

W&Wsens Devices Inc.

Thin Silicon Photosensors For The Next Generation

¹
www.wwsensdevices.com

W&W Breakthrough Innovation at a Glance

Technology

Thin Silicon PD / APD / SPAD / Phototransistor with microholes allow for ***Photon Trapping*** resulting in high efficiency & low jitter in a wide wavelength range:
800 nm – 1000 nm Si & 800 nm – 1650 nm Ge on Si

Process

Fully compatible with CMOS / BiCMOS manufacturing process ; microhole etch using shallow trench isolation etch (STI)

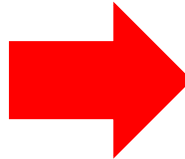
W&Wsens Light Trapping Technology

Impact on Current CIS / ToF

Core W&W Technology Advantages

Greater than 8X increase in sensitivity photosensors – for Red photosensors and IR night vision

Extremely low jitter – high depth resolution for ToF applications - 3D imaging



Performance Improvements Across Multiple Product Lines

Improve pixel performance at 850 nm
night vision, security / machine vision

Improve pixel performance at 905 nm
Time-of-Flight automotive ADAS

Improve pixel performance at 940 nm
Face recognition / 3D imaging for mobile phones & AR / VR

Improve depth resolution to millimeters accuracy for ToF applications, 3D imaging, AR / VR

W&W Light Trapping Technology Advantages

- ❖ Enhance sensitivity at Red and IR wavelengths
- ❖ Thin silicon, super low jitter, high depth resolution for ToF / 3D imaging
- ❖ 35X enhancement in absorption at 850 nm
- ❖ 37X enhancement in absorption at 905 nm
- ❖ Microholes dimension $\sim \lambda$
- ❖ Thin silicon less than 3 micron for BSI greatly reduce cost of manufacturing

W&Wsens Impact – Significant Improvement in IR Sensitivity

W&Wsens



High Speed Surface Illuminated Si Photodiode Using Microstructured Holes for Absorption Enhancement at 200–1000 nm Wavelength

Yang Gao,[†] Hilal Cansizoglu,[†] Soroush Ghandiparsi,[†] Cesar Bartolo-Perez,[†] Ekaterina Ponizovskaya Devine,[§] Toshishige Yamada,[‡] Aly F. Elrefaie,^{†,§} Shih-yuan Wang,[§] and M. Saif Islam^{*,†,§}

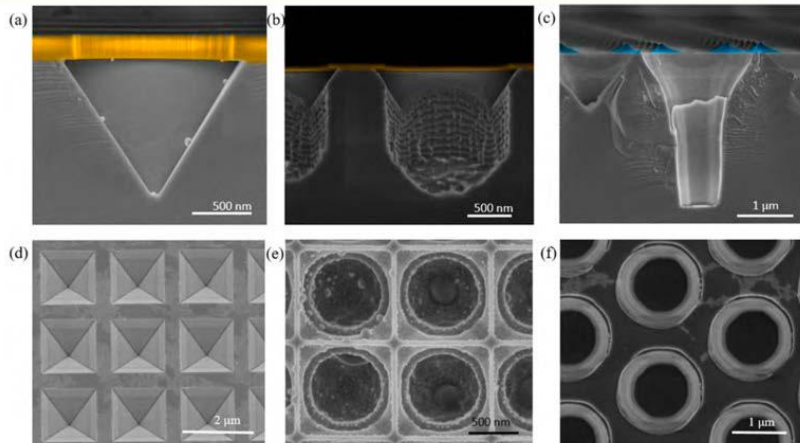
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ACS Photonics

Article



8X

Improvement

Sony

SCIENTIFIC REPORTS

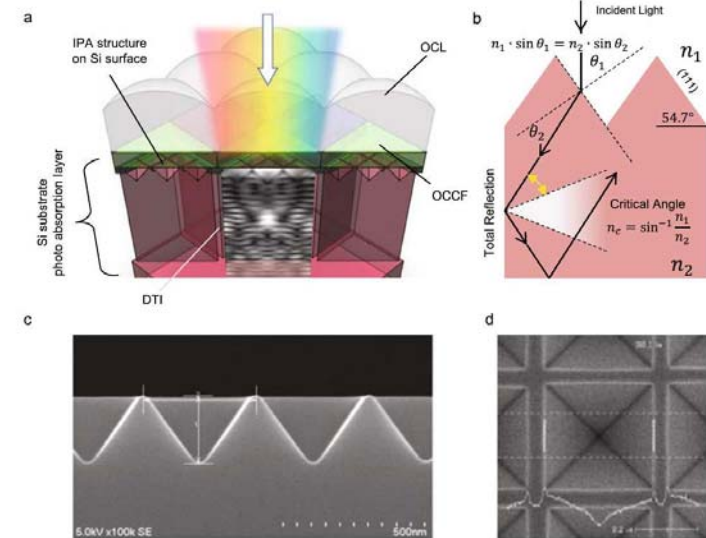
IR sensitivity enhancement of CMOS Image Sensor with diffractive light trapping pixels

Received: 30 January 2017

Accepted: 10 May 2017

Published online: 19 June 2017

Sozo Yokogawa, Itaru Oshiyama, Harumi Ikeda, Yoshiki Ebiko, Tomoyuki Hirano, Suguru Saito, Takashi Oinoue, Yoshiya Hagimoto & Hayato Iwamoto



1.8X

Improvement

W&Wsens Devices Inc. Worldwide IP Portfolio

32 Issued Patents and Published Patent Applications - Over 140 Provisional Patent Applications

United States Issued Patents:

1. US 9,496,435 B2 – Date issued: Nov. 15, 2016
2. US 9,525,084 B2 – Date issued: Dec. 20, 2016
3. US 9,530,905 B2 – Date issued: Dec. 27, 2016
4. US 9,818,893 B2 – Date issued: Nov. 14, 2017
5. US 10,446,700 B2 – Date issued: Oct 15, 2019
6. US 10,468,543 B2 – Date issued: Nov 5, 2019

United States Patent Allowed:

1. (application based on) US 2019/0019899 Publ: Jan. 17, 2019

United States Published Patents:

1. US 2020/0028000 A1 – Date published: Jan. 23, 2020
2. US 2019/0288132 A1 – Date published: Sep. 19, 2019
3. US 2019/0019899 A1 – Date published: Jan. 17, 2019
4. US 2018/0102442 A1 – Date published: Apr. 12, 2018
5. US 2016/0254407 A1 – Date published: Sep. 1, 2016
6. US 2016/0308075 A1 – Date published: Oct. 20, 2016
7. US 2017/0194522 A1 – Date published: Jul. 6, 2017
8. US 2016/0307939 A1 – Date published: Oct. 20, 2016
9. US 2016/0126381 A1 – Date published: May 5, 2016

International Published Patents:

1. WO 2019/018846 A3 – Date published: Jan. 24, 2019
2. WO 2019/089437 A1 – Date published: May 9, 2019
3. WO 2017/112747 A1 – Date published: Jun. 29, 2017
4. WO 2016/081476 A1 – Date published: May 26, 2016
5. WO 2014/190189 A2 – Date published: Nov. 27, 2014

China Issued Patents:

1. CN 107078145 B – Date issued: May 7, 2019
2. CN 105556680 B – Date issued: Dec. 22 2017

China Published Patent:

1. CN 109155340 A – Date published: Jan 4, 2019
2. CN 107078145 A – Date published: Aug. 18, 2017
3. CN 105556680 A – Date published: May 4, 2016

Japan Published Patents:

1. JP 2018-508970 A – Date published : Mar. 29, 2018

Japan Patent Allowed

1. JP 2016-526295 A – Date published : Sep. 1, 2016

Korea Published Patents:

1. KR 10-2016-0039150 – Date published: Oct. 2016

Europe Published Patents:

1. EP 3411906 A1 – Date published: Dec 12, 2018
2. EP 3221895 A1 – Date published: Aug. 15, 2018
3. EP 3000134 A2 – Date published: Mar. 30, 2016

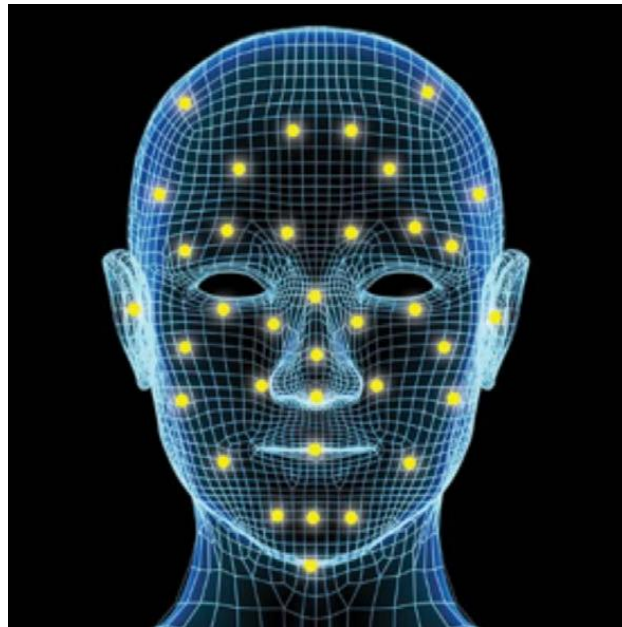
W&W Thin Silicon Photosensor Core

Application Sectors

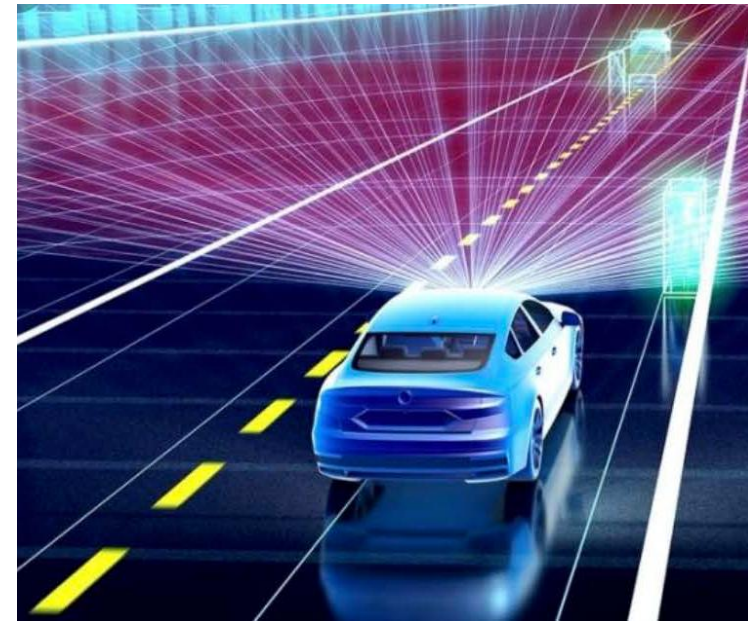
Optical Data Center Interconnect



3D Imaging & Gesture Recognition



LiDAR / Flash LiDAR for ADAS



Global 3D Imaging Market Outlook

**2017 - 3D Imaging & Sensing
revenue breakdown
by markets**



**X9
CAGR +44%**

YOLE
Développement



Courtesy of Apple

**2023e - 3D Imaging & Sensing
revenue breakdown
by markets**



Market	2017	2023e	CAGR
Consumer	375	13,773	82%
Automotive	391	2,383	35%
Medical	186	240	4%
Industry/Commercial	841	1,658	12%
Scientific/Defense/Space	268	471	10%
TOTAL	2,062	18,524	44%

3D Imaging & Sensing – Market & Technology Report | www.yole.fr | ©2018

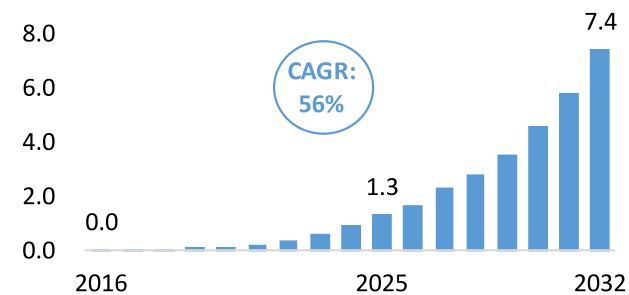
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Global LiDAR Market Outlook

LiDAR is a key enabler for capturing real-time 3D data

	LIDAR	Short Range Radar 24 GHz UWB	Long Range Radar 77 GHz	Ultrasonic	Vision	Infrared
Short Range (0-2MM)						
Nominal Range (2-30MM)						
Long Range (30-100MM)						
Narrow Vertical FOV <10deg						
Wide Vertical FOV >30deg						
Angular resolution						
Object speed measurement						
Bad weather operation						
Blockage (impurity on sensor)						
Night operation						
Sensitivity to Light						
Cost						

LiDAR Shipment Forecast⁽¹⁾
(mm units)



- **LiDAR is expected to be a \$7-8bn market by 2030**, with a majority of revenues coming from solid-state and flash LiDAR systems⁽¹⁾
- Between 2015 and 2025, **10 key auto OEMs are expected to spend ~\$345bn** on autonomous, connectivity, and electrification R&D⁽²⁾
- IEEE estimates that roughly **75% of road-borne traffic should include self-driving cars** by the year 2040⁽³⁾
- Prominent auto OEMs are asking for LiDAR modules to **cost less than \$100**
 - Currently, best-in-class LiDAR modules are almost **80x more expensive** today

(1) Source: Yole – The Automotive LiDAR Market April 2018.

(2) Source: Frost Perspectives – July 14, 2017.

(3) Source: Technavio – Global Automotive LiDAR Sensors Market 2016-2020.

Global DCI Market Outlook

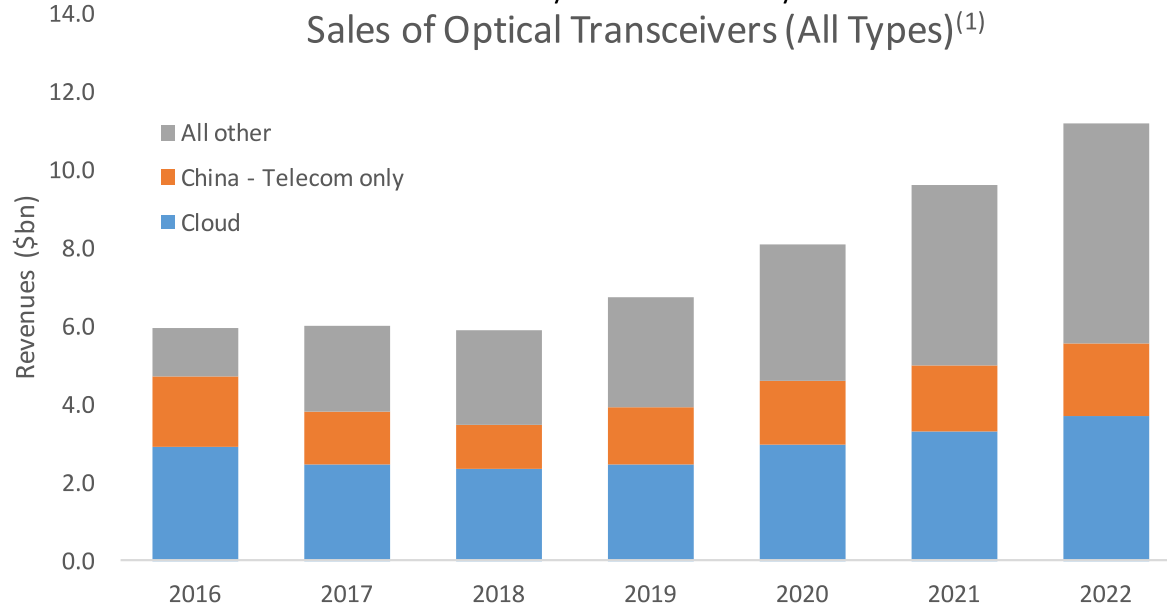
Optical Data Center Interconnect

W&W Total Addressable Market Size for Data Center Interconnect = \$3.7bn

850 nm (short reach) segmentation = 40% of optical data center interconnect market

Growth Drivers

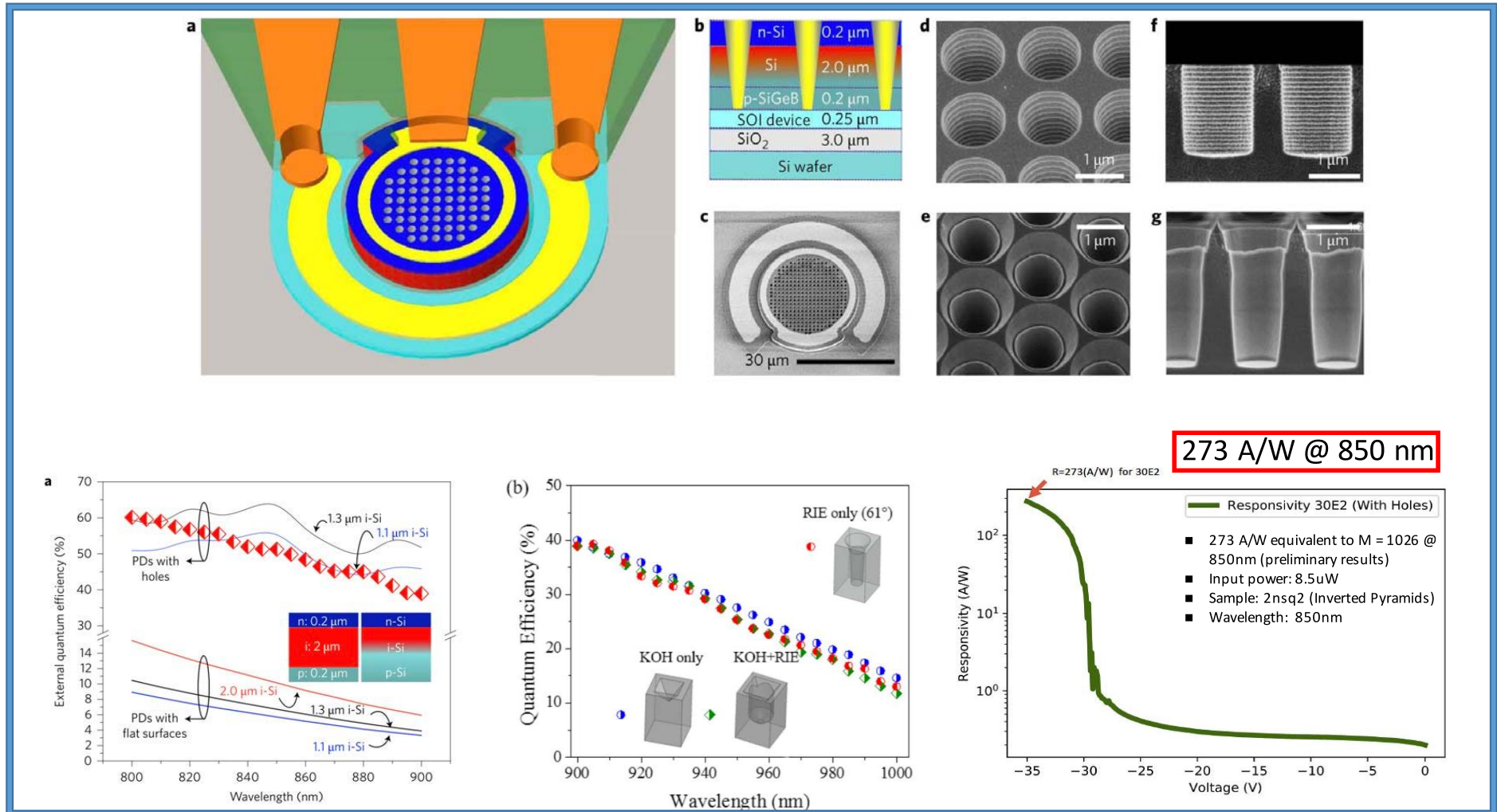
- Total Data Traffic CAGR [4yr] = 57%
- Monthly data traffic to reach 19.2 EB (1 Exabyte = 1 Billion Gigabytes)
- 73% of all data traffic stays within data centers
- Data centers set to increase by 60% over next 4 years



(1) Source: LightCounting April 2018.

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Microholes to Enhance Sensitivity 800 – 1000 nm Wavelength



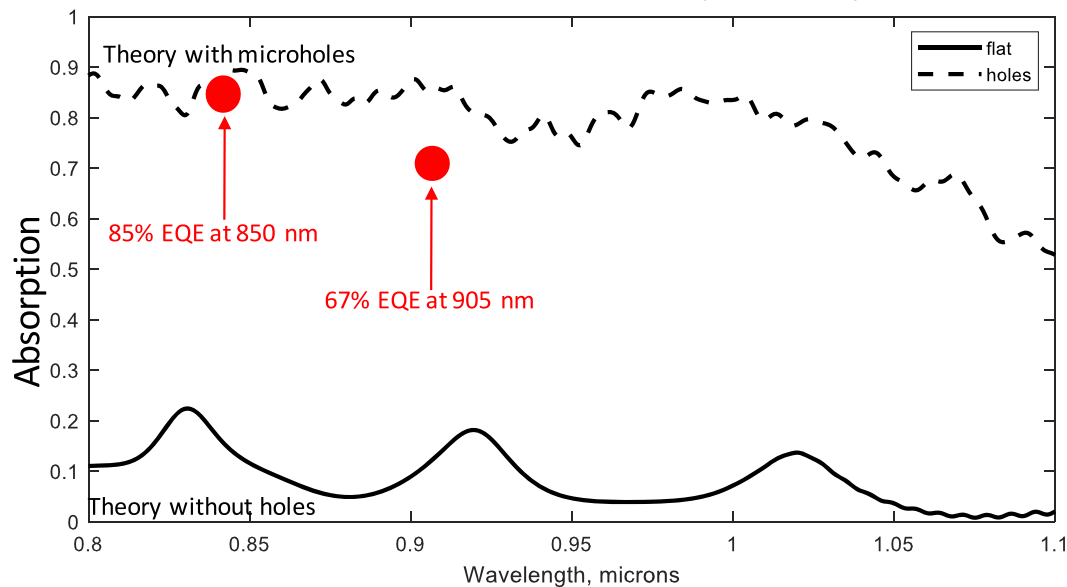
Y. Gao et al, Photon-Trapping Microstructures Enable High-speed High-efficiency Silicon Photodiodes ; Nature Photonics 3 April 2017

Y. Gao et al, High Speed Surface illuminated Silicon Photodiode Using Microstructure Holes for Absorption Enhancement at 900 – 1000 nm Wavelength ; ACS Photonics, DOI 10.1021/acsphotonics.7b00486

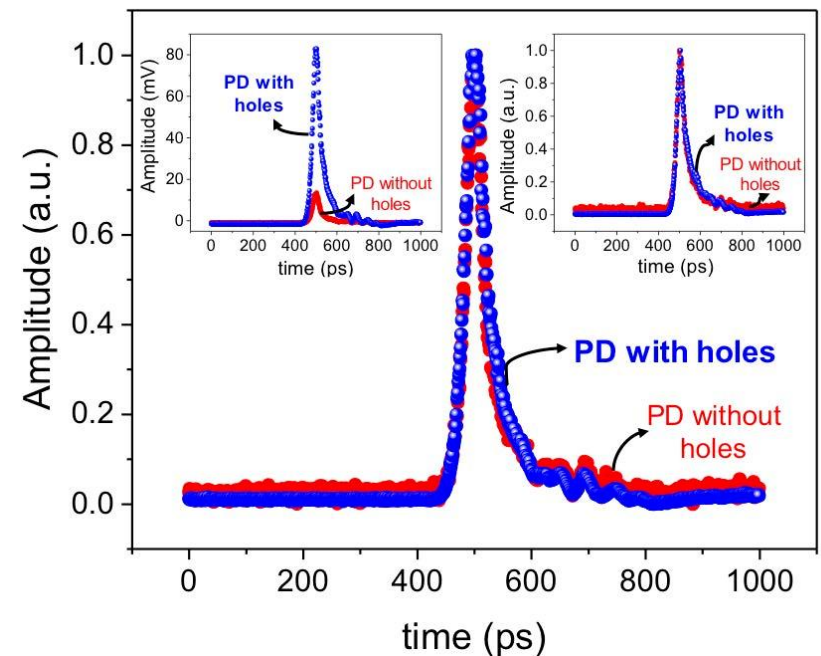
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1 Micron Thick Silicon with Microholes to Enhance Sensitivity and to Reduce Jitter

Si MSM Microstructure Hole Enhanced Absorption- FDTD Simulation 700 nm diameter, 1000 nm period, square lattice



MSM Impulse Response 850 nm



W&Wsens Summary

- ✓ **Disruptive photo detection technology with a simple microhole structure for seamless CMOS / BiCMOS monolithic integration**
- ✓ **IR Sensitivity Enhancement with light trapping**
- ✓ **Wavelength 800 – 1000 nm Si ; 800 – 1650 nm Ge on Si. Pico second rise time, <35 volt APD**
- ✓ **Pico second jitter for high depth resolution in ToF applications**
- ✓ **Addresses massive and fast growing markets (3D Imaging , AR/VR, DCI & LiDAR)**
- ✓ **Strong worldwide IP portfolio – 32 issued & published patents, 140+ provisional filings in US, EU, China, Japan and South Korea**
- ✓ **Strong publications, including 1 in Nature, 5 in IEEE and 3 in other journals**

W&Wsens Key Publications

All experimental results have been published in the following articles

Photon-Trapping Microstructures Enable High-Speed Efficiency Silicon Photodiodes ; Nature Photonics 2017

High Speed Surface Illuminated Si Photodiode Using Microstructured Holes for Absorption Enhancements at 900-1000nm Wavelength; ACS Photonics 2017

A New Paradigm in High-Speed and High-Efficiency Silicon Photodiodes for Communication Part I: Enhancing Photon-Material Interactions via Low-Dimensional Structures ; IEEE TED 2017

A New Paradigm in High-Speed and High-Efficiency Silicon Photodiodes for Communication Part II: Device and VLSI Integration Challenges for Low-Dimensional Structures ; IEEE TED 2017

High-Speed High-Efficiency Broadband Silicon Photodiodes for Short-Reach Optical Interconnects in Data Centers; OFC 2018

Surface-illuminated photon-trapping high-speed Ge-on-Si photodiodes with improved efficiency up to 1700nm ; Photonics Research OSA 2018

Enhanced Photon Detection Efficiency of Silicon Single Photon Avalanche Photodetectors Enabled by Photon Trapping Structure ; DOI:10.1109/PHOSST.2018.8456744 IEEE 2018

High-Speed High-Efficiency Photon-Trapping Broadband Silicon PIN Photodiodes for Short-Reach Optical Interconnects in Data Centers; IEEE 2019

Dramatically Enhanced Efficiency in Ultra-fast Silicon MSM Photodiodes with Photon-trapping Structures; IEEE 2019