

**DECLARATION OF JUNE ANN MUNFORD**

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent and able to testify to the same.
2. I earned a Master of Library and Information Science (MLIS) degree from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including as Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as **Appendix CV**.
3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In those roles, I have cataloged, purchased, and processed incoming library works. This includes purchasing materials directly from vendors, recording publishing data from the materials in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, cataloguing library records for optimal catalog search and retrieval, and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in a library. In preparing a material for public availability and accessibility, a library catalog record describing that material would be created. These records are typically created in **Machine Readable Cataloging** (herein referred to as “MARC”) format and contain information such as a physical description of the material, metadata from the material’s publisher, and date of library acquisition. In particular, the 008 MARC field tag is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access (*i.e.*, cataloguing), it is my experience that an item’s MARC record indicates the date of an item’s public availability.
5. Typically, in creating a MARC record, a librarian would gather information about the material including various bits of metadata such as book title, publisher, date, author, and subject headings among other information. The cataloguer would next assign a relevant numerical field (MARC field tag) to each piece of metadata identified in the material. For example, a book’s physical description is identified in MARC field tag 300 while title/attribution is tracked in MARC field tag 245. The 008 MARC field tag is reserved for denoting the creation date of the library record itself. As this

is the only date reflecting the inclusion of said materials within the library's collection, it is my experience that an item's MARC 008 field tag accurately indicates the date of an item's public availability.

6. During the process of drafting this declaration, I relied on the Online Computer Library Center's ("OCLC") Worldcat service to form my opinions. OCLC's Worldcat service is hosted on a publicly-accessible web interface commonly used by both librarians and library patrons to search for and identify worldwide library materials and to facilitate interlibrary loans, among other uses. The OCLC Worldcat service is powered by a multidimensional search engine that allows users to perform search queries to retrieve a listing of libraries holding a given publication within their collections. The Worldcat database is maintained by the OCLC organization based upon data provided from each individual member library. OCLC records provide a detailed bibliographic description of each item in its collection. I regularly rely on the OCLC Worldcat service to delineate between different versions and editions of publicly available worldwide publications.

7. I am also familiar with the Internet Archive, a digital online library accessible and available to the general public. The Internet Archive, a

501(c)(3) non-profit and founded in 1996, is a publicly available digital library of Internet sites and other cultural artifacts that can be searched and accessed in digital form. Its mission is to provide universal access to all knowledge including books, films, magazines, websites, videos, software programs, audio recordings, and television. Like a physical library, it provides free access to everyone. The Internet Archive is available here: <https://archive.org/>.

8. The Internet Archive created a resource known as the “Wayback Machine” (<https://web.archive.org/>). The Wayback Machine is named in reference to the famous Mr. Peabody’s WABAC (pronounced way-back) machine from the Rocky and Bullwinkle cartoon show. The Wayback Machine makes it possible to search and browse more than 450 billion publicly available web pages stored in the Internet Archive's web archive. Visitors to the Wayback Machine can search the Archive by keyword or a website URL. If archived records for a URL or the keywords are available, the visitor will be presented with a display of available dates. The visitor may select one of those dates and be taken to the collection of web captures associated with the specific web crawl and point in time the capture came from.

9. This archived data made viewable by the Wayback Machine is obtained using web archiving software that automatically stores copies of files available via the Internet, each file preserved as it existed at a particular point in time.
10. The Internet Archive assigns a URL to all archived files within the Wayback Machine in the following format: `http://web.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL]`. This is known as an “extended URL” format.
11. For example, the Internet Archive extended URL `http://web.archive.org/web/19970126045828/http://www.archive.org/` denotes the URL for the record of the Internet Archive home page archived on January 26, 1997 at 4:58 a.m. and 28 seconds (1997/01/26 at 04:58:28).
12. I have reviewed Exhibit EX-1007, “*Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays*,” by Nor Afifah Yahaya, et al, Optics Express Vol. 21 No. 5, p. 5924 – 5930 (March 2013) (“*Optics Express*”).
13. Attached hereto as **Appendix YAHAYA01** is a true and correct copy of the public catalog record for *Optics Express* as held by the Penn State

University Library at this link:

<https://catalog.libraries.psu.edu/catalog/47236435>. I secured this record myself from the library's public catalog on May 7, 2025. The public catalog record indicates that the library's collection includes the March 2013 electronic issue of *Optics Express* containing "*Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays*".

14. Attached hereto as **Appendix YAHAYA02** is a true and correct electronic copy of "*Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays*" as published in *Optics Express* as held by the Penn State University Library. This PDF copy was secured from the library's collection. In comparing Exhibit EX-1007 to **Appendix YAHAYA02**, it is my determination that Exhibit EX-1007 is a true and correct copy of "*Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays*" by Nor Afifah Yahaya, et al, *Optics Express*, Vol. 21 No. 5, p. 5924 – 5930 (March 2013) ("*Optics Express*").

15. Attached hereto as **Appendix YAHAYA03** is a true and correct copy of the MARC record for *Optics Express* as held by the Penn State University Library at this link:

[https://catalog.libraries.psu.edu/catalog/47236435/marc\\_view](https://catalog.libraries.psu.edu/catalog/47236435/marc_view). I secured this

record myself from the library's public catalog on May 7, 2025. The MARC record contained within **Appendix YAHAYA03** accurately describes the title, publisher and ISSN number of *Optics Express*. The first six digits of MARC 008 field tag in **Appendix YAHAYA03** indicates the date of record creation in the YYMMDD format. Digits 7 -10 of the 008 field tag indicates *Optics Express* is a continuing resources first published in 1997. Digits 11-14 of the 008 field tag indicate *Optics Express* was still being published as of the last revision of this MARC record. Digits 15-17 of the 008 field tag indicate *Optics Express* was published in the District of Columbia. Digits 18-19 of the 008 field tag indicate new issues of *Optics Express* are published on a regular basis. Digits 21-23 of the 008 field tag indicate *Optics Express* is a digital periodical. Digit 24 of the 008 field tag indicates *Optics Express* is not a conference publication. Digits 26-30 of the 008 field tag indicate *Optics Express* was published in English using the Roman alphabet, with new library catalog entries produced if and when the title/ownership of the publication changes. Digit 32 of the 008 field tag indicates the creator of this record is a participant in a cooperative cataloging program.

16. The 008 field of **Appendix YAHAYA03** indicates the Penn State University Library first acquired *Optics Express* as of June 20, 1997 and acquired new

issues of the journal in perpetuity until the publication of "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" in March 2013. Considering this information, it is my determination that *Optics Express* was made available to the public shortly after its initial publication in March 2013 via the Penn State University Library.

17. Attached hereto as **Appendix YAHAYA04** is a screen capture of the Internet Archive Wayback Machine entry for <http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-5-5924>. I secured these screen captures myself from <https://web.archive.org/web/20130526202937/http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-5-5924> on May 7, 2025. This record was captured as of May 26, 2013 at 8:29 p.m. and 37 second, as reflected in the URL date field entry reading '20130526202937' (2013/05/26 at 20:29:37).

18. **Appendix YAHAYA04** is an Internet Archive capture of a web page entitled Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays as hosted on the Optics InfoBase website. The 'History' field visible on page 2 of **Appendix YAHAYA04** indicates this paper was first published as of March 4, 2013. This date is consistent with

the March 2013 edition of Optics Express discussed in Appendices

**YAHAYA01, YAHAYA02 and YAHAYA03.**

19. Optics Express is an open access journal, indicating the publishers of Optics Express intended to make "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" accessible to the public with few access restrictions. The 'View Full Text Article' field visible on page 2 of **Appendix YAHAYA04** contains two links entitled 'Enhanced HTML' and 'Acrobat PDF', indicating any visitor to the Optics InfoBase would have been capable of downloading a true and correct copy of "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" soon after publication. As the Internet Archive first captured the page presented in **Appendix YAHAYA04** as of May 26, 2013, it is my determination that "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" was likely made available to the public no later than May 26, 2013 via the Optics InfoBase website.

20. In conclusion, it is my determination that "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" was first made available to the public via the Optics Express journal soon after initial publication in March 2013. **Appendices YAHAYA01, YAHAYA02 and**

**YAHAYA03** demonstrate Penn State University Library as one potential access point available to the public as of March 2013. **Appendix**

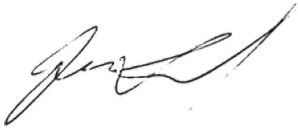
**YAHAYA04** demonstrates another access point for "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays", as the Optics InfoBase website indicates this paper would be available in full text to any member of the public as of May 26, 2013. As such it is my determination that "Characterization of Light Absorption in Thin-Film Silicon with Periodic Nanohole Arrays" was first made available to the public as of March 2013 and certainly no later than May 26, 2013.

21. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of \$200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

22. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made to 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: 6/16/2025

A handwritten signature in black ink, appearing to read 'June Ann Munford', with a stylized, flowing script.

June Ann Munford

# **Appendix CV**

June A. Munford  
Curriculum Vitae

## **Education**

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

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

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

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

## **Professional Experience**

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

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

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

- Executive administrator of the Dowagiac District Library. Located in Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over \$400,000 and total assets of approximately \$1,300,000.

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

November 2010 - January 2013

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

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

June 2004 - September 2005, September 2006 - October 2013

Library Assistant, Hart Area Public Library

Hart, MI

- Responsible for verifying imported MARC records and original MARC cataloging for the local-level collection as well as the Michigan Electronic Library.
- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

## **Professional Involvement**

Alaska Library Association - Anchorage Chapter

- Treasurer, 2012

#### Library Of Michigan

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

#### Michigan Library Association Annual Conference 2014

- New Directors Conference Panel Member

#### Southwest Michigan Library Cooperative

- Represented the Dowagiac District Library, 2013-2015

### **Professional Development**

#### Library Of Michigan Beginning Workshop, May 2008

##### Petoskey, MI

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

#### Public Library Association Intensive Library Management Training, October 2011

##### Nashville, TN

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

#### Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012

##### Fairbanks, AK

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

### **Depositions**

#### 2019 ● Fish & Richardson

Apple v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

#### 2019 ● Erise IP

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

#### 2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Case No. IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

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

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (Case No. IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (Case No. IPR2021-01182)

2023 ● Fish & Richardson

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

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (Case No. IPR2022-00735)

2023 ● Fish & Richardson

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

2023 ● Pillsbury Winthrop Shaw Whitman LLP

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

2024 ● Willkie-Farr

Netflix, Inc. v. VideoLabs. Inc. (Case No. IPR2023-00628)

2024 ● Quinn Emanuel Urquhart & Sullivan

Purdue University v. Wolfsped (Case No. 1:21-CV-840)

2024 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00393)

2025 ● Perkins Coie

Amazon.com, Inc. v. Nokia Technologies Oy (Case No. IPR2024-00572)

2025 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00373)

### **Limited Case and Clientele History**

Alston & Bird

- Ericsson

v. Collision Communications (Case No. IPR2022-01233)

- Nokia

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

- Universal Electronics Inc

v. Roku Inc (Case No. IPR2022-00818)

Alavi & Anaipakos PLLC

- Stingray Group Inc. and Stingray Music USA, Inc.

v. Edwin A. Hernandez-Mondragon and Eglia Corp. (Case No. 1:24-cv-21226-RAR)

Arnold & Porter

- Ivantis

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

- Samsung

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

Benesch Friedlander Coplan & Aronoff

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

Buchanan, Ingersoll & Rooney PC

- Google LLC, AT&T Service Inc., T Mobile USA Inc., Cellco Partnership, Ericsson Inc. & Nokia of America Corp.  
v. KT Corp & Pegasus Wireless Innovation LLC (Case No. IPR2025-00293)

Deschert LLP

- Smaxtec Animal Care  
v. ST Reproductive Technologies, LLC (Case No. IPR2024-00885)

Duane Morris

- Kangxi Communication Technologies  
v. Skyworks Solutions Inc. (Case No. IPR2025-00373)
- Microsoft  
v. Edge Networking Systems LLC (Case No. 1:24-cv-00215)

Erise I.P.

- Apple  
v. Ericsson Inc. (Case No. IPR2022-00715)  
v. Future Link Systems (Case No. IPRs 6317804, 6622108, 6807505, and 7917680)  
v. INVT (Case No. 20-1881)  
v. Navblazer LLC (Case No. IPR2020-01253)  
v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

- v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)
- v. Telefonaktiebolaget LM Ericsson (Case No. IPR2022-00275)
- v. Theta IP, LLC (Case No. IPR2024-00818)
- v. THL Holding Company LLC (Case No. 1:23-cv-00548)

- Fanduel

- v. CGT (Case No. 19-1393)

- Garmin

- v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)

- Netscout

- v. Longhorn HD LLC (Case No. 2:20-cv-00349)
  - v. Implicit, LLC (Case No. 2:18-cv-53-JRG)

- Sony Interactive Entertainment LLC

- v. Bot M8 LLC (Case No. IPR2020-01288)
  - v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)

- Tesla

- v. Charge Fusion Technologies LLC (Case No. IPR2025-00032)

- Unified Patents

- v. GE Video Compression (Case No. 2:19-cv-248)

Fish & Richardson

- Apple

- v. AliveCor (Case No. 3:21-cv-03958)
  - v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)
  - v. Koss Corporation (Case No. IPR2021-00305)

v. Masimo (Case No. IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)

v. Neonode (Case No. 21-cv-08872-EMC)

v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Resonant Sys. (Case No. 7:23-cv-00077-ADA)

- AsusTek Computer Inc.

v. Videolabs, Inc. (Case No. 22-CV-00720-ADA)

- Dell

v. Neo Wireless (Case No. IPR2022-00616)

- Dish Network

v. Entropic Communications, LLC (Case No. 2:2023-CV-01043)

v. Entropic Communications LLC (Case No. IPR2024-00393)

v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)

v. TQ Delta LLC (Case No. 18-1798)

- Evapco Dry Cooling

v. SPG Dry Cooling (Case No. IPR2021-00688)

- Genetec

v. Sensormatic Electronics (Case No. 1:20-CV-00760)

- Huawei

v. Bell Northern Research LLC (Case No. IPR2019-01174)

- Kianxis

v. Blue Yonder (Case No. 3:20-cv-03636)

- LG Electronics
  - v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)
- MediaTek
  - v. MOSAID (Case No. IPR2024-00718)
- Metaswitch
  - v. Sonus Networks (Case No. IPR2018-01719)
- Microsoft
  - v. Throughputer Inc (Case No. IPR2022-00757)
- Mom Enterprises
  - v. Ddrops Company (Case No. 1:22-cv-00332)
- MLC Intellectual Property
  - v. MicronTech (Case No. 3:14-cv-03657-SI)
- Nearmap Inc
  - v. EagleView Technologies (Case No. IPR2022-01009)
- Neuroderm Ltd.
  - v. Abbvie, Inc (Case No. PGR2022-00040)
- Posco Co Ltd.
  - v. Pascal Drillet et al. (Case No. IPR2025-00370)
- Realtek Semiconductor
  - v. Future Link (Case No. IPR2021-01182)

- Quectel
  - v. Koninklijke Philips (Case No. 1:20-cv-01710)
- Samsung
  - v. Aire Technology (Case No. IPR2022-00877)
  - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
  - v. Communication Technologies Inc (Case No. IPR2022-01221)
  - v. Jawbone Innovations (Case No. IPR2022-00865)
  - v. MemoryWeb LLC (Case No. IPR2022-00885)
  - v. Dodots Licensing Solutions (Case No. IPR2023-00701)
  - v. Telefonaktiebolaget LM Ericsson (Case No. IPR2021-00615)
- Texas Instruments
  - v. Vantage Micro LLC (Case No. IPR2020-01261)
- Xilinx
  - v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Goodwin Proctor

- Intel
  - v. Proxense, LLC (Case No. 6:24-cv-00283)
- Samsung Electronics
  - v. Mobile Data Technologies (Case No. 2:24-cv-00435)
- Taiwan Semiconductor Manufacturing Company Ltd.
  - v. Advanced Integrated Circuit Process LLC (Case No. 2:24-cv-00623)

Groombridge Wu

- Nearmap

v. Eagle View Technologies Inc. and Pictometry International Corp. (Case No. 2:21-cv-00283-TS-DAO)

Irell & Manella

- Curium

Latham & Watkins LLP

- Apple

v. Advanced Coding Research LLC

Leydig, Voit & Mayer, Ltd.

- Public Availability Consultancy

O'Melveny & Myers

- Apple

v. Maxell (Case No. 5:19-cv-00036-RWS)

- Disney Media & Entertainment Distribution LLC

v. Digital Media Technology Holdings, LLC (Case No. 2:22-cv-01642)

- Micron Technology Inc.

v. Besang Inc (Case No. IPR2023-00900)

- Samsung

v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Amazon
  - v. Nokia (Case No. IPR2024-00847 and IPR2024-00848)
  - v. Nokia Technologies Oy (Case No. IPR2024-00572)
- Heru Industries
  - v. The UAB Research Foundation (Case No. IPR2022-01148)
- Intel Corporation
  - v. BeSang Inc. (Case No. IPR2023-00991)
  - v. BitMICRO (Case No. 5:23-cv-00625)
  - v. Telefonaktiebolaget L M Ericsson (Case No. IPR2024-00610)
- Realtek Semiconductor
  - v. Future Link (Case No. IPR2021-01182)
- r-pac
  - v. Adasa, Inc. (Case No. 1:2024cv06102)
- Twitter Inc
  - v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)
- TCL Industries
  - v. Koninklijke Philips NV (Case No. IPR2021-00495, IPR2021-00496 and IPR2021-00497)
- VusionGroup
  - v. Hanshow (Case No. IPR2024-00857)

Pillsbury Winthrop Shaw Pittman

- Intel

- v. FG SRC LLC (Case No. 6:20-cv-00315)

- Gravel Rating Systems

- v. Costco (Case No. 4:21-cv-149)

- v. Lowe's Home Centers (Case No. 4:21-cv-150)

- v. T-Mobile USA (Case No. 4:21-cv-152)

- v. Kohl's Inc. (Case No. 4:21-cv-258)

- v. Under Armor (Case No. 4:21-cv-356)

Quinn Emanuel

- Exact Sciences Corporation

- v. Geneoscopy, Inc. (Case No. IPR2024-00459 and IPR2024-1330)

- ServiceNow, Inc.

- v. InQuisient, Inc. (Case No. 22-900-CJB)

- Wolfsped

- v. The Trustees of Purdue University (Case No. 1:2021-cv-00840)

Sheppard, Mullin, Richter & Hampton LLP

- Advanced Micro Devices, Inc and Pensando Systems, Inc.

- v. Concurrent Ventures LLC and Xtreamedge, Inc. (Case No. IPR2025-00478)

- Cadence Design Systems Inc.

- v. Semiconductor Design Technologies (Case No. 3:23-cv-01001)

Shook, Hardy & Bacon LLP

- HP Inc.

v. Universal Connectivity Technologies (Case No. 1:23-cv-01177)

Stern, Kessler, Goldstein & Fox

- Preliminary Research

Wilmer, Cutler, Pickering, Hale and Dorr

- Apple

v. Shunock (Case No. 1:23-cv-08598)

- Quest Diagnostics Inc., Haystack Oncology Inc. and Haystack Oncology GmbH

v. Natera, Inc. (Case No. 1:23-cv-08598)

- Roche Diabetes, Inc.

v. Trividia Health, Inc. (Case No. 1:24-cv-00668)

Willkie, Farr & Gallagher LLP

- Lenovo, Dell, HP

v. Universal Connectivity Technologies Inc. (Case No. 2:2023cv00449)

- Neurent

v. The Foundry, LLC (Case No. IPR2024-00669)

- Netflix, Inc.

v. VideoLabs, Inc. (Case No. IPR2023-00628)

# **Appendix YAHAYA01**



Keyword

Search...

Search

Advanced search Start Over

← Previous | 1 of 229 | Next →

Share

Bookmark

Report an Issue



# Optics express [electronic resource].

Additional Titles

Opt. express and Opt Express

Published

Washington, DC : Optical Society of America, 1997-

Additional Creators

[Optical Society of America](#)

Access Online

[serialssolutions.com](#)ASK  
A LIBRARIAN

## Dates of Publication and/or Sequential Designation

Vol. 1, no. 1 (July 7, 1997)-

## Subject(s)

[Optics—Periodicals](#)[Optics](#)

## Genre(s)

[Electronic journals](#)

## ISSN

1094-4087

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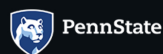
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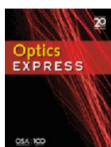
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## **Appendix YAHAYA02**

# Characterization of light absorption in thin-film silicon with periodic nanohole arrays

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**Abstract:** Light absorption in thin-film nanostructured monocrystalline silicon (c-Si) in a glass/Ag(0.2  $\mu\text{m}$ )/c-Si(1  $\mu\text{m}$ ) stack is characterized using simulations and measurements. Nanohole (NH) arrays designed for a practical thin-film solar cell configuration experimentally exhibit a significant improvement of the light absorption in the 1- $\mu\text{m}$  ultrathin c-Si layer that exceeds the theoretical Yablonovitch limit in the long wavelength range. Fabricated square-lattice and hexagonal NH arrays give relative improvements of 65 and 70%, respectively, in the total absorption compared to a nonpatterned stack. The effect of an indium-tin-oxide (ITO) coating is also simulated, and an empty NH configuration gives the lowest ITO parasitic absorption.

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**OCIS codes:** (310.0310) Thin films; (040.6040) Silicon; (040.5350) Photovoltaic; (160.4760) Optical properties; (050.5298) Photonic crystals.

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## 1. Introduction

Thin-film solar cells not only require less material for fabrication but also have a higher photocarrier concentration with less bulk recombination in the active layer compared to bulk crystal solar cells [1]. However, the light absorption depth in silicon is significantly longer at photon energies close to the band gap resulting in low absorption and therefore low efficiency.

To achieve better light absorption performance, several approaches such as diffraction gratings, photonic crystals, and metal nanoparticles [2–4] on the front or back surface of the solar cell have been introduced. Texturing the cell active layer with nanostructures has also been theoretically demonstrated to improve the possibility of enhancing the absorption [5–8]. Periodic high-aspect-ratio nanorod arrays with skewed pyramids exceed the Yablonovitch limit over a broad wavelength range [6], and periodic nanohole (NH) arrays exhibits better absorption than periodic nanorod arrays [9]. Motivated by these theoretical studies, the practical implementation of nanostructures in thin-film solar cells and its experimental verification has become an intriguing subject. Current silicon technology allows the low-cost fabrication of NH arrays over a large area with precise dimensions [10–12]. Experimental studies of periodic NH arrays on thick monocrystalline silicon (c-Si) solar cells have been reported [13–16]. Periodic NH arrays on thick silicon wafers reduce the reflection of broadband sunlight wavelengths [16] and increase the solar cell efficiency by 19% relative to nonpatterned silicon [14]. These experimental studies suggest the great potential of periodic NH arrays to enhance the light absorption of thinner thin-film c-Si solar cells. Studies focusing on absorption enhancement in ultrathin c-Si solar cells (e.g. <3  $\mu\text{m}$  thickness) with periodic NH arrays have been reported [7, 17–21], but, to the date, few have reported

experimental results [17, 19]. In addition, periodic NH geometry optimization has tended to be carried out using a rather simplified model and method.

In this paper, further investigation of the light absorption enhancement of periodic NH arrays on a 1- $\mu\text{m}$  ultrathin c-Si film with a silver back reflector was carried out to experimentally verify the optical performance with the aim of using these films in solar cell applications. We first optimize the NH array geometry and simulate the expected light absorption in the c-Si active layer by a 3D full-field finite difference time domain (FDTD) calculation using parallel supercomputing. Optical measurements of the optimized array geometry are then performed, and we examine the effects of different transparent conductive oxide (TCO) layer configurations.

## 2. Simulation model and methodology

Figure 1 shows a schematic diagram of a periodic NH array with the Ag back reflector; Ag is preferred due to its low loss characteristics [22]. The design parameters to be optimized are the lattice constant  $P$  and filling factor  $ff$ , defined as the volume ratio of air to one unit cell. The NH diameter is denoted by  $D$ . The NH depth  $h$ , thickness of the Ag back reflector, and c-Si layer thickness were fixed at 500 nm, 200 nm, and 1  $\mu\text{m}$ , respectively.

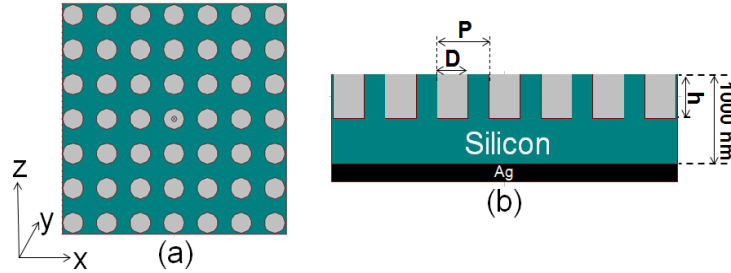


Fig. 1. Schematic of the c-Si NH arrays: (a) top view and (b) side view.

The spectral absorption characteristics of the proposed model were investigated by performing 3D full-field FDTD calculations using high-performance parallel supercomputing. The optical properties of Ag, c-Si, and indium-tin-oxide (ITO) were taken from the literature [23, 24]. Periodic boundary conditions were enforced in the  $x$  and  $z$  directions, while a perfectly matched layer (PML) boundary condition was applied in the  $y$  direction. Light was incident normal to the surface.

The total absorption in the c-Si layer can be expressed as

$$\alpha(\lambda) = \frac{\omega}{2} \int_V \text{Im}[\varepsilon(\omega)] |E(t)|^2 dV, \quad (1)$$

where  $E$  is the electric field,  $\varepsilon$  is the spatially dependent permittivity, and  $dV$  is the finite volume in the monitored volume  $V$ . According to theory describing the light to current conversion, the enhancement in the total light absorption can be quantified by the improvement in the short circuit current density. By assuming that each photon absorbed in the c-Si layer generates an electron-hole pair, the short circuit current density can be calculated as

$$J_{sc} = e \int_{300}^{1100} \alpha(\lambda) S(\lambda) d\lambda, \quad (2)$$

where  $e$  is the electron charge,  $\alpha(\lambda)$  is the optical absorption,  $\lambda$  is the wavelength, and  $S(\lambda)$  is the incident solar photon flux density from an air mass (AM) 1.5 G standard spectrum.

### 3. Results and discussion

#### 3.1 Optimization of the NH array geometry and comparison with perfect geometrical light trapping

The optimization was performed to maximize  $J_{sc}$  in the c-Si, that is, the active layer of a solar cell. The  $J_{sc}$  values for different  $P$  and  $ff$  combinations were compared. The maximum  $J_{sc}$  occurs at  $ff = 0.25$  for  $300 \text{ nm} \leq P \leq 600 \text{ nm}$ , and  $P = 600 \text{ nm}$  gives the highest  $J_{sc}$  value. For this  $P$  and  $ff$  combination, the effect of the NH depth  $h$  on  $J_{sc}$  is investigated for  $300 \text{ nm} \leq h \leq 900 \text{ nm}$ . Consequently,  $h = 500 \text{ nm}$  gives the highest  $J_{sc}$  value of around  $130 \text{ A/m}^2$ . It should be noted that, in general, surface recombination, which is not considered in the present  $J_{sc}$  calculation model, increases as the surface area increases, and hence degrades the conversion efficiency [25]. That is, in an actual thin-film NH solar cell, the best NH depth could be different from the present optimized depth.

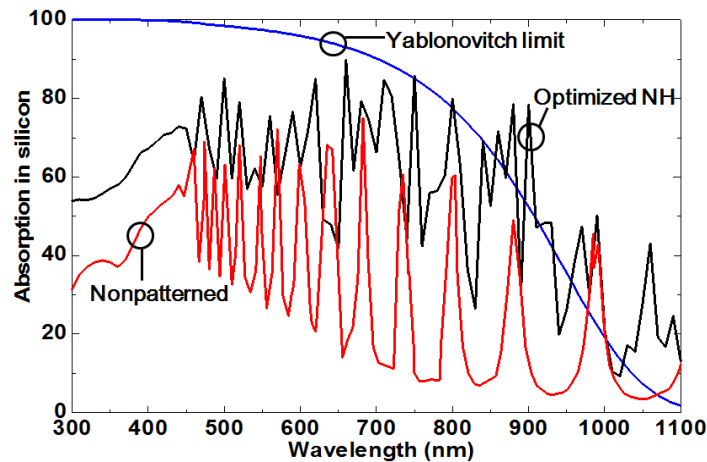


Fig. 2. Absorption spectra for the optimized c-Si NH array ( $P = 600 \text{ nm}$ ,  $ff = 0.25$ ,  $h = 500 \text{ nm}$ ) with a Ag back reflector compared to a nonpatterned c-Si with Ag back reflector, and the Yablonovitch limit. The incident angle is normal to the surface.

Figure 2 shows the spectral absorption in c-Si for the optimized NH geometry ( $P = 600 \text{ nm}$ ,  $ff = 0.25$ ,  $h = 500 \text{ nm}$ ). For comparison, the spectral absorption in a nonpatterned c-Si as well as the Yablonovitch limit (the theoretical limit of perfect geometrical light trapping [26]) are also shown. The NH array exhibits a higher absorption spectrum than the nonpatterned c-Si over the simulated spectrum range. The absorption enhancement seen in the short wavelength region is expected from the antireflective effect in which incident light sees the surface having a continuous refractive index gradient between air and the silicon [9]. However, in this short wavelength region, the NH array is unable to reach the Yablonovitch limit. In the longer wavelength region, the NH array absorption spectra shows absorption peaks with a complex, irregular shape. The absorption enhancement in this wavelength range could be expected from diffraction trapping of incident light [9] and resonant modes [27] attributed to the NH array. Several additional peaks caused by resonant modes can be observed in this wavelength range through a comparison with the nonpatterned c-Si. Some peaks exceed the Yablonovitch limit in the region where silicon is typically a poor absorber. These results support the recent literature emphasizing that NH arrays have a potentially good light trapping performance for thin-film silicon and consequently may contribute to efficiency enhancement in thin-film solar cells. Hereafter, “total absorption” refers to the integrated absorption weighted by a normalized AM1.5G standard spectrum. An increase of 100% relative to the nonpatterned c-Si was achieved.

### 3.2 Optical measurement of fabricated NH arrays

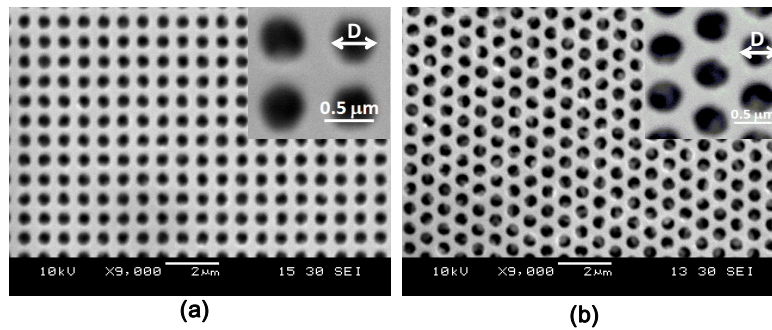


Fig. 3. SEM images of the fabricated (a) square-lattice and (b) hexagonal NH arrays on c-Si.

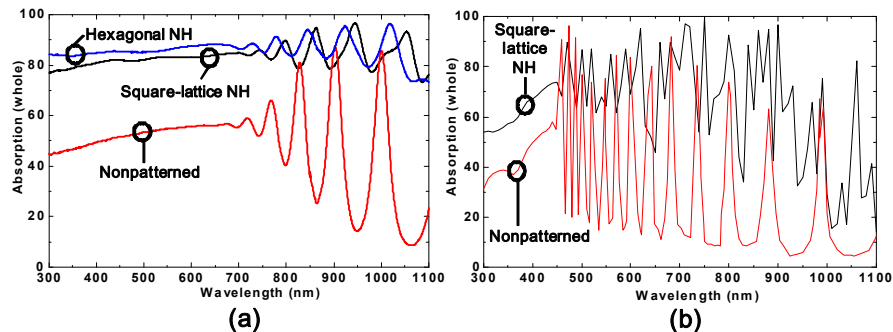


Fig. 4. Comparison of the (a) measured and (b) simulated absorption spectra of a whole stack.

NH arrays were fabricated with the optimized design parameters. A 1- $\mu\text{m}$  thick c-Si layer was fabricated on a silica glass substrate using magnetron sputtering, and the NH arrays were formed using an electron beam lithography technique and plasma etching. Both square-lattice and hexagonal NH arrays were fabricated, since hexagonal NH arrays on a “thick” (1 mm) c-Si wafer were shown in our previous study to have good absorption enhancement properties. A nonpatterned c-Si sample with the same dimensions was also fabricated as a reference. Figure 3 shows scanning electron microscope (SEM) images of the fabricated samples. The average NH depth measured using 3D laser scanning microscope (KEYENCE VK-X200) is approximately 470 nm. The reflectance measurements were performed using a ultraviolet-visible/near-infrared (UV-VIS/NIR) microscopic spectrophotometer (JASCO MSV-5200), which has a Cassegrain reflector that directs monochromatic light to the sample surface within a  $23^\circ$  incident angle of the normal and detects light reflected from the sample surface within the same  $23^\circ$  angle. The measurements were taken for wavelengths of 300 to 1100 nm in 0.5 nm steps, and the absorption of the whole stack was derived from  $\text{Abs}(\lambda) = 1 - \text{Ref}(\lambda) - \text{Trans}(\lambda)$ , where  $\text{Ref}(\lambda)$  and  $\text{Trans}(\lambda)$  are the reflection and transmission, respectively.

Figure 4 shows the measured and simulated absorption spectra of the NH arrays and the nonpatterned c-Si. The measured absorption of the NH arrays (Fig. 4(a)) shows remarkably higher values compared to the nonpatterned case as predicted by the simulations. However, the simulation showed more absorption peaks and a slightly lower absorption over the wavelength range than that seen in the measurement data. This could be caused mainly by the difference in the incident and detected angles in the measurement and simulation. In the measurement, the reflectance was observed as integrated reflectance within the  $23^\circ$  incident and detected angles and thus rapid fluctuations compensated each other, whereas in the simulation, the reflectance was obtained as hemispherical-integrated reflectance based on only the normal incidence. In addition, defects such as roughness, etched slopes, and a nonconstant

$ff$  could not be avoided in fabrication; these could also be responsible for a compensation of the rapid fluctuations. The measured relative improvements of the total absorption for the square-lattice and hexagonal NH arrays to the nonpatterned c-Si are 65 and 70%, which is a 7% improvement of that recently reported for the same silicon thickness [17].

### 3.3 Effect of ITO layer on NH arrays

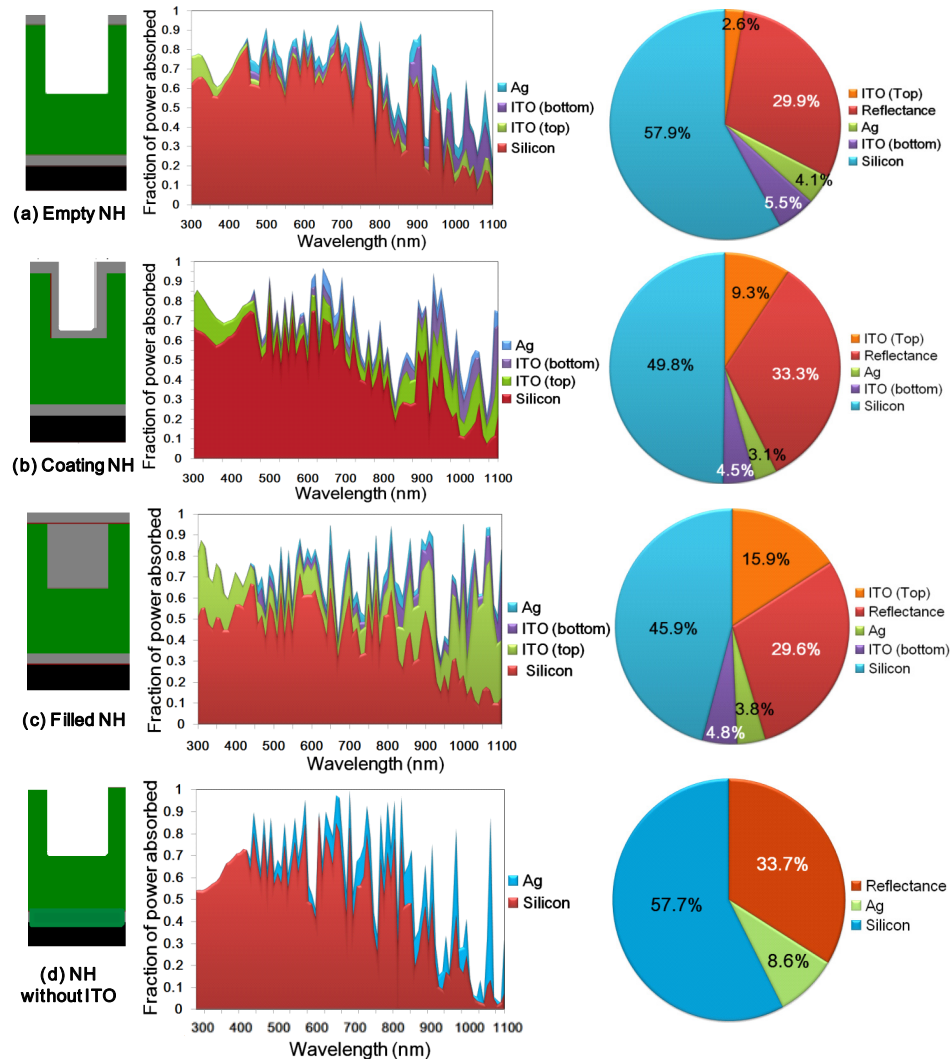


Fig. 5. (left) Three possible ITO layer configurations, (middle) calculated absorption in each layer of the stack, and (right) the total absorption and reflection percentages in each layer of the stack; (a) empty NH, (b) coated NH, (c) filled NH, and (d) NH without ITO. Optimized parameters for the square-lattice c-Si NH arrays are used for every configuration.

Introducing a transparent conductive oxide (TCO) layer into the solar cell will provide an antireflection effect contributed by the refractive index gradient at the TCO–c-Si interface and will reduce reflection losses. However, a portion of the trapped light can be absorbed by the TCO layer. This parasitic absorption will be counterproductive to improving the light absorption in the c-Si layer and the conversion efficiency. Therefore, it is important to investigate the effect of a TCO layer on the absorption spectrum. Here, ITO was selected as the TCO because of its suitable properties for thin-film solar cells [28].

Three possible top ITO layer configurations were modeled: an empty NH, a coated NH, and a filled NH as shown in Fig. 5 (left). The ITO layer was 85 nm thick, except in the case of the filled NH. This thickness has been reported to give the minimum reflectance [29]. Figure 5 (middle) shows the fraction of power absorbed in each layer of the whole stack. As expected, the empty NH shows the highest absorption in the c-Si layer and the filled NH shows the lowest. In the short wavelength range ( $<450$  nm), a substantial part of the incident light is absorbed by the top ITO layer for all configurations because at this wavelength range, the ITO extinction coefficient is relatively high. With the filled NH, the absorption in the c-Si is considerably decreased due to the excess volume of ITO. In the longer wavelength range ( $>450$  nm), the best case with the empty NH shows that the absorption in the top ITO layer remained low, but the absorption in the bottom ITO layer is slightly higher than that in the top ITO layer. A small amount of absorption loss occurs in the Ag back reflector. However, for the worse case with the filled NH, severe parasitic absorption occurs in the top ITO layer.

Figure 5 (right) shows the resulting total absorption and reflection percentages for each ITO configuration. Only the empty NH retains an approximately similar total absorption in c-Si (57.9% as compared to 57.7%). The coated and filled NH arrays decrease the absorption to 49.8 and 45.9%, respectively. Parasitic absorption in the top ITO layer is correlated to the ITO volume and accounted for 2.6, 9.3, and 15.9% in the empty, coated, and filled NH arrays, respectively. Absorption in the Ag layer and bottom ITO are very similar in all cases. Consequently, in terms of optical characterization, an empty NH array appears to be the best configuration. These results imply that investigating only the reflectance of the whole stack is not enough for evaluating the absorption in the c-Si layer. Furthermore, it should be noted that the above discussion is limited to the optical behavior of ITO. The electrical behavior of ITO also can play an important role in electron transport. Of these three configurations, the coated NH array may have the added advantage of fast electron transport.

#### 4. Conclusion

Improvement of the light absorption in periodic NH arrays on 1- $\mu\text{m}$  ultrathin c-Si with a Ag back reflector has been characterized through optical simulations and measurements. The simulation results show a relative improvement of 100% in the total absorption in the c-Si layer compared to nonpatterned c-Si. A stack fabricated with an optimized geometry shows a relative improvement of the total absorption in the whole stack of 65–70% compared to a nonpatterned stack. Owing to the parallel-supercomputing optimization, these improvements currently represent the best experimentally measured results for 1- $\mu\text{m}$  ultrathin c-Si NH arrays with a back reflector. Through investigations of different ITO configurations, an empty NH pattern was revealed to produce the lowest parasitic absorption of 2.6% in the top ITO layer. The present results support the optical advantages of NH arrays as an excellent thin-film silicon absorber, which implies a good potential for thin-film solar cell applications.

## **Appendix YAHAYA03**



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# **Appendix YAHAYA04**



 **Characterization of light absorption in thin-film silicon with periodic nanohole arrays**Nor Afifah Yahaya, Noboru Yamada, Yukio Kotaki, and Tadachika Nakayama  
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## OCIS Codes

(040.5350) Detectors : Photovoltaic  
(040.6040) Detectors : Silicon  
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