

DECLARATION OF JUNE ANN MUNFORD

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I, June Ann Munford, declare as follows:

I. INTRODUCTION

1. My name is June Ann Munford. I am over the age of 18 and am competent to testify to the same.

2. I have been retained on behalf of Hanwha Solutions Corporation (“Hanwha” or “Petitioner”) to provide assistance in evaluating the authenticity and public accessibility of documents discussed in this Declaration for proceedings before the United States Patent and Trademark Office. I understand that my Declaration will be submitted in the following *Inter Partes* Review proceedings:

Challenged Patent	Patent Owner	Case No.
8,222,516	Maxeon Solar Pte. Ltd.	IPR2024-01203
8,878,053	Maxeon Solar Pte. Ltd.	IPR2024-01199

3. I am being compensated for my services in this matter at the rate of \$200.00 per hour plus reasonable expenses. My compensation does not depend on the outcome of this matter. My testimony in this Declaration is based on the information cited in this Declaration and my experience in library science for nearly twenty years.

II. QUALIFICATIONS AND EXPERIENCE

4. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have nearly twenty years of

experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian, and Library Director. I have attached my Curriculum Vitae as **Appendix CV**.

5. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries, including the Dowagiac District Library in Dowagiac, Michigan; the Anchorage Public Library in Anchorage, Alaska; and the Hart Area Public Library in Hart, Michigan. These libraries relied on me and my expertise in the library sciences to catalogue, purchase, and process incoming library works correctly and efficiently. These responsibilities included purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs, and physically preparing that material for circulation.

6. In addition to my experience in acquisitions, during my time as a Library Director for the Dowagiac District Library, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog search performance, and creating lending agreements between libraries. As a part of my analysis of large collections, I audited library collections, including Machine Readable Cataloging (herein referred to as “MARC”) records, gathered usage statistics for various works, and evaluated MARC record fields to ensure

completeness and accuracy. Similarly, in my work as a researcher, I have examined thousands of MARC records authored by others. I am therefore familiar with and experienced in interpreting these records to make determinations based on the data contained within these records.

III. BACKGROUND INFORMATION

7. I have extensive experience with the catalog record creation process in the library sector. In preparing material for public accessibility, a library catalog record describing that material would be created. These records are typically written in MARC code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. MARC records are vital to the function of a library's services, as they facilitate the library staffs' and patrons' ability to search, explore, and secure materials within that library's collection. Libraries or similar institutions that rely upon MARC records dedicate significant resources to ensure that the records are accurate and sufficiently descriptive. Librarians and patrons alike therefore routinely rely on their accuracy and completeness.

8. Typically, in creating a MARC record, a librarian gathers various pieces of metadata, such as the publication's title, publisher and subject headings, among others, and assigns each datum to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked

in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. The 008 field accurately indicates the date of an item's public accessibility, as it is the only date reflecting the inclusion of said materials within the library's collection.

9. During the relevant time period, which I understand to be 1990-2014, MARC records and other digital library cataloging systems were typically indexed to facilitate searches. This indexing is necessary for both providing patron services and maintaining library records. Indexing is generally done using cataloging software, which creates searchable fields for data like the title and author of a work. Using searchable fields allows a librarian, for example, to ensure that the library does not duplicate works, which is an essential function for libraries.

10. Cataloging practices for librarians depend on the format of the material being catalogued. For instance, a one-time publication such as a textbook is cataloged as a "monograph," and only that specific edition of the book is described in the MARC record. Time-sensitive materials such as magazines, academic journals, and newspapers are cataloged as periodicals, with the MARC record describing the publication as a whole, rather than each individual issue. New issues of these periodicals do not receive their own MARC records, and are instead added to the inventory of the publication's existing MARC record. This ensures timely

access to new issues as soon as possible after publication by minimizing the effort required to catalogue the material.

11. For periodicals, the 008 field of the MARC record indicates date of first record creation at that particular library for the periodical. All subsequent issues are added to that same record and are often indicated in an individual holdings field that lists all issues held by the library. For example, a MARC record for an academic journal listing January 2000 in the 008 field indicates that the library first began housing the journal in January 2000. A separate item record for the same record might indicate that the library holds issues of the periodical, for example from the January 2000 issue through to the January 2022 issue. This would indicate that the library began subscribing to the periodical beginning with the January 2000 issue, and that the library continued to receive and hold subsequent issues until January 2022. Even if the subscription ceased, the presence of the record would indicate continuous accessibility to the public for all held issues indicated in the item record. This can be confirmed by, for example, obtaining the copy of the periodical associated with one of the holdings in the record.

12. Based on my experience, a library should make issues of periodicals available to the public within at least six months of the issue's date. This allows more than enough time to receive, catalogue, and shelve the issue. It would only be

under exceptional circumstances that a periodical issue is not shelved within six months.

13. I am also familiar with various digital and online practices relating to publications of periodicals, such as academic journals. For example, many academic journals have posted issues or individual articles online for public access as early as the late 1990s.

IV. SUMMARY OF OPINIONS

14. Based on my review of the documents cited in this Declaration and those included in Exhibits 1005, it is my opinion that the following journal articles are authentic and were publicly accessible on the dates identified below:

Journal Article	Date Publicly Accessible	Addressed In
“Polysilicon Emitters for Silicon Concentrator Solar Cells” by J.Y. Gan and R.M. Swanson as published in <i>IEEE Conference on Photovoltaic Specialists</i> , 1990	May 25, 1990	Section V

15. In addition to my experience in the field of library sciences, my opinions are supported by the appendices to my Declaration:

Appendices	Associated Journal Article
GAN01	MARC record for <i>IEEE Conference on Photovoltaic Specialists</i> as held by the University of Pittsburgh library
GAN02	“Polysilicon Emitters for Silicon Concentrator Solar Cells” by J.Y. Gan and R.M. Swanson as published in <i>IEEE Conference on Photovoltaic Specialists</i> , 1990
GAN03	Screen Capture of https://ieeexplore.ieee.org/document/111625

V. Gan

16. I have reviewed Exhibit 1005, “Polysilicon Emitters for Silicon Concentrator Solar Cells” by J.Y. Gan and R.M. Swanson as published in *IEEE Conference on Photovoltaic Specialists*, 1990 (hereinafter “Gan”). It is my opinion that Gan was publicly accessible to persons of skill in the art within six months of its publication date of May 25, 1990.

17. Attached hereto as Appendix GAN03 is a screen capture of a website entitled “Polysilicon emitters for silicon concentrator solar cells” as hosted on the IEEE Xplore website. I secured these screen captures myself from <https://ieeexplore.ieee.org/document/111625>. This web page, hosted by the publisher of *IEEE Conference on Photovoltaic Specialists*, indicates “Polysilicon emitters for silicon concentrator solar cells” was first published at the conference, held from May 21-24, 1990.

A. Public Accessibility of Gan at the University of Pittsburgh Library as of June 2015

18. Attached hereto as Appendix GAN01 is a true and correct copy of the MARC record for *IEEE Conference on Photovoltaic Specialists* as held by the University of Pittsburgh library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix GAN01 accurately describes the title, author, publisher, and ISSN number of *IEEE Conference on Photovoltaic Specialists*. The 'Location Items' field of this record visible on page 3 indicates this collection includes the 1990 edition of *IEEE Conference on Photovoltaic Specialists* containing "Polysilicon Emitters for Silicon Concentrator Solar Cells."

19. Attached hereto as Appendix GAN02 is a true and correct copy of "Polysilicon Emitters for Silicon Concentrator Solar Cells" as published in *IEEE Conference on Photovoltaic Specialists* as held by the University of Pittsburgh library. I secured these scans myself from the library's collection. In comparing Exhibit 1005 to Appendix GAN02, I determined that Exhibit 1005 is a true and correct copy of "Polysilicon Emitters for Silicon Concentrator Solar Cells" by J.Y. Gan and R.M. Swanson as published in *IEEE Conference on Photovoltaic Specialists* 1990.

20. The 008 field of the MARC record in Appendix GAN01 indicates the date of record creation. The 008 field of Appendix GAN01 indicates the University of Pittsburgh library first acquired these proceedings as of February 10, 1982 and still holds the new proceedings in perpetuity. Considering this information, I determined that *IEEE Conference on Photovoltaic Specialists* 1990 and therefore “Polysilicon Emitters for Silicon Concentrator Solar Cells” was made available to the public shortly after its initial release in 1990 and was likely made publicly available during the initial conference from May 21-25, 1990.

* * *

21. Considering this information, I determined that “Polysilicon Emitters for Silicon Concentrator Solar Cells” by J.Y. Gan and R.M. Swanson as published in *IEEE Conference on Photovoltaic Specialists*, 1990 was first made accessible to the public within six months of its initial release in 1990, if not earlier, by virtue of being accessible at the University of Pittsburgh.

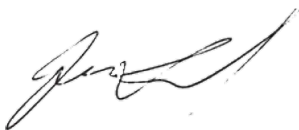
VI. CONCLUSION

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.

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

I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made 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: 8/5/2024

A handwritten signature in black ink, appearing to read 'June Ann Munford', with a stylized flourish at the end.

June Ann Munford

GAN01

leader 03473nas--2200661-a-4500
001 99110978978375937
005 20240413022717.0
008 820210c19709999nju-x---o-----1---a0eng-c
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035 ## \$a(CONSER)---84640812-
037 ## \$bCurran Associates, Inc., 57 Morehouse Lane, Red Hook, NY 12571
042 ## \$apcc \$ansdp
050 00\$aTK2960 \$b.P48a
082 14\$a537 \$211
111 2# \$aIEEE Photovoltaic Specialists Conference.
210 ## \$aCONF REC IEEE PHOTOVOLTAIC SPEC CONF
210 ## \$aIEEE PHOTOVOLTAIC SPECIALISTS CONFERENCE CONFERENCE RECORD
210 0# \$aConf. rec. IEEE Photovolt. Spec. Conf.
222 #0 \$aConference record of the IEEE Photovoltaic Specialists Conference
245 10\$aConference record of the ... IEEE Photovoltaic Specialists Conference.
246 1# \$iIssues for <2012-> have title: \$aIEEE Photovoltaic Specialists Conference
246 1# \$aPVSC \$f<2012->
260 ## \$31970- : \$a[New York] : \$bInstitute of Electrical and Electronics Engineers, \$c[1970?]-
260 3# \$3<2012-> : \$aPiscataway, NJ : \$bIEEE ; \$aRed Hook, NY : \$bAvailable from Curran Associates, Inc.
300 ## \$a1 online resource
310 ## \$aIrregular
336 ## \$atext \$btxt \$2rdacontent
337 ## \$acomputer \$bc \$2rdamedia
338 ## \$aonline resource \$bcr \$2rdacarrier
362 0# \$a8th (1970)-
510 0# \$aChemical abstracts \$x0009-2258
515 ## \$aIssued in parts: <2010-2012>
550 ## \$aEvery four years, beginning 1994, held in conjunction with the 1st- IEEE World Conference on Photovoltaic Energy Conversion.
550 ## \$aSponsored by the IEEE Electron Devices Society, <1994->
555 ## \$a1962-1980. 1 v.
588 ## \$aLatest issue consulted: 38th (2012).
650 0# \$aPhotovoltaic power generation \$vCongresses.
650 0# \$aSolar batteries \$vCongresses.
650 #7 \$aPhotovoltaic power generation. \$2fast \$0(OCOLC)fst01062167
650 #7 \$aSolar batteries. \$2fast \$0(OCOLC)fst01124919
650 17 \$aEnergie (exacte wetenschappen) \$2gtt
655 #7 \$aConference papers and proceedings. \$2fast \$0(OCOLC)fst01423772
762 0# \$t2009 34th IEEE Photovoltaic Specialists Conference (PVSC) \$w(CKB)1000000000710442 \$z1-4244-2950-1
762 0# \$t2010 35th IEEE Photovoltaic Specialists Conference \$w(CKB)2670000000054031 \$z1-4244-5892-7
762 0# \$t2008 33rd IEEE Photovoltaic Specialists Conference \$w(CKB)1000000000711038 \$z1-5090-7402-3
774 0# \$tConference Record of the Twenty Fifth IEEE Photovoltaic Specialists Conference - 1996 \$w(CKB)111055184238900
774 0# \$tConference Record of the Twenty Sixth IEEE Photovoltaic Specialists Conference - 1997 \$w(CKB)111026746718296
774 0# \$tConference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference - 2000 (Cat. No.00CH37036) \$w(CKB)111055184246062
774 0# \$tConference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, 2005 \$w(CKB)100000000022441 \$z1-5090-9675-2
780 00 \$tConference record of the Photovoltaic Specialists Conference \$w(CKB)991042726992738
776 08 \$iPrint version: \$tConference record of the ... IEEE Photovoltaic Specialists Conference. \$x0160-8371 \$w(DLC) 84640812 \$w(OCOLC)8145880
710 2# \$aInstitute of Electrical and Electronics Engineers.
710 2# \$aIEEE Electron Devices Society.
711 2# \$aWorld Conference on Photovoltaic Energy Conversion.
906 ## \$aCONFERENCE
920 ## \$aexl_impl conversion





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IEEE Electronic Library (IEL)



2005 31st IEEE Photovoltaic Specialists Conference (Contains)
IEEE Electronic Library (IEL)



1996 Twenty-Fifth IEEE Photovoltaic Specialists Conference
(Contains)
IEEE Electronic Library (IEL)



28th IEEE Photovoltaic Specialists Conference, 2000 (Contains)
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Item in place (0 requests)	22nd:v.1 1991	▼
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Details

Title	Conference record of the ... IEEE Photovoltaic Specialists Conference.
Other title	Issues for <2012> have title: IEEE Photovoltaic Specialists Conference

	PVSC <2012->
Creator	IEEE Photovoltaic Specialists Conference. >
Contributor	Institute of Electrical and Electronics Engineers. > IEEE Electron Devices Society. > World Conference on Photovoltaic Energy Conversion. >
Language	English
Frequency	Irregular
Publisher	Piscataway, NJ : IEEE ; Red Hook, NY : Available from Curran Associates, Inc. 8th (1970)-
Date	1970?-
Type	Journal
Description	1 online resource
Journal Notes	8th (1970)- Issued in parts: <2010-2012> Every four years, beginning 1994, held in conjunction with the 1st- IEEE World Conference on Photovoltaic Energy Conversion. Sponsored by the IEEE Electron Devices Society, <1994->
Indexed in/References	Chemical abstracts 0009-2258 >
Notes	1962-1980. 1 v.
Subject	Photovoltaic power generation -- Congresses > Solar batteries -- Congresses > Energie (exacte wetenschappen) >
Genre	Congresses. >
Related titles	Units : Conference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, 2005 > Units : Conference Record of the Twenty Fifth IEEE Photovoltaic Specialists Conference - 1996 > Units : Conference Record of the Twenty Sixth IEEE Photovoltaic Specialists Conference - 1997 > Units : Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference - 2000 (Cat. No.00CH37036) > Earlier title : Conference record of the Photovoltaic Specialists Conference > Available in other form: Print version: Conference record of the ... IEEE Photovoltaic Specialists Conference. > Has sub-series : 2008 33rd IEEE Photovoltaic Specialists Conference 1-5090-7402-3 > Has sub-series : 2009 34th IEEE Photovoltaic Specialists Conference (PVSC) 1-4244-2950-1 > Has sub-series : 2010 35th IEEE Photovoltaic Specialists Conference 1-4244-5892-7 > Has sub-series : 2011 37th IEEE Photovoltaic Specialists Conference > Has sub-series : 2012 IEEE 38th Photovoltaic Specialists Conference >
Identifier	ISSN : 0160-8371
Dedup Member Ids	995498213406236
Source	Library Catalog

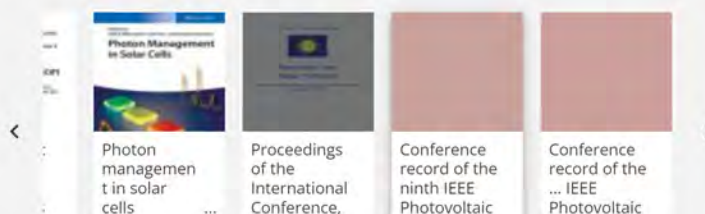
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May 21-25, 1990



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PROGRAM SCHEDULE

Tuesday, May 22, 1990

Time	Room	Session	Room
7:30 8:30	Boca Cocoa	Presenters' and Session Chairpersons' Briefing (Turn in manuscripts)	Boca Cocoa
8:30 9:30	Kissimmee	Opening Session Presentation of the William Cherry Memorial Award	St. Cloud
9:30 10:20		Plenary Session 1 Overview of Recent Photovoltaic Developments	
10:20 10:45		Break	
10:45 12:00		Plenary Session 1 (Cont.)	
12:00 1:30		Lunch	
1:30 3:00	Casselberry	Poster Session 2A III-V Single and Multijunction Cells	Orlando
		Poster Session 2B Utility PV System and Concentration Technology	
3:00 5:00	Kissimmee	Oral Session 3A High Efficiency III-V Cells	St. Cloud
		Oral Session 3B Utility Applications and Testing	
6:00 7:30	Exhibits Area	Reception Hosted by Exhibitors	Exhibits Area

Wednesday, May 23, 1990

Time	Room	Session	Room
7:00 8:00	Boca Cocoa	Presenters' and Session Chairpersons' Briefing (Turn in manuscripts)	Boca Cocoa
8:00 9:00	Kissimmee	Plenary Session 4 High Efficiency Solar Cells	St. Cloud
9:00 10:30	Casselberry	Poster Session 5A Silicon Solar Cells	Orlando
		Poster Session 5B Flight Experiments and Results	
10:30 12:00	Kissimmee	Oral session 6A High Efficiency Silicon Solar Cells	St. Cloud
		Oral Session 6B Space Environmental Effects	
12:00 1:30		Lunch	
1:30 2:30	Kissimmee	Plenary Session 7 Terrestrial Systems and Array technology	St. Cloud
2:30 4:00	Casselberry	Poster Session 8A Modeling and Characterization of Single Crystal Solar Cells	Orlando
		Poster Session 8B Terrestrial Systems, Applications and Technology	
4:00 5:30	Kissimmee	Oral Session 9A Modeling and Characterization of Single Crystal Solar Cells	St. Cloud
		Oral Session 9B PV Module Performance and Testing	
6:00 7:30	Exhibits Area	Reception Hosted by Photovoltaics Industry	Exhibits Area

Thursday, May 24, 1990

Time	Room	Session	Room
7:00 8:00	Boca Cocoa	Presenters' and Session Chairpersons' Briefing (Turn in manuscripts)	Boca Cocoa
8:00 9:00	Kissimmee	Plenary Session 10 Space Systems and Technology	St. Cloud
9:00 10:30	Casselberry	Poster Session 11A Space Solar Arrays and Components	Orlando
		Poster Session 11B Thin Film Compound Semiconductors	
10:30 12:00	Kissimmee	Oral session 12A Advanced Array Technology	St. Cloud
		Oral Session 12B Thin Film Compound Semiconductors	
12:00 1:30		Lunch	
1:30 2:30	Kissimmee	Plenary Session 13 Polycrystalline Solar Cells	St. Cloud
2:30 4:00	Casselberry	Poster Session 14A Amorphous Silicon Cells and Modules	Orlando
		Poster Session 14B Polycrystalline Silicon	
4:00 5:30	Kissimmee	Oral Session 15A Amorphous Silicon Based Cells	St. Cloud
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Friday, May 25, 1990

Time	Room	Session	Room
7:00 8:00	Boca Cocoa	Presenters' and Session Chairpersons' Briefing (Turn in manuscripts)	Boca Cocoa
8:00 9:00	Kissimmee	Plenary Session 16 Amorphous Silicon	St. Cloud
9:00 10:30	Casselberry	Poster Session 17A PV System Performance and Measurement	Orlando
		Poster Session 17B Modeling and Stability of Amorphous Silicon Alloys	
10:30 12:00		Poster Session 18A Polycrystalline Materials and Device Characterization	Orlando
		Poster Session 18B Amorphous Silicon; Materials and Processing	
12:00 1:30		Lunch	
1:30 3:00	Kissimmee	Oral Session 19A Stand Alone Systems and Concentrator Modules/Arrays	St. Cloud
		Oral Session 19B Modeling and Stability of Amorphous Silicon	
3:00 4:00		Oral Session 20A Polycrystalline Materials and Device Characterization	St. Cloud
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POLYSILICON EMITTERS FOR SILICON CONCENTRATOR SOLAR CELLS

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ABSTRACT

Polysilicon emitters with a thermally grown interfacial oxide are examined in great detail. Both J_o and ρ_c are measured for the polysilicon emitter (contact) which is annealed under various conditions. $J_o \leq 5 \times 10^{-14}$ A/cm² and $\rho_c \sim 1 \times 10^{-5}$ Ω -cm² are obtained for both n- and p-type polysilicon emitters. The results also indicate that the interfacial oxide is only broken by a very small fraction in order to have $\rho_c \sim 1 \times 10^{-5}$ Ω -cm². Under such a condition, J_o is primarily dominated by the recombination at the oxide interface.

INTRODUCTION

Polysilicon emitters, because of their important applications in high speed bipolar transistors, have been widely studied. It was found that, between the polysilicon and the substrate, there always exists a very thin oxide (interfacial oxide), which can be as a by-product of the cleaning process or is grown intentionally [1,2,3,4,5,6,7]. In either case, the oxide is not thermally stable; i.e., it tends to break up during high temperature anneals [1,2,3,4,5,6,7]. The breakup of the interfacial oxide has direct impact on both majority and minority carrier transport in the polysilicon emitter. This can be seen from the dependence of the specific contact resistivity (ρ_c) [6] and the emitter saturation current density (J_o) [1,2,3,4,5,6,7] upon either the anneal condition or the oxide integrity. When the effect of the interfacial oxide is negligible, such as when the interfacial oxide loses its integrity in high temperature anneals, the ρ_c is low ($\sim 2 \times 10^{-7}$ Ω -cm²) [6] and the J_o is high ($\sim 1 \times 10^{-12}$) [1,3]. Conversely, when both carriers are mostly blocked by the interfacial oxide, like for an intact chemical oxide (~ 15 Å), the ρ_c is high and the J_o is low. Typically, $\rho_c \geq 1 \times 10^{-4}$ Ω -cm², and the corresponding $J_o \sim 1 \times 10^{-14}$

A/cm² have been observed on the n-type polysilicon emitter [1,5,6].

With the extent of the oxide breakup between these two extremes, various combinations of ρ_c and J_o can be obtained. It is of particular interest to know the ρ_c and the corresponding J_o when only a small fraction of the interfacial oxide is broken. For silicon solar cells operated under high concentrated sunlight, the emitter recombination is one of the main recombination that limit the solar cell performance [8]. This is because the diffused-emitter, which is formed with dopant diffusion into the base (substrate), has high J_o ($= 4.5 \times 10^{-13}$ A/cm²). Consequently, the cell performance can be improved if the diffused-emitter is replaced with the polysilicon emitter, of which the J_o is less than 4.5×10^{-13} A/cm² and the ρ_c is low enough.

In this paper, detailed calibrations for the polysilicon emitter with a thermally grown interfacial oxide is presented. Compared with the the chemical oxide, the thermal oxide appears to be more robust to the high temperature anneal. Consequently, this lends more controllability on the oxide breakup process. In addition, two separate anneal steps were used in order to avoid any possible interference from the dopant diffusion. It has been reported that the interfacial oxide tends to break up more rapidly with the existence of dopant [3,5]. Moreover, J_o also depends on the surface dopant concentration and the emitter depth [9]. In order to see the effect of the oxide breakup on J_o and ρ_c alone, it is therefore desirable to separate these two processes. The first-step anneal, which serves to break the oxide, was performed at higher temperature than that for the second-step anneal which aims for the dopant drive-in.

EXPERIMENTAL

Procedures

In this work, the J_o and ρ_c were measured independently for each type of polysilicon emitter (or contact). J_o was measured with photoconductivity decay method which has been reported elsewhere [10]. Because high bulk lifetime is needed for such a measurement, the samples were prepared with high resistivity ($>100 \Omega\text{-cm}$) FZ wafers. In contrast, ρ_c was measured on devices made on CZ wafers of which resistivity is 0.28 and $0.5 \Omega\text{-cm}$ for p- and n- type respectively. The device for ρ_c -measurement is shown in Fig. 1 schematically. Except for the pattern-definition steps which were not required for J_o -measurement samples, the two sets of wafers were always processed together. The process sequence is shown as followings:

1. Field oxidation ($2000 \text{ \AA}$)*.
2. Polysilicon-substrate contact opening*.
3. Thin thermal oxide growth at 800°C *. (10-minute oxygen flow)
4. Polysilicon deposition ($6000 \text{ \AA}$) and first-step anneal (1050°C)*.
5. First-step anneal*.
6. Polysilicon finger definition.
7. Undoped glass deposition ($2000 \text{ \AA}$).
8. Metal-polysilicon and metal-substrate contact opening.
9. Doped glass deposition on both sides of the wafer*.
10. Drive-in; $900\text{-}1000^\circ\text{C}$ *.
11. Doped glass stripping and Al-1% Si alloy deposition.
12. Metal finger definition.

Note that the steps marked with "*" are the steps for J_o -measurement samples. In addition, the J_o -samples are divided into two sets; one set of samples had an additional 400°C -30 min forming gas anneal (FGA), the other did not. The growth of thin oxide was carried out with 200 sccm oxygen and 5 slm argon mixture. Typically, oxide thickness less than $20 \text{ \AA}$ was measured with ellipsometer. In step 2, a series of square contacts of size between 1 and $64 \mu\text{m}$ are opened for polysilicon-substrate contacts.

ρ_c Measurement

As shown in Fig. 1, the voltage difference, V_{ab} , between probe A and B is caused by several components of the series resistance along the current loop. They are the resistance imposed by the bulk of the polysilicon and the wafer, the metal-polysilicon contact resistance, and the polysilicon-substrate contact resistance. The potential drop across the polysilicon film is conceivably negligible because the film is heavily doped and very thin. The metal-polysilicon contact resistance is actually measured on the similar device (four-terminal resistor [11]) next to the device shown in the figure. Typi-

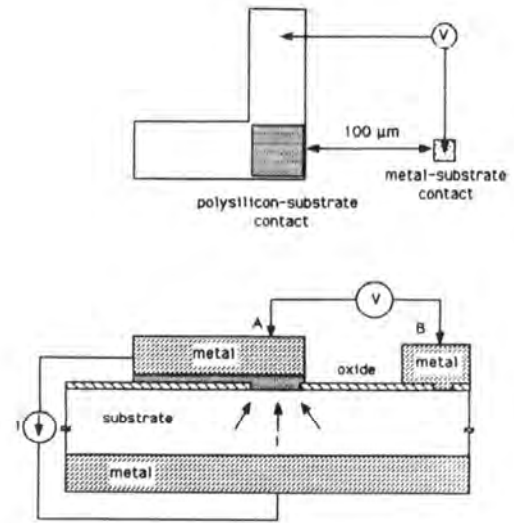


Figure 1: The device structure for the specific contact resistivity measurement.

cally, the ρ_c of the metal-polysilicon contact is less than $1 \times 10^{-6} \Omega\text{-cm}^2$. With such low ρ_c and large contact area between the metal and the polysilicon, the metal-polysilicon contact resistance can be ignored as well. As a result, the series resistance derived from V_{ab}/I is essentially determined by two terms; the bulk resistance of the silicon substrate and the polysilicon-substrate contact resistance. Such a series resistance can be expressed as a function of the size of the polysilicon-substrate square contact.

$$R = C \frac{\rho}{d} + \frac{\rho_c}{d^2}, \quad (1)$$

or

$$R_c = R \times d^2 = \rho_c + C \rho d; \quad (2)$$

where C is a constant that accounts for the contact geometry factor, ρ is the substrate resistivity, d is the width of the square contact, and ρ_c is the specific contact resistivity of the polysilicon-substrate contact. The contact size dependence of the last term in Eqn. (2) results from the crowding effect as the current flows toward the polysilicon-substrate contact. It is obvious that, from Eqn. (2), the ρ_c can be derived from the plot of R_c versus d which is obtained by measuring the series resistance of contacts of different sizes.

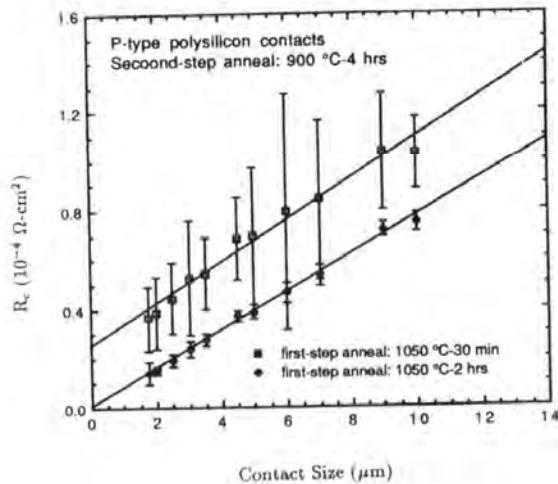


Figure 2: The R_c versus the contact size for p-type polysilicon contacts of different first-step anneals.

RESULTS AND DISCUSSIONS

Fig. 2 shows two R_c -plots for the p-type polysilicon contacts. One has the first-step anneal at 1050 °C for 30 minutes, the other has 1050 °C for 2 hours. Each data point is the average of 16 measurements across the wafer and the error bar is drawn with 4 standard deviations. Since devices were made on the wafers of about the same resistivity, the slopes of the linear-fit lines are almost identical. Note that, the devices that received a 30-minute first-step anneal have higher intercepts than those that received a 2-hour first-step anneal. This indicates that more oxide breakup occurs when the anneal time increases. Another characteristic of the interfacial oxide breakup can also be seen from the spread in the data (the length of the error bar). The magnitude of the error bar is not due to the measurement uncertainty; instead, it results from the random distribution of the oxide breakup. When only a very small fraction of the interfacial oxide is broken, it is possible that the interfacial oxide on each contact may not be broken equally. Consequently, this gives rise to the fluctuation of the resistance measured. On the other hand, the fluctuation will be subdued when more oxide is broken. This explains the different appearance of error bars observed between these two sets of data.

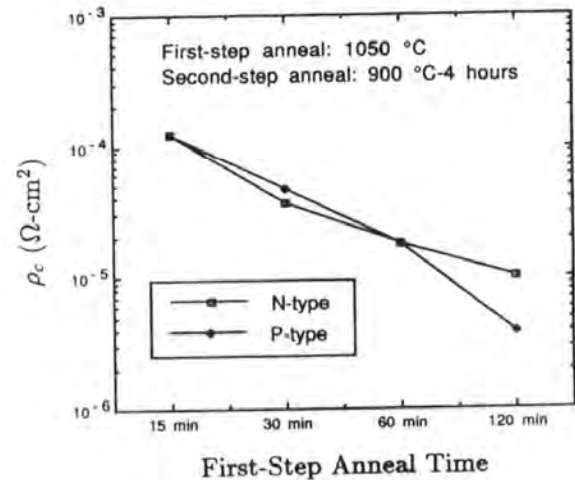


Figure 3: ρ_c of both n- and p- type polysilicon-substrate contacts is shown as a function of the time of the first-step anneal.

To see how the J_o and the ρ_c is affected by the first-step anneal, one set of samples (and device wafers) were first annealed at 1050 °C for various lengths of time (first-step anneal). After the doped-glass deposition, they were all annealed at 900 °C for 4 hours. The ρ_c measured from the device and the J_o measured from the photoconductivity decay are presented in the following figures.

In Fig. 3, ρ_c is plotted against the time of the first-step anneal for both types. Note that the ρ_c decreases as the anneal time increases. In addition, ρ_c measured from both n- and p- type devices are more or less the same, except those annealed with 120 minutes. The similarity of ρ_c between the n- and the p- type contact also indicates that the interaction between the dopant and the interfacial oxide is negligible; since such an interaction, if exists, would cause the ρ_c of the p-type to be lower [6].

The effects of the first-step anneal on J_o are presented in Fig. 4 and 5 for the n-type and the p-type polysilicon emitters respectively. In each figure, two sets of data are shown: the one with an FGA, and the one without. For the samples with an FGA, the J_o is significantly less than that without FGA for the same anneal condition. This indicates that the recombination

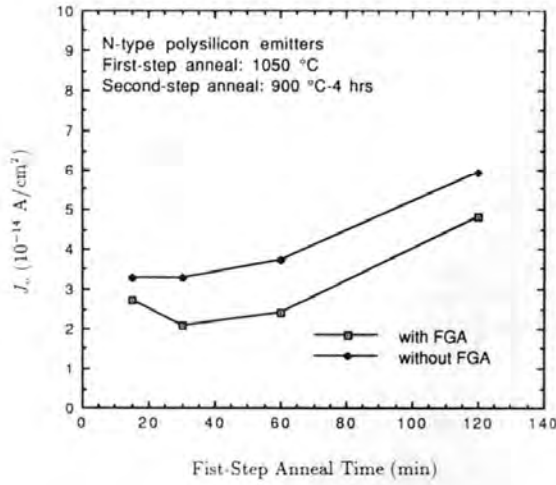


Figure 4: The J_o versus the first-step anneal time for n-type polysilicon emitters.

at the oxide interface is, at least, one of the dominant mechanisms for the emitter recombination. It is also important to note that the J_o of the p-type polysilicon emitter (Fig 5) appears to be much lower than what has been previously reported [1]. This may have to do to the use of thermal oxide as the interfacial layer in our samples. Either the thermal oxide is most robust during the high temperature anneal or the thermal oxide has lower interface defect state density (D_{it}) compared to the chemical oxide. Another interesting thing in these figures is that the J_o of the sample that received a 15-minute anneal is higher than the sample that received a 30-minute anneal. Moreover, such a behavior occurs in both the n- and the p- type samples. The possible explanation is that the interfacial oxide quality is improved by the high temperature anneal. This is not too surprising because the oxide was grown around 800 °C, in which higher D_{it} is expected [12,13]. Other than that, the J_o of both types appears to increase slowly with the anneal time. In addition, because the dominant recombination is likely at the oxide interface, it implies that the oxide must only be broken by very a small fraction, which is in consistent with what was observed in Fig. 2.

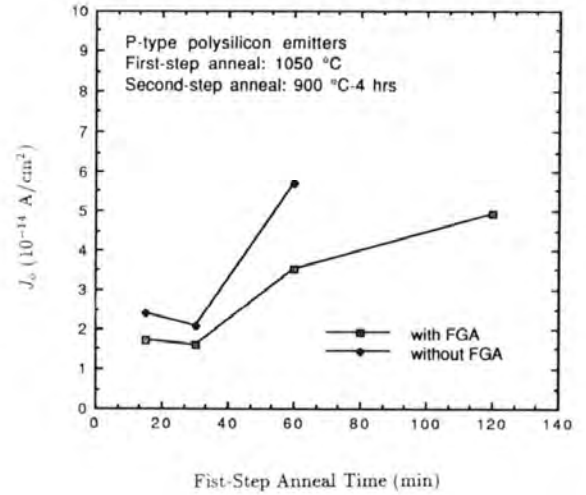


Figure 5: The J_o versus the first-step anneal time for p-type polysilicon emitters.

The effect of the second-step anneal (dopant drive-in) on both the J_o and the ρ_c were also investigated. All samples (and devices) received a first-step anneal at 1050 °C for one hour, followed with various treatments in the second-step anneal. The results are summarized in Table 1. The label on the right most column represents the second-step anneal condition of that sample. As shown in the table, the J_o increases with the temperature and time of the second-step anneal. In the meantime, the ρ_c decreases as the drive-in temperature increases. Considering the significant increase of J_o caused by increasing the drive-in temperature from 900 to 1000 °C, it is beneficial to use the two-step anneal to optimize J_o .

In Fig. 3, the decrease of ρ_c with the anneal time is what would be expected from the gradual breakup of the interfacial oxide. This is in consistent with the increase of J_o shown in Fig. 4 and Fig. 5, since J_o depends on the oxide integrity in the opposite way. This is especially clear when both ρ_c and J_o are plotted together. Fig. 6 is the ρ_c versus J_o plot for all the results obtained in this experiment. The inset is the list of the label

Table 1: The effect of the second-step anneal on J_o and ρ_c .

	N-type		P-type	
	$J_{o,e}$ ($\times 10^{-14}$ A/cm ²)	ρ_c ($\mu\Omega\cdot\text{cm}^2$)	$J_{o,e}$ ($\times 10^{-14}$ A/cm ²)	ρ_c ($\mu\Omega\cdot\text{cm}^2$)
900 °C-4 hour	2.4	18	3.5	18
1000 °C-30 min	4.5	~ 6	8.2	3.8
1000 °C-60 min	7.9		10.5	

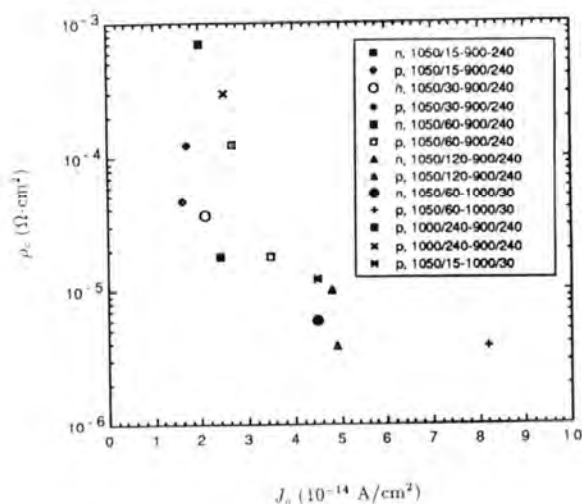


Figure 6: ρ_c - J_o of this work.

for each point. It specifies the type of polysilicon emitter, the first-step anneal (temperature/minute), and the second-step anneal (temperature/minute). As shown in the figure, the data runs from the upper-left corner to the lower-right corner which is similar to that reported by Crabbé [6] and is the typical trend when both ρ_c and J_o are regulated by the extent of oxide breakup. Nevertheless, from left to right, two distinct regimes are shown in the figure. In one regime, J_o is almost constant while ρ_c drops drastically. In the other regime, ρ_c decreases very slowly and J_o increases in much faster pace. In the first regime, that the J_o is inert to the oxide breakup is because the extent of the oxide breakup is very small such that the J_o is still dominated by the recombinations at the oxide interface and in the singly-crystal outdiffusion. On the other hand, the drastic change of the ρ_c can be attributed to the transition of the majority carrier transport from the tunneling to the channel resistance. When the interfacial oxide is intact, tunneling is the only process available for the majority carriers to pass through the interfacial oxide. This usually results in a high contact resistance because of low tunneling probability. As the oxide starts to break up, additional highly conductive channels are created due to the intimate contacts formed between the polysilicon and the substrate in the broken regions [3,4,5]. A drastic change of ρ_c is observed when more currents flow through those channels. In the other regime, J_o starts to increase because the recombination in the polysilicon becomes comparable to the recombination mentioned

previously. On the other hand, the slow decrease of the ρ_c in this regime is because the majority carrier transport is completely dominated by the channel resistance. The increase of the oxide breakup can be thought as more parallel resistors added together; consequently, a significant change of ρ_c will not be observed.

The data shown in Fig. 6 are quite useful for silicon solar cells. 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. This means that the potential drop across the contact is negligible as long as the current density is less than 100 A/cm². It is interesting to see how much of the cell efficiency can be improved with polysilicon emitters of characteristics given here. With the cell modeling, which is similar to the one reported by Sinton [8], more than one absolute percent of the cell efficiency is obtained for a backside contact solar cell with polysilicon emitters with characteristics shown here ($J_o=2 \times 10^{-14}$ A/cm² for the n-type, $J_o=3.5 \times 10^{-14}$ A/cm² for the p-type, and $\rho_c=1 \times 10^{-5}$ Ω·cm² for both types).

CONCLUSIONS

To conclude, we showed that polysilicon emitters with low J_o and ρ_c can be obtained with a very small fraction of interfacial oxide breakup. Typically, $\rho_c \sim 1 \times 10^{-5}$ Ω·cm² and $J_o \leq 5 \times 10^{-14}$ A/cm² are obtained for both n- and p- type polysilicon emitters. From the cell modeling, polysilicon emitters with these qualities can be quite useful for silicon concentrator solar cells. Because only small fraction of interfacial oxide is broken, the J_o is primarily dominated by the recombination at the oxide interface and in the single-crystal diffusion region. Consequently, an interfacial oxide of good quality is important to obtain low J_o . Our results also indicates that ρ_c drops drastically when the oxide starts to breakup. This is explained by the transition of the dominant majority-carrier transport from the tunneling to the channel resistance.

This work was supported by the Electric Power Research Institute.

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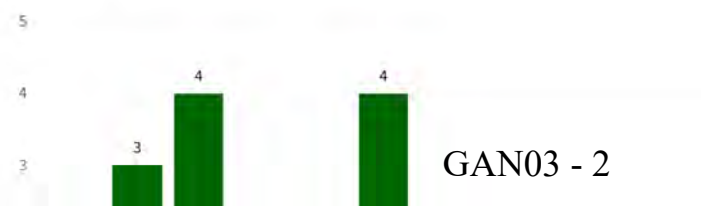
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APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.
- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.
- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in

Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over \$400,000 and total assets of approximately \$1,300,000.

- Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.
- Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.
- Led the organization and digitization of the library's archival records.
- Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.
- Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013

Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

- Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.
- Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.
- Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013

Library Assistant, Hart Area Public Library
Hart, MI

- Responsible for verifying imported MARC records and original MARC

cataloging for the local-level collection as well as the Michigan Electronic Library.

- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

- Treasurer, 2012

Library Of Michigan

- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014

- New Directors Conference Panel Member

Southwest Michigan Library Cooperative

- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008

Petoskey, MI

- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011

Nashville, TN

- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012

Fairbanks, AK

- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Civil Action No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Cases IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

2023 ● Pillsbury Winthrop Shaw Whitman LLP

Gravel Rating Systems v. Costco Wholesale Corp. (Civil Action No. 4:21-cv-149-ALM)

Limited Case and Clientele History

Alston & Bird

- Ericsson

v. Collision Communications (IPR2022-01233)

- Nokia

v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

- Universal Electronics Inc

v. Roku Inc (IPR2022-00818)

Arnold & Porter

- Ivantis

v. Glaukos (Case No. 8:18-cv-00620)

- Samsung

v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis

v. Cathx (Case No. 5:21-cv-00077-RWS)

Erise I.P.

- Apple
 - v. Ericsson Inc. (IPR2022-00715)
 - v. Future Link Systems (IPRs 6317804, 6622108, 6807505, and 7917680)
 - v. INVT (Case No. 20-1881)
 - v. Navblazer LLC (IPR2020-01253)
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 - v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)
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