Declaration of Dr. Zachary Holman
Appendix C (Challenged Claims)

APPENDIX C

Appendix C: Challenged Claims

Claim 1	
Element	Claim Language
1[pre]	A solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising:
1[a]	an N-type silicon substrate;
1[b]	a textured surface on the N-type silicon substrate on the front side of the solar cell;
1[c]	an antireflective layer over the textured surface of the N-type silicon substrate;
1[d]	a P-type polysilicon emitter formed over the N-type silicon substrate and forming a backside junction with the N-type silicon substrate;
1[e]	an oxide layer formed between the P-type polysilicon emitter and the N-type silicon substrate;
1[f]	a negative polarity metal contact making an electrical connection to the N-type silicon substrate from the front side of the solar cell; and
1[g]	a positive polarity metal contact making an electrical connection to the P-type polysilicon emitter from the backside of the solar cell.

Claim 2
The solar cell of claim 1 wherein the antireflective layer comprises a layer of silicon nitride.

Claim 3

The solar cell of claim 1 further comprising a dielectric layer over the P-type polysilicon emitter.

Claim 4

The solar cell of claim 3 wherein the dielectric layer comprises silicon dioxide.

Claim 5

The solar cell of claim 3 further comprising a trench cutting through the dielectric layer and the P-type polysilicon emitter and into a portion of the N-type silicon substrate on the backside of the solar cell.

Claim 6

The solar cell of claim 1 wherein the positive polarity metal contact comprises a metal forming an infrared reflecting layer with a dielectric layer.

Claim 7

The solar cell of claim 1 wherein the positive polarity metal contact comprises silver forming an infrared reflecting layer with a dielectric layer comprising silicon dioxide.

Claim 8

The solar cell of claim 1 wherein the negative polarity metal contact comprises a metal formed in a contact hole to the N-type silicon substrate.

Claim 9	
Element	Claim Language
9[pre]	A solar cell having a front side facing the sun to collect solar radiation during normal operation and a backside opposite the front side, the solar cell comprising:
9[a]	a substrate having a textured front surface;
9[b]	an emitter layer formed over a back surface of the substrate, the emitter layer forming a backside junction with the substrate;
9[c]	an oxide layer formed between the back surface of the substrate and the emitter layer;
9[d]	a first metal contact making an electrical connection to the substrate on the front side of the solar cell; and
9[e]	a second metal contact making an electrical connection to the emitter layer on the backside of the solar cell,
9[f]	the first metal contact and the second metal contact being configured to allow an external electrical circuit to be powered by the solar cell.

Claim 10
The solar cell of claim 9 further comprising an antireflective layer over the textured front surface of the substrate.

Claim 11
The solar cell of claim 9 wherein the substrate comprises an N-type silicon substrate and the emitter layer comprises a P-type doped polysilicon.

Claim 12
The solar cell of claim 9 wherein the second metal contact comprises silver formed over a layer of silicon dioxide.