UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

SEG SOLAR INC., PT. SEG SOLAR MANUFAKTUR INDONESIA, SEG ENERGY SINGAPORE PTE. LTD., NEW ENERGY IMPORTS INC., and SEG MANUFACTURING INC.,
Petitioners

v.

SHANGHAI JINKO GREEN ENERGY ENTERPRISE MANAGEMENT CO., LTD. AND ZHEJIANG JINKO SOLAR CO., LTD.,
Patent Owners

Case No. IPR2026-00230
Patent 11,824,136

DECLARATION OF SYLVIA D. HALL-ELLIS, PH.D.

I. INTRODUCTION

1. My name is Sylvia D. Hall-Ellis. I have been retained as an expert in connection with this matter by Baker Botts LLP ("Baker Botts"), whom I understand represent the Petitioners in this matter.

2. I have written this declaration at the request of Baker Botts to provide my expert opinion regarding the authenticity and public availability of a book and three journal articles. My declaration sets forth my opinions in detail and provides the basis for my opinions regarding the public availability of these publications.

3. I reserve the right to supplement or amend my opinions, and bases for them, in response any additional evidence, testimony, discovery, argument, and/or other additional information that may be provided to me after the date of this declaration.

4. I am being compensated for my time spent working on this matter at my normal consulting rate of $450 per hour, plus reimbursement for any additional reasonable expenses. My compensation is not in any way tied to the content of this declaration, the substance of my opinions, or the outcome of this litigation. I have no other interests in this proceeding or with any of the parties.

5. All of the materials that I considered are discussed explicitly in this declaration.

II. QUALIFICATIONS

6. I am currently an Adjunct Professor in the School of Information at San José State University. I obtained a Master of Library Science from the University of North Texas in 1972 and a Ph.D. in Library and Information Science from the University of Pittsburgh in 1985. Over the last fifty years, I have held various positions in the field of library and information resources. I was first employed as a librarian in 1966 and have been involved in the field of library sciences since, holding numerous positions.

7. I am a member of the American Library Association (ALA) and its Association for Library Collections & Technical Services (ALCTS) Division, and I served on the Committee on Cataloging: Resource and Description (which wrote the new cataloging rules) and as the chair of the Committee for Education and Training of Catalogers and the Competencies and Education for a Career in Cataloging Interest Group. I also served as the Chair of the ALCTS Division's Task Force on Competencies and Education for a Career in Cataloging. Additionally, I have served as the Chair for the ALA Office of Diversity's Committee on Diversity, as a member of the national Board of Directors for REFORMA, as a member of the Editorial Board for the ALCTS premier cataloging journal, *Library Resources and Technical Services*, as a Co-Chair for the Library Research Round Table (LRRT) of ALA, and a member of the LRRT Nominating Committee. Currently I serve as a member of

the CORE Margaret Mann Citation Committee and as a Member of the CORE Awards & Scholarship Coordination Committee.

8. I have also given over one hundred presentations in the field, including several related to library cataloging systems and Machine-Readable Cataloging ("MARC") standards. My current research interests include library cataloging systems, metadata, and organization of electronic resources.

9. My full curriculum vitae is attached hereto as Attachment 1 to this declaration.

III. PRELIMINARIES

A. Scope of Declaration and Legal Standards

10. I am not an attorney and will not offer opinions on the law. I am, however, rendering my expert opinion on the authenticity of the documents referenced herein and on when and how each of these documents was disseminated or otherwise made available to the extent that persons interested and ordinarily skilled in the subject matter or art, exercising reasonable diligence, could have located the documents before August 4, 2021.

11. I am informed by counsel that a printed publication qualifies as publicly accessible as of the date it was disseminated or otherwise made available such that a person interested in and ordinarily skilled in the relevant subject matter could locate it through the exercise of ordinary diligence.

12. While I understand that the determination of public accessibility under the foregoing standard rests on a case-by-case analysis of the facts particular to an individual publication, I also understand that a printed publication is rendered "publicly accessible" if it is cataloged and indexed by a library such that a person interested in the relevant subject matter could locate it exercising reasonable diligence (*i.e.*, I understand that cataloging and indexing by a library in a manner that permits a person of ordinary skill in the relevant subject matter to locate the publication is sufficient, though there are other ways that a printed publication may qualify as publicly accessible). One manner of indexing that I understand to be sufficient is indexing according to subject matter category. I understand that the cataloging and indexing by a single library of a single instance of a particular printed publication is sufficient, even if the single library is in a foreign country. I understand that, even if access to a library is restricted, a printed publication that has been cataloged and indexed therein is publicly accessible so long as a presumption is raised that the portion of the public concerned with the relevant subject matter would know of the printed publication. I also understand that the cataloging and indexing of information that would guide a person interested in the relevant subject matter to the printed publication, such as the cataloging and indexing of an abstract for the printed publication, is sufficient to render the printed publication publicly accessible.

13. I understand that routine business practices, such as general library cataloging and indexing practices, can be used to establish an approximate date on which a printed publication became publicly accessible.

B. Persons of ordinary skill in the art

14. I understand from counsel that the subject matter of this proceeding relates generally to solar cells and modules, which are sometimes referred to as "photovoltaic" cells and modules.

15. I have been informed by counsel that a "person of ordinary skill in the art" (POSITA) at the time of the invention is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the inventions. This hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles applicable to the pertinent field.

16. I understand from counsel that POSITAs relevant to this matter would have at least a bachelor's degree and/or a more advanced degree in a relevant engineering field and experience with the design and/or manufacture of solar cells or related technologies. I understand from counsel that this level of skill is approximate, and more education may substitute for industry experience or vice versa. I have been further informed by counsel that a POSITA would have been familiar with and able to understand the information known in the art relating to these fields, including the publications discussed in this declaration.

17. It is my opinion that such a POSITA would have been engaged in research, learning through study and practice in the field and possibly through formal instruction from the bibliographic resources relevant to his or her research. Before August 4, 2021, such a POSITA would have had access to a vast array of long-established print resources related to the relevant engineering fields, as well as a rich set of online resources providing indexing information, abstracts, and full text services for solar cells or related technologies.

18. Based on my experience working in research libraries with researchers having the qualifications described above, or even lesser qualifications, it is my opinion that such researchers would have been able to locate the material discussed herein on their own or with the assistance of a research librarian with relative ease using the tools and resources described herein.

IV. LIBRARY CATALOGING PRACTICES

19. In preparing this declaration, I used authoritative databases, such as the Wiley Online Library, Elsevier in *Science Direct* database, *ResearchGate*, *Semantic Scholar*, WorldCat database, MARC records, OCLC bibliographic database, the Library of Congress Online Catalog, and the Library of Congress Subject Authorities, to confirm citation details of the various publications discussed. Unless I note otherwise below in reference to a specific serial publication, it is my expert

opinion that this standard protocol was followed for the serial publication discussed below.

20. Based on my experience working in research libraries with researchers having the qualifications described above, or even lesser qualifications, it is my opinion that such researchers would have been able to locate the material discussed herein on their own or with the assistance of a research librarian with relative ease using the tools and resources described herein.

A. INDEXING

21. A researcher may discover material relevant to his or her topic in a variety of ways. One common means of discovery is to search for relevant information in an index of periodical and other publications. Having found relevant material, the researcher will then normally obtain it online, look for it in libraries, or purchase it from the publisher, a bookstore, a document delivery service, or other provider. Sometimes, the date of a document's public accessibility will involve both indexing and library date information. However, date information for indexing entries is sometimes unavailable. This is especially true for online indices.

22. Indexing services use a wide variety of controlled vocabularies to provide subject access and other means of discovering the content of documents. The formats in which these access terms are presented vary from service to service. The Library of Congress Subject Authorities includes standard forms of terms and

cross references that are included in bibliographic records. Subject headings are terms that an individual seeking a document regardless of format can enter in the search bar of the online catalog. Subjects also connect an authenticated term (one included in the Library of Congress subject headings list) with related, broader, and narrower terms.

23. Online indexing services commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document. A citation of a document is evidence that the document was publicly available and in use by researchers no later than the publication date of the citing document.

24. Before the widespread development of online databases to index articles in journals, magazines, conference papers, and technical reports, libraries purchased printed volumes of indices. Graduate library school education mandated that students learn about the bibliographic control of disciplines, the prominent indexing volumes, and searching strategies required to use them effectively and efficiently. Half of the courses that I studied in library school were focused on bibliography and resources in academic disciplines.

25. Librarians consult with researchers and other information seekers to verify citations, check availability in union catalogs, printed books catalogs, the

Online Computer Library Center ("OCLC") database, and make formal requests for materials (*e.g.*, books, conference proceedings, journal articles). Requests were transmitted using Telex machines, rudimentary email systems, and the United States Postal Service. During my career, I have performed and supervised staff who handled these resource sharing tasks.

26. A major firm known for the breadth of subjects and comprehensive treatment in the preparation of index volumes, the H. W. Wilson Company offered these reference resources since the firm was founded in 1898. The *Reader's Guide to Periodical Literature* is one of the best-known titles available from H. W. Wilson. Each volume includes a comprehensive index for 300 of the most popular and important periodicals published in the United States and Canada. Information seekers have subject access expressed in plain language terminology, author access, and cross references to find the desired results from their searches. The family of index titles included *Science & Technology Index*, *Business Periodicals*, *Applied Science & Technology Index, Humanities Index, Biological & Agricultural Index*, and *Industrial Arts Index*. These printed indices have been superseded by digital database offerings available to researchers online.

27. Prominent online indexing and discovery services include the Wiley Online Library, Elsevier in the *Science Direct* database, *ResearchGate*, *Semantic Scholar*, and the WorldCat database, amongst others.

a. Wiley Online Library

28. This scholarly research platform is produced by John Wiley & Sons, a major academic and professional publisher founded in 1807. The Wiley Online Library was first available online in 2010, and provides subscription-based access to peer-reviewed journals, scholarly books, reference works, and technical standards across the sciences, engineering, medicine, social sciences, and humanities, with coverage including both current publications and extensive historical backfiles. The database includes bibliographic records, abstracts, citation information, and full-text documents, and is commonly accessed through institutional subscriptions.

b. Elsevier in the *Science Direct* database

29. Online indexing services, such as the *Science Direct* database [1] managed by Elsevier—a major publisher, commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document. For example, the *Science Direct* database was first made available by Elsevier in 1997.

[1] https://www.sciencedirect.com/

c. WorldCat database

30. WorldCat is a global bibliographic database produced and maintained by OCLC and first launched in 1971. It aggregates catalog records from libraries worldwide, including books, journals, conference proceedings, dissertations, government documents, and other library-held materials across all major subject areas. The database commonly includes standardized bibliographic information such as titles, authors, publication dates, publishers, subject classifications, identifiers (*e.g.*, ISBN/ISSN), and library holding information, and is typically accessed through institutional or public library subscriptions.

B. MARC RECORDS AND THE ONLINE LIBRARY CATALOG

31. I am fully familiar with the library cataloging standard known as the MARC standard, which is an industry-wide standard method of storing and organizing library catalog information.[2] MARC was first developed in the 1960s by the Library of Congress. A MARC-compatible library is one that has a catalog consisting of individual MARC records for each of its items. Today, MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries.

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[2] The full text of the standard is available from the Library of Congress at https://www.loc.gov/marc/bibliographic/

32. Since at least the early 1970s and continuing to the present day, MARC has been the primary communications protocol for the transfer and storage of bibliographic metadata in libraries.[3] As explained by the Library of Congress:

> You could devise your own method of organizing the bibliographic information, but you would be isolating your library, limiting its options, and creating much more work for yourself. Using the MARC standard prevents duplication of work and allows libraries to better share bibliographic resources. Choosing to use MARC enables libraries to acquire cataloging data that is predictable and reliable. If a library were to develop a "home-grown" system that did not use MARC records, it would not be taking advantage of an industry-wide standard whose primary purpose is to foster communication of information.
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> Using the MARC standard also enables libraries to make use of commercially available library automation systems to manage library operations. Many systems are available for libraries of all sizes and are designed to work with the MARC format. Systems are maintained and improved by the vendor so that libraries can benefit from the latest advances in computer technology. The MARC standard also allows

[3] A complete history of the development of MARC can be found in *MARC: Its History and Implications* by Henrietta D. Avram (Washington, DC: Library of Congress, 1975) and available online from the Hathi Trust (https://babel.hathitrust.org/cgi/pt?id=mdp.39015034388556;view=1up;seq=1; last visited January 9, 2026).

libraries to replace one system with another with the assurance that their data will still be compatible.

Why Is a MARC Record Necessary? LIBRARY OF CONGRESS.[4]

33. Thus, almost every major library in the world is MARC-compatible. *See, e.g.*, *MARC Frequently Asked Questions (FAQ)*, LIBRARY OF CONGRESS.[5] ("MARC is the acronym for Machine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began fifty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today."). MARC is the ANSI/NISO Z39.2-1994 standard (reaffirmed in 2016) for Information Interchange Format. The full text of the standard is available from the Library of Congress.[6]

34. A MARC record comprises several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follow. For example, a work's title is recorded in Field 245; the primary author of the work is transcribed in Field 100; an item's International Standard Book Number ("ISBN") consisting of ten or

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[4] https://www.loc.gov/marc/umb/um01to06.html#part2

[5] https://www.loc.gov/marc/faq.html

[6] https://www.loc.gov/marc/bibliographic/

thirteen digits is transcribed in Field 020; an item's International Standard Serial Number ("ISSN") is transcribed in Field 022; the Library of Congress classification notation is recorded in Field 050; and the publication date is recorded in Field 260 under the subfield "c." If a work is a periodical, then its publication frequency is recorded in Field 310, and the publication dates (*e.g.*, the first and last publication) are recorded in Field 362, which is also referred to as the enumeration/chronology field.[7]

35. The library that created the record is recorded in Field 040 in subfield "a" with a unique library code. When viewing the MARC record online via OCLC's bibliographic database, hovering over this code with the mouse reveals the full name of the library. I used this method of "mousing over" the library codes in the OCLC database to identify the originating library for the MARC records discussed in this declaration. Where this "mouse over" option was not available, I consulted the Directory of OCLC Libraries to identify the institution that created the MARC record.[8] The library or database that is holding the document is recorded in Field 049 in subfield "a" with a unique code.

[7] https://www.loc.gov/marc/bibliographic/bd3xx.html

[8] https://www.oclc.org/en/contacts/libraries.html

36. MARC records also include several fields that include subject matter classification information. An overview of MARC record fields is available through the Library of Congress.[9] For example, 6XX fields are termed "Subject Access Fields."[10] Among these, for example, is the 650 field; this is the "Subject Added Entry – Topical Term" field.[11] The 650 field is a "[s]ubject added entry in which the entry element is a topical term." *Id.* These entries "are assigned to a bibliographic record to provide access according to generally accepted thesaurus-building rules (*e.g.*, *Library of Congress Subject Headings* (LCSH), *Medical Subject Headings* (MeSH))." *Id.* Further, MARC records include call numbers, which themselves include a classification number. For example, the 050 field is the "Library of Congress Call Number."[12] A defined portion of the Library of Congress Call (LCC) Number is the classification number, and "source of the classification number is *Library of Congress Classification* and the *LC Classification-Additions and Changes*." *Id*. Thus, included in the 050 field is a subject matter classification. Further, the 082 field is the "Dewey Decimal Call Number."[13] A defined portion of

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[9] https://www.loc.gov/marc/bibliographic/

[10] https://www.loc.gov/marc/bibliographic/bd6xx.html

[11] https://www.loc.gov/marc/bibliographic/bd650.html

[12] https://www.loc.gov/marc/bibliographic/bd050.html

[13] https://www.loc.gov/marc/bibliographic/bd082.html

the Dewey Decimal Call (DDC) Number is the classification number, and "source of the classification number is the *Dewey Decimal Classification and Relative Index*." Thus, included in the 082 field is a subject matter classification. Each item in a library has a single classification number. A library selects a classification scheme (*e.g.*, the Library of Congress classification scheme just described or a similar scheme such as the Dewey Decimal classification scheme) and uses it consistently. When the Library of Congress assigns the LCC classification number, it appears as part of the 050 field. When the Library of Congress assigns the DDC classification number, it appears as part of the 082 field. If a local library assigns the classification number, it appears in a 090 field. In either scenario, the MARC record includes a classification number that represents a subject matter classification.

C. OCLC

37. The OCLC was created "to establish, maintain and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary

SEG Solar, EX1020, Page 17

and educational knowledge and information."[14] Among other services, OCLC and its members are responsible for maintaining the WorldCat database,[15] used by independent and institutional libraries throughout the world.

38. OCLC also provides its members online access to MARC records through its OCLC bibliographic database. When an OCLC member institution acquires a work, it creates a MARC record for this work in its computer catalog system in the ordinary course of its business. MARC records created at the Library of Congress are directly uploaded or may be tape-loaded into the OCLC database through a subscription to MARC Distribution Services daily or weekly. Once the MARC record is created by a cataloger at an OCLC member institution or is tape-loaded from a participating institution, the MARC record is then made available to any other OCLC members online, and therefore made available to the public. Accordingly, once the MARC record is created by a cataloger at an OCLC member institution or is tape-loaded from the Library of Congress or another library anywhere in the world, any publication corresponding to the MARC record has been cataloged and indexed according to its subject matter such that a person interested

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[14] Third Article, Amended Articles of Incorporation of OCLC Online Computer Library Center, Incorporated (available at https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf)

[15] https://search.worldcat.org/

in that subject matter could, with reasonable diligence, locate and access the publication through any library with access to the OCLC bibliographic database or through the Library of Congress.

39. When an OCLC member institution creates a new MARC record, OCLC automatically supplies the date of creation for that record. The date of creation for the MARC record appears in the fixed Field 008, characters 00 through 05 in year, month, day format (YYMMDD). The MARC record creation date reflects the date on which, or shortly after which, the item was first acquired or cataloged. Initially, Field 005 of the MARC record is automatically populated with the date the MARC record was created in year, month, day format (YYYYMMDD) (some of the newer library catalog systems also include hour, minute, second (HHMMSS)). Thereafter, the library's computer system may automatically update the date in Field 005 every time the library updates the MARC record (*e.g.*, to reflect that an item has been moved to a different shelving location within the library).

40. Once one library has cataloged and indexed a publication by creating a MARC record for that publication, other libraries that receive the publication do not create additional MARC records—the other libraries instead rely on the original MARC record. They may update or revise the MARC record to ensure accuracy, but they do not replace or duplicate it. This practice does more than save libraries from duplicating labor. It also enhances the accuracy of MARC records. Further, it allows

librarians around the world to know that a particular MARC record is authoritative (in contrast, a hypothetical system wherein duplicative records were created would result in confusion as to which record is authoritative).

41. In addition, a local library may use a field in the 900-999 range to record local information regarding the cataloging, binding, storage, and status of an item. The 9XX fields are not part of the standard MARC 21 format.[16] For example, the Library of Congress uses Field 955 to track the movements of an item through the cataloging process. The date and initials of the staff member performing a task is recorded, including (but not limited to) transfer to the Dewey Decimal team for the assignment of a classification number, the verification of the CIP (cataloging in publication) data, and transfer to the BCCD (Binding and Collection Care Division) for binding and preservation services. Data transcribed at local libraries that are important to establish dates of public availability are described for each of the documents described in this declaration.

42. The date of creation of the MARC record by a cataloger at an OCLC member institution generally reflects when the underlying item is accessible to the public. Upwards of two-thirds to three-quarters of book sales to libraries come from a jobber or wholesaler for online and print resources. These resellers make it their

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[16] https://www.oclc.org/bibformats/en/9xx.html

business to provide books to their customers as fast as possible, often providing turnaround times of only a single day after publication. Libraries purchase a significant portion of the balance of their books directly from publishers themselves, which provide delivery on a similarly expedited schedule. In general, libraries make these purchases throughout the year as the books are published and shelve the books as soon thereafter as possible in order to make the books available to their patrons. Thus, books are generally available at libraries across the country within just a few days of publication.

D. JOURNALS

43. Catalogers can create MARC records for all types of print, online, and digital resources. For example, MARC records cover serial publications, including both serially published monographs and journals. OCLC hosts MARC records for more than 320 million serial publications. Serial publications are those publications that have the same collective title but are intended to be continued indefinitely with enumeration such as a volume or issue number (*e.g.*, magazines, journals, etc.). In the OCLC bibliographic database, the first issue of the serial publication is typically cataloged (*i.e.*, a corresponding MARC record is created), but the date is left open-ended with the use of a punctuation mark such as a dash. OCLC serial publication MARC records represent the entire run of the serial title. With knowledge of the first issue published, future issues can be predicted based on the information provided in

the MARC record, for example in Field 362. In my extensive professional experience, is it highly unusual for a library to stop collecting and shelving a serial publication prior to the end of its publication run. If a subscription to a serial publication ends its run or is cancelled before the end of its run, the library will denote that it has stopped receiving new volumes by filling in the end date in the MARC record.

44. The handling of printed journal subscriptions is shown on the covers of individual issues. As was the best practice among libraries, issues arrived at a central facility and were immediately received, verified as part of a subscription, checked in, and stamped with the institution's name and date. Determining that the issue was part of the library subscription ensured that the entire set of publications for the year had been received so that they could be professionally bound and retained. This process also verified that all of the published issues arrived so that the library staff did not have to request or claim an issue that did not arrive as expected. In large public libraries with branches and multi-campus libraries within academic institutions, the journals were sorted and delivered to the subscribing unit. The issues were frequently stamped again to acknowledge receipt. The new issue was placed in the public area; the older issue was stored so that it remained available.

45. The foregoing process has been standard library practice longer than I have been working in the profession. I first learned the steps in the process in the

late 1970s and later supervised it. Although the checking in process has become automated and now links electronically to holdings records for the MARC record for each serial title, the manual placement of a stamp or label and placing the issue in a public area has not changed for 50 years. Unless I note otherwise below in reference to a specific serial publication, it is my expert opinion that this standard protocol was followed for the publications discussed below.

V. PUBLICATIONS

A. Document 1: Exhibit 1012 ("Basu article")

46. Attached hereto as Exhibit 1012 (Attachment 2a) is a copy of the journal article titled "The Effect of Front Pyramid Heights on the Efficiency of Homogeneously Textured Inline-Diffused Screen-Printed Monocrystalline Silicon Wafer Solar Cells" by Prabir Kanti Basu, Ankit Khanna, and Ziv Hameiri (hereinafter "Basu article"). The Basu article was published in Volume 78 of the journal *Renewable Energy* and can be found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Basu article appears beginning on page 590 of this issue dated June 2015, and indicates public availability online on February 11, 2015, on page 1. Exhibit 1012 is a true and correct copy of the Basu article (pages 590-598) that I understand is being submitted as an exhibit in this proceeding. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the

next; further, there are no visible alterations to the document. The Basu article is also available from the publisher, Elsevier in the Science Direct database,[17] and the digital repositories *ResearchGate*[18] and *Semantic Scholar.*[19] Exhibit 1012 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Exhibit 1012 is a true and correct copy in a condition that creates no suspicion about its authenticity.

47. Attached hereto as Attachment 2b is a true and correct copy of the MARC record for the journal *Renewable Energy* at the Linda Hall Library of Science, Engineering & Technology. The library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 2b occurred on September 6, 2023, as shown in field 005 ("20230906"). I personally identified and retrieved the MARC record that is Attachment 2b.

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[17] https://www.sciencedirect.com/science/article/abs/pii/S0960148115000762

[18] https://www.researchgate.net/publication/272354606_The_effect_of_front_pyramid_heights_on_the_efficiency_of_homogeneously_textured_inline-diffused_screen-printed_monocrystalline_silicon_wafer_solar_cells

[19] https://www.semanticscholar.org/paper/The-effect-of-front-pyramid-heights-on-the-of-wafer-Basu-Khanna/e75a488cc9c72641834a036d6911ed71922d59ef

48. Based on finding a copy of Exhibit 1012 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 2b, it is my opinion that the Basu article was publicly available through libraries in a print issue in or shortly after June 2015. In view of the above, it is also my opinion that the Basu article was publicly available online on or shortly after February 11, 2015, as indicated on page 1 of Attachment 2a. Attachment 2b also shows that the journal *Renewable Energy* was catalogued with two descriptor terms reading "Renewable energy sources $v Periodicals" (*see* Attachment 2c, Library of Congress subject heading sh2010110747) and "Power resources $v Periodicals" (*see* Attachment 2d, Library of Congress subject heading sh2008109910) in the 650 fields.

49. As noted in the holdings information, the Linda Hall Library of Science, Engineering & Technology has received the journal *Renewable Energy* since 1991 and continues to receive the publication (*see* Attachment 2b, field 008 and field 362). In view of the MARC record for Exhibit 1012, the Basu article was publicly available no later than February 11, 2015, or alternatively by shortly after June 2015, because the serial title had been cataloged and indexed at the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

50. Attached hereto as Attachment 2e is a true and correct copy of the

MARC record for the journal *Renewable Energy* obtained from the OCLC bibliographic database. I personally identified and retrieved the MARC record that is Attachment 2e. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 2e, that library code is "AUM," which means that the MARC record for this serial was cataloged at the University of Massachusetts – Amherst Libraries (Amherst, Massachusetts). As can be seen in field 008 ("Date entered on file") of the MARC record (Attachment 2e), a cataloger at the University of Massachusetts – Amherst Libraries created OCLC record number 23609608 on April 26, 1991 ("910426"). The "BLvl" entry in Attachment 2e is "s," which indicates that the journal *Renewable Energy* is a serial publication. Field 310 of Attachment 2e reads "Monthly." Accordingly, the MARC record for Exhibit 1012 corresponds to those volumes of the journal *Renewable Energy* from the time of the serial title began publication in 1991 to the present day.

51. Attachment 2e further includes an entry in field 050 ("TJ809 $b .S6")—as described above, this includes a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("621.042"), a subject matter consistent with the Dewey Decimal classification system. Attachment 2e further includes two descriptor terms reading "Renewable energy sources $v Periodicals" (*see* Attachment 2c, Library of Congress subject heading sh2010110747) and

"Power resources $v Periodicals" (*see* Attachment 2d, Library of Congress subject heading sh2008109910) in the 650 fields. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Attachment 2e was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entries. Further, as of April 26, 1991, the MARC record attached hereto as Attachment 2e was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date.

52. WorldCat indicates that the journal *Renewable Energy* as cataloged at the University of Massachusetts – Amherst Libraries is available from 262 libraries as of the date of my most recent visit to the site.[20] In view of the above, this issue of the journal *Renewable Energy* was publicly accessible as early as February 11, 2015, or alternatively by shortly after June 2015, because by that date it had been cataloged and indexed at the University of Massachusetts – Amherst Libraries and made part of the OCLC bibliographic database.

[20] https://search.worldcat.org/title/23609608

B. Document 2: Exhibit 1013 ("Guan article")

53. Attached hereto as Exhibit 1013 (Attachment 3a) is a copy of the journal article titled "Double-Sided Pyramid Texturing Design to Reduce the Light Escape of Ultrathin Crystalline Silicon Solar Cells" by Guan Li, Guangming Shen, Yanan Liang, Fengxue Tan, Xiaofang Xu, Xinyu Tan, and Xu Lia (hereinafter "Guan article"). The Guan article was published in Volume 120 of the journal *Optics and Laser Technology* and can be found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Guan article appears beginning on page 105700 of this issue dated December 2019, and indicates public availability online on August 3, 2019, on page 1. Exhibit 1013 is a true and correct copy of the Guan article (page 105700, 7 pages) that I understand is being submitted as an exhibit in this proceeding. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. The Guan article is also available from the publisher, Elsevier in the Science Direct database,[21]

[21] https://www.sciencedirect.com/science/article/abs/pii/S003039921832173X

and the digital repositories *ResearchGate*[22] and *Semantic Scholar*.[23] Exhibit 1013 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Exhibit 1013 is a true and correct copy in a condition that creates no suspicion about its authenticity.

54. Attached hereto as Attachment 3b is a true and correct copy of the MARC record for the journal *Optics and Laser Technology* at the Linda Hall Library of Science, Engineering & Technology. The library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 3b occurred on September 6, 2023, as shown in field 005 ("20230906"). I personally identified and retrieved the MARC record that is Attachment 3b.

55. Based on finding a copy of Exhibit 1013 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 3b, it is my opinion that the Guan article was publicly

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[22] https://www.researchgate.net/publication/337659475_Double-sided_pyramid_texturing_design_to_reduce_the_light_escape_of_ultrathin_crystalline_silicon_solar_cells

[23] https://www.semanticscholar.org/paper/Double-sided-pyramid-texturing-design-to-reduce-the-Guan-Shen/a0b855513d6bf5127ba281d67b9285c5096e8314

available through libraries in a print issue in or shortly after December 2019. In view of the above, it is also my opinion that the Guan article was publicly available online on or shortly after August 3, 2019, as indicated on page 1 of Attachment 3a. Attachment 3b also shows that the journal *Optics and Laser Technology* was catalogued with two descriptor terms reading "Optics $v Periodicals" (*see* Attachment 3c, Library of Congress subject heading sh2008108683) and "Lasers $v Periodicals" (*see* Attachment 3d, Library of Congress subject heading sh2009128884) in the 650 fields.

56. As noted in the holdings information, the Linda Hall Library of Science, Engineering & Technology has received the journal *Optics and Laser Technology* since August 1970 and continues to receive the publication (*see* Attachment 3b, field 008 and field 362). In view of the MARC record for Exhibit 1013, the Guan article was publicly available no later than August 3, 2019, or alternatively by shortly after December 2019, because the serial title had been cataloged and indexed at the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

57. Attached hereto as Attachment 3e is a true and correct copy of the MARC record for the journal *Optics and Laser Technology* obtained from the OCLC bibliographic database. I personally identified and retrieved the MARC record that is Attachment 3e. As previously noted, the library that created the record is recorded

in field 040 with a unique library code. For Attachment 3e, that library code is "COO," which means that the MARC record for this serial was cataloged at the Mann Library at Cornell University (Ithaca, New York). As can be seen in field 008 ("Date entered on file") of the MARC record (Attachment 3e), a cataloger in the Mann Library at Cornell University created OCLC record number 4952296 on May 11, 1979 ("790511"). The "BLvl" entry in Attachment 3e is "s," which indicates that the journal *Optics and Laser Technology* is a serial publication. Field 310 of Attachment 3e reads "Eight no. a year, $b <1996->." Accordingly, the MARC record for Exhibit 1013 corresponds to those volumes of the journal *Optics and Laser Technology* from the time of the serial title began publication in August 1970 to the present day.

58. Attachment 3e further includes an entry in field 050 ("QC350 $b .O66")—as described above, this includes a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("535/.05"), a subject matter consistent with the Dewey Decimal classification system. Attachment 3e further includes two descriptor terms reading "Optics $v Periodicals" (*see* Attachment 3c, Library of Congress subject heading sh2008108683) and "Lasers $v Periodicals" (*see* Attachment 3d, Library of Congress subject heading sh2009128884) in the 650 fields. Thus, as of its cataloging, the publication

corresponding to the MARC record attached hereto as Attachment 3e was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entries. Further, as of May 11, 1979, the MARC record attached hereto as Attachment 3e was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date.

59. WorldCat indicates that the journal *Optics and Laser technology* as cataloged in the Mann Library at Cornell University is available from 2 libraries as of the date of my most recent visit to the site.[24] In view of the above, this issue of the journal *Optics and Laser Technology* was publicly accessible as early as August 3, 2019, or alternatively by shortly after December 2019, because by that date it had been cataloged and indexed in the Mann Library at Cornell University and made part of the OCLC bibliographic database.

C. Document 3: Exhibit 1014 ("Lozac'h article")

60. Attached hereto as Exhibit 1014 (Attachment 4a) is a copy of the journal article titled "Role of Silicon Surface, Polished (100) and (111) or Textured,

[24] https://search.worldcat.org/title/4952296. In addition, there are at least 26 other records receiving this journal and are available in several hundred other libraries.

on the Efficiency of Double-Sided TOPCon Solar Cells" by Mickaël Lozac'h and ShotaNunomura (hereinafter "Lozac'h article"). The Lozac'h article was published in Volume 28, Issue 10 of the journal *Progress in Photovoltaics* and can be found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Lozac'h article appears beginning on page 1001 of this issue dated October 2020, and indicates public availability online on June 25, 2020, on page 1 of the article hosted on the publisher's website (*see* Attachment 4h). Exhibit 1014 is a true and correct copy of the Lozac'h article (pages 1001-1011) that I understand is being submitted as an exhibit in this proceeding. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. The Lozac'h article is also available from the publisher, Wiley in the Wiley Online Library,[25] and the digital repositories *ResearchGate*[26] and *Semantic Scholar*.[27] Exhibit 1014 was found within the custody of a library – a place where

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[25] https://onlinelibrary.wiley.com/doi/abs/10.1002/pip.3304 (*see* Attachment 4h)

[26] https://www.researchgate.net/publication/342468407_Role_of_silicon_surface_polished_100_and_111_or_textured_on_the_efficiency_of_double-sided_TOPCon_solar_cells

[27] https://www.semanticscholar.org/paper/Role-of-silicon-surface%2C-polished-%E3%80%88100%E3%80%89-and-%E3%80%88111%E3%80%89-Lozac%E2%80%99h-Nunomura/ea0dbb04d1c0671ef824800ba5d81279ee112413

an authentic copy of this journal would likely be. Exhibit 1014 is a true and correct copy in a condition that creates no suspicion about its authenticity.

61. Attached hereto as Attachment 4b is a true and correct copy of the MARC record for the journal *Progress in Photovoltaics* at the Linda Hall Library of Science, Engineering & Technology. The library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 4b occurred on August 26, 2010, as shown in field 005 ("20100826"). I personally identified and retrieved the MARC record that is Attachment 4b.

62. Based on finding a copy of Exhibit 1014 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 4b, it is my opinion that the Lozac'h article was publicly available through libraries in a print issue in or shortly after October 2020. In view of the above, it is also my opinion that the Lozac'h article was publicly available online on or shortly after June 25, 2020, as indicated on page 1 of the article hosted on the publisher's website (*see* Attachment 4h). Attachment 4b also shows that the journal *Progress in Photovoltaics* was catalogued with three descriptor terms reading "Solar cells $v Periodicals" (*see* Attachment 4c, Library of Congress subject heading sh85124492 and Attachment 4d, Library of Congress subject heading

sh85099890), "Photovoltaic cells $v Periodicals" (*see* Attachment 4e, Library of Congress subject heading sh89006119 and Attachment 4d, Library of Congress subject heading sh85099890), and "Solar power plants $v Periodicals" (*see* Attachment 4f, Library of Congress subject heading sh85124535 and Attachment 4d, Library of Congress subject heading sh85099890) in the 650 fields.

63. As noted in the holdings information, the Linda Hall Library of Science, Engineering & Technology has received the journal *Progress in Photovoltaics* since January 1993 continues to receive the publication (*see* Attachment 2b, field 008 and field 362). In view of the MARC record for Exhibit 1014, the Lozac'h article was publicly available no later than June 25, 2020, or alternatively by shortly after October 2020, because the serial title had been cataloged and indexed at the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

64. Attached hereto as Attachment 4g is a true and correct copy of the MARC record for the journal *Progress in Photovoltaics* obtained from the OCLC bibliographic database. I personally identified and retrieved the MARC record that is Attachment 4g. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 4g, that library code is "NSD," which means that the MARC record for this serial was cataloged as part of the National Serials Data Program at the Library of Congress. As can be seen in field

008 (“Date entered on file”) of the MARC record (Attachment 4g), a cataloger in the Library of Congress created OCLC record number 25744745 on May 1, 1992 (“920501”). The “BLvl” entry in Attachment 4g is “s,” which indicates that the journal *Progress in Photovoltaics* is a serial publication. Field 310 of Attachment 4g reads “Bimonthly, plus 2 additional issues, total 8 issues, $b 2002-.” Accordingly, the MARC record for Exhibit 1014 corresponds to those volumes of the journal *Progress in Photovoltaics* from the time of the serial title began publication in January 1993 to the present day.

65. Attachment 4g further includes an entry in field 050 (“TK2960 $b .P76”)—as described above, this includes a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 (“621”), a subject matter consistent with the Dewey Decimal classification system. Attachment 4g further includes three descriptor terms reading “Solar cells $v Periodicals” (*see* Attachment 4c, Library of Congress subject heading sh85124492 and Attachment 4d, Library of Congress subject heading sh85099890), “Photovoltaic cells $v Periodicals” (*see* Attachment 4e, Library of Congress subject heading sh89006119 and Attachment 4d, Library of Congress subject heading sh85099890), and “Solar power plants $v Periodicals” (*see* Attachment 4f, Library of Congress subject heading sh85124535 and Attachment 4d, Library of Congress subject heading

sh85099890) in the 650 fields. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Attachment 4g was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entries. Further, as of May 1, 1992, the MARC record attached hereto as Attachment 4g was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date.

66. WorldCat indicates that the journal *Progress in Photovoltaics* as cataloged at the Library of Congress is available from 246 libraries as of the date of my most recent visit to the site.[28] In view of the above, this issue of the journal *Progress in Photovoltaics* was publicly accessible as early as June 25, 2020, or alternatively by shortly after October 2020, because by that date it had been cataloged and indexed in the Library of Congress and made part of the OCLC bibliographic database.

D. Document 4: Exhibit 1015 ("Shah textbook")

67. Exhibit 1015 is a copy of the book titled *Solar Cells and Modules*, 1st edition, edited by Arvind Shah and published by Springer Nature on July 16, 2020,

[28] https://search.worldcat.org/title/25744745

in both print and electronic versions as shown on the publisher's website[29] (hereinafter, the "Shah textbook"). I understand that the exhibit filed in this proceeding as Exhibit 1015 is a true and correct copy of the Shah textbook (346 pages) (*see* Attachment 5a). I obtained this copy of the book from counsel. Specifically, the text of the book is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. Exhibit 1015 was found within the custody of a library—a place where, if authentic, a copy of this volume would likely be. Exhibit 1015 is a true and correct copy in a condition that creates no suspicion about its authenticity.

68. Attached hereto as Attachment 5b is a true and correct copy of the MARC record for this book from the University of Wisconsin—Madison Libraries online catalog. The library ownership is indicated by the presence of the library's code ("GZM") in the 049 field. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 5b occurred on August 7, 2020, as shown in field 005 ("20200807"). I personally identified and retrieved the library catalog record which is Attachment 5b.

[29] https://link.springer.com/book/10.1007/978-3-030-46487-5

69. Based on finding a copy of Exhibit 1015 in the University of Wisconsin – Madison Libraries and a record in its online library catalog attached as Attachment 5b, it is my opinion that the book titled *Solar Cells and Modules*, 1st edition, was available as of July 29, 2020 ("200729"), as shown in field 008 ("Date entered on file").

70. Attached hereto as Attachment 5c is a true and correct copy of the MARC record for the book titled *Solar Cells and Modules*, 1st edition, obtained from the OCLC bibliographic database. I personally identified and retrieved the MARC record that is Attachment 5c. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Exhibit 1015, that library code is "YDX," which means that the MARC record for this book was cataloged at the book jobber Yankee Book Peddler (Contoocook, New Hampshire).[30] As can be seen in field 008 ("Date entered on file") in the MARC record for this exhibit, a cataloger at the book jobber Yankee Book Peddler created OCLC record number 1178712692 on July 29, 2020 ("200729").

71. Attachment 5c further includes an entry in field 050 ("TK2960")—as described above, this includes a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal

[30] The book jobber is also known as Gobi Library Services.

classification system) and an entry in field 082 ("621.31/244"), a subject matter consistent with the Dewey Decimal classification system. Attachment 5c further includes a descriptor term reading "Solar cells" (*see* Attachment 4c, Library of Congress subject heading sh85124492) in the 650 field. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Exhibit 1015 was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entry. Further, as of July 29, 2020, the MARC record attached hereto as Attachment 5c was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that acquired the Shah Textbook, which means that the corresponding publication was publicly available on or before that same date through any library with access to the OCLC bibliographic database or through an individual library.

72. WorldCat indicates that the book titled *Solar Cells and Modules*, 1st edition, as cataloged at the book jobber Yankee Book Peddler is available from 208 libraries as of the date of my most recent visit to the site.[31] Therefore, the Shah Textbook was publicly accessible as early as July 29, 2020, because by that time it

[31] https://search.worldcat.org/title/1178712692

had been received, cataloged, and indexed at the University of Wisconsin – Madison Libraries and made part of the OCLC bibliographic database.

E. Document 5: Exhibit 1016 ("Yu article")

73. Attached hereto as Exhibit 1016 (Attachment 6a) is a copy of the journal article titled "Selective Tunnel Oxide Passivated Contact on the Emitter of Large-Size N-Type TOPCon Bifacial Solar Cells" by Bo Yu, Jinchao Shi, Feng Li, Hongfang Wang, Long Pang, Keming Liu, Dongsheng Zhang, Cuigu Wu, Ying Liu, Junyu Chen, Wanbing Lu, Ridong Cong, and Wei Yu (hereinafter "Yu article"). The Yu article was published in Volume 870 of the *Journal of Alloys and Compounds* and can be found in the Linda Hall Library of Science, Engineering & Technology (Kansas City, Missouri). The Yu article appears beginning on page 159679 of this issue dated July 25, 2021, and indicates public availability online on March 27, 2021, on page 1. Exhibit 1016 is a true and correct copy of the Yu article (page 159679, 8 pages) that I understand is being submitted as an exhibit in this proceeding. Specifically, the text of the article is complete; no pages are missing, and the text on each page appears to flow seamlessly from one page to the next; further, there are no visible alterations to the document. The Yu article is also available from the publisher, Elsevier in the Science Direct database,[32] and the digital repositories

[32] https://www.sciencedirect.com/science/article/abs/pii/S0925838821010884

ResearchGate[33] and *Semantic Scholar.*[34] Exhibit 1016 was found within the custody of a library – a place where an authentic copy of this journal would likely be. Exhibit 1016 is a true and correct copy in a condition that creates no suspicion about its authenticity.

74. Attached hereto as Attachment 6b is a true and correct copy of the MARC record for the *Journal of Alloys and Compounds* at the Linda Hall Library of Science, Engineering & Technology. The library ownership is indicated by the presence of the library's code ("LHL") in field 049. The library continues to update and enhance this MARC record to meet current cataloging rules. The most recent enhancement to Attachment 6b occurred on May 24, 2024, as shown in field 005 ("20240524"). I personally identified and retrieved the MARC record that is Attachment 6b.

75. Based on finding a copy of Exhibit 1016 in the Linda Hall Library of Science, Engineering & Technology and MARC record in its online library catalog attached as Attachment 6b, it is my opinion that the Yu article was publicly available

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[33] https://www.researchgate.net/publication/350435314_Selective_tunnel_oxide_passivated_contact_on_the_emitter_of_large-size_n-type_TOPCon_bifacial_solar_cells

[34] https://www.semanticscholar.org/paper/Selective-tunnel-oxide-passivated-contact-on-the-of-Yu-Jinchao/b0d0e56d74bec7eab46bb3a6f3436ed1fc3d06c3

through libraries on or shortly after July 2021. In view of the above, it is also my opinion that the Yu article was publicly available online on or shortly after March 27, 2021, as indicated on page 1 of Attachment 6a. Attachment 6b also shows that the *Journal of Alloys and Compounds* was catalogued with four descriptor terms reading "Materials science $v Periodicals" (*see* Attachment 6c, Library of Congress subject heading sh2010100270), "Solid state chemistry $v Periodicals" (*see* Attachment 6d, Library of Congress subject heading sh85124636 and Attachment 4d, Library of Congress subject heading sh85099890), "Solid state physics $v Periodicals" (*see* Attachment 6e, Library of Congress subject heading sh2010114088), and "Metallurgy $v Periodicals" (*see* Attachment 6f, Library of Congress subject heading sh2008107541) in the 650 fields.

76. As noted in the holdings information, the Linda Hall Library of Science, Engineering & Technology has received the *Journal of Alloys and Compounds* since October 1991 and continues to receive the publication (*see* Attachment 6b, field 008 and field 362).[35] In view of the MARC record for Exhibit 1016, the Yu article was publicly available no later than March 27, 2021, or alternatively by shortly after July 2021, because the serial title had been cataloged

[35] The publication was originally titled *Journal of the Less-Common Metals* (January 1959-September 1991) and adopted the current title, *Journal of Alloys and Compounds*, in October 1991.

and indexed at the Linda Hall Library of Science, Engineering & Technology and made part of its online catalog database.

77. Attached hereto as Attachment 6g is a true and correct copy of the MARC record for the *Journal of Alloys and Compounds* obtained from the OCLC bibliographic database. I personally identified and retrieved the MARC record that is Attachment 6g. As previously noted, the library that created the record is recorded in field 040 with a unique library code. For Attachment 6g, that library code is "TXU," which means that the MARC record for this serial was cataloged at University of Texas – El Paso Libraries. As can be seen in field 008 ("Date entered on file") of the MARC record (Attachment 6g), a cataloger at the University of Texas – El Paso Libraries created OCLC record number 24768995. The "BLvl" entry in Attachment 6g is "s," which indicates that the *Journal of Alloys and Compounds* is a serial publication. Field 310 of Attachment 6g reads "Forty-two no. a year, $b 2004-." Accordingly, the MARC record for Exhibit 1016 corresponds to those volumes of the *Journal of Alloys and Compounds* from the time of the serial title adopted the current title in 1991 to the present day.

78. Attachment 6g further includes an entry in field 050 ("TN1 $b .J7")—as described above, this includes a subject matter classification number consistent with the Library of Congress classification system (analogous to the Dewey Decimal classification system) and an entry in field 082 ("669/.05"), a subject matter

consistent with the Dewey Decimal classification system. Attachment 6g further includes a descriptor term reading "Alloys $v Periodicals" (*see* Attachment 6h, Library of Congress subject heading sh85003721 and Attachment 4d, Library of Congress subject heading sh85099890) in the 650 field. Thus, as of its cataloging, the publication corresponding to the MARC record attached hereto as Attachment 6g was indexed according to its subject matter by virtue of at least three independently sufficient classifications: the field 050 entry, the field 082 entry, and the field 650 entry. Further, as of November 12, 1991, the MARC record attached hereto as Attachment 6g was accessible through any library with access to the OCLC bibliographic database or the online catalog at a library that subscribed to the serial, which means that the corresponding publication was publicly available on or before that same date.

79. WorldCat indicates that the *Journal of Alloys and Compounds* as cataloged at the University of Texas – El Paso Libraries is available from 507 libraries as of the date of my most recent visit to the site.[36] In view of the above, this issue of the *Journal of Alloys and Compounds* was publicly accessible as early as March 27, 2021, or alternatively by shortly after July 2021, because by that date it

[36] https://search.worldcat.org/title/24768995

had been cataloged and indexed at the University of Texas – El Paso Libraries and made part of the OCLC bibliographic database.

VI. SUMMARY OF OPINIONS

80. In view of the foregoing, it is my opinion that the publications described above were publicly available on or about the corresponding date listed in the table below:

Document	Publication	Publicly Available
EX1012	Prabir Kanti Basu, Ankit Khanna, Ziv Hameiri, "The Effect of Front Pyramid Heights on the Efficiency of Homogeneously Textured Inline-Diffused Screen-Printed Monocrystalline Silicon Wafer Solar Cells," *Renewable Energy*, Vol. 78, pp. 590-98 (2015).	February 11, 2015
EX1013	Li Guan, Guangming Shen, Yanan Liang, Fengxue Tan, Xiaofang Xu, Xinyu Tan, Xu Li, "Double-Sided Pyramid Texturing Design to reduce the Light Escape of Ultrathin Crystalline Silicon Solar Cells," *Optics and Laser Technology*, Vol. 120, pp. 105700-707 (2019).	August 3, 2019
EX1014	Mickaël Lozac'h and Shota Nunomura, "Role of Silicon Surface, Polished (100) and (111) or Textured, on the Efficiency of Double-Sided TOPCon Solar Cells," *Progress in Photovoltaics: Research and Applications*, Vol. 28, pp. 1001-11 (2020).	June 25, 2020
EX1015	Arvind Shah, *Solar Cells and Modules*, 1st ed., Springer Nature (2020)	July 29, 2020
EX1016	Bo Yu, Jinchao Shi, Feng Li, Hongfang Wang, Long Pang, Keming Liu, Dongsheng Zhang, Cuigu Wu, Ying Liu, Junyu Chen, Wanbing Lu, Ridong Cong, Wei Yu, "Selective Tunnel Oxide Passivated Contact on the Emitter of Large-Size N-Type TOPCon Bifacial Solar	March 27, 2021

Document	Publication	Publicly Available
	Cells," *Journal of Alloys and Compounds*, Vol. 870, pp. 159679-686 (2021).	

81. In signing this Declaration, I recognize that the Declaration may be filed as evidence in a 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.

82. 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 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: February 16, 2026 By: Sylvia D. Hall-Ellis

Sylvia D. Hall-Ellis, Ph.D.

ATTACHMENT 1

CURRICULUM VITAE SYLVIA D. HALL-ELLIS

EDUCATION

Ph.D., University of Pittsburgh, Pittsburgh, Pennsylvania, 1985
M.P.S., University of Denver, Denver, Colorado, 2014
Post Graduate Studies, University of Texas – San Antonio, Texas, 1975-1976
M.L.S., University of North Texas, Denton, Texas, 1972
B.A., Rockford University, Rockford, Illinois, 1971

PROFESSIONAL EXPERIENCE

1981- **Consultant for higher education, non-profit organizations, and corporations.**

2002- **Adjunct Professor, School of Information, San José State University, San José, California.** Serve as part-time faculty member teaching graduate students in technical services (cataloging, bibliographic control, classification), "core courses," and special topics.

2014-2016 **Director, Grants and Resource Development, Colorado Community College System.** Provided leadership and vision to foster the continued growth of rigorous scholarship, innovative projects, and creative work for statewide system, 13 campuses, and 50 teaching sites serving 155,000 students. Responsible for leadership and ensured efficient functioning of contract and grants in compliance with state & federal requirements and successful implementation and management. Served as a subject matter expert and liaison for college Grant Directors for all issues relating to grants and subcontracts.

2010-2014 **Senior Grant Administrator, Morgridge College of Education, University of Denver (Colorado).** Provided leadership and vision to foster continued growth of rigorous scholarship, innovative research, and creative work in the Morgridge College of Education. Ensure that contract and grants processes function effectively and efficiently for 60 faculty and researchers with a focus on the successful progression and efficient management of grants totaling $13M. Worked effectively and collegially with Department Chairs and Program Coordinators on operational grant-related management activities and with a broad range of internal and external constituencies. Supported the dissemination and promotion of faculty research and scholarship to outside constituents at conferences and through publications. Assisted Principal Investigators and grant project teams by coaching, mentoring, and financial management.

2011-2013 **Interim Director & Assistant Dean, Westminster Law Library, Sturm College of Law, University of Denver.** Planned, organized, and directed all administrative activities for the library serving students, faculty, and alumni; oversaw the employment, retention, promotion, transfer and termination of library personnel; represented the library at professional conferences and public meetings; created and promoted a climate and culture of acceptance for new programs and services, a positive high-quality image of the law library, and that reflect the organization's values, encourage excellent performance, and reward high productivity and innovation; provided leadership and set strategic direction of the organization; ensured that the library provided excellent customer service through solution-oriented staff response to patron needs and by responsiveness and continuous improvement of the organization; promoted, developed, and maintained positive working relationships with colleagues and customers including key stakeholders and groups, higher education institutions, the legal community, other regional libraries and districts statewide, and national library organizations.

2007-2014 **Associate Professor, Library & Information Science, Morgridge College of Education, University of Denver (Colorado).** Served in leadership role and worked collaboratively in program, college, campus and community environments. Advised and supervised students, taught core and specialized courses at the graduate level in an integrative, student-centered learning environment. Served on LIS, College, and University committees, and maintained working relationships with colleagues in other academic units and information professionals in the Rocky Mountain region and beyond. Served on and chair doctoral student dissertation committees. Oversaw and facilitated the College and LIS graduate student association.

2002-2007 **Assistant Professor, Library & Information Science, College of Education, University of Denver (Colorado).** Served as tenure-track faculty member teaching graduate students in "core courses," resource description and access, service learning, and independent studies. Advised graduate students, participate on LIS and College committees, and serve on doctoral student dissertation committees. Oversaw and facilitated the LIS graduate student association and alumni association.

2000-2002 **Affiliate Faculty, Library & Information Science, College of Education, University of Denver (Colorado).** Served as part-time faculty member teaching graduate students in technical services (cataloging, bibliographic control, classification), "core courses," and special topics. Oversaw and facilitated the LIS graduate student association and alumni association.

2000-2001 **Special Assistant to the Secretary's Regional Representative, U.S. Department of Education, Region VIII, Denver, Colorado.** Served as the principal advisor and representative of the U. S. Secretary of Education's Regional Representative (SRR). Ensured the implementation of major goals of the SRR and the Secretary. Provided leadership on behalf of the SRR in contacts with high-level officials in Region VIII requiring sensitive policy interpretation in communication with senior Department officials to solve problems and resolve issues raised by State and local education officials. Served as the primary contact for School-to-Work/Career, Children's Health Insurance Program, and Safe and Drug-Free Schools. Delivered technical assistance to local education agencies and institutions of higher education in technology, professional development, and school construction.

1999-2000 **Catalog Librarian, Jefferson County Public Library, Lakewood, Colorado.** Performed original, copy cataloging and classification of library materials (English and Spanish) using standard library protocols; completed original descriptive cataloging and subject analysis; enhanced brief catalog and authority records in III.

1997-1999 **Development Officer, McREL International, Aurora, Colorado.** Served as senior member of corporate management team in strategic planning, development of proposals and contracts, implementation, and evaluation of new services, products, and programs for educational agencies. Provided creative leadership to corporate committees to solicit ideas, identify goals and objectives, plan, develop, present, and evaluate professional development opportunities.

1995-1997 **Education Specialist, Education Service Center, Region One, Edinburg, Texas.** Served as member of Administrative Cabinet team in strategic planning, development of proposals and contracts, implementation, and evaluation of telecommunications capabilities, services, products, and programs for 40 school districts serving 283,000 students in 7 counties. Provided creative leadership to regional and state committees to solicit ideas, identify strategic goals and objectives, plan, develop, present, and evaluate funding opportunities and professional development for 400 librarians.

1993-1996 **Assistant Professor of Library Science, Sam Houston State University, Huntsville, Texas.** Served a faculty member teaching 400 graduate students in technical services (cataloging, bibliographic control, classification), automation, and networking. Participated in distance education program and coordinated annual conference. Conducted university and Texas Library Association-funded field research focused on library collection development and academic achievement.

1992-1993 **Head Librarian, Rocky Mountain College of Art & Design, Denver, Colorado.** Responsible for the daily operation, selection and acquisition of materials, formulation of policies for library operations, media center, and photography/slides archives. Designed and implemented library automation and delivery of electronic resources to college community.

1981-1985 **Development Officer, PRLC, Inc., Pittsburgh, Pennsylvania.** Served as senior member of corporate management team in strategic planning, development of proposals and contracts, implementation, and evaluation of new services, products, and programs for 100 institutional member organizations. Coordinated the development of proposals and contracts totaling $4,000,000 annually. Provided creative leadership to corporate committees to solicit ideas, identify goals and objectives, plan, develop, present, and evaluate professional development opportunities.

1981 **Director of Library Development, Pennsylvania Department of Education, Harrisburg, Pennsylvania.** Responsible for statewide development, technical assistance, professional development, resource sharing, children's services, institutional library services, networking, and state aid program for all libraries throughout the Commonwealth. Functioned as liaison to Governor's Advisory Council, LSCA Advisory Council, District Administrators, private colleges, universities, consortia managers, and network directors. Supervised $14,000,000 formula-based state aid program and $3,000,000 grant awards to individual libraries, consortia, and networks.

1978-1981 **Assistant Director, Southern Tier Library System, Corning, New York.** Coordinated operation of system-wide programs (technical assistance, professional development, resource sharing, technical services, outreach) to 40 public libraries in 5 counties serving 500,000 residents. Solicited ideas, identified goals, sponsored, and evaluated professional development opportunities and technical assistance sessions.

1976-1978 **Division Librarian for Technical Services, Corpus Christi Public Libraries, Corpus Christi, Texas.** Provided leadership in acquisitions, cataloging, serials control, and processing for main library and 4 branches serving 250,000 residents. Participated as senior member of library management team. Compiled and prepared technical evaluations, reports, and statistical analyses of Division operations to measure the achievement and cost of annual goals, objectives, and staff performance.

1975-1976 **System Coordinator, San Antonio Major Resource Center, San Antonio, Texas.** Served as senior member of the management team for District X Office, charged to provide technical assistance, resource sharing, media services, and professional development to librarians and staff representing 30 public library jurisdictions in 21 counties serving 1,500,000 residents. Functioned as liaison to System Director, staff, and members of governing bodies with the System Board of Directors and the Texas State Library and Historical Commission. Prepared LSCA grant applications and monitored awards totaling $1,100,000 annually.

1973-1975 **Bilingual Branch Librarian, San Antonio Public Library, San Antonio, Texas.** Worked as librarian providing reference, information, and readers' advisory services in branch serving 50,000 Spanish-speaking residents in southwest San Antonio. Participated in collection development and resource acquisition activities, specializing in children's work, Spanish language resources, and multicultural studies.

1972-1973 **Librarian, Holding Institute, Laredo, Texas.** Worked as high school librarian serving 500 boarding students in Spanish-speaking environment of private school. Provided reference, research assistance, and library instruction to students and 35 faculty members.

1966-1971 **Rockford Public Library, Rockford, Illinois.** Worked in branches as part-time as a Library Assistant, Clerk, and Page in city library serving 150,000 residents.

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Hall, Sylvia D. "Cooperation Improving Service in San Antonio System." *Texas Libraries* XXXVII (Spring 1976): 27-29.

Hall, Sylvia D. "Summer is Sea Monstrously Fun!" *Texas Library Journal* L (December 1974): 224-226.

Hall, Sylvia D. "A Brief Annotated Bibliography of Non-book Materials on the Mexican American." *Texas Library Journal* XLVIII (October 1972): 213-232.

Book Reviews

ALA Book of Library Grant Money. Ann Kepler, ed. 8th ed. Chicago, IL: American Library Association, 2011. 978-0-8389-1058-0, $175.00 [*Colorado Libraries,* June 2012]

Developing a Compensation Plan for Your Library. Paula M. Singer and Laura L. Francisco, comps. 2nd ed. Chicago, IL: American Library Association, 2009. 978-0-8389-0985-0, $57.00 [*Colorado Libraries,* March 2012]

Frugal Librarian. Carol Smallwood, ed. Chicago, IL: American Library Association, 2011. 978-0-83891-075-7, $42.00 [*Colorado Libraries,* February 2012]

Dowlin, Ken. *Getting the Money: How to Succeed in Fundraising for Public and Nonprofit Libraries.* Westport, Conn.: Libraries Unlimited, 2008. 978-1-59158-597-X, $50.00 [*Colorado Libraries,* February 2009]

Lundahl, Mats. *Bebo de Cuba; Bebo Valdés y Su Mundo*, by Mats Lundahl. Traducción de Linda Oakeshott Dragó. Barcelona: RBA Libros, 2008. 978-849-86-7259-6, $33.99 [*Críticas*, November 2008]

Bonelli, Florencia. *Marlene*, by Florencia Bonelli. Buenos Aires: Aguilar, Altea, Taurus, Alfaguara, 2008. 978-987-04-0995-3, $24.95 [*Críticas*, October 2008]

Keret, Etgar. Traducción de Ana María Bejarano. *Pizzería Kamikaze y Otras Relatos.* México, D.F.: Editorial Sexto Piso, 2008. 968-5679-29-0, no price given [*Críticas*, September 2008]

Littauer, Marita, and Florence Littauer. *Enriquece tu Comunicación. Miami, Fla.: Editorial Unilit, 2008.* 978-0-7899-1521-4, $11.99 [*Críticas*, August 2008]

Martínez, Guillermo. *La Muerte Lenta de Luciana B.* New York: Rayo Planeta, 2008. 978-0-06-156551-9, $14.95 [*Críticas*, May 2008]

Matthews, Joseph R. *The Evaluation and Measurement of Library Services.* Westport, Conn.: Libraries Unlimited, 2007. 978-1-59158-532-9, $50.00 [*Colorado Libraries,* April 2008]

Gómez-Jurado, Juan. *A Masacre de Virginia Tech: Anatomía de una Mente Torturada.* Barcelona: Ediciones El Andén, 2007. 978-84-935789-4-7, €16.50 [*Críticas*, February, 2008]

Matthews, Joseph R. *Library Assessment in Higher Education.* Westport, Conn.: Libraries Unlimited, 2007. 978-1-59158-531-2, $45.00 [*Colorado Libraries,* February 2008]

Chacón, Inma. *La Princesa India: Cuando el Viento Azul.* México: Alfaguara, 2006. 970-770398-9, $19.95 [*Críticas*, June 2006]

Vargas Llosa, Mario. *Israel/Palestina: Paz o Guerra Santa.* fotogs. by Morgana Vargas Llosa. Spain/U.S.: Aguilar: Santillana, 2006. 84-03-09691-7, paper, $19.95 [*Críticas*, May 2006]

Findlay, Diane. *Digging into Dewey.* Fort Atkinson, Wisc.: Upstart Books, 2005. 978-1-932146-18-9, $16.95 [*Colorado Libraries,* May 2006]

Pequeñas Resistencias 4: Antología del Nuevo Cuento Norteamericano y Caribeño. Menéndez, Ronaldo, Ignacio Padilla & Enrique del Risco, eds. Madrid**:** Páginas de Espuma, 2005. 84-95642-59-X, paper, $36.95 [*Críticas*, April 2006]

Rueda, André. *Vengo a Salvar a España: Biografía de Un Franco Desconocido.* Madrid**:** Nowtilus (Investigación Abierta), 2005. photogs., bibliog. 84-9763-202-8, paper, $23.95 [*Críticas*, March 2006]

Becerra, Ángela. *El Penúltimo Sueño.* 1st ed. Barcelona: Planeta, 2005. 84-08-05795-2, $25.95. [*Críticas*, January 2006]

Aguilar Camín, Héctor. *La Conspiración de la Fortuna.* 1st ed. México: Planeta, 2005. 970-37-0368-2, $19.95 [*Críticas*, October 2005]

México en Sus Libros. Enrique Florescano with Pablo Mijangos, editors & compilers. 1st ed. México, D.F.: Taurus Aguilar, 2004. 968-19-0783-3, $16.95 [*Críticas*, September 2005]

Historia Económica de México. Coordinator, Enrique Semo. México: Universidad Nacional Autónoma de México, Editorial Oceano de México, 2004. 13 vols. 970-32-0805+3 (obra completa), $9.25 each [*Críticas*, August 2005]

Czarnowsky, Christyne A. and Michael H. Williams. *Managing Your Wired Workforce: A Practical Guide.* Denver, Colo.: Bradford Pub., 2003. 1-883726-79-4, $24.95 [*Colorado Libraries,* 2004]

Abraham Lincoln. Colección Grandes Biografías. Madrid: Edimat Libros, 2003. 84-8403-858-0, €4.95 [*Críticas*, 2004]

Alponte, Juan María. *Colón: el Hombre, el Navegante, la Leyenda.* México, D.F.: Aguilar, 2003. 968-19-1260-8, $16.95 [*Críticas*, 2004]

Olcese Salvatecci, Alfieri. *Cómo Estudiar con Èxito: Téchnicas yHhábitos Para Aprender Major.* México, D.F.: Alfaomega Grupo Editor, 2002. 970-15-0764-9 [*Críticas*, 2003]

Mujeres Como Islas: Antología de Narradoras Cubanas, Dominicanas, Puertoriqueñas. Edición: Olga Marta Pérez, Thelma Jiménez, Andrés Blanco D., eds. Santo Domingo, República Dominicana: Ediciones Ferilibro, 2002. 959-209-419-5 [*Críticas*, 2003]

Tibol, Raquel. *Los Murales de Diego Rivera: Universidad Autónoma Chapingo.* México, D.F.: Editorial RM, Universidad Autónoma Chapingo, 2002. 968-5208-08-5 [*Críticas*, 2003]

Lindsay-Poland, John. *Emperors in the Jungle: the Hidden History of the U.S. in Panama.* Durham, N.C.: Duke University Press, 2003. 0-8223-3098-9, $18.95 [*Críticas*, 2003]

Kaplan, Allison G. and Ann Marlowe Riedling. *Catalog It! A Guide to Cataloging School Library Materials.* Worthington, Ohio: Linworth Pub., 2002. 1-58683-014-7, $44.95 [*Colorado Libraries,* 2002]

Bardach, Ann Louise. *Cuba Confidential: Love and Vengeance in Miami and Havana.* New York: Random, 2002. 0-375-50489-3, $25.95 [*Library Journal*, 2002]

Swan, James. *Fundraising for Libraries: 25 Proven Ways to Get More Money for Your Library.* New York: Neal Schuman, 2002. 1-55570-433-6, $69.95 [*Colorado Libraries,* 2002]

Puíg de Lange, Victoria. *Sol Con Agua.* Nashville, Tenn.: Editorial Vistazo/Ediciones Reio Negro, 2002. 0-9724506-0-2, $17.75 [*Críticas*, 2002]

The Encyclopedia of Latin American Politics. Edited by Diana Kapiszewski; assistant editor, Alexander Kazan. Westport, Conn.: Oryx Press, 2002. 1-57356-306-4, $74.95 [*Library Journal*, 2002]

Vargas Lizano, Isabel. *Y Si Quieres Saber de Mi Pasado.* Con la colaboración de J.C. Vales. Madrid: Santillana Ediciones Generales, S.L., 2002. 84-03-09278-4, $18.95 [*Críticas*, 2002]

Ruy Sánchez, Alberto. *Los Jardines Secretos de Mogador: Voces de Tierra.* México, D.F.: Alfaguara, S.A., 2001. 968-19-0879-1, $16.95 [*Críticas*, 2002]

Chávez, Ricardo and Celso Santajuliana. *El Final de las Nubes.* Barcelona: RBA Libros, S.A., 2001. 84-7901-760-0, $11.95 [*Críticas*, 2002]

The Power of Language / El Poder de la Palabra: Selected Papers from the Second REFORMA National Conference. Edited by Lillian Castillo-Speed and the REFORMA National Conference Publications Committee. Englewood, Colo.: Libraries Unlimited, 2001. 1-563089459, $35.00 [*Colorado Libraries,* 2001]

Martínez, Rubén. *Crossing Over: A Mexican Family on the Migrant Trail.* Metropolitan: Holt, 2001. 0-8050-4908-8, $26.00 [*Library Journal*, 2001]

Guevara, Ernesto "Che." *The African Dream: the Diaries of the Revolutionary War in the Congo.* Translated from the Spanish by Patrick Camiller. With an introduction by Richard Gott and a foreword by Aleida Guevara March. New York: Grove Press, 2001. 0-8021-3834-9, $13.00 [*Library Journal*, 2001]

Cooper, Gail and Garry Cooper. *New Virtual Field Trips.* Englewood, Colo.: Libraries Unlimited, 2001. 1-56308-887-8, $27.50 [*Colorado Libraries,* 2001]

NATIONAL SERVICE & PROFESSIONAL AFFILIATIONS

American Library Association, Life Member
Association for Library Collections & Technical Services (now CORE)
Cataloging, Classification, and Metadata Section
Awards & Scholarships Coordination Committee, 2025-
Margaret Mann Citation Committee, 2023-
ALCTS Editorial Board, Member, 2015-2019
Committee on Cataloging: Description and Access, Member, 2008-2012
Test Site for RDA, Manager, 2009-2011
Nominating Committee, Member, 2007-2008
Committee for Education and Training of Catalogers, Chair, 2006-2007, Member, 2003-2007
Competencies & Education for a Career in Cataloging Interest Group, Chair, 2010-2012; Member, 2010-
President's Program Committee, 2015-2016
Education Committee, Member, 2005-2007
Task Force on Competencies and Education for a Career in Cataloging, Chair, 2007-2009
2007 Annual Meeting Pre-conference, "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," Steering Committee Chair
Fundraising Committee, Member, 2004-2006
Office of Diversity
Committee on Diversity, Chair, 2010-2011
Diversity Research Advisory Committee, Member, 2009-2010
Spectrum Scholar Mentor, 2009
Diversity Grants Review Committee, Member, 2007, 2010, 2012
Office of Statistics and Research
Research and Statistics Committee, Member, 2005-2007; Intern, 2003-2005
Library Research Round Table
Nominating Committee, 2022-2023
Membership Committee, 2019-2021
Board of Directors, Member At-Large, 2009-2012
Office of Accreditation
Accreditation Panel Member (training completed 2004)
Accreditation Review Panel Member (training completed 2004)

REFORMA, Life Member
National Board of Directors, 2005-2013
National Fundraising Chair, 2005-2013
National Recruiting and Mentoring Committee, 2008-2010
Colorado Chapter, Secretary, 2004-2005
Colorado Chapter Liaison to National Board of Directors, 2004-2013

American Association of Law Libraries (AALL), Life Member Online Audiovisual Catalogers Association (OLAC) Colorado Association of Law Librarians (CoALL)

American Association of University Women Association for Library and Information Science Education (ALISE)
University of Denver ALISE Representative, 2003-2008; 2010-2011
Membership Advisory Committee, 2007-2010
Technical Services Education Special Interest Group, 2003-
Garfield Doctoral Dissertation Award Reviewer, 2012
Garfield Doctoral Dissertation Scholarship Reviewer, 2014

American Association of University Professors (AAUP), 2006-
American Grant Writers Association, 2014- Grant Professionals Institute, 2016- National Grants Management Association, 2014-
Grant Reviewer (National and Regional Team Leader), U.S. Department of Education, 1998- Grant Reviewer, Broadband Technologies Opportunity Program, U.S. Department of Commerce, 2009
Grant Reviewer, Institute of Museum and Library Services, 1998-2000
Grant Reviewer, Colorado Department of Education, 2014-
Grant Reviewer, Colorado State Library, 1998-
Grant Reviewer, American Association of Community Colleges *Working Connections* program, 1999
Peer Reviewer, *Journal for Library and Information Science Education,* 2005-
Peer Reviewer, *Journal of Library Metadata,* 2009
Peer Reviewer, *International Journal of Library and Information Science,* 2011
Regular Columnist, *The Bottom Line*, 2013-2016
Book Reviewer, *Library Journal*, 2001
Book Reviewer, *Críticas*, 2002-2009
Book Reviewer, *Colorado Libraries,* 2000-2012

REGIONAL SERVICE & PROFESSIONAL AFFILIATIONS

Mountain Plains Library Association
Professional Development Grants Committee, Member, 2005-2006
Professional Development Policy and Guidelines Sub-committee Chair, 2006

Colorado Association of Libraries
"Student Voices" Column Editor, *Colorado Libraries,* 2005-2006
Conference Planning Committee, Member, 2002
Technical Services and Automation Division, Chair, 2002-2003; Member, 2000-
Academic Libraries Division, Peer Review Conference Papers Committee, Member, 2007-2009
Education Committee, Member, 1988-1993
Diverse Populations Committee, Member, 2009-2013

SERVICE TO THE UNIVERSITY OF DENVER
Center for Teaching and Learning Faculty Advisory Board, 2007-2008; 2010-2012
Center for Community Engagement and Service Learning Advisory Board, 2007-2012
Faculty Senate
Executive Committee, 2008-2013
Nominations, Rules & Credentials Committee, Chair, 2008-2013; Member 2007-2013
Appointment, Promotion, and Tenure Revision Committee, 2010-2012
Grievance Policy Committee Member, 2007-2010
Law Library Director Search Committee Chair, 2012-2013
PROF Grant Review, College Representative to the University Review Team, 2006, 2008
Project Homeless Connect Evaluations, Principal Investigator, 2006-2009
University Technology Council, 2007-2009
University of Denver Hyde Interviews for Incoming Freshmen, 2003-2012

SERVICE TO THE MORGRIDGE COLLEGE OF EDUCATION
Appointment, Tenure & Review Committee
Member, voting, 2003-2005; 2007- 2009
Chair, Clinical Faculty Promotion & Tenure Policy Subcommittee, 2008-2009
Member, Community Engagement Subcommittee, 2007-2009
Member, Tenure Review Panel, 2003
Advancement and Alumni Relations Committee, Chair, 2003-2007; Member, 2002-2007

College Building Committee Member, 2004-2010
College of Education Student Association, Faculty Advisor, 2004-2007; 2009-2010
Faculty Senator, 2007-2013
Research and Scholarship Committee, Chair, 2008-2009; Member, 2002-2003, 2008-2009
Research and Grant Mentoring Committee, Chair, 2009-2010
Research Task Force Member, 2010-2012
Search Committee Member, Assistant Professor for Curriculum & Instruction, 2010-2011
Workload Task Force Member, 2010-2011

SERVICE TO THE LIBRARY & INFORMATION SCIENCE PROGRAM

Library and Information Science Student and Alumni Association, Faculty Advisor, 2002-2008
ALA Student Chapter, Faculty Advisor, 2005-2008
Beta Phi Mu Phi Chapter, Faculty Advisor, 2004-2014
Steering Committee Member, Accreditation by the American Library Association, 2001-2004
Search Committee Member, Associate Professor for LIS, 2006
Search Committee Chair, Assistant Professors for LIS, 2003, 2005, 2006, 2007
Search Committee Ex-Officio Member, Director for LIS, 2004

SERVICE TO SAM HOUSTON STATE UNIVERSITY

Rio Roundup: South Texas Literature Conference, Conference Coordinator, 1993
External Relations, Fund Raising, Grants Committee, Chair, 1993-1995
Advisory Council Committee, Chair, 1993-1995
Students, Admissions, and Advisement Committee, Chair, 1994
Institutional Effectiveness Committee, Member, 1993-1995

SERVICE TO THE COLLEGE OF EDUCATION AND APPLIED SCIENCE

Faculty Affairs Committee, Member, 1993-1995
Curriculum Committee, Member, 1993-1995
Continuing Education Committee, Member, 1993-1995

SERVICE TO THE COMMUNITY

French Teacher & Student Exchange with Laon, France, Monarch High School, Boulder Valley School District (Boulder, Colorado), 2017-
Denver/Boulder Games 2022, Board of Directors, Secretary-Treasurer, 2015-2018
United Way Campaign Committee, College of Education, 2006
Arapahoe County, Election Judge for the County Clerk and Recorder, 2000-2005
Arthritis Foundation, Rocky Mountain Chapter, Certified Educator & Trainer, 1999-2008
Bonfils Blood Center, Silver Level Donor, 2000-2016
Denver Museum of Natural History, Docent, 1992
Tech Prep of the Lower Rio Grande Valley, Inc. (Harlingen, Texas) Board of Directors, 1995-1997
Executive Committee, 1996-1997; Chair, Development Committee, 1995-1997; Chair, Fiscal Agency Committee, 1995-1996; Chair, Colleges and Universities Committee, 1996-1997
Gilpin County (Colorado) Public Library Board of Trustees, 1986-1989; Vice President, 1987-1989
City of Central (Colorado) Economic Development Committee, 1987-1989
Columbine Family Health Centers, Inc. (Nederland and Black Hawk, Colorado) Board of Directors, 1988-1989

CERTIFICATION

Permanent Public Librarian Certificate - Pennsylvania, New York, Texas
Westlaw Expert Witness, 2008-
Certified Grant Writer®, 2016-

AWARDS AND HONORS

Advanced Practitioner for Service Learning and Community Engagement, University of Denver, 2011
Platinum Star Alumnae, College of Information, Library Science & Technologies, University of North Texas, 2009
Commendation for Integration of Technologies in Teaching & Learning Environment, University of Denver, 2006
Outstanding Adjunct Faculty Member Award, College of Education, University of Denver, 2002
Beta Phi Mu, Pi, University of Pittsburgh, 1985
Alpha Lambda Sigma, University of North Texas, 1972
Albert Nelson Marquis Lifetime Achievement Award, Who's Who in America
Who's Who in American Women
Who's Who of Women Executives
Dictionary of International Biography
Who's Who in the East
Who's Who in the South and Southwest
Who's Who in the World
Who's Who of Online Professionals
Who's Who in Library and Information Science
2,000 Notable Women
Who's Who of Emerging Leaders
Who's Who in Professional and Executive Women
Who's Who in American Education
International Who's Who of Professional and Business Women
International Leaders in Achievement
International Educator of the Year
Who's Who in Finance and Industry
Who's Who in Finance and Business

Invited International and National Conference Presentations

Hall-Ellis, Sylvia D. *Presentation of the Robert O. Ellett Endowed Scholarship.* Presentation delivered to the School of Information at San Jose State University Alumni & Student Program, American Library Annal Conference, San Diego, Calif., June 29, 2024.

Driscoll, Margaret, Christy Confetti Higgins, Scott Brown, and Sylvia D. Hall-Ellis. *A View from Within: Open House Tour of Three Canvas Core Courses*. Presentation to be delivered at the School of Information, San José State University Professional Development Seminar, San José, California, October 17, 2019.

Hall-Ellis, Sylvia D. *Invest in Me -- I'm Your Future: Succession Planning for Libraries.* Keynote presentation delivered at the ALCTS President's Symposium, Boston, Mass., January 8, 2016.

Seidel, Kent E. and Sylvia D. Hall-Ellis. *Making Grants Work for You: Strategies for Doctoral Students and Early Career Scholars.* Presentation delivered at the University Council for Educational Administration, Early Career Scholars Session, Indianapolis, Ind., November 9, 2013.

Hall-Ellis, Sylvia D. *So You Want to be a Manager; Leadership Skills and Competencies for Technical Services Managers and Administrators.* Presentation delivered at the 138th Annual Conference, American Library Association, Chicago, Ill., June 29, 2013.

Seidel, Kent E., Karen S. Riley, Lyndsay Agans, Susan Korach, and Sylvia D. Hall-Ellis. *Making Grants Work for You (Instead of Just Working for Grants).* A panel discussion delivered at the University Council for Educational Administration, Early Career Scholars Session, Denver, Colo., November 17, 2012.

Hall-Ellis, Sylvia D. *After the Great TS Reorganization: The Westminster Law Library.* Presentation delivered at the 137th Annual Conference, American Library Association, Anaheim, Calif., June 23, 2012.

Hall-Ellis, Sylvia D. *Conversations with Catalogers in the 21st Century.* A panel discussion sponsored by the ALCTS Competencies for a Career in Cataloging Interest Group, delivered at the 137th Annual Conference, American Library Association, Anaheim, Calif., June 22, 2012.

Hall-Ellis, Sylvia D., moderator. *Mid-Career Leaders Program.* A panel discussion sponsored by the ALA Committee on Diversity delivered at the 136th Annual Conference, American Library Association, New Orleans, La., June 26, 2011.

Hall-Ellis, Sylvia D., moderator. *Diversity Town Hall.* A community conversation sponsored by the ALA Committee on Diversity delivered at the 136th Annual Conference, American Library Association, New Orleans, La., June 24, 2011.

LaBarre, Kathryn, Sylvia D. Hall-Ellis, Karen Anderson, Rick Hasenyager, Christopher Cronin, and Penny Baker. *Briefings from RDA Test Participants.* A panel discussion delivered at the Midwinter Conference, American Library Association, San Diego, Calif., January 7, 2011.

Miksa, Shawne, Marjorie Bloss, and Sylvia D. Hall-Ellis. *Educating the Next Generation of Catalogers: Teaching RDA.* A panel discussion delivered at the 97th Annual Conference, Association for Library and Information Science Education, San Diego, Calif., January 7, 2011.

Hall-Ellis, Sylvia D., Robert Maxwell, John Hostage, and George Prager. *RDA Panel: What Cataloging Managers Need to Know.* Presentation delivered at the 103rd Annual Conference, American Association of Law Librarians, Denver, Colo., July 12, 2010.

Hall-Ellis, Sylvia D. and Stacey L. Bowers. *Catalogers in the RDA Environment: Skill Sets, Expectations and Challenges.* Presentation delivered at the 103rd Annual Conference, American Association of Law Librarians, Denver, Colo., July 11, 2010.

Hall-Ellis, Sylvia D. *Comfortable in Your Cataloging and Metadata Specialist Skin? Or, So You Want to Hire a Cataloger.* Presentation delivered to the ALCTS Research Group at the 134th Annual Conference, American Library Association, Chicago, Ill., July 11, 2009.

Perez, Megan, Sylvia D. Hall-Ellis, and Denise Anthony. *From Novice to Expert: Collaboration for Succession Planning.* A "hot topic" presentation delivered at the 14th ACRL Conference, Seattle, Wash., March 13, 2009.

Hall-Ellis, Sylvia D. *Cataloging in the RDA Environment: Skill Sets, Expectations and Challenges.* Presentation delivered to the ALCTS Research and Publications Committee at the Midwinter Conference, American Library Association, Denver, Colo., January 24, 2009.

Hall-Ellis, Sylvia D. *LIS Cataloging Education for the 21st Century: Expectations and Challenges.* A panel discussion held at the 95th Annual Conference, Association for Library and Information Science Education, Denver, Colo., January 23, 2009.

Chu, Clara, Sylvia D. Hall-Ellis, and Mark Winston. *The Doctoral Degree & Building a Career.* A panel discussion delivered at the ALA Office of Diversity Spectrum Doctoral Fellows E.J. Josey Leadership Institute, Midwinter Conference, American Library Association, Denver, Colo., January 20, 2009.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Fundamentals of Cataloging Course: An Overview of the ALCTS Online Course.* Presentation delivered to the ALCTS Big Heads Group, 133rd Annual Conference, American Library Association, Anaheim, Calif., June 30, 2008.

Hall-Ellis, Sylvia D. *Employers' Expectations for Technical Services Librarians: What We Don't Know.* Presentation delivered to the ALCTS Research and Publications Committee Program, 133rd Annual Conference, American Library Association, Anaheim, Calif., June 28, 2008.

Hall-Ellis, Sylvia D., Virginia R. Maloney, and Mary Stansbury. *Institutional Responses to Engaged Scholarship: The Carnegie Foundation Engaged University Classification at Two Universities.* Presentation delivered to the 94th Annual Conference, Association for Library and Information Science Education, Philadelphia, Pa., January 11, 2008.

Hall-Ellis, Sylvia D. *Puzzles, Problems, and Predicaments.* Presentation delivered to the ALCTS Research Discussion Group, 132nd Annual Conference, American Library Association, Washington, D.C., June 23, 2007.

Hall-Ellis, Sylvia D. *Cataloging Education: A New Emphasis for the Library and Information Science Curriculum.* Presentation delivered to the ALCTS Pre-conference, 132nd Annual Conference, American Library Association, Washington, D.C., June 22, 2007. http://www.loc.gov/catdir/cpso/careercat.html

Ellett, Jr., Robert O. and Sylvia D. Hall-Ellis. *Copy Cataloging Done Smarter.* Presentation delivered to the International Conference on Interdisciplinary Information Sciences and Technologies (InSciT2006), October 25-28, 2006.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Cooperative Cataloging: Challenges and Opportunities for Defense Libraries.* Presentation delivered to the 1st Annual Conference of Defense Libraries, Spanish Ministry of Defense, Madrid, Spain, July 7, 2006.

Hall-Ellis, Sylvia D. *Cataloger Competencies: Do the Employers Require What the Professors Teach?* Presentation delivered to the ALCTS CCS Heads of Cataloging Discussion Group, 131st Annual Conference, American Library Association, New Orleans, La., June 26, 2006.

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *From Research to Practice: The Scholarship of Teaching and Learning in LIS Education.* Presentation delivered to the at the 92nd Annual Conference, Association for Library and Information Science Education, San Antonio, Tex., January 18, 2006.

Hall-Ellis, Sylvia D. *Employers' Expectations for Entry-Level Catalogers: What Position Announcement Data Indicate.* Research paper delivered to the Technical Services Special Interests Group, 91st Annual Conference, Association for Library and Information Science Education, Boston, Mass., January 12, 2005. http://dlist.sir.arizona.edu/

Hall-Ellis, Sylvia D. *Common Errors in MARC Records Prepared by LIS Students: What Does It Mean?* Research paper delivered to the ALCTS CCS Cataloging Norms Discussion Group, Mid-Winter Conference, 90th American Library Association, San Diego, Calif., January 10, 2004.

Hall-Ellis, Sylvia D. *Visual Arts as Foundation for Successful Library Automation: The Rocky Mountain College of Art & Design Experience.* Paper delivered at the 6th Annual Conference of Higher Education, Charleston, S. C., 1993.

Hall, Sylvia D. *Design Elements for Bibliographic Databases: An Overview.* Paper delivered at the 14th Online National Conference, New York, 1983.

Invited Regional Conference Presentations

Hall-Ellis, Sylvia D., Hudson, Christopher D., Brittany Cronin, and Kathryn Michaels. "The Colorado Law Project: Meeting the Public's Need for Legal Information." Panel discussion delivered at the Mountain Plains Library Association Conference, Billings, Mont., April 9, 2011.

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *Education for Information Professionals in New Mexico: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the New Mexico Library Education Summit, Las Vegas, N.M., September 26, 2005.

Hall-Ellis, Sylvia D. *Public Library-School Library Partnerships.* Presentation delivered at the 3rd Annual Colorado Association of Libraries Conference with the Mountain Plains Library Association, Denver, Colo., October 22, 2004.

Hall-Ellis, Sylvia D. *Learn All You Can – Educational Partnership Opportunities for the Lewis and Clark Bicentennial Commemoration.* Paper delivered at the 3rd Annual Lewis and Clark Bicentennial Council National Planning Conference, Bismarck, N.D., April 26, 1998.

Invited State Conference Presentations

Grealy, Deborah S. and Sylvia D. Hall-Ellis. *Academic Library Leadership Changes: Using Succession Planning and Mentoring*. Presentation delivered at the Minnesota Library Education Conference, St. Cloud, Minn., October 10, 2013.

Hall-Ellis, Sylvia D., Merrie Valliant, and Melissa Powell. *RDA: What Is It and What Do You Need To Do With It At Your Library?* Presentation delivered at the Colorado Library Consortium Spring Conference, Ft. Morgan, Colo., April 26, 2013.

Hall-Ellis, Sylvia D. *Service Learning and the Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 4th LEADS Scholars Orientation, Denver, Colo., August 5, 2009.

Hall-Ellis, Sylvia D. *Service Learning: Enhancement to Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 3rd LEADS Scholars Orientation, Denver, Colo., June 2008.

Hall-Ellis, Sylvia D. *Law Librarianship: A Community Conversation.* Sponsored by the Colorado Association of Law Libraries. Paper delivered at the Colorado Supreme Court Library, Denver, Colo., May 14, 2008.

Hall-Ellis, Sylvia D. *Opportunities and Challenges in Law Librarianship: A Community Conversation.* Presentation delivered at the Sturm College of Law, Denver, Colo., November 7, 2007.

Ellis, Sylvia D. *Grant Writing Resources for Nursing Professionals.* Presentation delivered at the Presbyterian / St. Luke's Health One Medical Center 1st Annual Research Symposium, Denver, Colo., October 17, 2007.

Hall-Ellis, Sylvia D. *Project Homeless Connect 4 Event Evaluation – Insights and Lessons Learned.* Presentation delivered at the Homelessness Research Symposium: What is DU Doing about Homelessness in Denver, Denver, Colo., September 14, 2007.

Hall-Ellis, Sylvia D. *Service Learning and the Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 2nd LEADS Scholars Orientation, Denver, Colo., August 10, 2007.

Hall-Ellis, Sylvia D. *Education for Information Professionals in a Digital Environment: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 15th Spring Mountains and Plains Parapros Conference, Denver, Colo., February 24, 2007.

Hall-Ellis, Sylvia D. *Public Library Service to Spanish-Speaking and Latino Residents in Denver: A Case Study.* Presentation delivered at the 4th Annual Colorado Association of Libraries Conference, Denver, Colo., November 10, 2005.

Hall-Ellis, Sylvia D. *Education for Information Professionals in a Digital Environment: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 14th Annual Mountains and Plains Parapros Conference, Aurora, Colo., July 29, 2005.

Hall-Ellis, Sylvia D. *Educational Opportunities: Library & Information Science Graduate Education at the University of Denver.* Presentation delivered at the 13th Annual Mountains and Plains Parapros Conference, Centennial, Colo., August 6, 2004.

Hall-Ellis, Sylvia D. *Library Education & Training: Focus on the West: An LIS Faculty Member's Personal Response*. Presentation delivered at the 1st Annual Colorado Association of Libraries Conference, Keystone, Colo., October 18, 2002.

Hall-Ellis, Sylvia D. *Grant Writing for School Librarians.* Presentation delivered at the 2002 Annual Colorado Education Media Association Conference, Colorado Springs, Colo., February 15, 2002.

Hall-Ellis, Sylvia D. *Grants – Opportunities for the Future.* Paper delivered at the Southeast Regional Accountability Annual Conference, Lamar, Colo., November 12, 1998.

Hall-Ellis, Sylvia D. *The Texas Library Connection and Interlibrary Loan: An Experiment in Resource Sharing.* Paper delivered at the Texas Computer Educators' Association Annual Conference, Austin, Tex., February 6, 1997.

Hall-Ellis, Sylvia D. *Finding Grant Sources on the Internet: A Guide for Librarians.* Paper delivered at the 2nd Annual Institute for School Library Personnel, Pharr-San Juan-Alamo North High School, Pharr, Tex., July 29, 1996**.**

Hall-Ellis, Sylvia D. *Mathematical and Logical Thinking: A Critical Intelligence.* Paper delivered at the 3rd Annual Paraprofessional Conference at the University of Texas - Pan American, Edinburg, Tex., March 8, 1996.

Hall-Ellis, Sylvia D. *Cataloging Trends and Issues: Update Session.* Paper delivered at the 1st Annual Institute for School Library Personnel, South Texas Community College, McAllen, Tex., July 19, 1995.

Hall-Ellis, Sylvia D. *Grant Writing: Tips and Encouragement for School Librarians.* Paper delivered at the 1st Annual Institute for School Library Personnel, South Texas Community College, McAllen, Tex., July 18 and 19, 1995.

Hall-Ellis, Sylvia D. *How to Become an Expert Grant Writer.* Paper delivered at the 3rd Annual High School Principals' Academy, South Padre Island, Port Isabel, Tex., June 19, 1995.

Texas Library Study: Results from Regions I and II. Paper delivered at the 3rd Annual Technology Conference, Texas A&M University, College Station, Tex., November 18, 1994.

Hall-Ellis, Sylvia D. *Academic Achievement and Middle School Students.* Paper delivered at the 8th Annual Young Adult Conference, Sam Houston State University, Huntsville, Tex., November 5, 1994.

Hall-Ellis, Sylvia D. *Multimedia Resources for Library Leaders.* Paper delivered at the Institute for Librarians in A Multicultural Environment, Sam Houston State University, Huntsville, Tex., June 10, 1994.

Hall-Ellis, Sylvia D. *Finding the Resource: Empowering the User, or, the Case for Curriculum Based Subject Access to Learning Resource Center Collections.* Paper delivered at the 81st Annual Texas Library Association Conference, Corpus Christi, Tex., April 12-16, 1994.

Hall-Ellis, Sylvia D. and William H. Pichette. *Sam Houston State University Makes Use of OCLC/AMIGOS Collection Analysis CD.* Paper delivered at the 81st Annual Texas Library Association Conference, Corpus Christi, Tex., April 12-16, 1994.

Hall, Sylvia D. *Funding and Library Development in Pennsylvania: A Symbiotic Relationship.* Paper delivered at the Annual Graduate Student Colloquia, University of Pittsburgh, School of Library and Information Science, 1982.

Hall, Sylvia D. *Leadership for Public Library Trustees.* Paper delivered for the Trustees Division, Pennsylvania Library Association Annual Conference, Lancaster, Penn., 1981.

Seminar and Professional Development Presentations

Taylor, Meredith, and Sylvia D. Hall-Ellis. *Talent Management and Succession Planning.* ALCTS eForum, held March 22, 2017.

Hirsh, Sandra, Heather O'Brien, Michelle Holschuh Simmons, Michael Krasulski, and Sylvia D. Hall-Ellis. *Information Services Today: An Introduction. Part 3: Information Services: Roles in the Digital Age*. Rowan and Littlefield in partnership with Library Journal webinar, recorded February 5, 2015.

Hall-Ellis, Sylvia D. and Jennifer Sweda. *Copy Cataloging in an RDA Environment.* ALCTS eForum, held May 14 and 15, 2013.

Hall-Ellis, Sylvia D. *Law Librarianship: A Community Conversation.* Sponsored by the Colorado Association of Law Libraries, presented at the Colorado Supreme Court Library, Denver, Colo., May 14, 2008.

Hall-Ellis, Sylvia D. and Beatrice Z. Gerrish. *Reading and Libraries: Recent Research in Reading.* Presentation at the Ricks Center for Gifted Education, Denver, Colo., March 4, 2008.

Hall-Ellis, Sylvia D. *Cataloger Competencies: Do the Employers Require What the Professors Teach?* Presentation for the School of Library and Information Science, San José State University, February 12, 2008.

Hall-Ellis, Sylvia D. and Robert O. Ellett, Jr. *Cooperative Cataloging: Rules, Tools, and Conventions for Building a Multi-institutional Catalog.* Sponsored for the Spanish Ministry of Defense, Madrid, Spain, July 10, 2006.

Hall-Ellis, Sylvia D. *Cash for Kids: Grant Writing Opportunities for Youth Services Librarians.* Sponsored by the Colorado Young Adult Librarians; presented at Bemis Memorial Library, Littleton, Colo., November 13, 2002.

Hall-Ellis, Sylvia D. *MARC Records and Authority Control: Planning for Bibliographic Database Migration.* Sponsored and held at the Douglas County Public Library, Castle Rock, Colo., May 28, 2002.

Grant Writing: A Refresher for Librarians. Sponsored by Library and Information Science Program, College of Education, University of Denver; presented at University Center at Chaparral, August 12, 2000.

Hall-Ellis, Sylvia D. *Shaking the Money Tree – Basic Grant Writing for Colorado Educators.* Sponsored by the Office of Educational Telecommunications of the Colorado Department of Education.
Pikes Peak Community College, Colorado Springs, Colo., November 16, 1998.
Pueblo School District 60, Pueblo, Colo., November 12, 1998.

University of Northern Colorado, Greeley, Colo., November 10, 1998.
United Technology Educational Partnership, Grand Junction, Colo., November 9, 1998.

Hall-Ellis, Sylvia D. *Cataloging Multimedia, Kits, Globes and Map Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 24, 1997 and December 12, 1996.

Hall-Ellis, Sylvia D. *New Standards for School Library Media Centers.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 15, 1997.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., April 4, 1997.

Hall-Ellis, Sylvia D. *Cataloging Sound Recordings and Audio Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., March 20, 1997 and November 21, 1996.

Hall-Ellis, Sylvia D. *Evaluating and Selecting CD-ROMS for School Library Media Collections.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., March 18, 1997.

Hall-Ellis, Sylvia D. *Cataloging Audiovisual Materials in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., February 27, 1997, November 7, 1996 and October 24, 1996.

Hall-Ellis, Sylvia D. *Introduction to Dialog: Basic Searching Strategies.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., February 14, 1997.

Hall-Ellis, Sylvia D. *Cataloging Books in USMARC.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., January 30, 1997, October 10, 1996, September 26, 1996 and August 8, 1996.

Hall-Ellis, Sylvia D. *Advanced Internet Searching Techniques for Librarians.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., January 21, 1997.

Hall-Ellis, Sylvia D. *Texas Library Connection Full-Text Searching.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., December 13, 1996 and October 25, 1996.

Hall-Ellis, Sylvia D. *Developing Evaluation Strategies for Grants and Proposals.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., December 10, 1996.

Hall-Ellis, Sylvia D. *Developing Needs Assessment for Grants and Proposals.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., November 12, 1996.

Hall-Ellis, Sylvia D. *Texas Library Connection Union Catalog Searching.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., November 8, 1996 and September 6, 1996.

Hall-Ellis, Sylvia D. *Grant Resources on the Internet.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., October 23, 1996.

Hall-Ellis, Sylvia D. *Preparing a Response to the Telecommunications Infrastructure Fund Board: Needs Assessment, Professional Development Framework, and Evaluation Strategies.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., October 16, 1996.

Hall-Ellis, Sylvia D. *Texas Library Connection: Building the Districtwide Bibliographic Database.* Sponsored and hosted by Mercedes Independent School District, Mercedes, Tex., September 13, 1996 and August 8, 1996. Sponsored and hosted by Los Fresnos Consolidated Independent School District, Los Fresnos, Tex., August 12, 1996.

Hall-Ellis, Sylvia D. *School-to-Work and Special Education: An Inclusive Partnership for Success.* Sponsored and hosted by the Office of Special Education, Region One Education Service Center, Edinburg, Tex., September 11, 1996.

Hall-Ellis, Sylvia D. *Telecommunications Infrastructure Fund Board: An Overview of Funding for Secondary Schools.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., August 31, 1996.

Hall-Ellis, Sylvia D. *Cataloging Books, Multimedia, and Realia in USMARC.* Sponsored and hosted by Edinburg Consolidated Independent School District, Edinburg, Tex., August 6, 1996.

Hall-Ellis, Sylvia D. *Internet Resources for Grant Writers.* Sponsored and hosted by Region One Education Service Center, Edinburg, Tex., April 20, 1996.

Hall-Ellis, Sylvia D. *Enhanced Grant Writing Skills for Mathematics Educators: Writing Skills for Campus Teams.* Sponsored and hosted by the Office of General Education, Region One Education Service Center, Edinburg, Tex., March 22, 1996.

Hall-Ellis, Sylvia D. *Internet Resources for Grant Writers.* Sponsored and hosted by the College of Education and Applied Science, Sam Houston State University, Huntsville, Tex., March 9, 1996.

Hall-Ellis, Sylvia D. *Grant Writing for Mathematics Educators: A Development Process for Campus Teams.* Sponsored and hosted by the Office of General Education, Region One Education Service Center, Edinburg, Tex., March 4, 1996.

Hall-Ellis, Sylvia D. *Shaking the Money Tree: Preparing Successful Technology Grant Applications.* Sponsored and hosted by the Office of Technology and Media Services, Region One Education Service Center, Edinburg, Tex., February 29, 1996 and April 29, 1996.

Hall-Ellis, Sylvia D. *District-wide Technology Planning: Technical Assistance for the Texas Education Agency Initiative.* Sponsored and hosted by the Office of Technology and Media, Region One Education Service Center, Edinburg, Tex., February 2, 1996.

Hall-Ellis, Sylvia D. *Enhanced Grant Writing Skills.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., January 27, 1996.

Hall-Ellis, Sylvia D. *United States Copyright Act of 1976, Video Transmissions, Computer Software and the Internet.* Sponsored and hosted by the Office of Technology and Media, Region One Education Service Center, Edinburg, Tex., January 24, 1996.

Hall-Ellis, Sylvia D. *The Grant Writing Development Process.* Sponsored and hosted by Pharr-San Juan-Alamo Independent School District, Pharr, Tex., January 20, 1996.

Hall-Ellis, Sylvia D. *MARC Cataloging of Materials for Library Media Centers.* Sponsored and hosted by the Office of Media Services, Region One Education Service Center for the Donna Independent School District, Donna, Tex., August 17, 1995.

Hall-Ellis, Sylvia D. *Classification.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., May 10, 1995.

Hall-Ellis, Sylvia D. *Library Technical Services.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., April 26, 1995.

Hall-Ellis, Sylvia D. *Grant Writing: An Introduction for Public School Administrators.* Sponsored and hosted by the Office of Administrative Services, Region One Education Service Center, Edinburg, Tex., April 19, 1995.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by the United Independent School District, Laredo, Tex., March 31, 1995.

Hall-Ellis, Sylvia D. *Using USMARC.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., March 29, 1995.

Hall-Ellis, Sylvia D. *Library Media Center Policies and Guidelines: How to Prepare for School Board Adoption.* Sponsored and hosted by the Office of Technology and Media Services, La Joya Independent School District, La Joya, Tex., March 10, 1995.

Hall-Ellis, Sylvia D. *Developing District-wide Policies and Guidelines for Library Media Centers.* Sponsored and hosted by the Office of Technology and Media Services, La Joya Independent School District, La Joya, Tex., January 10, 1995.

Hall-Ellis, Sylvia D. *MARC Cataloging of Audiovisual Materials for Library Media Centers.* Sponsored and hosted by the Office of Library Media and Technology Services, Cypress-Fairbanks Independent School District, Houston, Tex., December 1, 1994.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by United Independent School District, Laredo, Tex., October 14, 1994.

Hall-Ellis, Sylvia D. *The School Library Media Specialist in the 21st Century: Visions for the Future.* Sponsored and hosted by the Laredo Independent School District, Laredo, Tex., October 7, 1994.

Hall-Ellis, Sylvia D. *MARC Cataloging for Library Media Centers.* Sponsored by the Office of Library Media and Technology Services, Cypress-Fairbanks Independent School District, Houston, Tex., October 5, 1994.

Hall-Ellis, Sylvia D. *Jump to the Head of the Class: Undergraduate Library Resources Available at Sam Houston State University.* Sponsored by the Office of the Associate Vice President for Student Services, Sam Houston State University, Huntsville, Tex., October 4, 1994.

Hall-Ellis, Sylvia D. *CD-ROMs - 1994's Newest and the Best for Secondary Level Media Centers.* Sponsored and hosted by Clear Lake Independent School District, Houston, Tex., June 3, 1994.

Hall-Ellis, Sylvia D. *Introduction to Classification.* Sponsored by AJ Seminars, Rockville, Maryland; presented at Holiday Inn, Market Center, Dallas, Tex., May 18, 1994.

Hall-Ellis, Sylvia D. *Basic Descriptive Cataloging.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., May 4, 1994.

Hall-Ellis, Sylvia D. *Shaking the Money Tree - Part II: Writing Successful Grant Applications.* Sponsored by Donna Independent School District, Donna, Texas, and Region One Education Service Center Edinburg, Texas; presented at South Texas Community College Library, McAllen, Tex., April 29, 1994.

Hall-Ellis, Sylvia D. *Using MARC.* Sponsored by AJ Seminars, Rockville, Maryland; presented at Holiday Inn, Market Center, Dallas, Tex., April 6, 1994.

Hall-Ellis, Sylvia D. *Automated Authority Control.* Sponsored by AJ Seminars, Rockville, Maryland; presented at University Hilton Hotel, Houston, Tex., March 23, 1994.

Hall-Ellis, Sylvia D. *Automating the District School Library Media Centers: Choices and Opportunities.* Sponsored and hosted by the Office of Technology and Library Media Services, Fort Bend Independent School District, Sugar Land, Tex., March 4, 1994.

Hall-Ellis, Sylvia D. *Shaking the Money Tree - Part I: Preparing Successful Grant Applications.* Sponsored and hosted by the Office of Library Media Services, Donna Independent School District, Donna, Tex., February 4, 1994.

GRADUATE COURSES TAUGHT

San José State University, School of Library and Information Science
INFO 249 – Advanced Cataloging and Classification (Fall 2015, 2016; Summer 2016)
INFO 287 – Special Topics in Cataloging and Classification (Spring 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026; Fall 2020, 2021, 2022, 2023, 2024, 2025, 2026)
LIBR 248 – Beginning Cataloging and Classification (Summer 2002, 2003, 2004, 2005, 2006)
LIBR 249 – Advanced Cataloging and Classification (Summer 2003; Fall 2014; Summer 2015)

University of Denver, University College
Grant Writing Certificate Seminar for Non-Profit Organizations (Fall 2020, 2021; Spring 2021)

University of Denver, Morgridge College of Education HED
5991 – Grant Writing in Higher Education (Spring 2011)
LIS 4010 – Organization of Information (Fall 2002-2009; Winter 2005; Spring 2004-2006)
LIS 4020 – Professional Principles and Ethics (Summer 2000)
LIS 4040 – Management of Libraries and Information Centers (Fall 2010; Spring 2003, 2009 (DS); Winter 2005)
LIS 4070 – Cataloging and Classification (Winter 2008, 2009, 2010, 2011, 2012; Fall 2009 (DS)) LIS 4321 – Collection Management (Spring 2005)
LIS 4326 – LIS Research (Winter 2009 (DS); Spring 2009 (DS))
LIS 4350 – Adult Materials and Services (Summer 2006, 2009)
LIS 4379 – Social Sciences Resources (Spring 2009)
LIS 4400 – Cataloging and Classification (Spring 2000, 2001; Winter 2002-2009; Summer 2005, 2006 – course renumbered LIS 4070, September 2007)
LIS 4401 – Descriptive Cataloging (Winter 2001; Spring 2002, 2003, 2006-2009; Summer 2005)
LIS 4402 – Subject Cataloging (Spring 2001, 2009; Summer 2005, 2006, 2007, 2008)
LIS 4403 – Classification Schemes (Fall 2007, 2008, 2009 (DS)) LIS
LIS 4405 – Authority Control (Winter 2009)
LIS 4510 – Materials and Services for Children (Winter 2004; Summer 2005)
LIS 4620 – Grant Writing and Fundraising (Summer 2000, 2002, 2004, 2010; Winter 2006; Fall 2006-2009)
LIS 4700 – Seminar in Technical Services (Fall 2001)
LIS 4700 – Seminar in Public Libraries (Summer 2002)
LIS 4804 – Management of Electronic Records (Spring 2004; Fall 2005)
LIS 4902 – Capstone Projects (Winter 2003, Spring 2008, 2009, 2011)
LIS 4910 – Independent Study (every quarter Winter 2000 through Spring 2011)
LIS 4920 – Service Learning (every quarter Summer 2004 through Spring 2011)
RMS 4954 – Grant Writing (Summer 2013, 2014)
RMS 4959 – Content Analysis Methodology (Spring 2015)
QRM 4978 – Grant Writing (Summer 2011, 2012)

Rutgers University, School of Communication and Information
SC&I 522 – Cataloging and Classification (Summer 2013)

University of Arizona, College of Behavioral and Social Sciences
LIS 602 – Cataloging and Classification (Summer 1995)
LIS 612 – Advanced Online Search and Retrieval (Summer 1995)

Sam Houston State University, College of Education & Applied Science
LIS 532 - Cataloging and Classification (Fall 1993, 1994, 1995)
LIS 563 - Advanced Cataloging and Classification (Summer 1994)
LIS 567 - Research Methods (Spring 1994, Spring 1995)
LIS 591 - Educational Technology (Spring 1994, 1995)
LIS 596 - Networking and Computer Technologies in Education (Fall 1993, Summer 1994, Fall 1995)

Dissertations at the University of Denver

Bowers, Stacey L. *Library Anxiety of Law School Students: A Study Utilizing the Multidimensional Library Anxiety Scale.* Chair, May 5, 2010.

Fattor, Melissa M. *Student Engagement Differences by Ethnicity and Scale for Ninth Grade Students.* Chair, November 1, 2010.

Fulton, Roseanne. *A Case Study of Culturally Responsive Teaching in Middle School Mathematics.* Kent Seidel, Chair, June 18, 2009, Outside Chair.

Grealy, Deborah S. *Tribes and Territories in Library and Information Studies Education.* Bruce Uhrmacher, Chair, June 10, 2008, Committee Member.

McCord, J. Michael. *Developing a Standard of Care for Educational Malpractice.* Chair, April 15, 2011.

Priebe, Sarah J. *Distinguishing Effects of Domain and General Knowledge on Passage Fluency and Comprehension.* Jan Keenan, Chair. July 21, 2011, Outside Chair.

Snyder-Mondragon, Sandra M. *Institutional Factors that Impact the Retention of Graduate Students of Color in Schools of Library and Information Science: A Metaregression of Accredited Library School Statistics on Student Retention and Graduation Rates.* Kathy Green, Chair, July 24, 2009, Committee Member.

Taylor, Karen Pickles. *Effective Teaching.* Elinor Katz, Chair, July 15, 2009, Outside Chair.

Thompson, Jennifer. *Distinguishing a Western Women's College: A History of the Curriculum and Student Experience at Colorado Women's College.* Edith W. King, Chair, July 16, 2010, Committee Member.

Walker, Emelda. *Influence of Organizational Factors on Job Satisfaction of Disability Service Providers at Postsecondary Institutions.* Chair, April 29, 2010.

Dissertation Proposals at the University of Denver

Bowers, Stacey L. *Library Anxiety of Law School Students: A Study Utilizing the Multidimensional Library Anxiety Scale.* Chair, November 5, 2009.

McCord, J. Michael. *Developing a Standard of Care for Educational Malpractice.* Edith W. King, Chair. April 23, 2010.

Thompson, Jennifer. *History of Colorado Women's College.* Edith W. King, Chair, October 30, 2008. Committee Member.

Walker, Emelda. *Influence of Organizational Factors on Job Satisfaction of Disability Service Providers at Postsecondary Institutions.* Chair, July 21, 2009.

Dissertations at Other Institutions

Rodríguez-Mori, Howard. *The Information Behavior of Puerto Rican Immigrants to Central Florida, 2003-2009: Grounded Analysis of Six Case Studies Use of Social Networks during the Migration Process.* Kathleen Burnett, Chair, April 10, 2009, Florida State University, Committee Member.

Schwartz, Brian *More than a Look-up Skill: Medical Information Literacy Education in Osteopathic Medical Schools.* D. Mirah Dow, Chair, July 18, 2017. Emporia State University, Committee Member.

Snow, Karen. *A Study of the Perception of Cataloging Quality among Catalogers.* Shawne D. Miksa, Chair, August 1, 2011. University of North Texas, Committee Member.

Dissertation Proposals at Other Institutions

Schwartz, Brian *More than a Look-up Skill: Medical Information Literacy Education in Osteopathic Medical Schools.* D. Mirah Dow, Chair, December 4, 2015. Emporia State University, Committee Member.

Snow, Karen. *A Study of the Perception of Cataloging Quality among Catalogers.* Shawne D. Miksa, Chair, May 11, 2010. University of North Texas, Committee Member.

Master's Thesis at the University of Denver

Hemingson, Jeff. *Recital Paper.* Lamont School of Music, February 2010, Outside Chair.

Capstones at the University of Denver

Anthony, Alisa. *Correlation of Library and Information Science Program outcomes and Vacant Position Qualifications Listed on the Colorado State Library Jobline by Employers During the Period September 1, 2000 through August 31, 2002.* Chair, Winter Quarter, 2003.

Borden, Donna M. *Improving Emergency Communications Systems: Is a Radio Communications Network the Answer?* Fall Quarter, 2014.

Bowden, Heather L.M. *Exploring Biological Models for Long-term Data Preservation.* Chair, Spring Quarter, 2008.

Casenada, Cassandra Y. *Challenges to the Recruitment, Education, and Retention of Librarians of Color*. Chair, Spring Quarter, 2008.

Chang, Jennifer C. *Legal Research Practice and Preference: A Law Firm Perspective.* Chair, Spring Quarter 2011.

Ellis, Megan S. Fitzgerald. *Design of a Public Library Adult Volunteer Recruitment Program and Training Curriculum.* Chair, Winter Quarter, 2003.

Kircher, Kathy. *Development of a Library Pathfinder for Exobiology and Posting it on the Internet.* Chair, Winter Quarter, 2003.

Melhado, Loretta. *Design of St. John's Episcopal Church Library.* Chair, Spring Quarter, 2008.

Radcliff, Kathy. *Original Cataloging of Archival materials in the HERS Collection in Penrose Library.* Chair, Winter Quarter, 2003.

Sass, Carol Ann. *ACT Periodical Index: Access to Catholic Thinking Periodical Index: Web Index to Select Catholic Periodicals.* Spring Quarter 2000.

Stone, Sergio D. *Conducting Community Analysis for the Bemis Public Library (Littleton, Colorado) Using 2002 U.S. Census Data and the Online Outcome-Based Evaluation Toolkit.* Chair, Winter Quarter, 2003.

Tureson, Tamara. *Design and Use of an Information Audit Tool for Use in a Law Library.* Chair, Winter Quarter, 2003.

Tweed, Beth. *Evaluation of Email Reference Service in a Consumer Health Library Environment.* Chair, Winter Quarter, 2003.

GRANTS AND CONTRACTS

Student Learning in Agriculture STEM through Teacher Professional Development. Research team: Stanton Gartin (PI) and Cyndi Hofmeister, Northeast Junior College; Jeff Cash, Cheryl Sánchez, Anne-Marie Crampton, Lamar Community College; Suzanna Spears, Morgan Community College; Jack Wiley, Kerry Gabrielson, Trinidad State Junior College; Michael J. Miller, Colorado State University; Michael Womochil (Co-PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Agriculture, Agriculture and Food Research Initiative, Food, Agriculture, Natural Resources and Human Sciences Education and Literacy Initiative, $404,460 (2017-2020)

Leading and Achieving: the Colorado Agriculture Regional Consortium. Research team: Jack Wiley (PI), Kerry Gabrielson, Trinidad State Junior College; Jeff Cash (PI), Cheryl Sánchez, Anne-Marie Crampton, Lamar Community College; Suzanna Spears, Morgan Community College; Cyndi Hofmeister, Northeast Junior College; Michael Womochil (Co-PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Agriculture, Hispanic Serving Institutions Education Grants Program, $504,414 (2017-2020)

Cyber Prep Program Planning Grant. Research team: Debbie Sagen (PI), Brenda Lauer, Pikes Peak Community College; Gretchen Martin, Koiosa Insights; and, Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Commerce, Regional Alliances and Multi-stakeholder Partnerships to Stimulate (RAMPS) Cybersecurity Education and Workforce Development, $199,681 (2016-2018)

Career and Technical Education in Colorado: Pathways to Education and Employment. Research team: Heather McKay (PI), Rutgers University; Sarah Heath, Casey Sacks, Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Education, Institute of Education Sciences, $1,400,000 (2017-2021)

Pre-Alliance Planning Grant Colorado Community College Alliance. Research team: Victor Vialpondo (PI) and Janel Highfill, Community College of Aurora; Heidi Loshbaugh (Co-PI), Community College of Denver; Rick Reeves, Bill McGreevy, Liz Cox, and Kristin Aslin, Red Rocks Community College; Cathy Pellish, Front Range Community College; Samuel DeVries, Arapahoe Community College; Sylvia D. Hall-Ellis, Colorado Community College System. National Science Foundation, Louis Stokes Alliance for Minority Participation (LSAMP), $86,817 (2016-2017)

Towards Scalable Differentiated Instruction Using Technology-enabled, Competency-based, Dynamic Scaffolding. Research team: Karen Wilcox (PI) and Vijay Kumar, Center for Computational Engineering, Massachusetts Institute of Technology; Flora McMartin, Broad-based Knowledge; Quinsigamond Community College; and, Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Education, First in the World Developmental Grant, $2,891,882 (2015-2019)

Colorado Strategic Partnerships Emergency Grant. Research team: Elise Lowe-Vaughn (PI), Amy Hodson, Celia Hardin, Barbara McBride, James Newby, Christopher Dewhurst, Nina Holland, Kate Anderson, MaryAnn Roe, Chrystalynn Chrystalynn, Elaine Edon, Mona Barnes, Tom Morgan, Rob Hanni, and Marie Valenzuela, Colorado Department of Labor and Employment; Steve Anton, Joelle Brouner, and, Katie Griego, Colorado Department of Human Services; Rebecca Holmes, Judith Martinez, and Jennifer Jirous, Colorado Department of Education; Emily Templin Lesh, Colorado Workforce Development Council; Cory Everett, Colorado Department of Regulatory Agencies; and, Casey Sacks and Sylvia D. Hall-Ellis, Colorado Community College System. U.S. Department of Labor, Strategic Partnerships Emergency Grant, $5,000,000 (2015-2017)

CAEL Jump Start Program: Competency-Based Education. Research team: Jerry Migler (PI), Casey Sacks, Debra Cohn, Thomas Hartman, and Sylvia D. Hall-Ellis, Colorado Community College System; Matt Jamison, Front Range Community College; Mike Coste, Red Rocks Community College; Amanda Corum, Pueblo Community College; Janet Colvin, Pikes Peak Community College; and, MaryAnn Matheny, Community College of Denver. Council for Adult and Experiential Learning, $15,000 (2015)

Summit on the Redesign of Developmental Education. Research team: Jerry Migler (PI), Casey Sacks, and Sylvia D. Hall-Ellis, Colorado Community College System; Chip Nava, Pueblo Community College; Kim Moultney, Arapahoe Community College; Debbie Ulibarri, Trinidad State Junior College; and, Kris Bernard, Front Range Community College. American Association of Community Colleges, $15,000 (2015-2016)

Equity in Excellence at Colorado Community Colleges. Research team: Keith Howard (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Estela Mata Bensimon, Center for Urban Education, University of Southern California; and Kerry Gabrielson, Trinidad State Junior College. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $150,000 (2015-2016)

MBA High School of Business in Colorado. Research team: Laurie Urich (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Rudolph Sumpter and Beatrice Gerrish, Boulder Valley Schools; Keith Curry Lance, RSL Research Group. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $501,295 (2015-2016)

Fullbridge Program in Colorado. Research team: Keith Howard (PI) and Sylvia D. Hall-Ellis, Colorado Community College System; Suzanna Spears, Fort Morgan Community College; and, Cheryl Sánchez and Anne-Marie Compton, Lamar Community College. Colorado Department of Higher Education, Colorado Opportunity Scholarship Program, $300,000 (2015-2017)

Colorado Community College System Alternative Credit Program. Research team: Jerry Migler (PI), Keith Howard, and Sylvia D. Hall-Ellis, Colorado Community College System. American Council on Education, $13,000 (2015)

Internationalization in Higher Education. Researcher: Samuel D. Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $8,000 (2014-2015)

International Perspectives on Bilingual Education. Researcher: Sharolyn Pollard-Durodola. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $3,700 (2014-2015)

Cultivating Culturally Relevant and Responsive Curriculum and Pedagogy in College. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, iRise Grant, $5,000 (2014-2015)

Project EMERGE (Educational Model for Evaluation and Replicability in Gifted Environments). Research team: Norma Hafenstein (PI) and Bruce Uhrmacher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Lynde and Harry Bradley Foundation, $235,000 (2014-2015)

Collecting Asian American Refugee Stories. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. American Educational Research Association, Research Grant, $5,000 (2014-2015)

Developing Expertise in Teaching K-5 Mathematics. Research team: Julie Sarama (PI) and Douglas H. Clements (Co-PI), in partnership with the School of Education at the University of Michigan. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $130,344 (2013-2015)

Investigation of the Long-Term Outcomes for Special Education Students. Researcher: Antonio Olmos-Gallos. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Jefferson County School District, Office of Assessment, $40,000 (2014)

Refugee Community Collaboration. Researcher: Vicki Tomlin (PI) in partnership with the African Community Center and Jewish Family Service. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $14,854 (2014-2015)

Access to Mathematics for All. Research team: Richard S. Kitchen (PI), Nicole M. Russell (Co-PI), and Terrence Blackman (Co-PI), Curriculum Studies and Teaching Program, Morgridge College of Education; Álvaro Árias (Co-PI, Department of Mathematics); and, James Gray (Co-PI), Department of Mathematics, Community College of Aurora. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, The Robert Noyce Scholarship Program, Capacity Building Project, $349,926 (2014-2016)

Cognitive Test Battery for Intellectual Disabilities. Research team: Karen Riley (PI), Lyndsay Agans, Jessica Lerner, and Karin Dittrick-Nathan in partnership with David Hessl (PI), The MIND Institute at the University of California – Davis, and Elizabeth Berry-Kravis, Rush University Medical Center. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Institutes of Health, Outcome Measures for Use in Treatment Trials for Individuals with Intellectual and Developmental Disabilities (R01), $2,499,996 ($588,672 at DU) (2014- 2019)

Broadening Participation in Engineering among Women and Latino/as: A Longitudinal, Multi-Site Study. Researcher: Patton Garriott (PI) in partnership with the University of North Dakota and the University of Missouri. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, HER Core Research, $677,390 ($69,992 at DU) (2014-2019)

Designing a Teacher Evaluation System to Improve Teacher Effectiveness for Culturally and Linguistically Diverse Learners. Research team: María del Carmen Sálazar (PI), Jessica Lerner, and Kathy Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $29,988 (2014-2016)

Developing a College-Going Culture in Latina/O Families: Exploring the Influence of Funds of Knowledge on Family Outreach Programs. Researcher: Judy Marquez Kiyama. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $18,720 (2014-2016)

Assessment of Quality of Life in Neutral Implantation Surgery for the Treatment of Parkinson's Disease. Researcher: Cynthia McRae. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $3,967 (2014-2015)

Pura Vida: Cloud Forest, Curriculum and Cross-Cultural Study. Research team: Norma Hafenstein (PI) and Bruce Uhrmacher (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $8,000 (2014-2015)

Online Course Development for Curriculum and Instruction. Researcher: Ruth Chao. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: María del Carmen Sálazar. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: Jessica Lerner. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

Online Course Development for Curriculum and Instruction. Researcher: Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2014)

The Mathematics Education of African Americans, 1866 – 1954. Researcher: Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Academy of Education, Spencer Foundation Postdoctoral Fellowship, $55,000 (2014-2016)

Early Childhood Care and Education Study. Research team: Carrie Germeroth (PI), Melissa Mincic, and Douglas H. Clements. Technical reviewer for MCE: Sylvia D. Hall-Ellis. State of North Dakota, Department of Public Instruction, $73,500 (2013-2014)

Graduate Level Specialty in Addiction Counselor Training with Emphasis on Integration of Native American Specific Content. Research team: Ruth Chao (PI) and Michael J. Faragher (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. The Galena Foundation, $289,732 (2013-2016)

The Collecting Asian American and Pacific Islander Refugee Stories (CARS) Project. Researcher: Samuel Museus. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $15,000 (2014)

Parents in Transition: A Multiple Case Study of Parent and Family Orientation Programs. Researcher: Judy Marquéz Kiyama. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $1,500 (2014-2015)

The Sistah Network: Black Women Graduate Students Supporting and Retaining Each Other. Researcher; Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,708 (2014-2015)

Evaluation of the Northeast Denver Babies Ready for College Program. Research team: Carrie Germeroth (PI), Melissa Mincic, and Douglas H. Clements. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High Montessori, $9,922 (2013-2014)

Developing Teaching Expertise in K-5 Mathematics. Research team: Julie Sarama (PI) and Douglas Clements (University of Denver), in partnership with Timothy Boerst (PI), Meghan Shaughnessy, Deborah Ball, Hyman Bass (School of Education at the University of Michigan). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $449,827 ($130,344 at the University of Denver (2013-2015)

Early Learning Care and Education Study Program Grant for the State of North Dakota. Research team: Carrie Germeroth (PI), Melissa Mincic, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. State of North Dakota Department of Public Instruction, $73,500 (2013-2014)

Local Professional Learning Community for School Leaders. Research team: Susan Korach (PI), Kristina Hesbol, and Rebecca McClure. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Education Development Center, $10,950 (2013)

Healthy Eaters, Lifelong Movers 2: Implementing Evidence-Based School Environment, Policy, and Curricular Changes to Increase Opportunities for Healthy Eating and Physical Activity in Low Income, Rural Colorado. Research team: Elaine Berlansky, University of Colorado at Denver (PI), Nicholas Cutforth, University of Denver (Co-PI), and Allison Reeds. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $3,103,108 (2013-2017)

Hughes Rare Books Library Room Renovation in the Sturm College of Law. Project team: Patti H. Marks, Sylvia D. Hall-Ellis, and Leigh Elliott. Mabel T. Hughes Charitable Trust, $34,000 (2013-2014)

The Promise Center Partnership with the Marsico Institute for Early Learning and Literacy and the City and County of Denver. Research team: Karen Riley (PI), Douglas H. Clements (Co-PI), and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. The Piton Foundation, $223,468 (2013-2014)

Center of Excellence for Problem Gambling. Research team: Ruth Chao (PI) and J. Mike Faragher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $68,021 (2012-2013)

United Way Implementation and Validation Review. Research team: Douglas H. Clements (PI), Amanda Moreno, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High United Way, $19,737 (2013)

Math/Science Partnership in Rural Districts. Research team: Kristen Bunn (PI, Eagle County Schools), Paul Michalec (Co-PI), and Alegra Reiber. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Education, Colorado's Mathematics and Science Partnership Program, $750,000 (2013-2014)

Mathematics and Science Education of African Americans. Research team: Nicole Russell (PI), Sylvia D. Hall-Ellis, Steve Fisher (Penrose Library). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $29,994 (2013-2015)

Online Course Development for Curriculum and Instruction. Researcher: Nicole Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $3,000 (2013)

Discourse and Opportunity: Undocumented Students and Higher Education Policy. Researcher: Ryan Gildersleeve. Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Academy of Education, Spencer Foundation Postdoctoral Fellowship, $55,000 (2012-2014)

An Anthropological Study of the Latino Graduation Ceremony. Researcher: Ryan Gildersleeve. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Spencer Foundation, $39,900 (2012-2013)

Fragile-X and Pharmaceutical Company: Clinical Trial of AFQ056. University of California – Davis Children's Hospital MIND Institute (Sacramento), Children's Hospital Denver, and Rush Children's Hospital at Rush University Medical Center (Chicago). Karen Riley, PI. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Novartis Pharmaceuticals Corporation, $394,206 (2012-2014)

Project Engage, Phase 2, a DAPRA Grant in partnership with Total Immersion Systems, Inc., and Texas A&M University. Research team: Karen Riley (PI) and Lyndsay Agans (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Defense, $60,000 (2011-2013)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $14,951 (2012-2013)

Online Course Development for Curriculum and Instruction. Research team: Bruce Uhrmacher (PI) and Norma Hafenstein (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Teaching and Learning, $18,193 (2012-2014)

Writers in the Schools. Research team: Karen Riley (PI) and Amanda Moreno (Co-PI).Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Humanities, $4,965 (2012-2013)

Learning Ecosystem Validation Grant. Research team: Karen Riley (PI), Lyndsay Agans, Kent Seidel, and Shimelis Assefa. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Bill & Melinda Gates Foundation, $315,000 (2012-2013)

Project Words of Oral Reading and Language Development (WORLD). Research team: Jorge E. Gonzalez (PI), Texas A&M University; Laura Saenz (Co-PI), University of Texas – Pan American; and, Sharolyn Pollard-Durodola (Co-PI), University of Denver. Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $53,354 (2012-2015); award $640,718, transfer from Texas A&M University

Increasing the Efficacy of an Early Mathematics Curriculum with Scaffolding Designed to Promote Self-Regulation. Research team: Douglas H. Clements (PI) and Julie Sarama (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $1,445,315 (2008-2014); award $4,541,975, transfer from University at Buffalo, The State University of New York

Using Rule Space and Poset-based Adaptive Testing Methodologies to Identify Ability Patterns in Early Mathematics and Create a Comprehensive Mathematics Ability Test. Research team: Douglas H. Clements (PI) and Julie Sarama (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $323,791 (2010-2014); award $1,194,944, transfer from University at Buffalo, The State University of New York

Comprehensive Postdoctoral Training in Scientific Education Research. Researcher: Julie Sarama (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Education, Institute of Education Sciences, $133,458 (2010-2014); award $613,353, transfer from University at Buffalo, The State University of New York

Longitudinal Study of a Successful Scaling Up Project: Extending TRIAD. Research team: Douglas H. Clements (PI), Julie Sarama (Co-PI), and Abt Associates (Carolyn Layzer, Fatih Unlu, Laurie Bozzi, Lily Fesler, Alina Martinez, Cristofer Price, James van Orden). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Institute of Education Sciences, $384,940 (2011-2015; award $1,250,286, transfer from University at Buffalo, The State University of New York

Early Childhood Education in the Context of Mathematics, Science, and Literacy. Research team: Julie Sarama (PI), Douglas H. Clements (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. National Science Foundation, $990,020 (2010-2014; award $2,285,228, transfer from University at Buffalo, The State University of New York

Early Childhood Clearinghouse Information Center Redesign. Research team: Karen Riley (PI) and Amanda Moreno (Co-PI).Technical reviewer for MCE: Sylvia D. Hall-Ellis. Office of the Lt. Governor of Colorado, $12,000 (2012-2013)

Morgridge Rural Educational Leadership Initiative. Research team: Lyndsay Agans (PI), Linda Brookhart (Co-PI), Susan Korach, and Rebecca McClure. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Morgridge Family Foundation, $100,000 (2012-2014)

Center of Excellence for Problem Gambling. Research team: Patrick Sherry (PI) and J. Mike Faragher. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $55,000 (2012-2013)

Intermodal Transportation Institute Research Initiatives. Researcher: Patrick Sherry. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University Transportation Centers Program, Research and Innovative Technology Administration, U.S. Department of Transportation. $600,000 (2012-2014)

Mile High United Way Social Innovation Fund Early Literacy Initiative. Gloria L. Miller, PI, Amanda Moreano, Kim Hartnett-Edwards, and Sheridan Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Mile High United Way, $89,992 (2012-2013)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, $1,000 (2012-2013)

Refugee Student Art Outreach. Researcher: Karin Dittrick-Nathan. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $3,000 (2012-2013)

Resistance, Resilience, and Reciprocity: Centering the Voices of Black Doctoral Women with Faculty Aspirations. Researcher: Nicole M. Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,965 (2012-2013)

Assessing Learning through Student Notebooks. Research team: Keith Miller, Nancy Sasaki, and Kathy Green. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Professional Research Opportunities for Faculty, $30,000 (2012-2014)

International School Psychology Practicum Exchange. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $2,000 (2012-2013)

ELO in Colorado. Research team: Cynthia Hazel and Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Legacy Foundation, $150,000 (2012-2013)

Creating Online LIS Courses. Research team: Mary C. Stansbury (PI), Shimelis Assefa, Denise Anthony, Xiao Hu, and Krystyna Matusiak. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $15,000 (2011-2013)

Maritime Piracy Seminar. Researcher: Ved Nanda, The Nanda Center, Sturm College of Law. Technical reviewer for Sturm College of Law: Sylvia D. Hall-Ellis. Arsenault Family Foundation, $15,000 (2012-2013).

Early Childhood Librarianship: An Interdisciplinary, Experiential Learning MLIS. Researcher: Mary C. Stansbury (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Laura Bush's 21st Century Librarians Program, Institute for Museums and Library Services, $249,066 (2012-2014)

Learning Ecosystem Planning Grant. Research team: Karen Riley (PI), Lyndsay Agans, Kent Seidel, and Shimelis Assefa. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Bill & Melinda Gates Foundation, $281,217 (2011-2012)

Advanced Service Learning Practitioner Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Community Engagement and Service Learning, $400 (2011)

Evaluating and Enhancing the EspeciallyMe Program. Research team: Lori D. Patton and Nicole Russell. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, Public Good Fellowship Grant, $24,780 (2012)

Choosing Excellence: Let Every Child Bloom. Research team: Shimelis Assefa (PI) and Mary C. Stansbury (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Community Engagement and Service Learning, Public Good Grant, $7,657 (2012)

K-8 STEM Content Specific Professional Development to Improve Elementary Student Achievement. Research team: Kent Seidel (PI), Nicole Russell (Co-PI), Kimberly Hartnett-Edwards, Paul Michalec, Jeff Farmer, Keith Miller, Alegra Reiber, and Nancy Sasaki. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Education, Improving Teacher Quality Grant, (Title II ESEA), $307,299 (2011-2012)

Building a Better Principal Pipeline to Boost Student Achievement. Researcher: Susan Korach. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Denver Public Schools; a subcontract from the Wallace Foundation Grant, $170,000 (2011-2017)

Center of Excellence for Problem Gambling. Research team: J. Mike Faragher (Co-PI) and Bobbie Vollmer (PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Department of Behavioral Health, $79,999 (2011-2012)

An Exploration of Novice Teachers' Core Competencies: Impacts on Student Achievement, and Effectiveness of Preparation. Research team: Kent Seidel (PI), Kathy Green (Co-PI), Kimberly Hartnett-Edwards, and Duan Zhang. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Institute of Education Sciences, Effective Teachers and Effective Teaching, $990,987 (2012-2015)

Project Engage, a DAPRA Grant in partnership with Total Immersion Systems, Inc., and Texas A&M University. Research team: Karen Riley (PI) and Lyndsay Agans (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. U.S. Department of Defense, $49,964 (2011-2014)

User-centered Evaluation of Music Search Engines. Researcher: Xiao Hu. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Faculty Research Fund, $2,931 (2011-2012)

Educational Practicum in Vietnam and China to Promote the Inclusion of Young Children with Disabilities. Researcher: Gloria L. Miller. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Office of Internationalization, $5,000 (2011-2012)

Evaluation of Colorado's Enhancing Quality in Infant-Toddler (EQIT) Initiative. Research team: Virginia R. Maloney and Amanda Moreno. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Buell Foundation, $395,884 (2011-2013)

Creating Engaging Environments to Teach Pre-Algebra Mathematics to Elementary Students. Research team: Álvaro Arias, Mario López, María del Carmen Salazar, and Lyndsay Agans. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver Interdisciplinary Grant, $60,000 (2011-2012)

Morgridge Education Technology Accessible (META) Resource Project. Research team: Lyndsay Agans (PI) and Shimelis Assefa (Co-PI). Technical reviewer for MCE: Sylvia D. Hall-Ellis. Morgridge Family Foundation, $36,000 (2011)

MCE Connect: A 21st Century Framework for Faculty Development. Research team: Bruce Uhrmacher (PI), Shimelis Assefa (Co-PI), Lyndsay Agans (Co-PI), Kimberly Hartnett-Edwards, Norma Hafenstein, Xiao Hu, Paul Michalec (Co-PI), María del Carmen Salazar (Co-PI), and Sandra Snyder-Mondragon. Technical reviewer for MCE: Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $22,355 (2011-2012)

Parent Education and Parent Leadership and Advocacy. Research team: Virginia Maloney (PI) and Amanda Moreno, Marsico Institute for Early Learning and Literacy. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $27,358 (2010-2011)

Intentional School Culture. Researcher: Cynthia Hazel. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Denver Public Schools, $38,040 (2010-2011)

Healthy Eaters, Lifelong Movers: Implementing Evidence-Based School Environment, Policy, and Curricular Changes to Increase Opportunities for Healthy Eating and Physical Activity in Low Income, Rural Colorado. Research team: Elaine Berlansky, University of Colorado at Denver (PI), Nicholas Cutforth, University of Denver (Co-PI), and Allison Reeds. Technical reviewer for MCE: Sylvia D. Hall-Ellis. Colorado Health Foundation, $1,683,277 (2011-2014)

Second Life Learning Community. Research team: Don McCubbrey (PI), Sylvia D. Hall-Ellis (Co-PI), Walter LaMendola, and Paul Novak. University of Denver, Center for Teaching and Learning, $13,000 (2010-2011)

Reintroducing the Value of Law Librarians to Academic and Public Librarians in Colorado through the Identification and Use of Emerging Technologies. Research team: Sylvia D. Hall-Ellis (Co-PI), Stacey L. Bowers (PI), and Christopher Hudson, in partnership with Denver Public Library, Arapahoe Library District, and the Colorado State Supreme Court Library. University of Denver, Center for Community Engagement and Service Learning, $5,773 (2010-11)

Reintroducing the Value of Law Librarians to Public Librarians through the Identification and Use of Emerging Technologies and Resources. Research team: Stacey Bowers (PI) and Sylvia D. Hall-Ellis (Co-PI). American Association of Libraries, Wolters Kluwer Law & Business Grant Program, $2,725 (2010-2011)

Faculty Service Learning Pod. Research team: María del Carmen Salazar and Nicholas Cutforth (Curriculum and Instruction Program), Frank Tuitt (Higher Education Program), Cynthia Hazel and Gloria Miller (Child, Family, and School Psychology Program), and Sylvia D. Hall-Ellis (Library and Information Science Program). University of Denver, Center for Community Engagement and Service Learning, $8,000 (2010-2011)

Lincoln Collaborative. Research team: Antonio Esquibel (Principal, Lincoln High School), María del Carmen Salazar (Curriculum and Instruction Program), and. Sylvia D. Hall-Ellis. School Improvement Grant, Denver Public Schools, $375,000 (2010-2012)

Future LEADers of America: Leaders III. Research team: Denver Public Library (Kristen Svendson, PI), the University of Denver (Sylvia D. Hall-Ellis), the Colorado Chapter of REFORMA (Orlando Archibeque), and the Colorado Association of Libraries (Martin Garnar). Laura Bush's Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $988,366 (2009-2012)

Teaching for Success in the Library Environment: LIS 4030 in Library 2.0. Research team: Deborah S. Grealy (PI) and Sylvia D. Hall-Ellis (Co-PI). University of Denver, Center for Teaching and Learning, $ 9,350 (2009-10)

Writing Group Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Community Engagement and Service Learning, $750 (2008-2009)

Collaborative Learning Faculty Grant, Sylvia D. Hall-Ellis, University of Denver, Center for Teaching and Learning, $1,500 (2008)

Connecting Information Literacy to Learning. Research team: Lori Micho, Merrie Valliant, Amanda Samland, and Sylvia D. Hall-Ellis. Colorado State Library, LSTA Discretionary Grant Program, $19,548 (2008-2009)

Law Librarianship Fellows Program. Research team: Sylvia D. Hall-Ellis (PI), Stacey Bowers (Co-PI), and Christopher Hudson, Westminster Law Library. Laura Bush's 21st Century Librarians Program, Institute for Museums and Library Services, $999,370 (2008-2012)

Grant Writing in a Cooperative Learning Environment. Sylvia D. Hall-Ellis. University of Denver, Center for Teaching and Learning, $2,000 (2008-2009)

Project Homeless Connect 6 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $9,785 (2008)

Project Ecuador: International Learning Service Libraries – A Faculty Development Experience in Ecuador. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $600 (2007)

Project Ecuador: International Learning Service Libraries – A Faculty Development Experience in Ecuador. Sylvia D. Hall-Ellis, International Service Learning Office, University of Denver, $400 (2007)

Project Homeless Connect 5 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $1,000 (2007)

Project Homeless Connect 4 Event Evaluation. Research team: Sylvia D. Hall-Ellis and Duan Zhang. University of Denver Center for Community Engagement and Service Learning, $4,595 (2007)

Future LEADers of America: Leaders II. Research team: Denver Public Library (Kristen Svendson, PI), the University of Denver (Sylvia D. Hall-Ellis), and the Colorado Chapter of REFORMA (Orlando Archibeque). Laura Bush's Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $988,518 (2007-2010)

Strategic Planning Assistance for the Denver Medical Library. Sylvia D. Hall-Ellis. Denver Medical Library, Inc., $30,000 (2006-2007)

Destiny Software for JMAC Student Lab. Sylvia D. Hall-Ellis, gift from the Sagebrush Corporation, Minneapolis, Minnesota, $10,000 (2006)

Libraries: Tools for Education and Development Worldwide: A Faculty Development Experience in France. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $800 (2005)

Denver Public Library: Opportunities for Change. Sylvia D. Hall-Ellis, Colorado Community Based Research Network, $2,000 (2005)

Future LEADers of America. Research team: Denver Public Library (Letty Icolari and Steve Taylor, PIs), Emporia State University (Jim Agee), and the University of Denver (Sylvia D. Hall-Ellis). Recruiting Librarians for the 21st Century Program, Institute for Museums and Library Services, $670,315 (2005-2008)

American Association of University Professors Summer Institute Professional Development Grant. Sylvia D. Hall-Ellis, American Association of University Professors, $300 (2005)

Beta Phi Mu Alumni Tea. Sylvia D. Hall-Ellis, gift from the Office of Alumni and Parent and Relations, University of Denver, $2,000 (2005)

Spectrum Software for LIS Student Lab. Sylvia D. Hall-Ellis, gift from the Sagebrush Corporation, Minneapolis, Minnesota, $5,000 (2005)

Developing Research Capacity in Community Organizations and Residents through Training and Technical Assistance. Nicholas J. Cutforth (PI) and Sylvia D. Hall-Ellis. Piton Foundation, $25,000 (2005-2006)

Libraries: Tools for Education and Development Worldwide: A Faculty Development Experience in Argentina. Sylvia D. Hall-Ellis, Office of Internationalization, University of Denver, $500 (2004)

Developing Research Capacity in Community Organizations and Residents through Training and Technical Assistance. Research team: Nicholas J. Cutforth (PI), Gary Lichtenstein and Sylvia D. Hall-Ellis, Piton Foundation, $25,000 (2003-2004)

Increasing Spanish-Speaking and Hispanic Diversity among Library and Information Science Students at the University of Denver: Development of a Student Recruitment Model. Researcher: Sylvia D. Hall-Ellis (PI), Office of Multicultural Excellence, University of Denver, $2,750 (2003-2004)

Collection Development Enrichment to Support the Cataloging & Classification Specialization and School Librarianship within the Library & Information Science Program at the University of Denver. Research team: Sylvia D. Hall-Ellis (PI) and Deborah S. Grealy. Women's Library Association, University of Denver, $4,000 (2003)

Collection Development Enrichment to Support the Library & Information Science Program at the University of Denver. Research team: Deborah S. Grealy (PI) and Sylvia D. Hall-Ellis. Women's Library Association, University of Denver, $4,000 (2001)

Wireless LAN for Library Education. Research team: Deborah S. Grealy (PI) and Sylvia Hall-Ellis. University of Denver, Center for Teaching and Learning, $24,000 (2001-2002)

Upward Bound – A Program for South Texas Youth. Research team: Monte Churchill, Executive Director of Community Relations; Gary R. Sauceda, Outreach Coordinator; Raymond Hernandez, (PI) Associate Dean for Student Success; and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). U.S. Department of Education, Office of Postsecondary Education, $2,672,003 (1999-2003)

Write Now! Improving Elementary Students' Writing Skills. Research team: Caryl G. Thomason, Assistant Superintendent (PI); Karen Tankersley, Principal; and, Hal Anderson, Director of Technology, Cheyenne Mountain School District 12 (Colorado Springs, Colorado); and Sylvia D. Hall-Ellis. Colorado Department of Education, Educational Telecommunications Unit, $189,453 (1999-2001)

Operation Quick Start -- Distance Learning in Rural Colorado. Research team: Randal Weigum, Technology Coordinator (PI); Bonnie Barns, Director of Federal Programs and Staff Development; and, Adam "Joe" Raskop, Executive Director, Southeastern Board of Cooperative Educational Services (Lamar, Colorado); and Sylvia D. Hall-Ellis. Colorado Department of Education, Educational Telecommunications Unit, $400,000 (1999-2001)

Advanced Technological Training for Information Professionals for the 21st Century. Research team: Mario Reyna, Division of Business Director (PI) and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). Phi Delta Kappa and the National Science Foundation, $250,000 (1999-2001)

Working Connections – Training Information Technologies Professionals for the 21st Century. Research team: Mario Reyna, Division of Business Director (PI) and Sylvia D. Hall-Ellis, South Texas Community College (McAllen, Texas). Microsoft Corporation and the American Association of Community Colleges, $1,147,775(1999-2001)

The ROAD (Research Oriented Amplification of Development to Literacy) Program. Research team: Deborah J. Leong (PI), Metropolitan State University; Elena Bodrova, Metropolitan State University; Dmitri Semenov, Robert J. Marzano, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Foundation, $25,000 (1998-1999)

Press to Literacy. Research team: Deborah J. Leong (PI), Metropolitan State University; Elena Bodrova, Metropolitan State University; Dmitri Semenov, Robert J. Marzano, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). The Denver Post and the Robert S. McCormick Foundation, $49,818 (1998-1999)

International Telementor Center. Research team: David Neils, David B. Frost (PI), and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Philanthropy, $100,000 (1998-1999)

America Reads: Providing Tutor Training for the America Reads Challenge. Research team: Louis F. Cicchinelli (PI) and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Department of Education, Office of Educational Research and Improvement, $306,000 (1998-1999)

Comprehensive School Reform. Research team: Louis F. Cicchinelli (PI), J. Timothy Waters, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Department of Education, Office of Educational Research and Improvement, $285,000 (1998-1999)

Sustainable Energy Education (SEE) Program for Grades 4-8: Preparing Today's Youth for Lifelong Learning and Responsible Actions in Energy Conservation. Research team: Mary Gromko, Colorado Department of Education; Gene McCarthy, Rocky Flats Field Office, U.S. Department of Energy; Gina Kissell, National Renewable Energy Laboratory; and Barbara L. McCombs (PI), Janet L. Bishop, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). State of Colorado Governor's Office for Energy Conservation, $499,936 (1997-1999)

Review of Kansas Curriculum Standards in Mathematics and Language Arts. Research team: Robert J. Marzano (PI), John S. Kendall, David B. Frost, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Submitted to the Kansas State Department of Education, $25,903 (1998)

International Telementor Center. Research team: David Neils, John Kuglin, Chris Rapp, David B. Frost (PI), and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). Hewlett-Packard Company, $54,752 (1998)

Genesis Mission: Education Public Outreach. Developed in partnership by the Jet Propulsion Laboratory, California Institute of Technology, Los Alamos National Laboratory, Lockheed Martin Astronautics, and the Mid-continent Regional Educational Laboratory (Aurora, Colorado). Research team: John T. Sutton (PI), Alice Krueger, Martha Henry, Greg Rawls, Shae Isaacs, Jeff Johnson, Deb Jordan, Arlene Mitchell, David B. Frost, Jana Caldwell, J. Timothy Waters, and Sylvia D. Hall-Ellis. National Aeronautics and Space Administration, $139,700,000; subcontract award, $4,750,000 (1997-2007)

North Dakota Mathematics Assessment Project. Developed in partnership by the North Dakota Department of Education and Mid-continent Regional Educational Laboratory (Mid-continent Regional Educational Laboratory). Research team: Ann Clapper, Clarence Bina, Greg Gallagher, North Dakota Department of Education; Don Burger (PI), Hillary Michaels, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Office of Education, $1,618,214; subcontract award, $389,076 (1997-2001)

Pacific Resources for Education and Learning Distance Education: Project Evaluation. Developed in partnership by the Pacific Educational Community, the Pacific Resources for Education and Learning (PREL), and Mid-continent Regional Educational Laboratory (McREL). Research team: John W. Kofel (PI), Executive Director, PREL; J. Timothy Waters, Executive Director; Joan Buttram, Robert Keller, and Sylvia D. Hall-Ellis, Mid-continent Regional Educational Laboratory (Aurora, Colorado). U.S. Office of Education, Star Schools Program, $10,000,000; subcontract award, $500,000 (1997-2002)

Identification of Bilingual Gifted and Talented Children: A Comprehensive School Grants for Bilingual Education. Developed in partnership by Hidalgo (Texas) ISD, Los Fresnos (Texas) CISD, Progreso (Texas) ISD, University of Texas – Pan American (Edinburg, Texas), and Education Service Center, Region One (Edinburg, Texas). Research team: Hilda Medrano, Dean, College of Education, University of Texas – Pan American; Linda Phemister (PI), Janie Navarro, and Sylvia D. Hall-Ellis, Education Service Center, Region One. U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs, $1,670,633 (1997-2002)

Academics 2000: First Things First -- The Texas Goals 2000. Developed for Jim Hogg (Hebbronville, Texas) County ISD, Mirando City (Texas) ISD, and San Isidro (Texas) ISD. Research team: Hilda Medrano, Dean, College of Education, University of Texas - Pan American (Edinburg, Texas); Angie Lehmann, Amy Mares, Ellen Gonzalez (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg, Texas). Texas Education Agency, $339,987 (1997-2000)

Southwestern Bell's Learning Communities Initiative. Developed for Tech Prep of the Rio Grande Valley, Inc. (Harlingen, Texas); the Center for Professional Teacher Development, University of Texas – Brownsville; Teach for America – Rio Grande Valley (McAllen, Texas); and Education Service Center, Region One (Edinburg, Texas). Research team: Patricia G. Bubb, Executive Director (PI), Tech Prep of the Rio Grande Valley; Martin Winchester, Executive Director, Teach for America – Rio Grande Valley; Aileen Johnson, Director, School of Education, University of Texas – Brownsville; and Sylvia D. Hall-Ellis. Southwestern Bell Foundation, $100,000 (1997-1998)

Texas School to Work: Regional Implementation. Developed for Tech Prep of the Rio Grande Valley, Inc. (Harlingen), South Texas Community College (McAllen), Texas State Technical College (Harlingen), Texas Southmost College (Brownsville), Empowerment Zone of the Rio Grande Valley (Mercedes), Project VIDA (Weslaco), Youth Fair Chance (McAllen), and Education Service Center, Region One (Edinburg). Research team: Patricia G. Bubb (PI), Tech Prep of the Rio Grande Valley; Stephen Vassberg, Texas State Technical College; Ellen Trevino, Youth Fair Chance; Wanda Garza, Project VIDA; Leonardo Olivares, University of Texas – Pan American; Michael Bell, South Texas Community College; and Sylvia D. Hall-Ellis. Texas Workforce Commission, $4,250,000 (1997-2002).

Comprehensive Bilingual Education Grant for Hidalgo ISD and Roma ISD. Developed for Hidalgo (Texas) ISD, Roma (Texas) ISD, College of Education, University of Texas – Pan American (Edinburg, Texas), and Education Service Center, Region One (Edinburg, Texas). Research team: Tomas Thomas (PI), Director, Office of Bilingual Education and Sylvia D. Hall-Ellis. U.S. Department of Education, Office of Bilingual Education and Minority Languages Affairs, $1,531,361 (1997-2002)

Lopez High School, Porter High School, Rivera High School, Central Middle School, and Perkins Middle School, Brownsville (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $1,473,611 (1997-1998)

Donna High School, Todd Middle School, and Solis Middle School, Donna (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $704,052 (1997-1998)

Memorial Middle School and Nellie Schunior Middle School, La Joya Independent School District (Texas). Telecommunications Infrastructure Fund Board, $293,641 (1997-1998)

Martin High School, Christen Middle School, Cigarroa Middle School, Lamar Middle School, Laredo (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $1,200,000 (1997-1998).

Lasara Middle School, Lasara (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $246,210 (1997-1998)

Los Fresnos High School and Resaca Middle School, Los Fresnos (Texas) Consolidated Independent School District. Telecommunications Infrastructure Fund Board, $500,000 (1997-1998)

Lyford Junior High School, Lyford (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $354,997 (1997-1998)

Travis Middle School, McAllen (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $269,139 (1997-1998)

Mission High School, Mission (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $297,010 (1997-1998)

Progreso High School, Progreso (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $300,000 (1997-1998)

San Perlita High School, San Perlita (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $293,490 (1997-1998)

Myra Green Junior High School, Raymondville (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $225,000 (1997-1998)

Rio Grande City High School, Ringgold Middle School, Gruella Middle School, Rio Grande City (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $809,934 (1997-1998)

Rio Hondo Junior High School, Rio Hondo (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $297,024 (1997-1998)

Roma High School, Roma (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $333,178 (1997-1998)

San Benito High School, Miller Jordan Junior High School, San Benito (Texas) Consolidated Independent School District. Telecommunications Infrastructure Fund Board, $547,000 (1997-1998)

Santa Maria High School and Santa Maria Middle School, Santa Maria (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $400,000 (1997-1998)

Salvador High School, United Independent School District (Laredo, Texas). Telecommunications Infrastructure Fund Board, $250,879 (1997-1998)

Weslaco High School, Cabaza Middle School, Cuellar Middle School, Weslaco (Texas) Independent School District. Telecommunications Infrastructure Fund Board, $874,242 (1997-1998)

Principals' Assessment and Training Center. Developed for Education Service Center, Region One (Edinburg, Texas). Research team: Roberto Zamora, Leonel Barrera, William H. Parry, and Sylvia D. Hall-Ellis. Texas Principals' Leadership Initiative, Texas Association of Secondary School Principals, Texas Association of Elementary School Principals, and the Sid Richardson Foundation. $461,439 (1996-1998)

The Texas Library Connection -- Integrating and Sharing Resources. Developed for Hidalgo County Library System (McAllen), Cameron County Library System (Brownsville), South Texas Community College (McAllen), the University of Texas - Pan American (Edinburg), University of Texas – Brownsville, and Education Service Center, Region One (Edinburg). Research team: William R. McGee, Coordinator, Hidalgo County Library System; Joe Garcia, Director, Cameron County Library System; Michael D. Bell, Library Director, South Texas Community College; Eleanor Folger Foster, University Library, University of Texas - Pan American; Jaime Vela (PI), Director of Instructional Technology and Media Services, Ron Pontius, Instructional Technology, and Fabiola Fuentes, Media Services, Education Service Center, Region One; and Sylvia D. Hall-Ellis. Office of Library Media Services, Technology Services, Texas Education Agency. $8,000 (1996-1997)

Developing Leadership Communities for Improving Algebra I for All Students. Developed for a partnership of the Region One Statewide Systemic Initiative Team. Research team: Noel Villarreal (PI), Eduardo Cancino, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Statewide Systemic Initiative for Reform in Mathematics, Science and Technology Education to The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin. $25,000 (1996-1997)

Academics 2000: First Things First -- The Texas Goals 2000. Developed for Edinburg (Texas) CISD. Research team: Hilda Medrano, Dean, College of Education, University of Texas - Pan American (Edinburg); Helen Jones, Director (PI), Gifted and Talented Education, Edinburg CISD; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $750,000 (1996-2001)

Texas Teachers Empowered for Achievement in Mathematics (TEXTEAM) Institute for Algebra I. Developed for Hidalgo ISD, Jim Hogg (Hebbronville) County ISD, La Joya ISD, La Villa ISD, Lyford ISD, Mission CISD, Pharr-San Juan-Alamo ISD, Rio Hondo ISD, San Isidro ISD, San Perlita ISD, Santa Maria ISD, Santa Rosa, Sharyland ISD, Valley View ISD, Webb (Laredo) CISD, Weslaco ISD, and Zapata County (Zapata) ISD. Research team: Noel Villarreal (PI), Chuck McInteer, Ellen M. Gonzalez, Education Service Center, Region One (Edinburg); and Sylvia D. Hall-Ellis. Charles A. Dana Center for Mathematics and Science Education, University of Texas - Austin, $15,975 (1996)

Community Learning Center for La Villa, Texas. Developed for Edcouch-Elsa Independent School District. Research team: Noe Gonzalez (PI), Assistant Superintendent, Edcouch-Elsa Independent School District, and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $325,000 (1996-1997)

Monte Alto (Texas) Community Learning Center. Developed for Monte Alto Independent School District. Research team: Homero A. Diaz (PI), Superintendent, Monte Alto Independent School District, and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $300,000 (1996-1997)

Community Learning Center for La Villa, Texas. Developed for La Villa Independent School District. Research team: Sam Gonzalez (PI), Assistant Superintendent, La Villa Independent School District; and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $325,000 (1996-1997)

Building Project for Taylor Elementary. Developed for Mercedes (Texas) Independent School District. Research team: Mrs. Denise Rivera, Librarian, and Eduardo Infante, Principal, Taylor Elementary School; Ismael S. Cantu (PI), Federal Programs Director, Mercedes Independent School District; and Sylvia D. Hall-Ellis. Delta Region Subzone, Rio Grande Valley (Texas) Rural Empowerment Zone, $375,000 (1996-1997)

Border Education Network (BEN) - Distance Education through Cable Television. Developed for Edinburg (Texas) Consolidated Independent School District. Research team: Noe Torres (PI), Library Media Specialist, Magdalena Rosas, Library Media and Technology Coordinator, Edinburg Consolidated Independent School District; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Edinburg (Texas) Consolidated School District, $250,000 (1996-1997)

Multiservice One-Stop Open Enrollment Charter School. Developed for the Information Referral Resource Assistance, Inc. (McAllen, Texas). Research team: Pablo Perez and Aguie Pena (PI), Executive Director, Information Referral Resource Assistance, Inc.; Roberto Zamora and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $3,066,000 (1996-2001)

Project OK: A Community Youth Opportunities Grant for Summer, 1996. Developed for McAllen (Texas) Independent School District, St. Joseph the Worker Catholic Church, and the Office of Adult Education, Education Service Center, Region One. Research team: Father Bart Flatt, St. Joseph the Worker Catholic Church; Noe Calvillo (PI), Office of Adult Education; Maria Louisa Garcia, McAllen Independent School District; and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Protective and Regulatory Agency through the Office of the Mayor, City of McAllen, $350,000 (1996-2001).

Early Childhood: a Time of Discovery. Developed for a partnership of Lasara ISD, Rio Hondo ISD, San Perlita ISD, the School of Education, University of Texas - Brownsville, and Education Service Center, Region One (Edinburg). Research team: Hugo Rodriguez, Dean, School of Education, University of Texas - Pan American; Leonel Barrera and Jack Damron, Field Service Agents, Ellen M. Gonzalez (PI), Administrator for Student Instructional Services, Ruth Solis, Education Specialist in Special Education, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $722,090 (1996-2001)

Innovative Gifted and Talented Programs for Early Childhood and Elementary Education Students. Developed for a partnership of Edinburg (Texas) CISD, the School of Education, University of Texas - Pan American (Edinburg), and Education Service Center, Region One (Edinburg). Research team: Hilda Medrano, Dean, School of Education, University of Texas - Pan American; Helen de la Garza (PI), Director of Elementary Curriculum and Instruction, Edinburg CISD; and Sylvia D. Hall-Ellis. Texas Education Agency, $750,000 (1996-2001)

Reading Recovery in Early Elementary Grades. Developed for a partnership of La Villa (Texas) ISD the School of Education, University of Texas - Pan American (Edinburg), and Education Service Center, Region One (Edinburg). Research team: Hilda Medrano, Dean, School of Education, University of Texas - Pan American; Marcario Salinas (PI), Supervisor of Elementary Curriculum and Instruction, La Villa ISD; and Sylvia D. Hall-Ellis, Education Service Center, Region One. Texas Education Agency, $750,000 (1996-2001)

Connected Mathematics Project for Middle and Junior High Students. Developed for a partnership of Michigan State University, The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin and Region One Statewide Systemic Initiative Team. Research team: Jack Damron, Chuck McInteer, Noel Villarreal (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). National Science Foundation through Michigan State University to the Charles A. Dana Center at the University of Texas - Austin, $539,610 (1996-1999)

Sharing Resources: Testing the Interlibrary Loan Potential of the Texas Library Connection -- Integrating Media Resources. Developed under the sponsorship of the Hidalgo County Library System (McAllen) and Education Service Center, Region One (Edinburg). Research team: William H. McGee, Hidalgo County System Coordinator; Fabiola Fuentes, Library Media; Ronald Pontius (PI), Instructional Technology, Education Service Center, Region One; and Sylvia D. Hall-Ellis. Library Media Services Program, Office of Technology Services, Texas Education Agency, $25,000 (1996-1997)

State and Federal Adult Education JOBS Program. Developed for Education Service Center, Region One (Edinburg). Research team: Noe Calvillo (PI), Director, Adult Education Program, and Sylvia D. Hall-Ellis. Adult Education Program, Texas Education Agency, $532,846 (1995-1996)

Creating Safe and Drug-Free Schools and Communities. Developed for a partnership of the Region One Consortium for Safe and Drug-Free Education Environments. Research team: Clara Contreras (PI), Health Specialist, and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Education Agency, $150,000 (1995-1996)

Developing Leadership Communities for Improving Mathematics Performance for All Students on Title I Campuses. Developed for a partnership of the Region One Statewide Systemic Initiative Team. Research team: Jack Damron, Chuck McInteer, Noel Villarreal (PI), and Sylvia D. Hall-Ellis, Education Service Center, Region One (Edinburg). Texas Statewide Systemic Initiative for Reform in Mathematics, Science and Technology Education to The Charles A. Dana Center for Mathematics and Science Education, The University of Texas at Austin, $50,669 (1995-1996)

The Impact of Library Resource Centers on Academic Achievement in Selected Public Schools in South Texas. Sylvia D. Hall-Ellis (PI). Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville). Texas Association of School Librarians, Children's Services Round Table, and Young Adults Round Table (Austin, Texas), $2,500 (1995)

School Library Media Specialists Fellowship Program. Sylvia D. Hall-Ellis (PI). Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville, Texas). U.S. Department of Education, HEA Title II-B, Library Education and Human Resource Development Program, $44,000 (1995-1996)

Planning for Educational Technology. Research team: Ruth Ann Riggins (PI), Director of Library Media and Technology Services, Donna (Texas) Independent School District; Noe Torres, Education Service Center, Region One; Patricia G. Bubb, Tech Prep of the Rio Grande Calley, Inc; Michael D. Bell, South Texas Community College; and Sylvia D. Hall-Ellis, Sam Houston State University. Developed under the sponsorship of Donna (Texas) Independent School District, Education Service Center, Region One (Edinburg), Tech Prep of the Rio Grande Valley, Inc. (Harlingen), South Texas Community College (McAllen), and the Department of Library Science, Sam Houston State University (Huntsville). Funded through Infusion of Educational Technology Planning Grant Program (H.B. 18: Models). Texas Education Agency, $18,000 (1993-1994)

The Impact of Library Resource Centers on Academic Achievement in Selected Public Schools in South Texas. Sylvia D. Hall-Ellis (PI) and Mary Ann Berry. Developed under the sponsorship of the Department of Library Science, College of Education and Applied Science, Sam Houston State University (Huntsville). Sam Houston State University Research Enhancement Fund, $7,500 (1993-1994)

Electronic Mail Resource Sharing System: Management and Operation of the Iowa Computer-Assisted Network. State Library of Iowa, $294,000 (1986-1993)

The Iowa Locator: A CD-ROM Resource Sharing Tool. State Library of Iowa, $567,000 (1986-1992)

Statewide Database Development: An OCLC Tape Analysis To Determine Feasibility. State Library of South Dakota, $15,000 (1987)

The Iowa Locator: A Feasibility Study. State Library of Iowa, $50,000 (1986)

Electronic Mail Resource Sharing System: A Feasibility Study for Libraries in the State of Iowa. State Library of Iowa, $5,000 (1985)

Access Pennsylvania: A Feasibility Study. State Library of Pennsylvania, $50,000 (1984)

Automating Library Administrative and Management Tasks: Procurement and Distribution of Microcomputer Systems for District Library Centers in the Commonwealth of Pennsylvania. State Library of Pennsylvania, $495,000 (1982)

Sharing Serial Titles Resources: Procurement and Distribution of Microfiche Readers for 550 Libraries in the Commonwealth of Pennsylvania. State Library of Pennsylvania, $500,000 (1982)

Electronic Mail System: A Pilot Project for Libraries throughout the Commonwealth of Pennsylvania. State Library of Pennsylvania, $125,000 (1982)

Literacy Program for Adults in Rural Upstate New York State: Program Outreach and Evaluation - Phase 3. Appalachian Regional Commission, $50,000 (1981)

Database Building: A Cooperative Project of the Finger Lakes Library System (Ithaca), Four County Library System (Binghamton), and the Southern Tier Library System (Corning). New York State Library, $450,000 (1980-1985)

Faces of the Southern Tier: A Professional Photographer-in-Residence. New York State National Endowment for the Humanities, $25,000 (1980)

Literacy Program for Adults in Rural Upstate New York State: Program Implementation - Phase 2. Appalachian Regional Commission, $50,000 (1980)

Small Business Resources Center: A Pilot Project for Rural Public Libraries. New York State Library, $50,000 (1980)

Media Programming: A Professional Development Program for Public Librarians in Upstate New York: A Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $35,000 (1979)

Information and Library Resources for Inmates and Prisoners in Selected Upstate New York Facilities: A Cooperative Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $25,000 (1979)

Library Resources for Homebound Adults in Upstate New York: An Outreach Program in Allegheny, Chemung, Schuyler, Steuben, and Yates Counties. New York State Library, $40,000 (1979)

Literacy Program for Adults in Rural Upstate New York State: Program Initiation and Establishment - Phase 1. Funded by the Appalachian Regional Commission. Awarded to the Corning (New York) Public Library, $50,000 (1979)

Information Reference Services to Homebound Adults. New York State Library, $31,000 (1978)

Books-By-Mail Services to Homebound Adults. New York State Library, $31,000 (1978)

System Headquarters Services and Programs for Public Libraries in District 10. Funded through Library Services and Construction Act Title I. Texas State Library and Historical Commission, $880,000 (1976)

County Library Development Grant for Atascosita County. Funded through Library Services and Construction Act Title I. Texas State Library and Historical Commission, $15,000 (1976)

Spanish Language Materials Collection Development Program. Texas State Library and Historical Commission, $40,000 (1975)

Establishment of System Headquarters for Alamo Regional Library System (District 10) Headquartered at the San Antonio (Texas) Public Library. Texas State Library and Historical Commission, $800,000 (1975)

SELECTED CONSULTANTSHIPS

Project Strategic Planning & Funding Proposal Development

Walden University, 2015.
Pikes Peak Library District, 2014.
Douglas County Public Libraries, 2011-2012.
Denver School for Science and Technology, 2008-2011.
Johnson & Wales University, Denver Campus, 2007-2009.
Challenges, Choices, and Images K-12 Charter School, Denver Public Schools, 2007.
Denver Medical Library, Inc., 2006-2010.
Bemis Public Library (Littleton), Ergonomic Design and Facilities Enhancement Consultant, 2003.
Curtis Park Community Center (Denver), Community Technology Center Evaluation and Proposal Development Consultant, 2003.
Colorado Community Based Research Network (Denver), Funding Research Associate, 2002.
Our Lady of the Rosary Academy (Edgewater), Learning Resource Center Development Project Consultant, 2001-2003
University of Southern Colorado (Pueblo). Technology Integration and Curriculum Enhancement into Higher Education Learning Environment. Proposal Development Consultant, 2000.
Jefferson County Library System (Lakewood), 1999-2000.
Southeastern BOCES (Lamar, CO). Distance Learning Curriculum Content Development Project. Proposal Development Consultant, 1998-2004.
Cheyenne Mountain School District 12 (Colorado Springs, CO). Technology Integration into Elementary Writing Curriculum Project. Proposal Development Consultant, 1998.
Telecommunications Infrastructure Fund Board Round #2 Application, 1997. Technical assistance to the following: La Villa (Texas) Independent School District; Mirando City (Texas) Independent School District; Monte Alto (Texas) Independent School District; San Isidro (Texas) Independent School District.
Telecommunications Infrastructure Fund Board Round #1, 1996. Technical assistance to the following: Brownsville (Texas) Independent School District; Donna (Texas) Independent School District; Edinburg (Texas) Consolidated Independent School District; Harlingen (Texas) Consolidated Independent School District; Jim Hogg County Independent School District (Hebbronville, Texas); La Feria (Texas) Independent School District; La Joya (Texas) Independent School District; La Villa (Texas) Independent School District; Los Fresnos (Texas) Consolidated Independent School District; Progreso (Texas) Independent School District; Raymondville (Texas) Independent School District; Rio Hondo (Texas) Independent School District; San Benito (Texas) Independent School District; Sharyland Independent School District (Mission, Texas); Weslaco (Texas) Independent School District; Zapata (Texas) County Independent School District.
South Texas Community College (McAllen). Strategy Development to Meet the Technology Instructional Needs for Vocational, School-To-Work and Academic Programs, 1994-2000. Development Consultant.
Donna (Texas) Independent School District. Planning for the Infusion of Technology in Middle Schools Serving High At-Risk Students, 1994-1995. Research Associate.
Pettus (Texas) Independent School District. Planning for District-wide Automation in School Library Media Centers: Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1994. Principal Investigator.
Fort Bend Independent School District (Sugar Land, TX). Planning for District-wide Automation in School Library Media Centers, Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1994-1995. Principal Investigator.
Northern Waters Library Services (Ashland, WI). Professional Consulting Services to Make Recommendations on the Development of System-Wide Efforts of the Northern Waters Library Service, 1988-1989. Research Associate.
State Library of Iowa (Des Moines). The Iowa Locator Compact Disc to Support Multi-Type Libraries Resource Sharing including Database Design, Building, Production, and Distribution, 1986-1991. Project Director.
State Library of Iowa (Des Moines). Iowa Computer-Assisted Network Development, Enhancement, and Operation, 1985-1992. Technical Director.
State Library of South Dakota (Pierre). Statistical Sampling and Analysis of Multi-Institutional OCLC Archive Tape for Statewide Online Database Building, 1985-1986. Research Associate.
District of Columbia Public Library (Washington, DC). Planning Document for the Retrospective Conversion of Bibliographic Records and Automation Issues in the 1990's, 1984-1985. Research Associate.

State Library of Pennsylvania (Harrisburg). Database Development for High School Libraries, 1984-1985. Research Associate.
MINITEX (Minneapolis, MN). Workshops for Retrospective Conversion, Bar Coding, Library Statistics, and OCLC Serials Format, 1985. Presenter and Research Associate.
ABC Film Consortium (Altoona, Bellefonte, Johnstown, PA). Database Building, System Design, and Implementation of Online Film Booking System, 1983-1985. Database Manager.

Library Automation -- System Design & Implementation

Douglas County Library District (Castle Rock, CO). Library Automation Technical and System Performance Specifications, 2001.
Pharr-San Juan-Alamo Independent School District (Pharr, TX). Library Automation Technical and System Performance Specifications, 1997. Project Development Consultant.
Harlingen (Texas) Independent School District. Planning for District-wide Automation in Junior High School Library Media Centers: Preparation of Data, and CD-ROM Hardware/Software Configuration Evaluation, 1996. Principal Investigator.
Sharyland (Texas) Independent School District. Design and Construction of New Elementary School Library and Technology Resources Center, 1995-1996. Principal Investigator.
South Texas Independent School District (Mercedes, TX). Design and Construction of a New High School Library and Technology Resources Center, 1995-1996. Principal Investigator.
Citizens' Library (Washington, PA). Online Community Resources Files: Design and Implementation, 1984. Research Associate.
Altoona (Pennsylvania) Hospital. Integrated Online System Upgrade Study, 1984. Research Associate.
State Library of South Dakota (Pierre). Automation Plan and State Database Development, 1982-1983. Principal Investigator.
State Library of Pennsylvania (Harrisburg). COM Production and Preparation of the Technical Specifications Document, Procurement, and Distribution of Microcomputers in the Commonwealth of Pennsylvania, 1983-1984. Research Associate.
Altoona (Pennsylvania) Area Public Library. Integrated System (Circulation/Online Catalog) Study, 1982-1983. Principal Investigator.
COPSCAULD (Council of Pennsylvania State College and University Library Directors, Edinboro, PA). Design of Online Media Catalog, 1982. Principal Investigator.
Erie (Pennsylvania) County Library System. Operations Research and Design for Automated Circulation, Hardware Upgrade and Re-Retrospective Conversion, 1982. Research Associate.
Michigan Library Consortium (Lansing, MI). Tape Management System Design and Implementation, 1982-1984. Research Associate.
State Library of Pennsylvania (Harrisburg). Preparation of the Technical Specifications Document, Procurement and Distribution of Microfiche Readers in the Commonwealth of Pennsylvania, 1982. Research Associate.
Community College of Allegheny County, Allegheny Campus (Pittsburgh, PA). Integrated Systems Study, 1981. Principal Investigator.
Community College of Allegheny County, South Campus (West Mifflin, PA). Retrospective Conversion Training Program for Handicapped Students, 1981. Technical Director.
Southern Tier Library System (Corning, NY). OCLC Acquisitions Subsystem Evaluation, 1981. Principal Investigator.
South Central Reference and Research Council (Ithaca, NY). South Central Regional Delivery System, 1980. Principal Investigator.
Southern Tier Library System (Corning, NY). Newspapers on Microfilm in the Chemung-Southern Tier Library System, 1979-1981. Principal Investigator.

Cataloging & Bibliographic Database Building

Challenges, Choices, and Images K-12 Charter School, Denver Public Schools, 2007.
Denver Medical Library, Inc., 2006-2010.
Ricks Gifted and Talented School Library, 2005-
American Humane Society (Englewood), 2004-2006.
Fisher Early Learning Center Library, 2004-

Colorado Community Based Research Network (Denver), 2004-
Boulder Valley School District (Boulder), 2002-2003.
Douglas Public Library District (Castle Rock), 2001-2002.

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The effect of front pyramid heights on the efficiency of homogeneously textured inline-diffused screen-printed monocrystalline silicon wafer solar cells

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ABSTRACT

The majority of industrial monocrystalline silicon (c-Si) wafer solar cells are alkaline textured (at least the illuminated surface) to reduce reflection and increase absorption of incident light. Therefore, understanding the influence of front pyramid heights on the solar cell parameters is essential for further improving cell efficiency. In this work we report the impact of pyramid height on the performance of inline-diffused c-Si solar cells. Three alkaline texture processes with potassium silicate additives are optimised to result in homogeneous coverage of pyramids. By modifying the process, surface textures with small (~5 μm maximum), medium (~6 μm maximum) and large (~8 μm maximum) pyramid heights are formed. The impact of pyramid size on cell parameters is experimentally studied using industrial-grade 156-mm pseudo-square *p*-type Czochralski wafers. It is found that within the pyramid size range studied here, there is no significant variation in effective minority carrier lifetime, reflectance, open-circuit voltage or short-circuit current. However, fill factor and hence efficiency is significantly impacted by pyramid size. While cells in all three groups demonstrate high fill factor (>79%), it is shown that an average fill factor gain of up to 1% absolute can be achieved by using the best-suited texture process.

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1. Introduction

The large availability of crystalline silicon (both mono and multi) wafers helps in rapid expansion of the global photovoltaic market. The key challenge for monocrystalline silicon (mono-Si) wafer solar cell is further reduction of the dollar per Watt cost. A route to achieve higher solar cell efficiency is optimisation of key processes, such as an alkaline texturisation. The textured surface, due to the so-called 'double-bounce' effect, reduces the reflectance from the illuminated surface [1–3]. The anisotropic selective chemical etching of the <100> Si surface with sodium hydroxide (NaOH) or potassium hydroxide (KOH) solutions has been used to form random upright pyramidal textured surface [1]. Iso-propyl alcohol (IPA) is commonly added to the alkaline texture solution; it modifies the surface wettability to controllably nucleate the texturing process [4] and thus helped to achieve good lateral uniformity of the pyramids across the entire wafer. Recently Basu et al. [5] have used potassium silicate (K_2SiO_3) as an additive to the alkaline textured solution. This advanced solution reduces IPA consumption, while enhancing texturing process; thus, increases throughput.

Previous studies have analysed the influence of pyramid height on the solar cell performance by simulations or experiments [6–11]. From a geometric optics (ray tracing) point-of-view the size of regular upright pyramids does not affect the front surface reflectance and the obtained short circuit current (J_{sc}). However the geometric optics simulation approach is only valid when surface feature sizes are larger than the interacting wavelength, this condition is not strictly fulfilled for solar cells as wavelengths up to 1100 nm are relevant for crystalline silicon solar cells and random pyramid texture processes may lead to some sub-micrometre pyramids. A rigorous simulation study by Llopis and Tobías [6]

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involving numerical solution of the electromagnetic wave equations concluded that diffraction effects are significant only for pyramid smaller than 300 nm, in this case the reflectance increases beyond the geometric optic limit. Typically simulation studies are limited to include the effects of the pyramids size distribution and therefore experimental studies provide better insights on this effect on the solar cell's optical performance. In terms of open-circuit voltage (V_{oc}) pyramidal textured surfaces increase surface recombination due to an enhancement of surface area (corresponding to the planar surface). For pyramids of standard geometry the area enhancement is independent of the pyramid size (if the surfaces are fully textured) and no effect on V_{oc} is expected. The influence of pyramid sizes on the fill factor (*FF*) has been studied, however contradicted results were reported. Cabrera et al. [7] and Han et al. [8] observed reduction in *FF* for pyramid sizes smaller than 300 nm. However, while Cabrera et al. observed no impact of pyramid height (KOH–IPA texture chemistry) on *FF* for pyramids larger than 300 nm [7]. Han et al. [8] observed a variation in *FF* without a clear trend (NaOH–IPA + variable additives). Note that modification of the pyramids size can resulted with non-uniformity of the texturing. Ximello et al. [9] used an alkaline texture process based on a KOH and "high boiling alcohol (HBA)" process chemistry (different from standard KOH–IPA chemistry) and varied texture time to generate different pyramid sizes. Although a significant variation was observed in J_{sc}, V_{oc} and *FF* [9], the variations were attributed to texture uniformity.

Other studies focused only on the impact of the pyramid size. For examples, King and Buck [10] investigated only the impact on front surface reflectance, while Kegel et al. [11] studied the influence on intrinsic amorphous-Si passivation for heterojunction cells. It seems that comprehensive study regarding the impact of pyramids height on the solar cell electrical parameters is required.

In this study, three different texturing recipes were developed to generate three different homogeneous pyramidal structures with maximum heights varying from 5 μm to 8 μm, with good uniformity of pyramid heights within each group. The pyramids size was controlled by varying the alkali concentration, the texturing temperature and the amount of potassium silicate in the KOH–IPA solution. It was found that textured wafers from all the three groups have similar solar spectrum weighted average reflectance (WAR) in the range of 11.5–11.8%. Wafers from all groups were used to fabricate conventional 156 mm pseudo-square inline-diffused screen-printed solar cell with average efficiencies in the range 18.4–18.6%, using the pilot line at the Solar Energy Research Institute of Singapore (SERIS). Details and characterisation of the new texturing process and the resulting solar cells will be presented, including scanning electron microscope (SEM) images, reflectance, quasi-steady state photoconductance (QSSPC) and contact resistance measurements, series resistance imaging from a combination of photoluminescence (PL) and electroluminescence (EL) images, and 1-Sun *I*–*V* measurements.

2. Experimental details

2.1. Texturisation

In this experiment 150 wafers of industrial grade monocrystalline Cz silicon wafers were used (156 mm pseudo-square, *p*-type, boron doped, <100> orientation, 1-2 Ω-cm resistivity, 170–190 μm thickness). Pre-cleaning and damage removal process of the wafers prior the texturing was performed following the process developed by Basu et al. [12]. It used KOH (20% by weight) and sodium hypochlorite (NaOCl) solution in a ratio of 1:3 (by volume). The wafers were immersed in the solution for 2 min (min) at 80 °C to remove the surface damage (~3 μm per side, as measured by measuring the change of the wafer's weight). The wafers were split into three groups of 50 wafers each, corresponding to three different pyramid heights (groups A, B and C). A mixture of KOH, IPA and K_2SiO_3 was used to form homogeneous (or uniform) pyramidally textured surfaces [5]. The texturing chemical bath was made from polyvinylidene difluoride (PVDF) material and was heated from the bottom by a flat Teflon coated heater. This bath is an overflow bath fitted with an external pump which circulates the texturing solution in order to minimise variation of the solution concentration and temperature. The texturing solution temperatures were maintained at a constant value of 80 °C and 85 °C corresponding to different texturisation recipes. However, the texturing time maintained constant as 20 min for all the processes. In this study, the KOH concentration was varied from 1.4% to 2.5% (by weight), while the amount of K_2SiO_3 and IPA were varied from 60 to 100 ml and from 2.5 to 3.2 L, respectively in a 40 L bath.

After texturing, all the wafers were neutralised in 1:1 solution of hydrochloric (HCl) acid and de-ionised (DI) water at 60 °C for 10 min followed by a dip in dilute hydrofluoric acid (HF). The complete process flow of the different groups is shown in Fig. 1. Following the texturing, the wafers were processed together as a single batch.

2.2. Cell fabrication

The textured wafers were diffused in an industrial inline-diffusion furnace (Despatch, DCF-3615). After an atmospheric-plasma pre-treatment step at the entry to the doper (to create a hydrophilic Si surface), a spray-on dopant source was applied uniformly to both sides of the wafer at 30 L/min rate [ortho-phosphoric acid (H_3PO_4) mixed with ethyl alcohol]. The diffusion was performed at a belt speed of 390 mm/min using a peak diffusion temperature of 895 °C for all the wafers to achieve an emitter sheet resistance (R_{sq}) of ~40 Ω/sq, as measured by four-point-probe measurements (Cresbox, NAPSON). The parasitic rear-junction and the front phosphosilicate glass (PSG) were removed in an industrial inline wet chemical tool (InPilot, RENA GmbH) using solution mixture of HF, nitric acid (HNO_3) and sulphuric acid (H_2SO_4) at 6–8 °C. The etch-back was performed using 'SERIS etch' [13,14] to achieve the targeted final R_{sq} of ~70 Ω/sq. Amorphous silicon nitride (SiN_x) antireflection coating (ARC) was then deposited onto the front surface using an industrial plasma enhanced chemical vapour deposition (PECVD) system from Roth & Rau (SiNA-XS). The film thickness and refractive index (at 633 nm) were measured to be 70 nm and 2.05, respectively. Lastly, front and rear contacts were formed by screen printing (PVP1200, DEK) and subsequently co-fired in an industrial fast firing furnace (Ultraflex, Despatch), using a Monocrystal PASE 12D aluminium (Al) paste for the rear and DuPont PV17F Ag paste for the front contacts. The summary of the complete cell fabrication process flow is shown in Fig. 2.

2.3. Characterisation

Representative samples from the three groups were removed after various process stages for additional surface characterisation studies. Prior to these measurements, the representative samples were cleaned in IPA, followed by DI rinsing and drying. A scanning electron microscope (SEM) from Carl Zeiss Auriga was used for the surface topography analysis and a spectrophotometer (Perkin Elmer, Lambda 950) was used for the reflectance measurement. For calculation of the WAR, the diffuse reflectance of the textured surfaces was measured using a 150 mm diameter integrating sphere over the wavelength range of 300–1000 nm and weighted with the AM1.5 spectrum. The effective minority carrier lifetime was subsequently measured using a lifetime tester (Sinton

SEG Solar, EX1020, Page 103

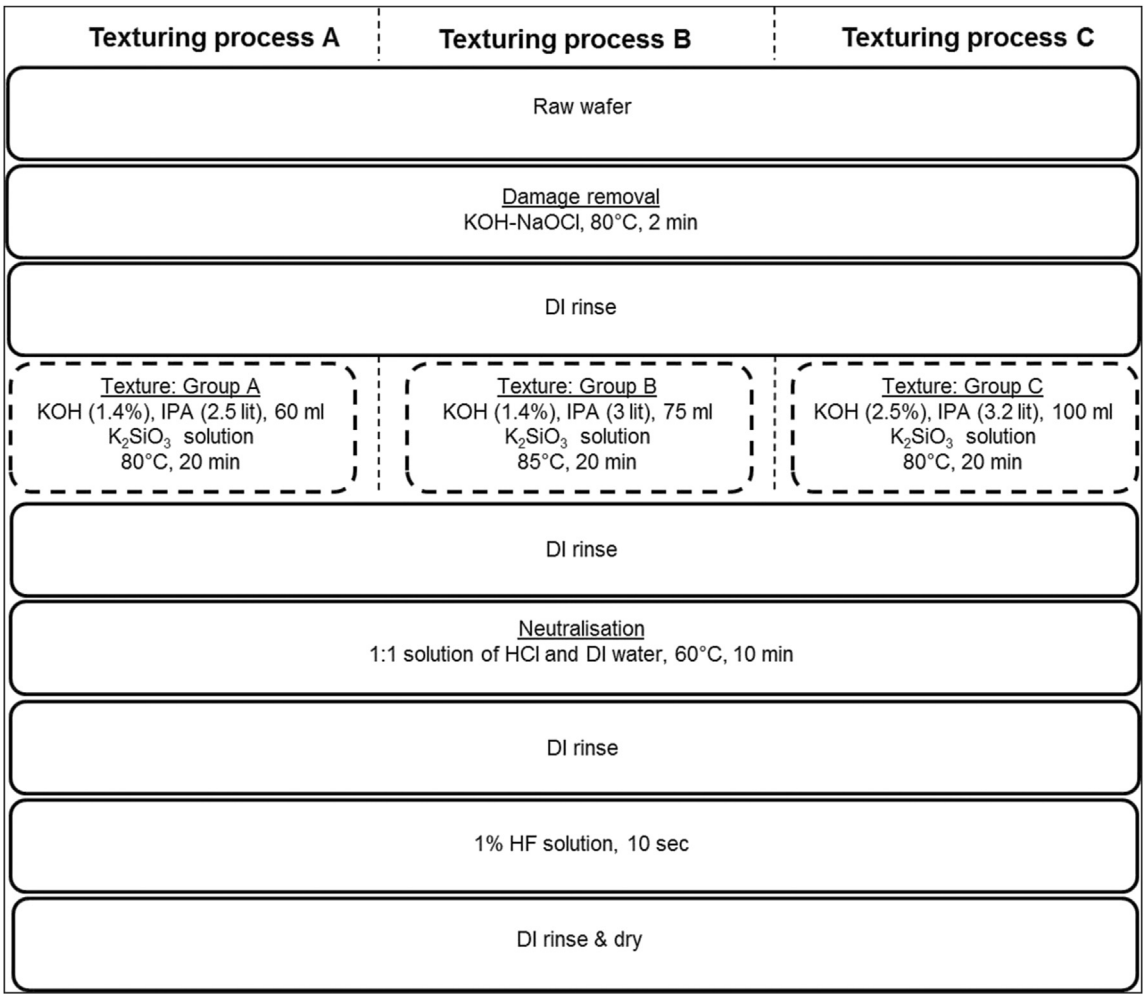


Fig. 1. Process flow diagrams of the three texturing processes. For the texturing processes, the modified texture recipes are shown as dashed box.

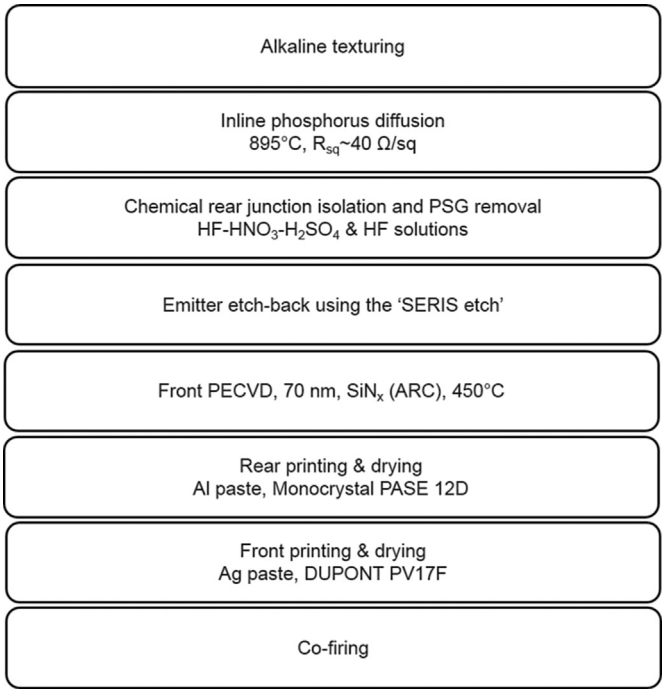


Fig. 2. Schematic illustration of the solar cell processing flow used in this work.

Consulting WCT-120). A BT Imaging LIS-R1 system was used for electroluminescence and photoluminescence imaging. The illuminated current–voltage (I–V) characteristics of the solar cells were measured on a super class-A solar simulator (AESCUSOFT, SolSim

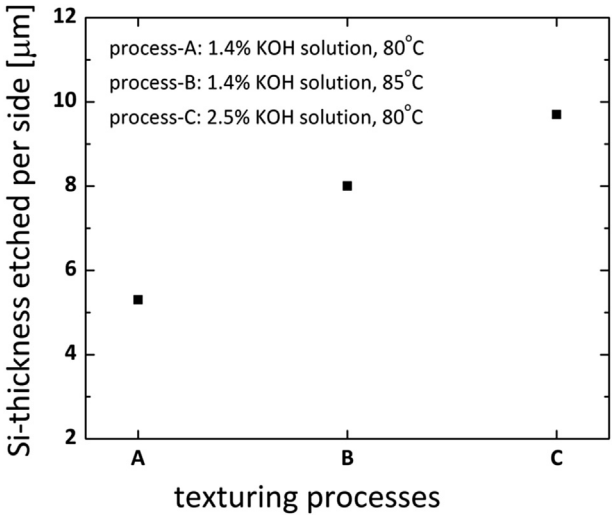


Fig. 3. Graph indicating the average variation of the amount of Si thickness etched per wafer side for the texturing processes A, B and C.

SEG Solar, EX1020, Page 104

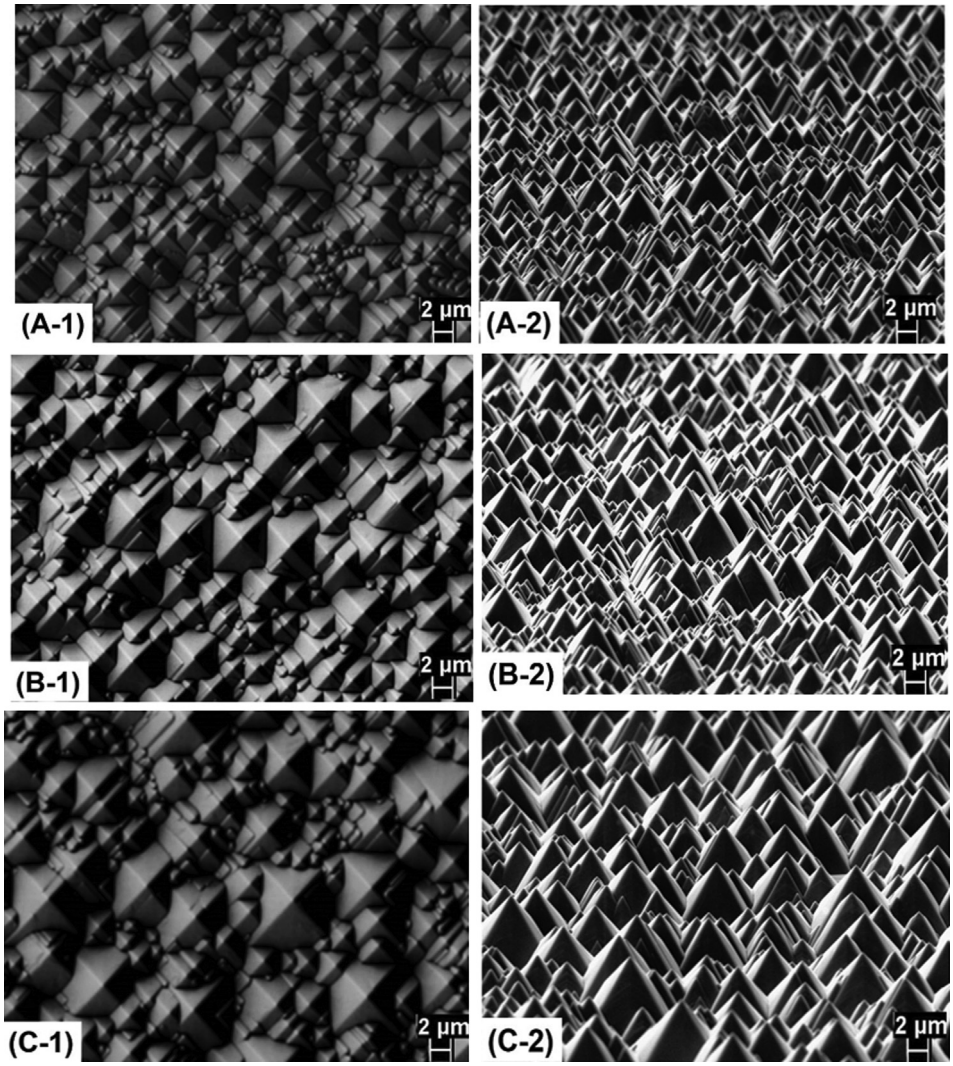


Fig. 4. Plane-view (A-1, B-1 and C-1) and angular-view (A-2, B-2 and C-2) SEM micrographs of textured wafers (magnification = 2000×) of process A (A-1 and A-2), process B (B-1 and B-2), and process C (C-1 and C-2).

210) under standard testing conditions (STC). The calibration solar cell used during the measurements was certified by Fraunhofer ISE Cal Lab, Germany. After the *I–V* measurements, three representative finished cells from each group cut into 5 mm × 156 mm strips (parallel to the busbars) using a dicing saw and the specific front contact resistances were measured using an automated tool (Kalio Binder GbR, KB-100).

3. Results

3.1. Texture process

The KOH-based alkaline texturisation process is governed by the following chemical reaction [15]:

$$Si + 2KOH \rightarrow K_2SiO_3 + 2H_2 \quad (1)$$

During the anisotropic etching of Si by KOH hydrogen (H_2) bubbles are released [see Eq. (1)]. These H_2 bubbles have a tendency to stick to the Si surface [15] and to act as a locally mask which prevents texturing at those spots resulting in a non-uniform texturing. IPA enhances Si surface wettability and effectively removes these H_2 bubbles from the entire wafer's surface, improving the uniformity and homogeneity of the texturing process. The concentration of the reaction by-product, K_2SiO_3, also has stronger influence in Si etching rate and stability of the texturing solution; it can even lead to uncontrolled texturing with wide variation in pyramid sizes [5]. Basu et al. [5] have added K_2SiO_3 to the texturing baths to "initialise" the solution by raising the dissolved Si concentration (i.e. silicates) in attempt to stabilise the concentration of both reactants and products in the solution.

In this work we have varied the amounts of K_2SiO_3 and IPA in the process (namely, A, B and C) to control the etching rate. Fig. 3 presents the thickness change at the end of 20 min processes. The processes were optimised in earlier experiments which are not in the scope of this work. Process A used solution with 1.4% KOH, 60 ml K_2SiO_3 and 2.5 L of IPA in a fresh bath at temperature of 80 °C. The amount of Si removal per wafer's side was determined to be ~5–6 μm (see Fig. 3). In process B, the KOH concentration was maintained the same; however, bath temperature was increased to 85 °C. The higher temperature resulted in a faster etching rate (~8–9 μm per wafer's side). The larger amount of K_2SiO_3 (75 ml) needed to stabilise this process resulted with increased Si etching rate. Besides, due to the higher temperature, higher formation rate

SEG Solar, EX1020, Page 105

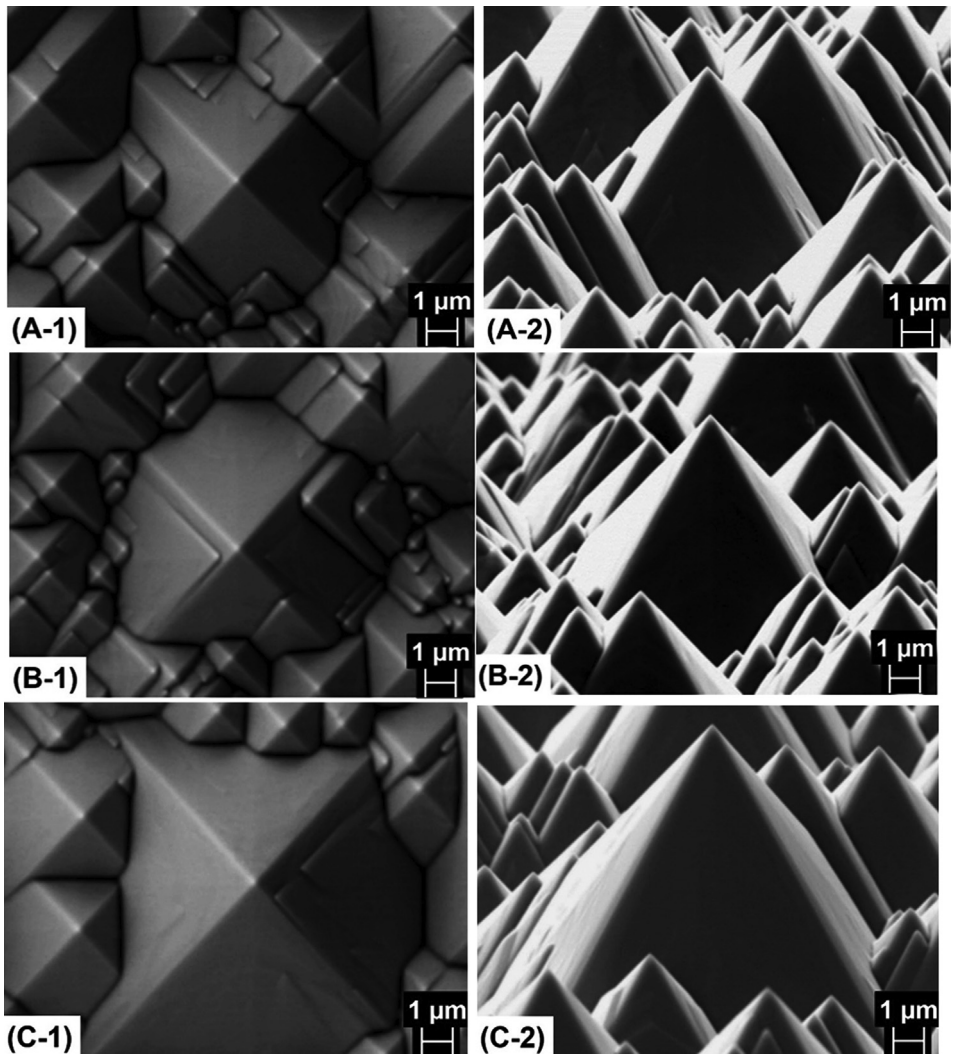


Fig. 5. Plane-view (A-1, B-1 and C-1) and angular-view (A-2, B-2 and C-2) SEM micrographs of textured wafers (magnification = 8000×) of process A (A-1 and A-2), process B (B-1 and B-2), and process C (C-1 and C-2).

of H_2 and higher evaporation rate of IPA, lead to higher consumption of IPA (3 L) as compared to process A. In process C, the KOH concentration was changed to 2.5%; however, bath temperature was maintained at 80 °C. The high KOH concentration leads to the highest Si etching rate (~10–11 μm per side) with higher H_2 formation rate [17]. This process requires 100 ml of K_2SiO_3 and 3.2 L of IPA in order to establish a homogeneous texturing process window.

3.1.1. Surface morphology study

The uniformity of the texturing and the pyramid heights were analysed by SEM at relatively low magnification. Fig. 4 shows both the plane-view and angular-view (at 70°) SEM micrographs of the textured surfaces of processes A, B and C under a magnification of 2000×. Unlike previous reported results [7], all the texturing processes lead to uniform texturing, with no planer untextured regions are observed. As can be seen from Fig. 4(A-1) and (A-2) process A creates, pyramids with height in the range 2–5 μm. Process B [Fig. 4(B-1) and (B-2)] forms slightly larger pyramids (~6 μm maximum height), while process C [see Fig. 4(C-1) and (C-2)] generates larger pyramids with a maximum height of ~8 μm. The maximum pyramid heights were estimated using the SEM at higher magnification. Fig. 5 shows both the plane-view and angular-view (at 70°) SEM micrographs of the different processes under a magnification of 8000×. The SEM study seems to indicate that the pyramid size primarily depends on the KOH concentration in the texture solution; whereas, the texturing bath temperature has only a secondary influence.

3.1.2. Surface reflectance study

Achieving low surface reflectance values is very important from the point of view of photocurrent generation of the completed solar cell. The surface reflectance of representative wafers from groups A, B and C was measured. The front surface reflectance was first measured after texturing and was re-measured after ARC SiN_x deposition and densification. For each wafer the reflectance measurements were carried out at five points and the average WAR value was calculated. Fig. 6 presents the variation of the WAR values. After texturing the WAR values are 11.6%, 11.6% and 11.7% for processes A, B and C, respectively; whereas, after ARC SiN_x deposition, the WAR is 1.9% for all the processes. Due to the minimal WAR variations (both with and without SiN_x), it can be concluded that the investigated homogeneous pyramidal surfaces are optically similar, irrespective of the pyramid heights.

3.1.3. Lifetime study

Symmetrical lifetime test structures were fabricated to investigate the impact of the surface texturing on the effective lifetime and related parameters. Emitter was formed, on both sides of

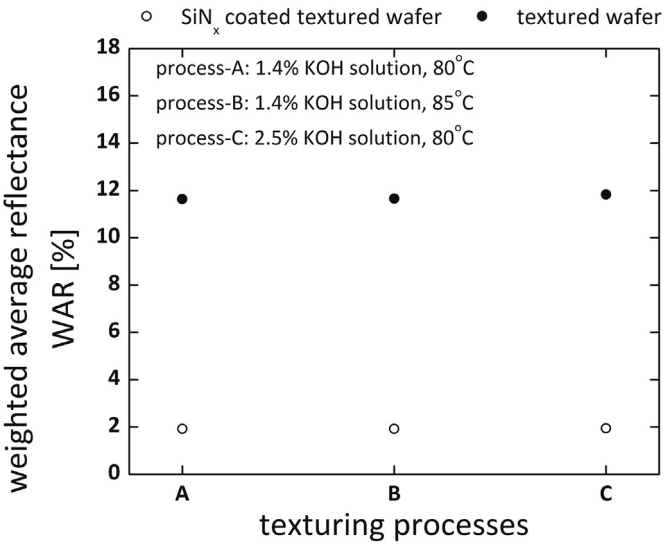


Fig. 6. Variation of WAR values of the front surfaces with or without ARC SiN_x deposition for the textured wafers from processes A, B and C. The weighted average reflectance (WAR) is weighted using the AM1.5G solar spectrum over the 300–1000 nm wavelength range.

wafers from all three groups (as described in Section 2.2), using inline diffusion and emitter etch-back. The process was completed by deposition of a 70 nm thick ARC SiN_x layer on both surfaces followed by fast firing in an industrial belt furnace to simulate a realistic effective lifetime expected after contact firing. The injection dependant effective lifetime was measured under quasi-steady-state (QSS) conditions [16] using the Generalised analysis [17]. In this study the effective lifetime (τ_{eff}) at excess carrier of 10^{15} cm^{-3} is reported, together with the implied V_{oc} (iV_{oc}) at one sun. The emitter saturation current density (J_{oe}) was extracted at excess carrier concentration of 10^{16} cm^{-3} using the Kane–Swanson method [18].

Fig. 7 shows the variations of τ_{eff}, iV_{oc} and J_{oe}, for representative wafers from groups A, B and C. No significant variation is observed in these three parameters for the different texture processes. As the impact of the relatively low bulk quality on J_{oe} is small, this parameter is more suitable to evaluate the influence of the texturing process on the surface recombination. It was concluded that the surface passivation quality offered by the SiN_x layer is not significantly affected by the pyramid height. Since wafers from the same brick (and from the same region in the brick) were used in this study, similar bulk lifetime can be assumed. Four-point probe mapping indicates that all emitters have identical sheet resistance (R_{sq} ~70 Ω/sq). We therefore assume that variation of τ_{eff} indicates only variation of the surface passivation quality. Note that the reported τ_{eff} values are without an activation of the boron–oxygen defects (before light induced degradation [19,20]).

3.2. Solar cell results

3.2.1. Cell electrical parameters

The statistical distribution of the one-sun electrical I–V parameters (J_{sc}, V_{oc}, FF and efficiency) for all the cells, measured directly after fabrication, is shown in Fig. 8. Each group consists of 45 cells textured using different processes (A, B and C). Fig. 8 clearly indicates negligible variation of J_{sc} and V_{oc} between the groups. This is as expected given the minimal variation in WAR and the iV_{oc}, observed on test structures (Figs. 6 and 7). However, a variation of

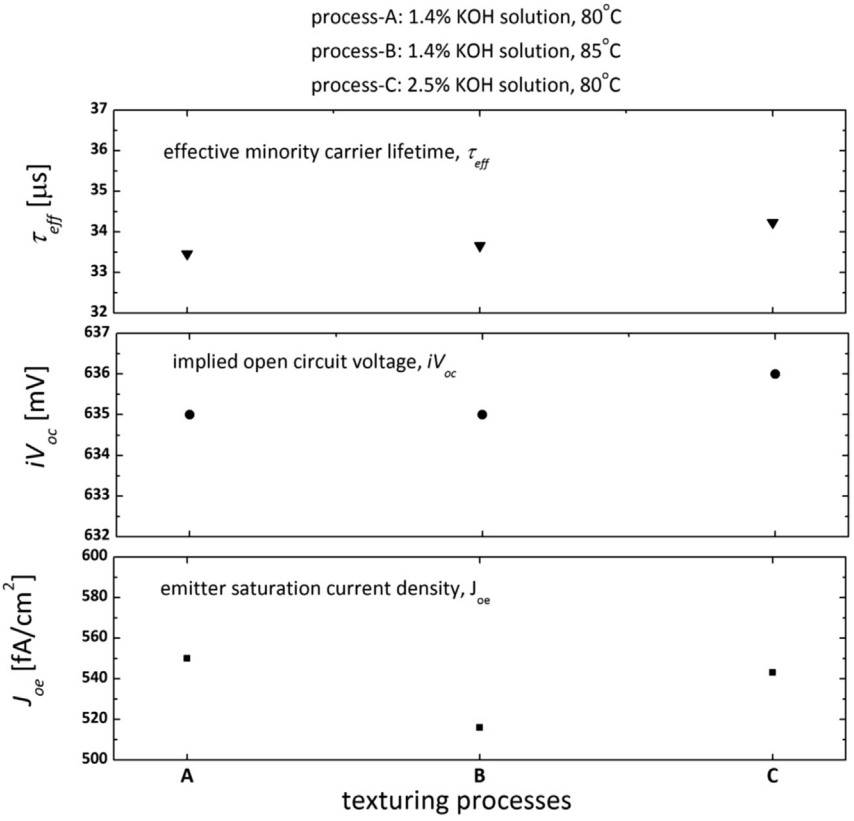


Fig. 7. The average J_{oe}, τ_{eff} and iV_{oc} of representative samples from groups A, B and C.

SEG Solar, EX1020, Page 107

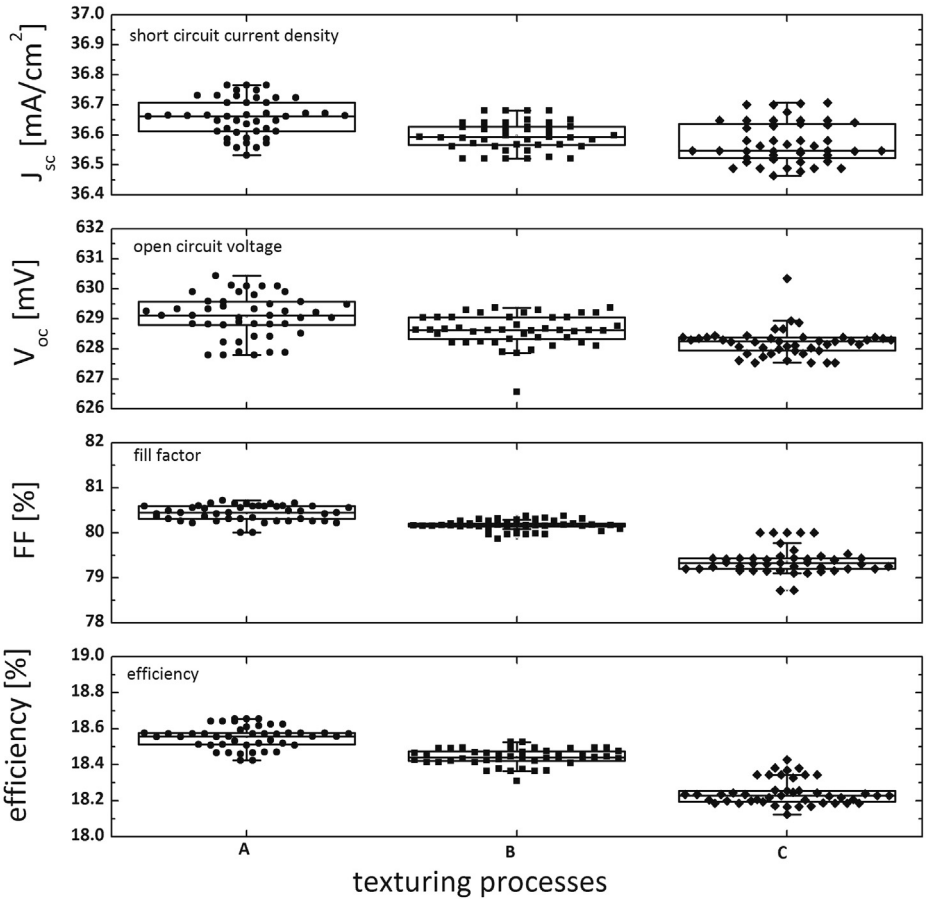


Fig. 8. Distribution of the electrical one sun parameters (J_{sc}, V_{oc}, *FF* and efficiency) for all the cells fabricated using the texturing processes A, B and C (45 cells each).

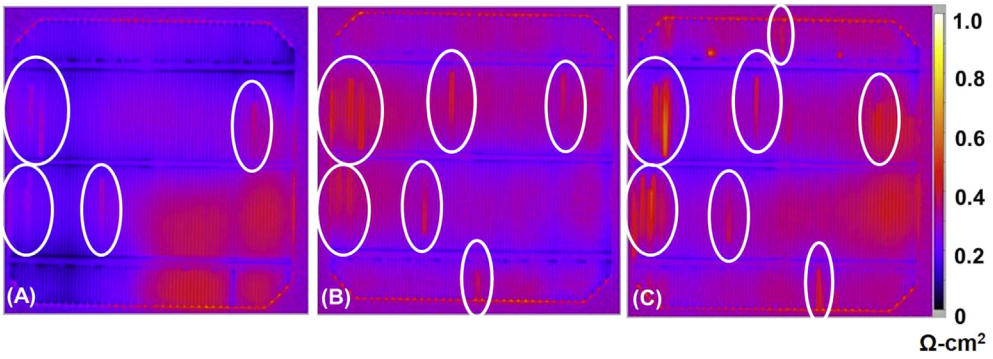


Fig. 9. R_s images of the inline-diffused emitter solar cells (best cells) textured with processes A (*FF* = 80.7%), B (*FF* = 80.4%) and C (*FF* = 80%).

the average *FF* values (80.4%, 80.2% and 79.4% for wafers with different texturing processes A, B and C respectively) was observed. This variation in *FF* leads to variation of up to 0.4% absolute in the cell efficiency [between the largest pyramid height (group C) and the smallest pyramid height (group A)].

3.2.2. Series resistance study by luminescence imaging

Fig. 9 shows series resistance (R_S) images extracted from photoluminescence (PL) and electroluminescence (EL) images based on the method of Kampwerth et al. [21] for the best solar cells from each group. All images were taken under the same illumination and using the same exposure time. All cells show an R_S distribution typical of screen printed solar cells. Some broken fingers are observed in the different locations (marked by white loops in Fig. 9) for all the cells, indicating some issues with the printing screen. However, the numbers of broken fingers seems to be increasing from process A to C. As such broken finger issues are common, the screen was designed such that the fingers are connected in pairs at the edges (see Fig. 10) to minimise the influence of broken fingers. As can be seen, the percentage of regions with local R_S values above 0.3 Ω cm^2 increases for the cells from process A to process B to process C. Given that the three solar cell groups have identical processing, apart from the surface texturing, the difference can arise only from variations of the sheet resistance (diffusion) or in the metallisation. We confirmed similar sheet resistances (70 Ω/sq) and comparable finger width/height after screen printing.

SEG Solar, EX1020, Page 108

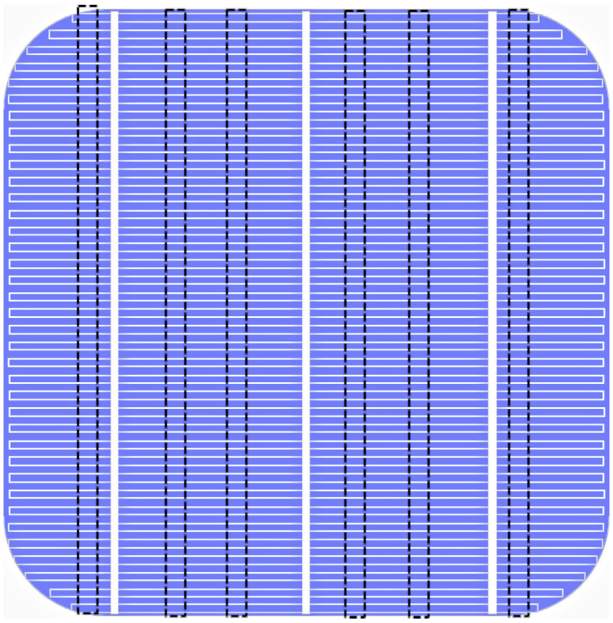


Fig. 10. Schematic showing the approximate locations (black dashed lines) of the sawed strips used for the specific contact resistance measurement.

Therefore, the differences are likely to be due variation in the contact formation.

3.2.3. Contact resistance analysis

To analyse possible differences in front contact resistance due to the different texture processes, three representative finished cells from each group were chosen. The cells were cut using a dicing saw into 5 mm × 156 mm strips to isolate measurement structures from the rest of the cell as shown in the schematic in Fig. 10. Transfer length method (TLM) and contact end resistance measurements [22] were performed on the cut strips. While specific contact resistivity (ρ_c) can also be measured via TLM alone, this approach assumes that the sheet resistance under the contacts is the same as the sheet resistance between the contacts. For fired screen printed solar cells, it is desirable to avoid this assumption as the contact formation process involves etching and crystallite growth which may alter the sheet resistance under the contact. The use of TLM and contact end resistance measurements in tandem is a rigorous approach that avoids this assumption and includes the possibility of different sheet resistances directly under the contact and between the contacts. The fingers on isolated strips were contacted using probes and ladder pattern TLM measurements and Contact End Resistance measurement were carried out which included eight fingers per measurement. On each strip measurements were carried out in three locations: in the centre, between top edge and centre, and between bottom edge and centre. Specific contact resistivity was determined from these measurements as per the procedure described in Ref. [20]. Two reliability criteria were set for these measurements: (1) the TLM linear fit coefficient of determination (r^2) should be ≥0.999 and (2) the R_{sq} determined from the TLM linear fit slope should be within 70 Ω/sq ± 10%. The measurements that fulfilled criteria (1) and (2) are summarised in Fig. 11. The average ρ_c for front contacts on cells textured with processes A, B and C were 2.9 mΩ cm^2, 3.4 mΩ cm^2 and 5.3 mΩ cm^2 respectively. While all cells have acceptably low ρ_c, the ρ_c is found to deteriorate with increasing pyramid height, within the pyramid height variation studied here. As other causes to explain a variation in *FF* were ruled out in Section 3.2.2, it follows that variation in the contact resistance is responsible for the *FF* variation for these texture process groups.

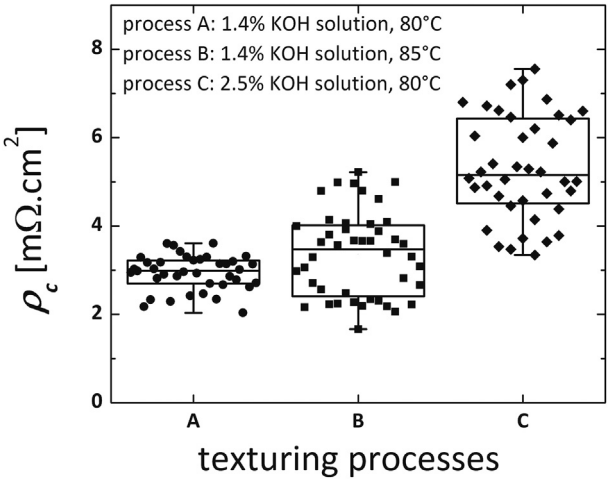


Fig. 11. Boxplots of ρ_c extracted from TLM and contact end resistance measurements for front contacts on cells textured with processes A, B and C.

A detailed microstructural investigation of the front contacts revealed that the difference in contact resistance for the three pyramid groups is linked to the difference in the pyramid count density (number of pyramids per unit area) [23]. Pyramid tips represent favourable sites for screen printed silver–silicon contact formation [23,24] and increasing average pyramid height reduces the pyramid count density and hence the number of potential sites for contact formation. Consequently, the small pyramid group achieved the lowest ρ_c, followed by the larger pyramid groups.

4. Conclusions

In the present work three alkaline texture processes were optimised to lead to three different pyramid heights. The texturisation bath chemistry (amounts of KOH, IPA and K_2SiO_3) and the bath temperature were varied to develop three processes leading to surface textures with small (~5 μm maximum), medium (~6 μm maximum) and large (~8 μm maximum) pyramid heights. The pyramid structures were analysed through a comprehensive SEM study. Within each process group a relatively narrow range of pyramid heights was observed. The front surface reflectance and lifetime analysis indicated that WAR, τ_{eff}, iV_{oc} and J_{oe}, are nearly identical for all the three groups. Screen printed solar cells made using these texturing processes demonstrate a variation in the *FF*. The *FF* was found to decrease with increasing maximum pyramid heights within the variation studied here and smaller pyramids were found to give the highest *FF* and hence efficiency. A variation in specific contact resistance was identified experimentally as the most likely cause for this *FF* variation. While all the texturing processes led to high *FF* (>79%), it was demonstrated that by using the optimised texture process a *FF* gain of up to 1% absolute can be obtained (corresponding to an efficiency gain of 0.4% absolute). Average solar cell efficiency (of 45 cells) of 18.6% (18.7% max) and an average *FF* of 80.4% (80.7% max) was achieved using the optimised pyramid process and inline-diffusion.

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SEG Solar, EX1020, Page 109

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SEG Solar, EX1020, Page 110

ATTACHMENT 2b

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SEG Solar, EX1020, Page 119

ATTACHMENT 3a

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Full length article

Double-sided pyramid texturing design to reduce the light escape of ultrathin crystalline silicon solar cells

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HIGHLIGHTS

- A comparative study on planar, front textured and double-sided textured structures.
- Double-sided textured structure remarkably suppresses light escape.
- Double-sided textured structure improve light absorption in long wavelength range.
- Double-sided textured structure show a small angle dependence.

ARTICLE INFO

Keywords:
Ultrathin c-Si solar cells
Double-sided texture
Photocurrent density
Conversion efficiencies
Angular dependence

ABSTRACT

Reducing the light absorption loss of ultrathin crystalline silicon (c-Si) solar cells is significant to achieve high photocurrent density and photoelectric conversion efficiency. Here, we designed and simulated ultrathin c-Si cells with front pyramids and double-sided pyramids. By adjusting the shape of pyramids, the maximum photocurrent densities reach 36.23 and 37.71 mA/cm^2 for the cells with front pyramids and double-sided pyramids, respectively. The reflectivity spectrum indicates that the double-sided pyramidal architecture remarkably suppresses light escape and then enhances the light absorption in long wavelength range, which makes the absorption approach the Yablonovitch limit. The calculated conversion efficiencies of planar, front and double-sided textured cells are 16.94%, 19.65% and 20.45% respectively. Additionally, the difference between randomly and periodically textured cells was investigated and the results show that although the randomly front pyramid texture has a better light absorption in the range of 900–1200 nm, the periodically double-sided pyramids texture exhibit almost the same light absorption in the whole range as the random one. Besides, the solar cells with double-sided pyramids show extremely small angular dependence of incident light. Thus, the double-sided light trapping structure designed in the present work provides an alternative pathway to improve the performance of ultrathin c-Si cells.

1. Introduction

Thicker absorption layer materials in traditional c-Si solar cells lead to very high costs. Ultrathin solar cells can effectively reduce costs, but they have poor efficiency due to low light absorption [1–3]. Therefore, it is crucial to improve the optical absorption of ultrathin c-Si cells through optical design. For the sake of this purpose, single-layer anti-reflective coating (ARC) was commonly used to reduce the surface reflectivity of solar cells. Alternatively, surface texture for light trapping such as pyramids [4,5], cones and nanopillar [6] can increase the optical path length and thereby improve the light absorption. The textured pyramid formation on Si surface through alkaline texturing is a well-known process [7]. Due to the so-called “double bounce effect”, the pyramid surface texture suppresses the front-surface reflectance to improve the light absorption [8,9]. Typically, high-efficiency silicon solar cells consist of a textured front surface and a planar rear surface [10–12]. However, although the ARC films and front-side surface texture can greatly reduce the reflection of incident light, there is still a part of the light escaping from the cell, resulting in a certain amount of optical loss [13,14]. Broadband absorption enhancement in ultrathin c-

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Si cell with double-sided texture has been proved in recent theoretical simulations [15–17]. More recently, some experiments proved that the c-Si solar cells with double-sided pyramids can provide more superior light absorption compare to single front-textured cells [18,19], but they focused on the pyramid texture at a particular angle and size and a further discussion about the rear pyramid texture is still lacking. Moreover, the angle dependence of incident light for the cells with double-sided texture also needs a detailed investigation.

In this paper, we present a double-sided pyramid texture model and study the influence of pyramid size on the optical absorption of ultrathin c-Si cells. The wet-etching preparation of micro-scale pyramidal texture is not only very cheap but also mature for large-scale photovoltaics (PV) industrial application [20]. In the present work, we chose the 20 μm ultrathin c-Si cells to investigate the influence of pyramidal texture. The front surface reflection, the light escaping and the optical absorption in cells with different light trapping structures are simulated. Moreover, the J-V response and the absorption spectra of ultrathin c-Si solar cells with surface texture were calculated.

2. Modelling and simulation methods

Fig. 1 shows the schematic diagram of ultrathin c-Si solar cell models investigated in this work. The Wafer Optics Calculator (WOC) [21] incorporates the effect of the wafer bulk and both of its surfaces, which was used to assess all optical losses and light trapping of a cell. The WOC combines Monte Carlo ray tracing with thin film optics. The optical path length factor adopts “Limit: Green 02”, which is a more realistic limit than an ideal limit of $4n^2$ [22].

$$Z = 4 + \ln[n^2 + (1 - n^2)e^{-4aW}]/aW \tag{1}$$

where a, W, n are the absorption coefficient, thickness and refractive index of c-Si, respectively.

In order to accomplish the present simulation, the refractive indices (n, k) of all materials are required including ARC SiO_2, Si_3N_4, Al_2O_3, SiN_x, c-Si and Ag, which are cited from the experimental data [23–28]. Here, the absorption spectrum $A(\lambda)$ of c-Si can be calculated. It is assumed that all electrons and holes contribute to the generation of photocurrent and therefore the photocurrent density J_{SC} is expressed as [29]:

$$J_{SC} = e \int \frac{\lambda}{hc} A(\lambda) I_{AM1.5}(\lambda) d\lambda \tag{2}$$

where e is the amount of electron charge, c is the speed of light in vacuum, h is the Planck constant, λ is the wavelength of incident light, $A(\lambda)$ is the absorption of c-Si at the wavelength λ, and $I_{AM1.5(\lambda)}$ is the solar irradiance under the global 37° tilt Air Mass 1.5 spectrum [30]. The integration is conducted for c-Si in the wavelength range of 300–1200 nm.

As for single-layer ARC films, the reflectivity has a minimum value when the refractive index of the single-layer material and its thickness satisfies the following equation:

$$\lambda = 4n_1 d_1 \tag{3}$$

where n_1 and d_1 are the refractive index and thickness of the single-layer ARC material, respectively.

Assuming perfect antireflection and light trapping, the absorption spectrum in a thin film with thickness d_2 and refractive index n_2 is given by the Yablonovitch limit:

$$A_{Yablonovitch} = 1 - \frac{1}{1 + 4n_2^2 \alpha d_2} \tag{4}$$

To find out the optimal planar structure, we firstly studied the effect of the thickness of back Ag electrode on the planar ultrathin c-Si solar cell (shown as Fig. 1(a)). When the thickness of back Ag electrode reaches 100 nm, the transmission no longer decreases any more. The calculated result suggests that the 100 nm Ag film is optimal, which is in agreement with the previous experiments [31]. Hence, the 20 μm c-Si absorber and 100 nm Ag back electrode are selected in the following work.

Besides investigating light trapping of surface texture, the Quokka software (Version: Quokka 2.2.5) [21] is used to simulate the J-V response and calculate the PV parameters of the cells. All input parameters for the present simulation are listed in Table S1 of the supplementary information.

3. Results and discussion

In order to improve the absorption efficiency (the ratio of the light absorbed by the active layer to the total sunlight) in ultrathin c-Si solar cells, it is essential to study the distribution of incident light through the cell. As shown in Fig. 2, 35% of incident light is reflected by the front surface of the cell and 15% escapes from the cell. Simultaneously, the active layer only absorbs 49% of the incident light effectively utilized to excite carriers, and about 1% of incident light is absorbed by the back Ag layer. Therefore, it is very necessary to reduce the reflection of incident light, suppress the light escape and improve the optical absorption of the active layer through structural design and optical management.

Firstly, we added an ARC layer on the front surface to reduce the surface reflectivity of solar cells. Here, some common ARC materials including Si_3N_4, SiO_2, Al_2O_3, SiN_x are compared [32–37]. Among all the calculated ARC materials, Si_3N_4 shows the most superior antireflection and it can effectively reduce the reflection efficiency to below 10% when its thickness reaches 80 nm. Therefore, in the following simulations, we chose the 80 nm Si_3N_4 film as the ARC layer of ultrathin c-Si cells. Based on the above calculations, an optimal planar structure of ultrathin c-Si cell is obtained, which will be used as a reference cell to investigate the optical absorption enhancement of other cells with pyramidal texture.

Based on the planar reference cell, we added pyramid texture to the front surface (shown as Fig. 1(b)) to increase the light path length in the cells. Recent experiments found that compared to the micropyramid texture, the nanopyramid textured wafer has a little higher reflectance

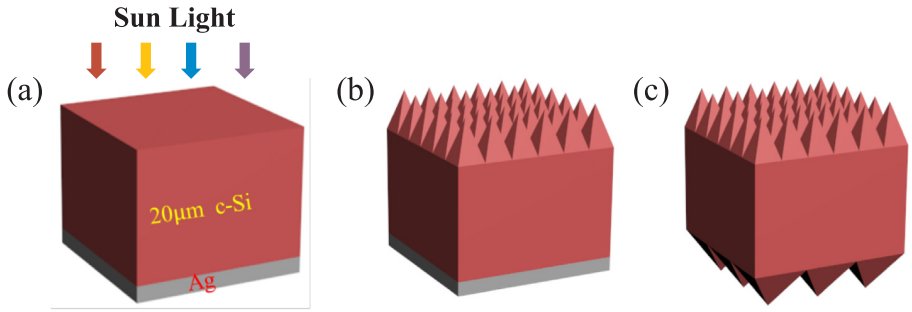


Fig. 1. 3D models of planar ultrathin c-Si solar cell (a), cell with front pyramids texture (b) and cell with double-sided pyramids texture (c).

SEG Solar, EX1020, Page 122

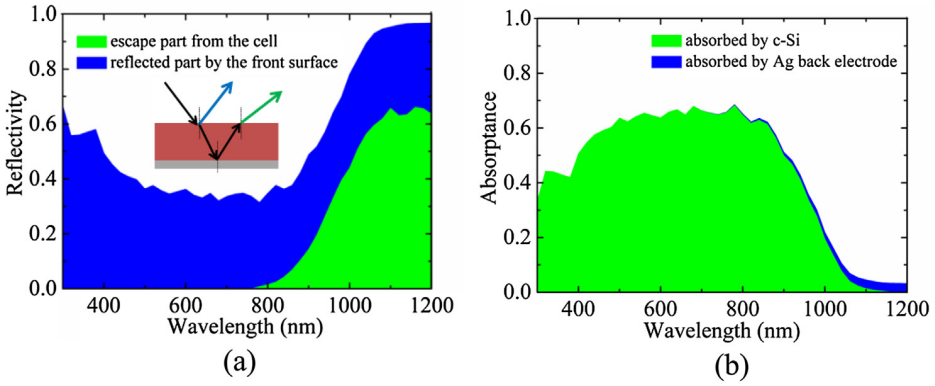


Fig. 2. (a) The reflectivity of planar solar cell; (b) The absorptance of c-Si layer and Ag back electrode of planar solar cell. In (a), the blue area represents the reflected light on the front surface of the cell (just as the blue line of the inset), and the green area represents the escape part of light in the cell (just as the green line of the inset). In (b), the blue and green portions represent the absorptance of light in the Ag back electrode and the planar c-Si layer, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

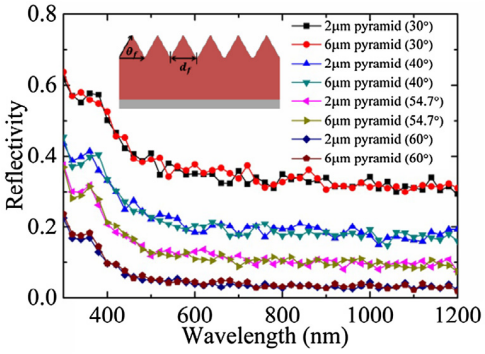


Fig. 3. Reflectivity spectra of ultrathin c-Si cells with different textures. The inset indicates the cross-sectional structure of front-textured ultrathin c-Si solar cell.

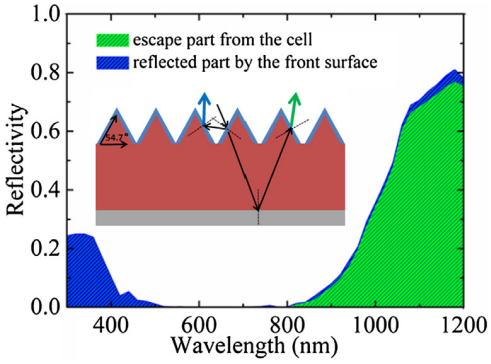


Fig. 4. The reflectivity spectrum of the solar cell in the wavelength range of 300–1200 nm. The blue area represents the reflectivity of light on the front surface, and the green area represents the escape part of light in the cell. The inset is the cross-sectional schematic of front-textured ultrathin c-Si solar cell with Si_3N_4 ARC film. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

due to its much smoother surface [38]. In addition, since the technique to fabricate micropyramid textured surface is more mature in practical applications, the micropyramid texture was employed in the present work. The reflectivity spectrum of front textured c-Si cell was calculated by sweeping characteristic angle θ_f and size d_f of front pyramids. Fig. 3 presents the reflectivity spectra (300–1200 nm) of the cells with various front pyramids textures.

From Fig. 3, it can be seen that at a fixed angle of pyramid, the reflectivity spectra are almost the same for different bottom lengths. The result indicates that the bottom length of pyramid has no remarkable influence on the reflectivity of cells when the characteristic angle of pyramid is fixed, which is consistent with the previous reports [39]. When the length of bottom edge of pyramid is fixed, with the increase of pyramid characteristic angle, the reflectivity decreases obviously in the whole wavelength range of 300–1200 nm. It is concluded that the reflectivity of the front surface of ultrathin c-Si solar cells depends greatly on the pyramid angle rather than the bottom length. Here, we chose the pyramid with characteristic angle 54.7 commonly used in experiments in the following calculations [40,41].

In Fig. 4, one can see that based on the optimized scale of pyramid, the reflectivity of the cells with front texture is reduced to 1% and it almost becomes zero in the wavelength range of 500–800 nm. However, although the remaining 81% is absorbed by the c-Si layer, there is still 14% of the sunlight escaping from the cell. The light trapping in these structures suffers from the first-pass light incident to the rear surface being reflected into the escape cone of a front pyramid and coupled out [42]. Experimentally, in order to further suppress the escape of light, a doubled-sided pyramid texture on the front and rear of ultrathin c-Si solar cells has been attempted in tradition silicon solar cells and it has been observed that the double-sided architecture helps to randomize the direction of light within the cell thereby reducing the chance of escape [43].

To give a deeper understanding of double-sided texture of ultrathin c-Si solar cells, we constructed pyramid texture on the back of the cell (shown as Fig. 1(c)). Here, the front optimized pyramid with 2 μm bottom and 54.7 angle was fixed, and the absorption efficiency of ultrathin c-Si soar cell was calculated by sweeping the characteristic angle θ_r (from 25 to 70°) and the size of the bottom length d_r (from 2 to 6 μm) of rear pyramids. Moreover, to make clear the difference of upright and inverted texture, four double-sided texture cells with equivalent Si thickness of 20 μm were investigated. The four cell structures (shown as the insets in Fig. 5) includes: (a) the cell with upright pyramids on front surface and inverted pyramids on the rear surface (*cell* 1), (b) the cell with inverted pyramids on the front surface and inverted pyramids on the rear surface (*cell* 2), (c) the cell with upright pyramids on the front surface and upright pyramids on the rear surface (*cell* 3), (d) the cell with inverted pyramids on the front surface and upright pyramids on the rear surface (*cell* 4). Fig. 5 shows the calculated mapping of the light absorption efficiency as functions of the characteristic angle and bottom length of the pyramids for the four kinds of cells.

In Fig. 5, it can be seen that the achieved maximum absorption efficiencies are 86.18% (*cell* 1 with rear pyramid of characteristic angle 35° and bottom length 6 μm), 86.03% (*cell* 2 with rear pyramid of characteristic angle 35° and bottom length 6 μm), 86.64% (*cell* 3 with rear pyramid of characteristic angle 35° and bottom length 4 μm) and 86.42% (*cell* 4 with rear pyramid of characteristic angle 25° and bottom length 4 μm), respectively. Among all the four structures, *cell* 3 has the maximum absorption efficiency 86.64%, and which is 6% higher than that of the cell with front pyramids, and 17% higher than that of the planar cell. In the four cases, all the cells show a relatively high absorption zone in the characteristic angle range of 25 to 40°. Especially,

SEG Solar, EX1020, Page 123

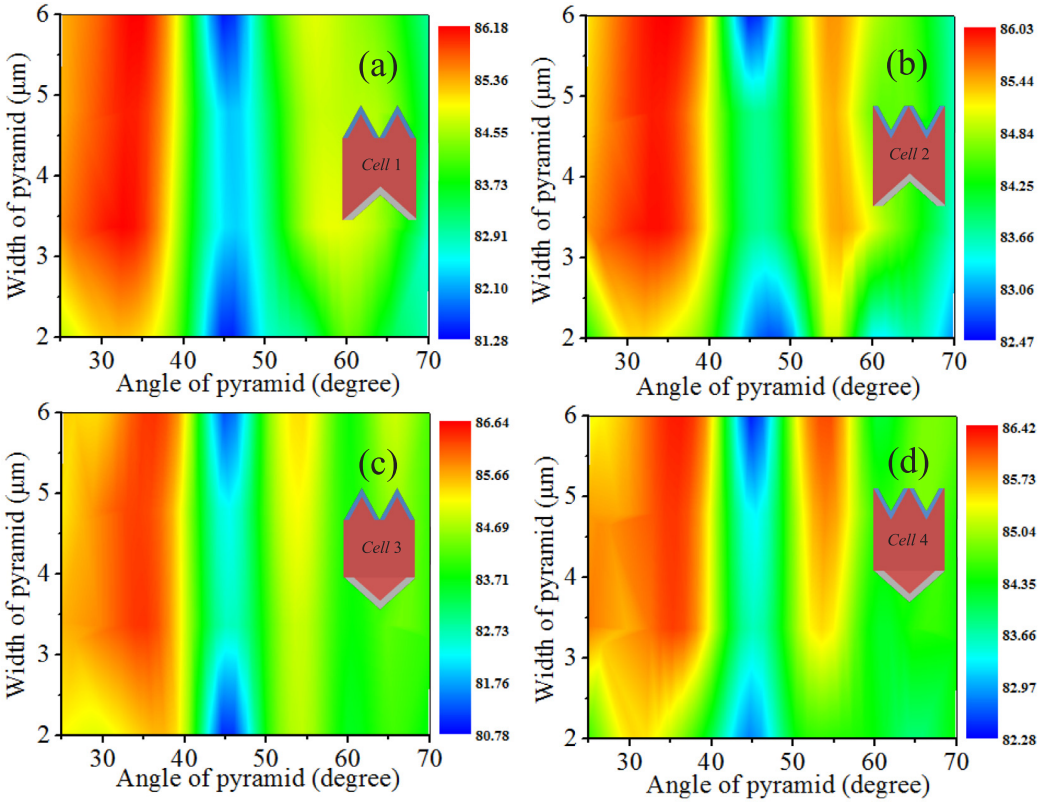


Fig. 5. The plotted mapping of the absorption efficiency as functions of the characteristic angle and the length of the bottom side of pyramid. The insets are the cross-sectional schematic of ultrathin c-Si solar cells with double-sided pyramids texture.

it was also found that a lower absorption area appears at the characteristic angle at 45° ± 2.5°. The possible reason is the total internal reflection occurring at this angle on the back Ag layer, which suggests that 45° rear pyramids hardly has a significant impact on the light escape. Thus, the rear pyramids of angle 45° should be avoided in the fabrication of c-Si solar cells.

According to the optimal light trapping structure, the electrical performance of cells also was investigated by Quokka software. In Fig. 6(a), one can see that compared with the reference planar cell, the cell with front pyramids significantly increase the light absorption, but it has not reached the Yablonovitch limit yet. Experimentally, it is a common issue that c-Si cells have a weaker light absorption in the longer wavelength range. Compared with only front texture, the double-sided light trapping structure designed in this work substantially enhances the light absorption in the range of 850–1200 nm, which closes to the Yablonovitch limit [16–18]. By analyzing the reflectivity spectra of cells, it was found that the absorption enhancement mainly originates from the rear pyramid texture suppressing light escaping from cells. However, it also should be recognized that the cell with double-sided texture shows a lower light absorption in short wavelength range (300–500 nm) than the Yablonovitch limit, which should be associated with the designed double-sided pyramids structure with relatively low aspect ratio. However, much larger surface area, more defects were introduced. Thus, with the increase of pyramid characteristic angle, significantly higher surface recombination results in poor performance of solar cells, so we chose the characteristic angle 54.7° and 35° with lower surface recombination [44]. In fact, the light trapping structure with low aspect ratio involving surface recombination and degradation of electronic properties should be less severe than those of other high aspect ratio structures [16]. That is to say, the

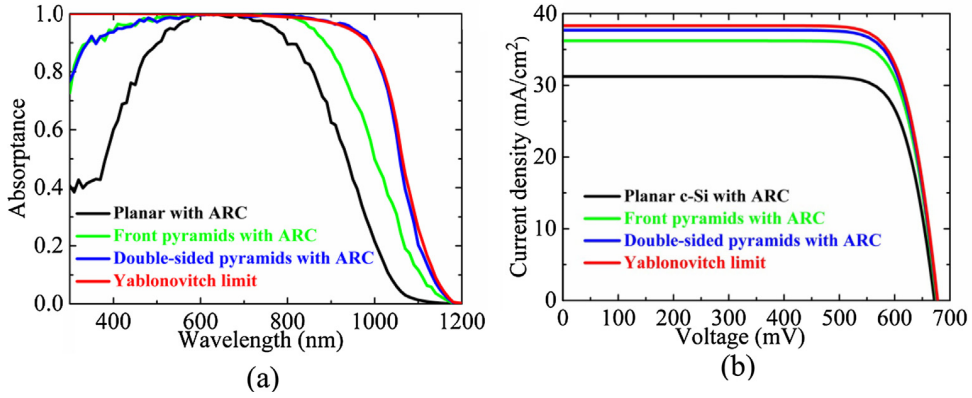


Fig. 6. Comparison of the absorption spectra (a) and J-V responses (b) for three cells.

SEG Solar, EX1020, Page 124

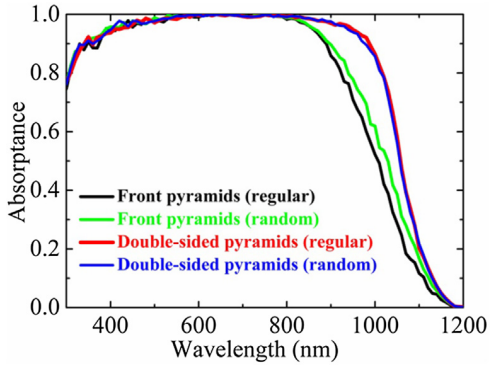


Fig. 7. Absorption spectra generated by structures as a function of wavelength.

present light trapping structure with low aspect ratio is more practical for c-Si solar cells.

In Fig. 6(b), the achieved maximum short circuit current densities are 36.23 mA/cm^2 and 37.71 mA/cm^2 for the cell with front pyramid texture and double-sided pyramid texture, which are 15.97% and 20.71% higher than that of the planar reference cell, respectively. Correspondingly, the conversion efficiencies of the planar reference cell, the cell with front pyramids and the cell with double-sided pyramids are 16.94%, 19.65% and 20.45%, respectively. It is concluded that double-sided surface texture is an optimal strategy to enhance short circuit current densities and conversion efficiency.

In practical applications, common industrial alkaline etching method easily produce fully randomized surface texture, while most of designed light trapping structures are in periodic mode [15–17]. To explore the difference between random and periodic mode, we calculated the light absorption spectra of both surface texture modes. As can be seen from the Fig. 7, for the front pyramid structure, the random mode exhibits a better light absorption in long wavelength range (900–1100 nm) compared with the periodic mode. However, the absorption of periodic double-sided texture is almost the same as that of random texture. The results indicate that the double-sided pyramid texture not only improves the optical absorption of long wavelength range, but also overcomes the influence of randomness on the structure absorption.

Fig. 8(a) shows that the relation between the photocurrent density of cells and the size of the bottom of the front and rear pyramids. Here, the pyramid characteristic angle in the double-sided textured structure is fixed. It can be seen that as the size of the bottom length of the pyramid changes from micron to nanometer, the photocurrent density of the cell increases up to the maximum value and then decreases. When the bottom length of the pyramid is 1 μm, the height of the front pyramid is 700 nm and the height of the rear pyramid is 350 nm, and the photocurrent density of the cell reaches an optimal value of 41.5 mA/cm^2. Fig. 8 (b) shows the absorption spectra of the double-sided pyramidal cell when the bottom lengths of pyramid are 0.5 μm, 1 μm and 1.5 μm, respectively. From Fig. 8 (b), we can see that with the reduction of pyramid size, the absorption efficiency in short wavelength range gradually increases. The cell with the bottom length 1 μm of the pyramid shows better absorptance in the longer wavelength range than other two cases.

The angle dependence of the incident light is another important issue in the practical applications of solar cells, and installing sun-tracking component is a common way to produce maximum daily power throughput. Therefore, the angle-dependent absorption, reflection and escape efficiency of the three kinds of cells are compared in Fig. 9. It can be seen that the absorption efficiency of ultrathin c-Si cells with front pyramids and double-sided pyramids show a lower dependence on the incident angle relative to the planar reference cell, and the double-sided architecture has more excellent performance in the absorption of solar light. The cells with front and double-sided pyramids show weakly angle-dependent reflection efficiency than the planar cell does. Also, it is interesting that a weakly angle-dependent escape efficiency of the cell with double-sided texture can be observed in Fig. 9(c). The results show that the double-sided pyramidal structure provides a more effective method to reduce the escape efficiency and then improve the angle dependence for ultrathin c-Si cells.

As can be seen from Fig. 10, when the angle of incident light changes from 0° to 80°, the absorptance of planar structure cell decreases significantly at 400–1100 nm, which fully shows that the planar structure is highly angle-dependent. For the front-pyramidal cell, the angle dependence of the absorption spectra is remarkable in the wavelength range of 300–950 nm. However, when the wavelength is longer than 950 nm, the light absorption at the incident angle 80° is superior to that at zero incident angle. For the double-sided pyramidal cell, it has obvious advantages over the front-pyramidal cell in the long wavelength range. When the incident light angle is 80°, the absorptance of the double-sided pyramidal cell at 950–1200 nm is higher than that of the front-pyramidal cell. However, only from the perspective of angle dependence, the light absorption of double-sided cell at incident angle 0° in the range of 300–1200 nm is always superior to that at 80°, which suggests that the double-sided pyramidal cell exhibit the larger angular loss in long wavelength range than the front-pyramidal cell. The result is accordance with the difference on absorption efficiency at larger incident angles between front-pyramidal and double-sided pyramidal cell (shown as Fig. 9(a)).

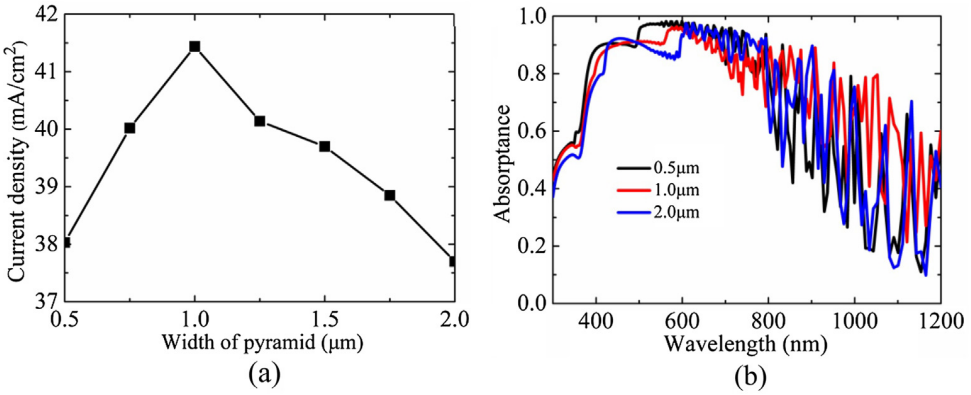


Fig. 8. (a) The photocurrent density as a function of the bottom length of pyramid; (b) The absorption spectra of the double-sided pyramidal cell when the bottom length of pyramid is 0.5 μm, 1 μm and 1.5 μm, respectively.

SEG Solar, EX1020, Page 125

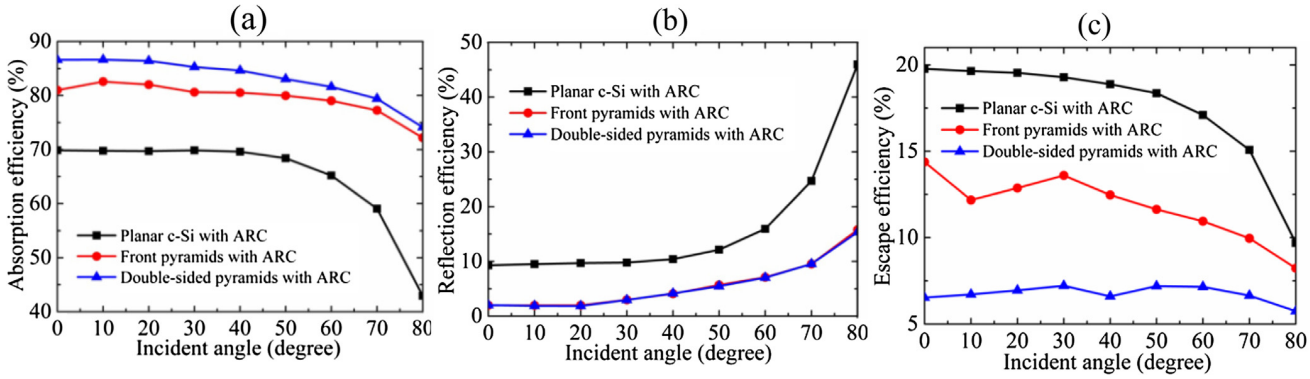


Fig. 9. The absorption efficiency (a) , reflection efficiency (b) and escape efficiency (c) of the three kinds of solar cells as a function of the angle of incidence in the range of 0–80°.

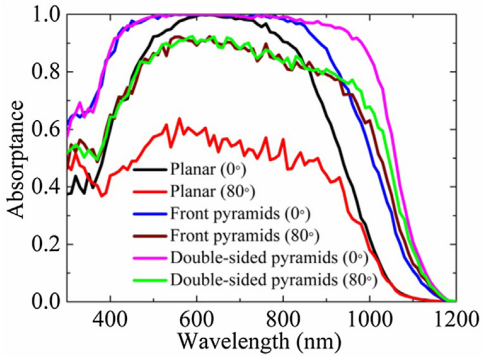


Fig. 10. Absorption spectra ofplanar, front-pyramidal and double-sided pyramidal cell with incident light angles of 0° and 80°.

4. Conclusions

In summary, in order to achieve enhanced photocurrent density and conversion efficiency of ultrathin c-Si solar cells, we designed the double-sided pyramids texture for ultrathin c-Si cells. Through the simulations and optimizations, it is found that the maximum photocurrent densities 37.71 mA/cm^2 and conversion efficiency 20.45% are achieved for the cell with the upright pyramids (characteristic angle 54.7° and bottom length 2 μm) on the front surface and upright pyramids (characteristic angle 35° and bottom length 4 μm) on the rear surface. The double-sided pyramids texture exhibits better light absorption comparable to the fully-randomized pyramids texture. Moreover, the absorption and reflection efficiency of ultrathin c-Si cells with double-sided pyramids show a less dependence on the incident angle of light. The cell with the bottom length of the pyramid 1 μm shows better light absorptance. This architecture has more excellent performance in reducing the light escape in longer wavelength range, leading to its light absorption approaching the Yablonovitch limit.

The designed double-sided pyramid texture in this work provides a realistic strategy in conversion efficiency improvement and cost reduction for ultrathin c-Si solar cells.

Acknowledgments

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.optlastec.2019.105700.

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SEG Solar, EX1020, Page 127

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310 ##$aBimonthly $b<, 1982->
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362 1#$aBegan in Aug. 1970. $zCf. New serial titles.
500 ##$a1971- incl. Special Suppls. titled ` ` Electro-optics intl.'' (varies slightly). Incl. special suppls. containing ann. exhibit catalog; Library does not own 1982.
500 ##$aPublisher varies: 1995- , Elsevier Science.
506 ##$aAlso available online.
510 2#$aElectronics and communications abstracts journal (Riverdale), $x0361-3313
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650 #0$aOptics $vPeriodicals
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210 0 Opt. laser technol.
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246 1 **$i** Issue for <Nov. 1996-> has title: **$a** Optics & laser technology
260 Oxford **$b** Elsevier Advanced Technology
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310 Eight no. a year, **$b** <1996->
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336 text **$b** txt **$2** rdacontent
337 unmediated **$b** n **$2** rdamedia
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362 1 Began in Aug. 1970 with v. 2, no. 3. **$z** Cf. New serial titles.
510 2 Chemical abstracts **$x** 0009-2258
530 Also issued on microfilm from the publisher.
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650 7 Lasers. **$2** fast **$0** (OCoLC)fst00992842
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936 Unknown **$a** Vol. 43, issue 2 (Mar. 2011)
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SEG Solar, EX1020, Page 137

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RESEARCH ARTICLE

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Role of silicon surface, polished ⟨100⟩ and ⟨111⟩ or textured, on the efficiency of double-sided TOPCon solar cells

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Abstract

We investigate the role of the silicon surface and orientation on double-sided TOPCon solar cells properties. The solar cells of front and rear, (p) and (n), poly-Si/SiO$_x$ stack, fabricated on polished surfaces oriented ⟨100⟩ and ⟨111⟩ and pyramid textured surfaces, are characterized as a function of the thickness of an ultrathin SiO$_x$ layer, controlled at atomic scale from one- to four-cycle atomic layer deposition (ALD). Our findings underline that the optimized thickness of the ultrathin SiO$_x$ is about 1.1 ± 0.1 nm, corresponding to a two-cycle ALD, regardless of the surface and orientation of the c-Si substrate. The open-circuit voltage is about 10 mV higher on the polished ⟨100⟩-oriented surface, associated with lower defect density at the interface of SiO$_x$/c-Si. On the other hand, the contact resistance is much lower, about 0.45 Ω/cm^2, on the polished ⟨111⟩-oriented surface. On textured surfaces, we demonstrate a photoconversion efficiency of 19.1% for the double-sided TOPCon structure strictly for a SiO$_x$ thickness with two-cycle ALD, which underlines the importance of the ALD technique for the precise control of the ultrathin SiO$_x$ thickness on textured surface.

KEYWORDS

atomic layer deposition (ALD), polycrystalline silicon (poly-Si), pyramid texture, silicon oxide (SiO$_x$), surface orientation, tunnel oxide passivated contact (TOPCon)

1 | INTRODUCTION

Since a photoconversion efficiency (PCE) over 25% is reported, the tunnel oxide passivated contact (TOPCon) solar cell structure[1] and more generally the doped polycrystalline silicon/silicon oxide (poly-Si/SiO$_x$) stack such as SIPOS[2] or POLO[3,4] have gained interest with already industrialized processes presenting an impressive median PCE close to 24%.[5] For both-side contacted solar cells, the best performance at industrial level, with a PCE about 24.6%,[5,6] are remarkably close to the best PCE at research level, reported at 25.8% for a TOPCon structure[1] and at 25.1% for a HIT heterojunction structure.[7] Further improvements are expected by employing also a TOPCon structure for the boron-doped (p-type) front side instead of the boron-diffused emitter, to limit the number of high-temperature processes, and thus the impurities introduced over the surface.[8] For this purpose, front and rear, p- and n-type, double-sided TOPCon solar cells are an important structure to investigate the details of the front p-type contact. This structure can be integrated into a full industrial fabrication process with front and rear contacts, if the direct tunneling process for holes through the thin silicon oxide layer (SiO$_x$) is well controlled. Indeed, SiO$_x$ layer exhibits a higher barrier for holes than for electrons (ΔE_V = 4.5 eV and ΔE_C = 3.1 eV).[9,10] Besides, due to their excellent thermal stability, such structure can be also integrated into tandem solar cells, for example, like perovskite-silicon tandem structure that presents a PCE close to 30%.[11,12]

The fabrication of TOPCon solar cell involves a high temperature (high T) annealing about 850°C, where the dopants diffuse from the doped poly-Si layer to the SiO$_x$ interface creating a field effect passivation and also inside the c-Si wafer generating a junction. The high

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SEG Solar, EX1020, Page 139

T annealing also induces the effusion of hydrogen from the SiO_x/c-Si interface, and thus, a hydrogenation step is necessary to terminate chemically the dangling bonds.[13] The dopant diffusion and hydrogenation phenomena are highly dependent on the SiO_x thickness, the dopant concentration in the poly-Si layer,[14] the hydrogenation method, and the surface morphology, which complicate the process optimization of TOPCon solar cells.

For the poly-Si/SiO_x stack, the ultrathin SiO_x layer must be below 1.5 nm to allow the tunneling of photogenerated carriers,[13] usually deposited by wet chemical oxide,[13,15] dry oxide,[3] or UV-O_3[16] on silicon wafer with polished surface. Interestingly, lower passivation properties are generally reported on textured surfaces.[15,17] The double-sided TOPCon structures have been recently investigated[9,15,18–21]; however, some works use only the front side textured with the (n) stack.[15,19,20] PCE about 19.6% is reported using TCO-free device with T-seeded Cu-plated front contact,[20] and the best PCE about 22.6% used doped silicon carbide on front-side textured and back-side polished.[21] To further enhance the PCE, it is necessary to study the role of the surface orientation ⟨100⟩ or ⟨111⟩ and the effect of polished or textured surfaces as a function of the ultrathin SiO_x thickness.

In this work, the photovoltaic properties of double-sided, front (p) and rear (n), TOPCon solar cells are presented on polished silicon surface-oriented ⟨100⟩ and ⟨111⟩ and on textured wafer as a function of the ultrathin SiO_x thickness. The structure consists of (p) poly-Si/SiO_x/(n) c-Si/SiO_x/(n) poly-Si (Figure 1). The SiO_x layer is formed by atomic layer deposition (ALD), which yields excellent conformal coverage over the textured surface and a thickness control at atomic level.[22] Here, we particularly concentrate on the photovoltaic properties, surface passivation, and boron and hydrogen profiles realized by SIMS, depending on the silicon surface orientation and the polished or textured surfaces.

2 | EXPERIMENTAL

2.1 | Silicon wafer preparation

Floating zone (FZ) silicon wafers, phosphorus-doped (n-type), 1–5 Ω cm, 280-μm-thick, polished double sides with surface-oriented ⟨100⟩ and ⟨111⟩ are used in this study. Some wafers oriented ⟨100⟩ are textured by KOH-based chemical etching at 80°C for 15 min

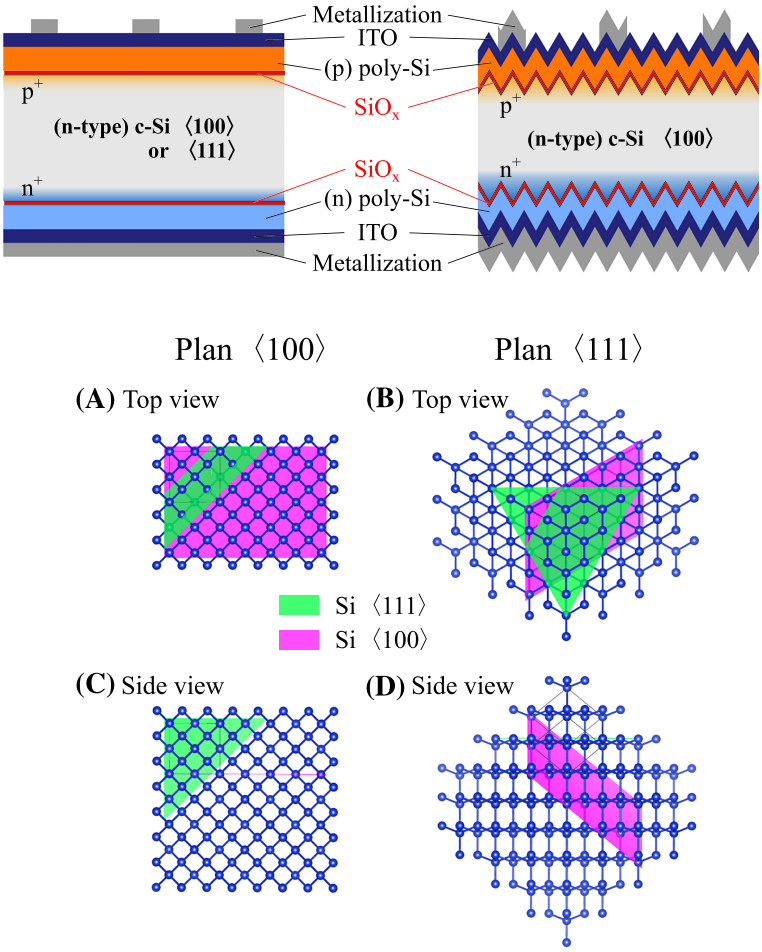


FIGURE 1 Illustration of the solar cell structures fabricated on n-type c-Si wafer with polished surfaces oriented ⟨100⟩ and ⟨111⟩ and textured surfaces. The (A, B) top views and (C, D) side views of the ⟨100⟩ and ⟨111⟩ surface orientations are also represented at atomic scale. The surface atom density is $\frac{2}{a_{Si}{}^2}$ = 6.78 × 10^{14} at/cm^2 for the plan ⟨100⟩ and $\frac{2}{\frac{\sqrt{3}}{2}\times a_{Si}{}^2}$ = 7.83 × 10^{14} at/cm^2 for the plan ⟨111⟩ [Colour figure can be viewed at wileyonlinelibrary.com]

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removing about 10 μm on front and rear surfaces cumulated and forming pyramidal shape with ⟨111⟩ facets.[23] The size of the pyramid structure is typically 3 to 5 μm. Next, the wafers are cleaned by our standard cleaning process[24] to remove the native oxide and the impurities on surface. This process consists of (i) native oxide removal and chemical oxide growth by a self-heated solution at 75°C for 15 min (H_2SO_4:H_2O_2 ratio 4:1), (ii) an oxide etching for 2 min (HF:HCl:H_2O ratio 1:1:20), (iii) an oxide growth for 15 min (HCl:H_2O_2:H_2O ratio 1:1:5), and then (iv) a diluted HF (DHF) solution for 30 s (HF:H_2O ratio 1:20) to remove the oxide layer and to saturate the surface termination with H atoms. The cleaned wafers are transferred into a vacuum box between each process to reduce the oxidation and contamination. The H-terminated surface of silicon wafer is stable up to roughly 30 min under ambient air.[25,26]

2.2 | Silicon oxide, a-Si:H deposition, and post annealing

The ultrathin SiO_x is deposited by means of plasma-assisted ALD (Oxford Instruments FlexAL® system). The deposition temperature is set at 300°C for the full ALD process. The tris(dimethylamino)silane (3DMAS) precursor is used as a silicon source. An oxygen (O_2) plasma is used as an oxygen source, generated by an inductively coupled plasma (ICP) with 13.56-MHz radio frequency (RF) power of 250 W at an O_2 pressure of 15 mTorr. The sources' exposure time (3DMAS and O_2 plasma) is kept constant at 5 s. The thicknesses of SiO_x films are controlled by the number of ALD cycles set at 1, 2, 3, or four cycles, symmetrically at the front and the rear sides. By using spectroscopic ellipsometry (SE) in situ for polished wafers, the thickness is monitored throughout the ALD processes. The SiO_x films with three and four ALD cycles are measured at 7 ± 1 and 9 ± 1 Å, respectively; however, the determination of the thicknesses with only one or two ALD cycles are more uncertain due to fitting difficulties, estimated about ∼3 and ∼5 Å,* respectively. The SiO_x thickness is determined under the assumption of a Cauchy model for polished wafers.

Next, the c-Si wafers are transferred into the plasma-enhanced chemical vapor deposition (PECVD) system in a downflow configuration for the deposition of a-Si:H layers. For the front (p) stack, an intrinsic (i) a-Si:H layer, about 20 ± 1 nm estimated on a polished surface, is deposited at 165°C with a mixture of SiH_4 and H_2 flows,[27] followed by a (p) a-Si:H layer about 2 nm deposited at 140°C with a mixture of SiH_4, H_2, and B_2H_6 flows. For the rear (n) stack, a (n) a-Si:H layer about 22 ± 1 nm is deposited at 140°C with a mixture of SiH_4, H_2, and PH_3 flows. The thicknesses of (i), (p), and (n) a-Si:H layers are determined on polished surface from SE assuming a Tauc-Lorentz model.

Polished wafers oriented ⟨100⟩ and ⟨111⟩ and textured wafers are loaded at the same time during ALD and PECVD processes to prevent any condition and thickness discrepancies. Then the samples are annealed in a furnace at 820°C for 1 h in vacuum. The temperature ramps are set as low as 100°C/h for both the annealing and cooling down to prevent blistering effect on surface.[28,29]

The doping concentration and the junction depth of the boron and hydrogen atoms from the front (p) stack are confirmed by SIMS measurements. Besides, the oxygen, carbon, and nitrogen concentrations are also analyzed.

2.3 | Hydrogen plasma treatment

A hydrogenation step is necessary to passivate the defects, mainly the dangling bonds,[30,31] at the SiO_x/Si interface and inside the poly-Si/SiO_x stack due to the effusion of hydrogen from the material during the high T annealing step.[22] For this, hydrogen plasma treatment (HPT) is performed at 300°C for 1 min, using the capacitively coupled discharge in a parallel-plate configuration.[32,33] During HPT, the hydrogen pressure is set at 0.5 Torr with a power density at 60 mW/cm^2 and a frequency at 85 MHz. The distance between the discharge electrodes is set about 2 cm.

2.4 | Characterization of the surface passivation

The passivation properties are characterized at room temperature by the quasi-steady-state photoconductance method (QSSPC, Sinton WTC-120).[34] The measurements of the effective lifetime (τ_{eff}) of minority carriers and the implied open-circuit voltage (iV_{oc}) are performed at an injection level of 1×10^{15} cm^{-3}on non-symmetric structures, with (p) poly-Si at the front and (n) poly-Si at the rear, on polished and textured c-Si surfaces. A high τ_{eff} reflects a high-quality passivation. The saturation current density (J_0) is also measured by QSSPC at high injection level.[35]

2.5 | Solar cell structures

A stacked layer of doped poly-Si and silicon oxide passivates the c-Si surface of n-type wafers. As described above, boron-doped (p-type) a-Si:H is deposited on the top, and phosphorus-doped (n-type) a-Si:H is deposited on the back. The as-deposited structure is (p) a-Si:H (2 ± 1 nm)/(i) a-Si:H (20 ± 1 nm)/SiO_x/c-Si/SiO_x/(n) a-Si:H (22 ± 1 nm). After high T annealing, the structure becomes (p) poly-Si (22 ± 1 nm)/SiO_x/c-Si/SiO_x/(n) poly-Si (22 ± 1 nm) (Figure 1), where the (p) a-Si:H/(i) a-Si:H stack is used as a precursor of the front (p) poly a-Si:H layer to control the boron diffusion through the ultrathin SiO_x layer.[36] Hereafter, we denote the (p) and (n) poly-Si/SiO_x stacks as (p) and (n) stacks, respectively. The (p) stack is about 22 nm to avoid severe ITO sputtering damage.[37] The solar cell structures are annealed with a single high T annealing step, thus making a TOPCon-type structure for both front and back surfaces.

After high T annealing and HPT steps, 70-nm ITO films are deposited by RF sputtering technique at the front and rear surfaces as an

*After the fabrication process, the SiO_x (ALD 2c) thickness is accurately measured by TEM at 1.1 ± 0.1 and 1.3 ± 0.1 nm on polished ⟨100⟩- and ⟨111⟩-oriented surface, respectively.

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anti-reflective and conductive coating. A low temperature annealing step is performed at 160°C for 2 h to recover from the ITO sputtering damage.[38] Then, the ohmic contacts are formed by DC magnetron sputtering a 3.6-μm-thick Ag for the front grid and a 0.7-μm-thick Ag for the rear contact on the full area. During the sputtering, the TOPCon surface is heated by the magnetron plasma,[39] which may induce the H effusion from the interfacial area of (p) poly-Si/SiO_x/c-Si, and could result in the passivation degradation.

The current–voltage (*I*–*V*) characteristics of the solar cells are performed under the standard AM 1.5G (100 mW/cm^2) irradiance. The illuminated area used for the measurement of the short-circuit current (J_{sc}) and thus the photoconversion efficiency is measured at 1.045 cm^2, which includes the grid shadowing (0.028 cm^2) over the single cell (1.017 cm^2).

The contact resistivity ρ_c with the (p) poly-Si layer is evaluated by the transmission line method (TLM) on a specific front line patterned beside the solar cells from the same c-Si wafer.

2.6 | Polycrystalline layers on textured surfaces

The crystallization of the boron-doped front polycrystalline layers has been investigated at a valley and at the top of a tip of the textured surface by analyzing the fast Fourier transform (FFT) patterns on localized areas from the high-resolution transmission electron microscopy (HR-TEM) images.

3 | EXPERIMENTAL RESULTS

3.1 | Solar cells performances

The solar cells' performances are shown in Figure 2. A comparison between the open-circuit voltage (V_{oc}), the short-circuit current (J_{sc}), the fill factor (FF), and the photoconversion efficiency (PCE) is presented as a function of the ultrathin SiO_x thickness with one, two, three, and four ALD cycles between identical double-sided TOPCon solar cells fabricated on c-Si polished ⟨100⟩ and ⟨111⟩ and textured surfaces (Figure 2A). Hereafter, we use the notation SiO_x 1c, 2c, 3c, and 4c for the SiO_x thicknesses with one, two, three, and four ALD cycles. For each case, the *I*–V characteristics (Figure 2B) and the external quantum efficiencies, EQE, (Figure 2C) are also displayed.

On Figure 2A, the highest V_{oc} values are measured at 641, 631, and 624 mV on polished ⟨100⟩ and ⟨111⟩ and textured surfaces, respectively. Interestingly, these V_{oc} are obtained for SiO_x 2c regardless of the surface and orientation. V_{oc} quickly decreases for thicker SiO_x at 3c and 4c.

For J_{sc} (Figure 2A), the textured wafers provide much higher J_{sc} due to a more efficient absorption of the AM 1.5G spectrum in infrared region.[40] The highest J_{sc} value is obtained for the thinnest SiO_x 1c at 39.24 mA/cm^2 and decreases for thicker SiO_x layer on textured surfaces. For polished ⟨100⟩ and ⟨111⟩ wafers, the best J_{sc} is measured at 34.25 mA/cm^2 and 34.32 mA/cm^2 with SiO_x 2c, respectively, and also decreases with thicker SiO_x layer. J_{sc}, obtained by integration of EQE spectra, are presented in Table S1.

Regarding FF (Figure 2A), the values are relatively similar for SiO_x 1c and 2c and then quickly drop. The best FF are observed for SiO_x 2c regardless of the surface and orientation. As shown, FF are measured at 0.76, 0.76, and 0.79, on polished ⟨100⟩ and ⟨111⟩ and textured surface, respectively. Here, we can notice that the loss in FF for thicker SiO_x at 3c and 4c is more pronounced for polished surfaces. This is well observed on the current–voltage characteristics (Figure 2B).

For each solar cell structures, regardless of the surface and orientation, the best PCE is observed at SiO_x 2c (Figure 2A,B). The PCE are measured at 16.76%, 16.59%, and 19.11% on polished ⟨100⟩ and ⟨111⟩ and textured surfaces, respectively. The loss in performance for thicker SiO_x layer, at 3c and 4c, seems mainly attributed to a degradation of the FF due to a large series resistance (Figure 2B) and a weak back surface field, indicated by the EQE response at long wavelength range (Figure 2C), and also discussed in Figure S1.

Regarding the EQE (Figure 2C), for polished ⟨100⟩ and ⟨111⟩ wafers, the full spectral response is affected for thicker SiO_x. On the contrary, for textured wafers, the short wavelength response (∼300 to ∼600 nm) is not affected. The difference occurs only at longer wavelengths from ∼750 to ∼1200 nm; for example, at wavelength of 1010 nm, the EQE is 0.88 for SiO_x 2c and drop at 0.60 for SiO_x 4c.

3.2 | Evolution of the effective lifetime

The effective lifetime, τ_{eff}, is monitored throughout each step of the fabrication process for the double-sided TOPCon solar cell structures (Figure 3). As described, solar cell (non-symmetric) structures, with (p) poly-Si at the front and (n) poly-Si at the rear side, are used in this study. The evolution of τ_{eff} is presented for polished ⟨100⟩ wafers (Figure 3A), polished ⟨111⟩ wafers (Figure 3B), and surface-textured wafers (Figure 3C) depending on the SiO_x thickness 1c, 2c, 3c, and 4c.

Concerning the evolution of τ_{eff} on polished ⟨100⟩ wafers (Figure 3A), we observe a lifetime improvement after high *T* (at 820°C for 1 h, as described in Section 2), which is again enhanced after hydrogen plasma treatment (HPT). The highest τ_{eff} is measured after DHF at 1041 μs for SiO_x 2c, which corresponds to an implied iV_{oc} at 680 mV and a saturation current density J_0 at 21 fA/cm^2. For thinner or thicker SiO_x with 1c or 4c, τ_{eff} and iV_{oc} strongly drop. Thus, the optimized thickness for the SiO_x is 2c, and τ_{eff} for SiO_x 3c is slightly below. A strong reduction of τ_{eff} is observed after ITO deposition, due to the passivation losses induced by ITO and Ag sputtering processes,[41] which is not sufficiently recovered after an annealing at 160°C for 2 h,[†] and τ_{eff} is measured at 596 μs (iV_{oc} at 669 mV) for SiO_x 2c.

The evolution of τ_{eff} on polished ⟨111⟩ wafers (Figure 3B) is quite different; almost no τ_{eff} improvement is observed after high

[†]An optimization of the recovery was attempted: slightly higher temperature or longer time have a negative effect on the lifetime recovery.

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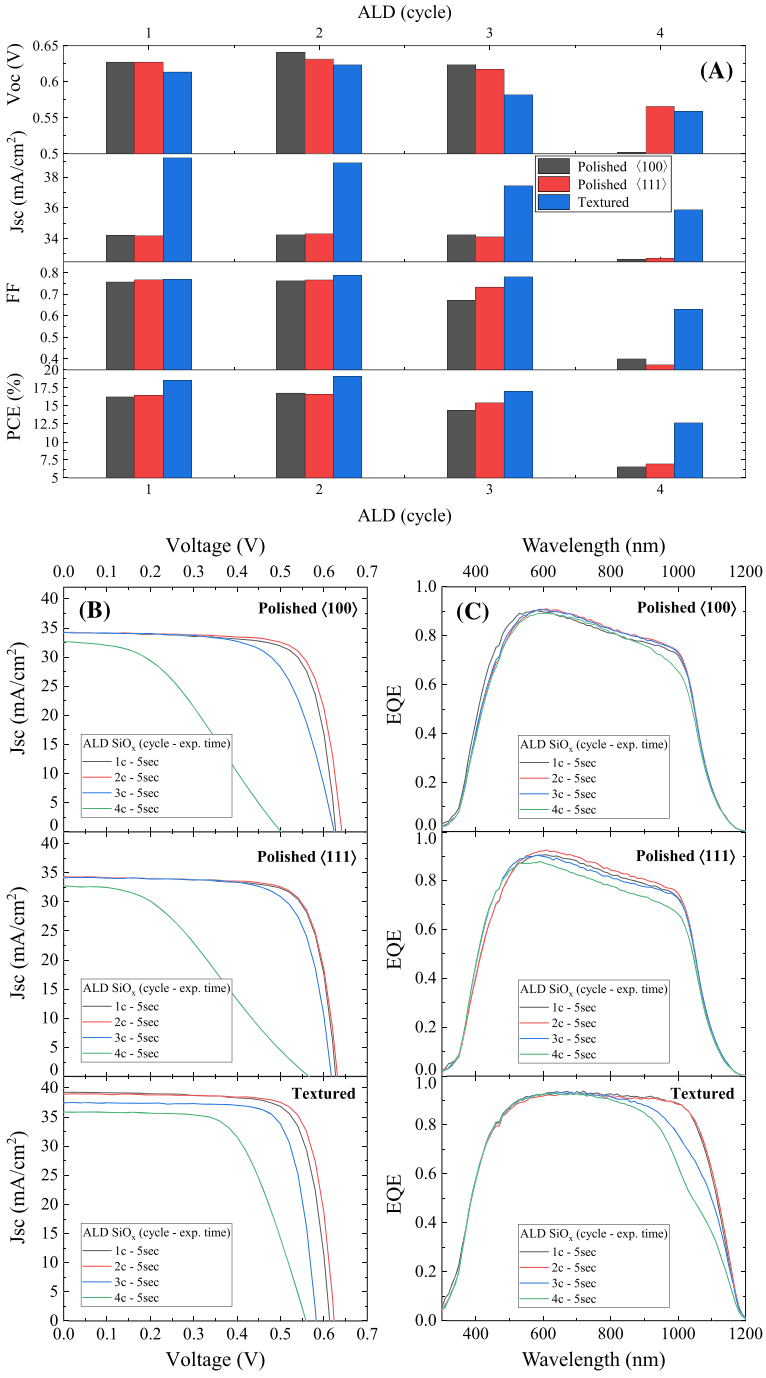


FIGURE 2 (A) Solar cell characteristics as a function of the ALD cycles for the SiO_x ultrathin film and the wafer surface: polished oriented ⟨100⟩ and ⟨111⟩ and textured. (B) Related current–voltage (*I*–*V*) characteristics and (C) external quantum efficiencies (EQE) [Colour figure can be viewed at wileyonlinelibrary.com]

T step, and then an improvement is observed after the HPT. The highest τ_{eff} is measured prior DHF at 854 μs for SiO_x 3c, which corresponds to an iV_{oc} at 665 mV and a J_0 at 205 fA/cm^2. After the ITO deposition followed by annealing, the lifetime recovery is again relatively low at 518 μs (iV_{oc} at 651 mV) for SiO_x 3c.We should note that the optimized SiO_x thickness is 2c on polished ⟨100⟩ surface and slightly thicker with SiO_x 3c on ⟨111⟩-oriented surface (Figure 3A,B).

Finally, the evolution of τ_{eff} on textured wafers (Figure 3C) is also unique; similarly to polished ⟨100⟩ surface, the optimized SiO_x layer thickness is 2c ALD. However, contrary to the polished surfaces, the SiO_x with 3c does not provide sufficient passivation, which underlines the precise thickness control necessary that can be obtained by the plasma-assisted ALD deposition. Similarly to polished ⟨111⟩ wafers, τ_{eff} does not improve much after high *T*; an enhanced passivation property is only observed after HPT for the structure with SiO_x 2c.

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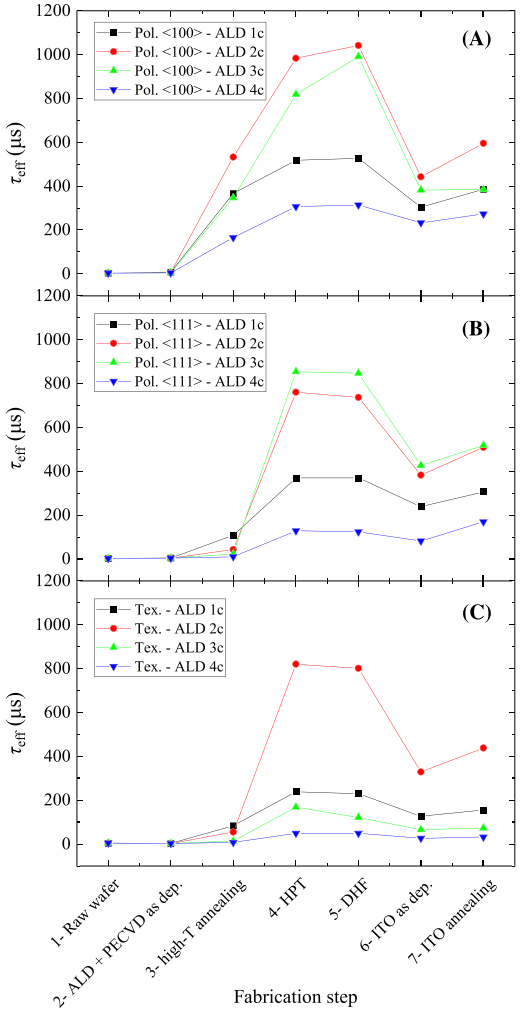


FIGURE 3 Evolution of the effective lifetime τ_{eff} measured at each fabrication step as a function of the ALD cycle for the SiO_x ultrathin film and the wafer surface: polished oriented ⟨100⟩ and ⟨111⟩ and textured [Colour figure can be viewed at wileyonlinelibrary.com]

The highest τ_{eff}, corresponding iV_{oc}, and J_0 are measured at 820 µs, 677 mV, and 100 fA/cm^2 for SiO_x 2c prior DHF and at 802 µs, 676 mV, and J_0 104 fA/cm^2 after DHF. The best τ_{eff} is in the same range as the one measured on polished ⟨111⟩ wafers over 800 µs. Here also, after ITO deposition and annealing, the lifetime recovery is limited; τ_{eff} is measured at 438 µs (iV_{oc} at 659 mV) for SiO_x 2c.

3.3 | Conformal thickness analyzed by TEM

High-resolution TEM images are investigated for the front (p) poly-Si/SiO_x stack of the double-sided TOPCon solar cells with SiO_x 2c fabricated on polished ⟨100⟩ and ⟨111⟩ and textured surfaces (Figure 4).

On polished surfaces (Figure 4A,B), the thickness of the (p) poly-Si layer is measured at 17.3 ± 0.2 nm and at 17.4 ± 0.2 nm for ⟨100⟩ and ⟨111⟩ surfaces, respectively. The thicknesses of (p) poly-Si layer are confirmed to be similar between ⟨100⟩ and ⟨111⟩ surfaces. The ultrathin SiO_x layers are measured at 1.1 ± 0.1 and 1.3 ± 0.1 nm for ⟨100⟩ and ⟨111⟩ surfaces, respectively. Thus, the ultrathin SiO_x 2c is slightly thicker for ⟨111⟩ surface. Besides, the SiO_x 2c thickness determined from TEM images (1.1 ± 0.1 and 1.3 ± 0.1 nm) is thicker than those estimated from in situ SE (∼0.5 nm) on polished surface. The nature of the (p) poly-Si is well underlined with some atomic plans clearly visible in some areas, and still amorphous in the other areas, thus the diffraction pattern from nanobeam diffraction (NBD) does not present a clear diffracted pattern.

For the textured surface, HR-TEM is performed at a valley (Figure 4C) and at the top of a tip (Figure 4D). At the textured valley, the thickness of the (p) poly-Si is measured at 10.3 ± 0.2 nm on the slope and at 12.2 ± 0.2 nm at the bottom. The thickness at the bottom is well about 30% thinner than on polished surface by using the exact same recipe at the same time. However, on the slope, the thickness measured is quite thinner about 40% compared with the same deposition over a polished surface. The ultrathin SiO_x is measured at 1.2 ± 0.1 nm. In the valley, the nature of the (p) poly-Si is well poly-crystallized, which is underlined by the diffraction pattern with both crystallized and amorphous areas.

The same measurements are performed at the top of a tip. Here, the (p) poly-Si is also about 10.5 ± 0.2 to 10.8 ± 0.2 nm on the slopes and at 14.3 ± 0.2 nm at the very top, which is about 40% to 20% thinner than on a polished surface. The ultrathin SiO_x is measured about 1.1 ± 0.1 nm on one slope to 1.0 ± 0.1 nm on the other. The polycrystalline nature of the (p) poly-Si layer is here also well underlined with the diffraction patterns. Thus, some disparities are underlined by HR-TEM images concerning mainly the variation of the (p) poly-Si on a textured surface, but also slight variations of the ultrathin SiO_x itself from 1.0 to 1.2 nm.

3.4 | Dopant profile by SIMS analysis

SIMS analysis is performed to investigate the boron dopant and the hydrogen profiles at the front of the double-sided TOPCon solar cell structure with SiO_x 2c on polished ⟨100⟩ and ⟨111⟩ surfaces (Figure 5). After the fabrication steps processed at the same time, the boron dopant profiles (Figure 5A) are similar from the (p) poly-Si surface to the ultrathin SiO_x where a peak about 1.4 × 10^{20} at/cm^3 is measured at 16.3 ± 0.5 nm depth. Then, up to 60 nm depth, the boron concentration is slightly larger on polished ⟨111⟩ surface, above the detection limit of the SIMS measurement for the boron element (∼10^{16} cm^{-3}). And the boron concentration profile is slightly deeper on polished ⟨100⟩ surface with a junction depth measured at ∼110 nm compared with ∼100 nm on ⟨111⟩ surface, above the SIMS depth resolution (∼2 nm). This can be attributed to a slightly thicker SiO_x film ⟨111⟩ surface, as described above.

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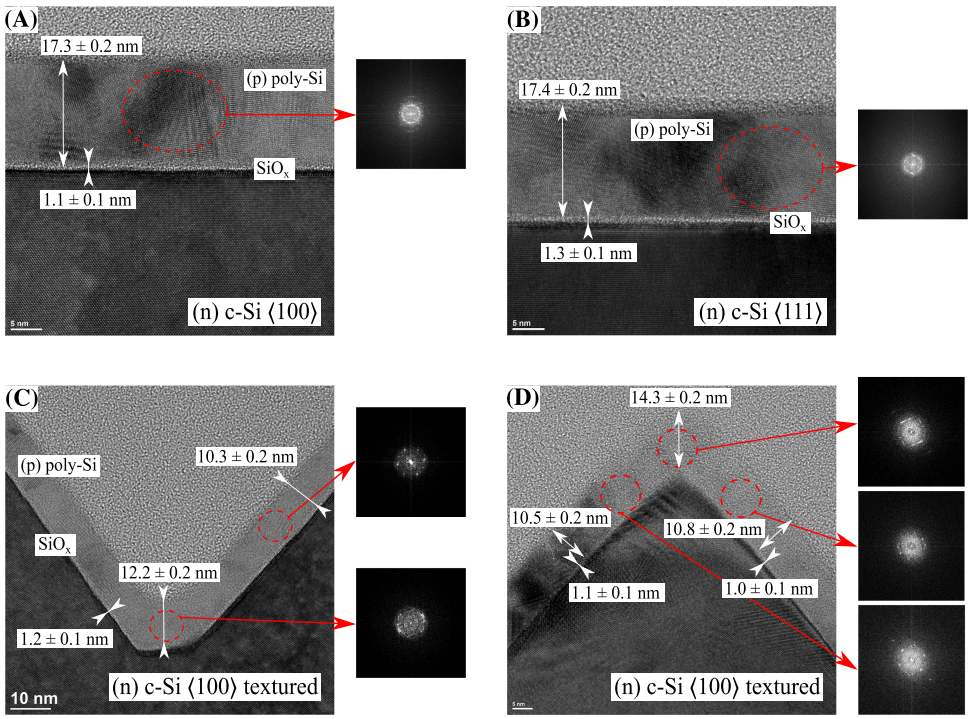


FIGURE 4 TEM images of the front (p) poly-Si/SiO_x stack on the best solar cell structure using SiO_x ALD two cycles, with a comparison between polished oriented (A) ⟨100⟩ and (B) ⟨111⟩ and textured surfaces' (C) bottom of a valley and (D) top of a tip. For each case, the areas used for the nanobeam diffraction (NBD) patterns are in red circle and underline the polycrystalline silicon layers [Colour figure can be viewed at wileyonlinelibrary.com]

Concerning the hydrogen profile (Figure 5B), both profiles are quite similar within the incertitude of the measurement. The hydrogen peak concentration in the ultrathin SiO_x is measured at 1.35×10^{21} and 1.45×10^{21} at/cm^3 for ⟨100⟩ and ⟨111⟩ surfaces, respectively, and localized about 15 ± 0.5 nm. The measurements underline a slightly deeper profile for the ⟨111⟩ surface at 20.5 ± 0.5 nm compared with 19.3 ± 0.5 nm for ⟨100⟩ surface; however, it may be within the detection limit and incertitude of measurement.

3.5 | Ohmic contacts

By using the TLM pattern present on each solar cell structure at the front (p) stack, the contact resistances are measured as a function of the SiO_x thickness for ALD 1c, 2c, 3c, and 4c depending on the surface and orientation (Figure 6). A striking difference is observed between the orientations ⟨100⟩ and ⟨111⟩. For the thinnest SiO_x 1c, the contact resistances are measured at 0.63, 0.20, and 0.37 Ω cm^2 for polished ⟨100⟩ and ⟨111⟩ and textured surfaces, respectively. On polished ⟨100⟩ surface, the contact resistance increases drastically with the SiO_x layer thickness, while on polished ⟨111⟩ and textured surfaces, the contact resistance remains relatively low up to SiO_x 3c. For SiO_x 4c, both polished surfaces present a larger contact resistance compared with the textured surface. The observed low contact resistance for the textured surface can be owing to the geometrical effects. The surface area is larger for the pyramidal texture, and the contact between the (p)-poly Si and ITO is better. Also, for the same front Ag grid pattern, the contact area with Ag is larger on textured surface, so the collection of the current would be better. Another consideration of a lower contact resistance for textured surfaces could be attributed to the dopant diffusion profile. Near the top of a tip, the diffusion profile from the four facets may overlap, whereas at a valley, a single point-source remains.

4 | DISCUSSIONS

4.1 | Carrier lifetime and open-circuit voltage

The effective carrier lifetime τ_{eff}, closely related to V_{oc}, is an important parameter of the surface passivation of TOPCon structure. The lifetime strongly depends on the density of defects such as dangling bonds at the SiO_x/c-Si interface and in (p) stack.[42] These defects are mostly passivated by the field effect and also chemically with hydrogen. In this study, the field effect is manipulated with the boron diffusion into the c-Si bulk through the SiO_x layer, where the SiO_x layer thickness plays important roles. The chemical passivation is performed during the hydrogenation step,[32,42,43] where the dangling bonds are terminated with hydrogen.

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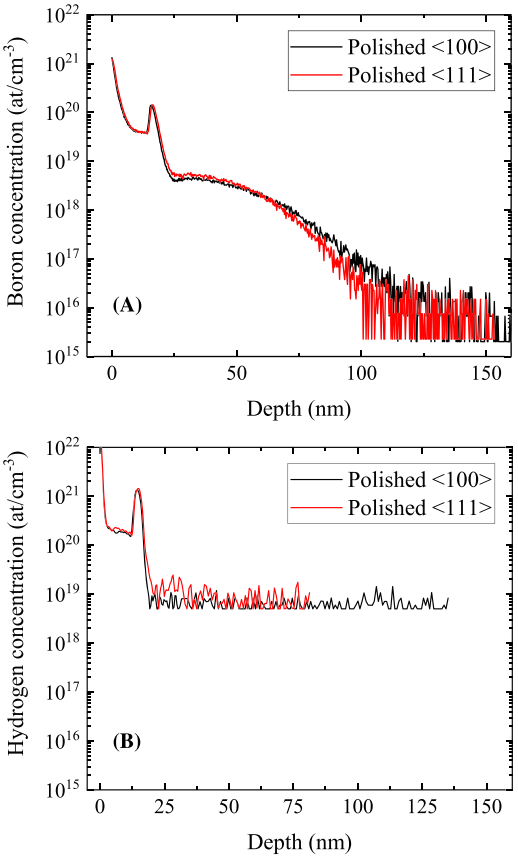


FIGURE 5 SIMS profiles of (A) boron and (B) hydrogen concentrations as a function of the polished surface orientation ⟨100⟩ and ⟨111⟩ for the best solar cell structures using SiO_x ALD two cycles [Colour figure can be viewed at wileyonlinelibrary.com]

The SiO_x thickness influences the boron diffusion and so the quality of the p-n junction at the front (p) stack and also the phosphorus diffusion at the rear (n) stack, that is, the quality of the n-n^+ junction generating the back surface field. If the SiO_x thickness is too thin (e.g., SiO_x with one-cycle ALD), a stronger dopant diffusion occurs generating some Auger recombination, and the interfaces with SiO_x cannot be well passivated after the hydrogen plasma treatment (HPT) step. On the other hand, if the SiO_x thickness is too thick (but still within the carrier tunneling condition below 2 nm[44]), the dopant diffusion is strongly attenuated, and the front and rear field effects are weakened, where the τ_{eff} and V_{oc} remain slow even after HPT. For the optimized SiO_x thickness (i.e., SiO_x with two-cycle ALD), the dopant diffusion and so the field effects (front and rear) are optimized; however, an HPT step is still necessary to terminate the dangling bonds at the interfaces poly-Si/SiO_x and SiO_x/c-Si. Thus, enhanced τ_{eff} and V_{oc} are obtained after an optimization of the field effects (junction formation) and the chemical passivation (H-termination of the dangling bonds by HPT).

The best lifetime over 1000 μs is observed on the polished ⟨100⟩ surface with a SiO_x thickness of 2c ALD for non-symmetric solar cell structures with a front (p) stack and a rear (n) stack. Concerning the solar cell properties, this is translated by an enhanced open-circuit voltage V_{oc} at 641 mV also observed on the polished ⟨100⟩ surface using a SiO_x thickness of 2c ALD. This can be primary attributed to the SiO_x/Si interface that presents a lower interface state density D_{it}, about ~10^{10} cm^{-2} eV^{-1}, on ⟨100⟩-oriented surface compared with D_{it} on ⟨111⟩, about ~3×10^{11} cm^{-2} eV^{-1},[17,45,46] yielding a higher carrier mobility at the interface with c-Si ⟨100⟩. Besides, it is known that the surface recombination velocity $S_{n,0}$ at the interface SiO_x/c-Si doped with the same boron concentration at 2×10^{18} cm^{-3} is lower about 220 cm s^{-1} on polished ⟨100⟩ surface than on polished ⟨111⟩ surface, which is estimated about 2400 cm s^{-1}.[17]

The enhanced τ_{eff} and V_{oc} obtained for the ⟨100⟩ surface can be also explained by the boron doping profile associated with the thickness of the SiO_x layer formed over the ⟨100⟩ and ⟨111⟩ surfaces (Figure 4A,B). The SiO_x thickness is slightly thinner on the ⟨100⟩ surface and thus having a stronger boron doping that generates a better field effect. From SIMS analysis (Figure 5), the boron dopant profiles are similar on polished ⟨100⟩ and ⟨111⟩ surfaces, with a boron peak concentration about 1.4×10^{20} at/cm^3 at the interface with SiO_x 2c, due to its higher solubility in SiO_x than in Si.[47] However, the junction depth is slightly different between these two cases: the junction depth is about 110 nm for the polished ⟨100⟩ and 100 nm for the ⟨111⟩ surfaces. The diffusivity of the boron is similar for c-Si-oriented ⟨100⟩ and ⟨111⟩ up to 1200°C, about 10^{-12} cm^2/s, with an activation energy about 3.42 eV.[48] Therefore, for the exact same structures on c-Si-oriented ⟨100⟩ and ⟨111⟩, the boron profile should be similar. However, here, a slightly thicker SiO_x on ⟨111⟩ surface is underlined (Figure 4), which can be the origin of a thinner junction depth at 100 nm. Indeed, for the optimized condition at SiO_x 2c ALD, the HR-TEM images could provide an accurate thickness measured at 1.1 ± 0.1 nm on polished ⟨100⟩ surface and at 1.3 ± 0.1 nm on polished ⟨111⟩ surface (Figure 4), which is consistent with a higher oxide growth rate reported on ⟨111⟩ oriented silicon.[49]

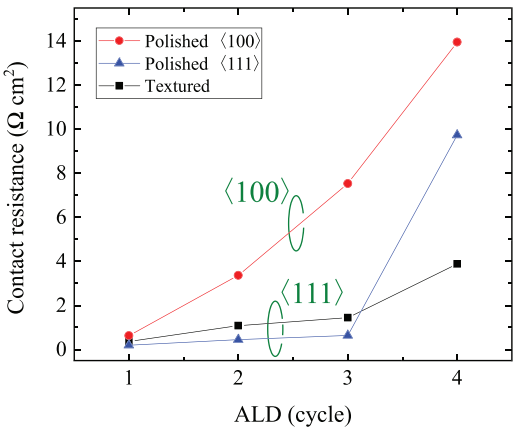


FIGURE 6 Contact resistance of the front (p) poly-Si/SiO_x stack depending on the ALD cycles for the SiO_x ultrathin film and the wafer surface: polished oriented ⟨100⟩ and ⟨111⟩ and textured [Colour figure can be viewed at wileyonlinelibrary.com]

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For the hydrogen concentration profile, the SIMS analysis shows that the H element profiles are similar on the ⟨100⟩- and ⟨111⟩-oriented surfaces, within the detection limit for H element ($\sim 10^{19}$ cm^{-3}). The hydrogen accumulation at the interfaces (p) poly-Si/SiO_x and SiO_x/c-Si is the about $\sim 1.4 \times 10^{21}$ at/cm^3 after hydrogen plasma treatment (HPT) (Figure 5). Thus, the termination of the interface defects with hydrogen is expected to be similar regardless of the orientation.

On textured surface, the window of optimum thicknesses is found to be extremely narrow with a good passivation obtained exclusively for SiO_x 2c above 800 μs (Figure 3C). With 1 atomic cycle more or less, τ_{eff} is measured only about 200 μs. Such drastic change can be also explained by the SiO_x thickness. For a SiO_x thickness of 1c ALD, a larger quantity of boron diffuses into the c-Si wafer generating some Auger recombination and decreasing τ_{eff} and V_{oc}. For a thicker SiO_x of 3c and 4c ALD, the boron diffusion is attenuated, which affects the p-n junction formation and also the field effect passivation.

EDNA simulation is performed to further investigate and separate the Auger recombination from the surface recombination in the heavily doped emitters.[50] SIMS profiles for the boron concentration with SiO_x 2c are used for polished ⟨100⟩ and ⟨111⟩ surfaces with the saturation current density J_0 from QSSPC measurement as input parameters (Table S2 and Figure S2). For polished ⟨100⟩ surface, the surface recombination is predominant about 58% over the Auger recombination about 42%. Whereas for the polished ⟨111⟩ surface, the surface recombination is largely predominant about 79% over the Auger recombination about 21%.

4.2 | Poly-Si and SiO_x layers

Because of the importance of the dopant diffusion, it is also necessary to evaluate the nature of the polycrystalline on textured n-type Si wafers, especially at the front (p) poly-Si/SiO_x stack that was reported to have a weaker passivation property than (n) poly-Si/SiO_x stack.[9,17,18,22,51–57] The polycrystalline nature of the boron doped (p) poly-Si layer is analyzed by nanobeam diffraction pattern on HR-TEM (Figure 4). The well poly-crystallized (p) poly-Si nature, with clear atomic plans and amorphous parts, is observed regardless of the surface and orientation, even at the bottom of a valley and the top of a tip on textured surface (Figure 4). Thus, a textured surface does not modify locally the nature of the (p) poly-Si layer.

To further investigate the nature of the (p) poly-Si layers, UV Raman (λ = 325 nm) spectroscopy is also performed on polished surfaces (Figure S3). The short wavelengths only penetrate about 10 nm depth into the (p) poly-Si,[58] which is useful to separate the signal from the front (p) poly-Si and the c-Si substrate. We find that the residual amorphous signal is slightly more pronounced on polished ⟨100⟩ surface, which could contribute to a more efficient diffusion of the H atoms in the (p) poly-Si to the interface SiO_x/c-Si and thus could enhance the τ_{eff} and V_{oc}.

The stoichiometry x of SiO_x is estimated at 1.65 ± 0.2 after high T annealing for all samples on polished surfaces by FTIR method,[22] regardless of the surface orientation and the SiO_x thickness (Figure S4). So the stoichiometry of the ultrathin SiO_x film does not explain the differences observed in terms of τ_{eff} and V_{oc} between the different surfaces and orientations.

4.3 | Short circuit current and external quantum efficiency

The double-sided TOPCon solar cells present a very high J_{sc} over 39 mA/cm^2 (Figure 2) for such structure with a front shadowing grid.[36] The textured surface provides a clear benefit in term of short-circuit current J_{sc} compared with the polished surfaces (Figure 2A) about 4.7 mA/cm^2 for a SiO_x thickness of 2c ALD. The EQE analysis underlines an enhanced absorption from 600 to 1200 nm for textured surface over polished surfaces (Figure 2C). Besides, the (p) poly-Si deposited on textured surface is also thinner (Figure 4C,D), which can contribute to an enhanced J_{sc}.

Regarding the SiO_x thickness, the J_{sc} is decreasing with thicker SiO_x regardless of the surface condition and orientation (Figure 2A). Moreover, from the EQE on textured surface (Figure 2C), the absorption at longer wavelengths from 750 to 1200 nm is strongly affected by thicker SiO_x. Possibly, the diffusion of phosphorus dopant at the rear of the device is strongly reduced for SiO_x 3c and 4c, which could affect directly the properties of the n-n$^+$ junction and thus the back surface field. For the best devices with SiO_x 2c, the EQE is excellent at short and long wavelength compared with conventional heterojunction solar cells using a (p) a-Si:H layer.[59]

4.4 | Fill factor and conversion efficiency

A notable difference between the surface orientations is observed in the contact resistance ρ_c (Figure 6). The ⟨100⟩ surface clearly underlines its weakness, with ρ_c at 3.4 Ω cm^2 for SiO_x 2c, seven times larger than on polished ⟨111⟩ surface at 0.45 Ω cm^2 and three times larger than on textured surface at 1.1 Ω cm^2. This observation can be attributed to a higher surface atom density at 7.83×10^{14} at/cm^2 for the c-Si-oriented ⟨111⟩ surface, compared with 6.78×10^{14} at/cm^2 for the c-Si-oriented ⟨100⟩ surface (Figure 1).[60] On textured surface, lower ρ_c can be attributed to the Al contact recovering the pyramidal surfaces that presents a larger interacting area with the ITO/poly-Si-doped layer compared with a flat surface. For thicker SiO_x at 3c and 4c, ρ_c is enhanced, which increases the series resistance and degrades strongly the FF (Figure 2A,B).

The optimized photoconversion efficiency is a compromise between the open-circuit voltage and the contact resistance. The double-sided TOPCon solar cells reach a PCE of 19.1% on textured wafer with V_{oc} = 624 mV and ρ_c = 1.08 Ω cm^2 for an optimized SiO_x thickness with two-cycle ALD. A lifetime over 800 μs is reached strictly for two ALD cycles (Figure 3), because of the thickness discrepancy of the (p) poly-Si and the ultrathin SiO_x observed on textured wafer (Figure 4). This underline the advantage of using the ALD

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facility to precisely control the thickness of the ultrathin SiO_x layer on textured surface.

5 | SUMMARY

Double-sided TOPCon solar cells are fabricated on polished surfaces oriented ⟨100⟩ and ⟨111⟩ and pyramid-textured surfaces. The thickness of the ultrathin SiO_x is precisely controlled at atomic scale by ALD, enhancing the photoconversion efficiency at 19.1% on textured surfaces. The surface orientation plays an important role concerning the contact resistances that affect the series resistance and, thus, the fill factor. This observation can be attributed to the surface atom density between the orientations ⟨100⟩ and ⟨111⟩. Interestingly, the SiO_x thickness is optimized at 1.1 ± 0.1 nm, regardless of the surface and orientation. This work underlines the importance of a precise control of such SiO_x thickness, especially on textured surface where the poly-Si/SiO_x stack provides a sufficient passivation strictly for two-cycle ALD. A slight discrepancy of the SiO_x thickness, from 1.0 ± 0.1 to 1.2 ± 0.1 nm, is observed on textured surface between a valley and the top of a tip. Besides, the SiO_x is slightly thicker on polished ⟨111⟩ surface compared with the polished ⟨100⟩ surface. This thickness variation may have an impact on the properties of the n-p junction, where a thicker SiO_x reduces the dopant diffusion.

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RESEARCH ARTICLE

Role of silicon surface, polished 〈100〉 and 〈111〉 or textured, on the efficiency of double-sided TOPCon solar cells

Mickaël Lozac'h, Shota Nunomura

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Abstract

We investigate the role of the silicon surface and orientation on double-sided TOPCon solar cells properties. The solar cells of front and rear, (p) and (n), poly-Si/SiO_x stack, fabricated on polished surfaces oriented 〈100〉 and 〈111〉 and pyramid textured surfaces, are characterized as a function of the thickness of an ultrathin SiO_x layer, controlled at atomic scale from one- to four-cycle atomic layer deposition (ALD). Our findings underline that the optimized thickness of the ultrathin SiO_x is about 1.1 ± 0.1 nm, corresponding to a two-cycle ALD, regardless of the surface and orientation of the c-Si substrate. The open-circuit voltage is about 10 mV higher on the polished 〈100〉-oriented surface, associated with lower defect density at the interface of SiO_x/c-Si. On the other hand, the contact resistance is much lower, about 0.45 Ω/cm^2, on the polished 〈111〉-oriented surface. On textured surfaces, we demonstrate a photoconversion efficiency of 19.1% for the double-sided TOPCon structure strictly for a SiO_x thickness with two-cycle ALD, which underlines the importance of the ALD technique for the precise control of the ultrathin SiO_x thickness on textured surface.

Supporting Information

Back

Filename	Description
pip3304-sup-0001-SuppMaterial.docx Word 2007 document , 2.4 MB	Table S1 Comparison of the J_{sc} measured by I-V measurements and the J_{sc} estimated from integrated EQE measurements for all solar cell structures. Figure S1: EQE spectra of solar cells realized on polished 〈100〉, 〈111〉, and textured surfaces with thicker SiO_x (ALD 4 cycles). Table S2: EDNA simulation performed to separate the Shockley-Read-Hall (SRH) recombination at the surface and the Auger recombination using the SIMS dopant profiles, measured on polished 〈100〉 and 〈111〉 with SiO_x of ALD 2 cycles. Figure S2: Recombination mechanisms of the boron emitter underlined by EDNA simulation as a function of the saturation current density (J_0). The emitter saturation current (J_{0E}) is divided into the radiative, Auger, Shockley-Read-Hall, and surface recombination for the front side of (p) poly-Si/SiO_x (ALD 2 cycles) deposited on a) polished 〈100〉 and b) polished 〈111〉 surfaces according to their respective boron profile. **Figure S3:** UV Raman (λ = 325 nm) spectra of the front (p) stack on polished surfaces as-deposited **a)**, **b),** and after high-*T* annealing **c)**, **d)** depending on the surface orientation 〈100〉 and 〈111〉 of the silicon wafer, and the SiO_x layer with 1, 2, 3, and 4 ALD cycles. **e)** The areas integrated of the crystallized silicon (c-Si) component at 520 cm^{-1} and the amorphous silicon (a-Si) component below 500 cm^{-1} are also presented after high-*T* for each case. **Figure S4:** FTIR spectra of the full solar cell structures after high-*T* annealing depending on the surface orientation 〈100〉 and 〈111〉, and

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