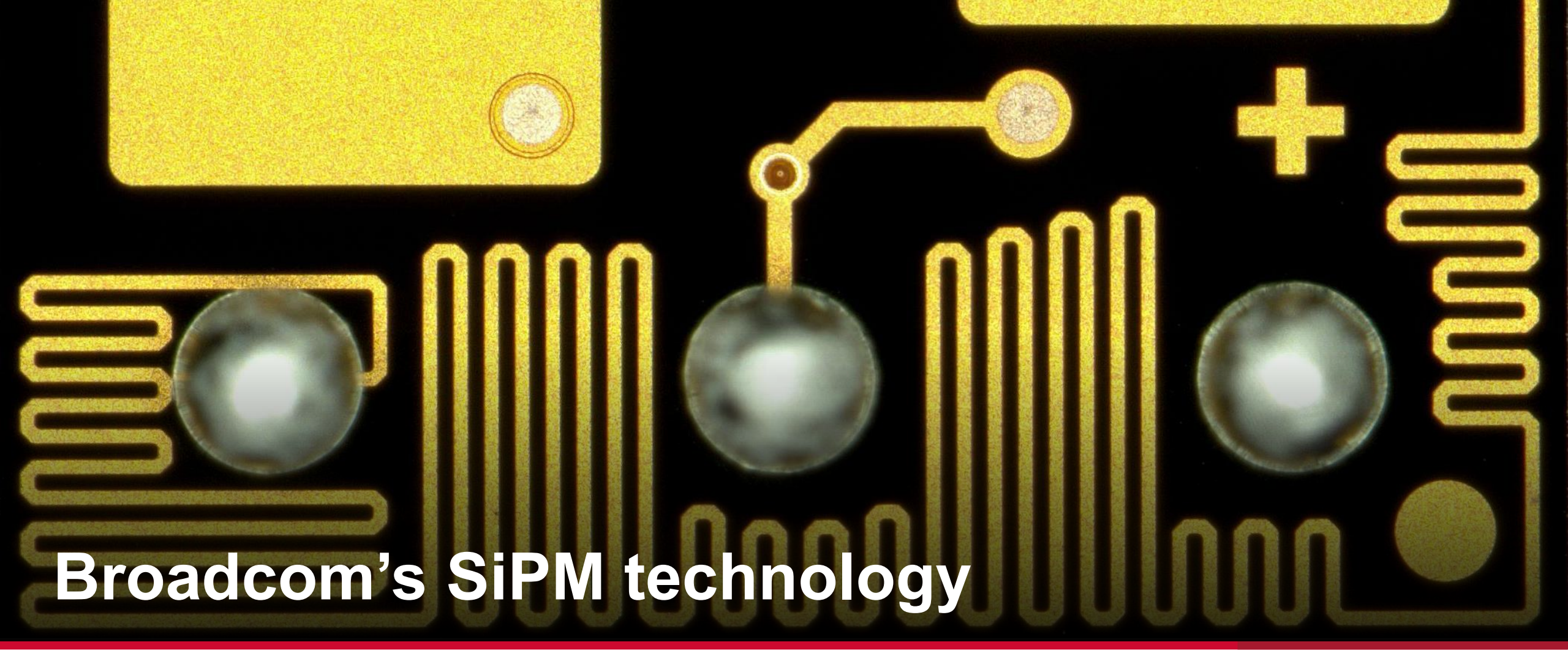


Broadcom’s SiPM technology

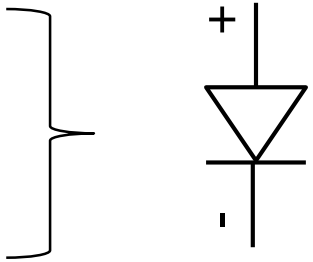
IFPD

November 2022

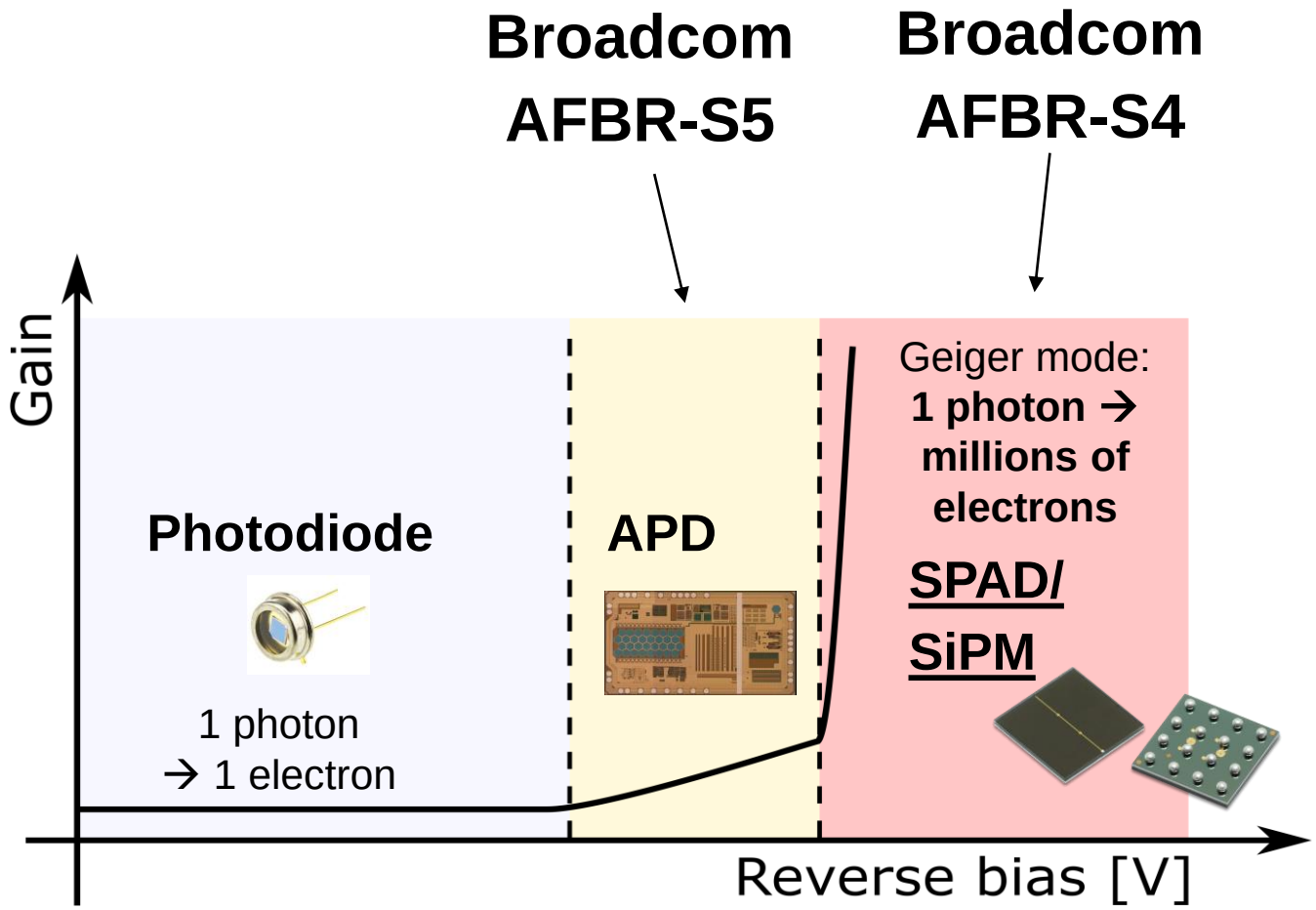
BROADCOM®

Photodiode – APD – SPAD/SiPM

- p-n junctions in semiconductors are the basis of
  - **Photodiodes**
  - **APDs**
  - **SPADs**



- Can be differentiated by gain
- Gain can be driven by reverse bias
- Photodiode: no gain
- **APD:** Avalanche Photodiode, internal gain 10 to 100
- **SPAD:** single photon avalanche diode, internal gain few k up to 10M
- **SiPM:** is an array of SPADs



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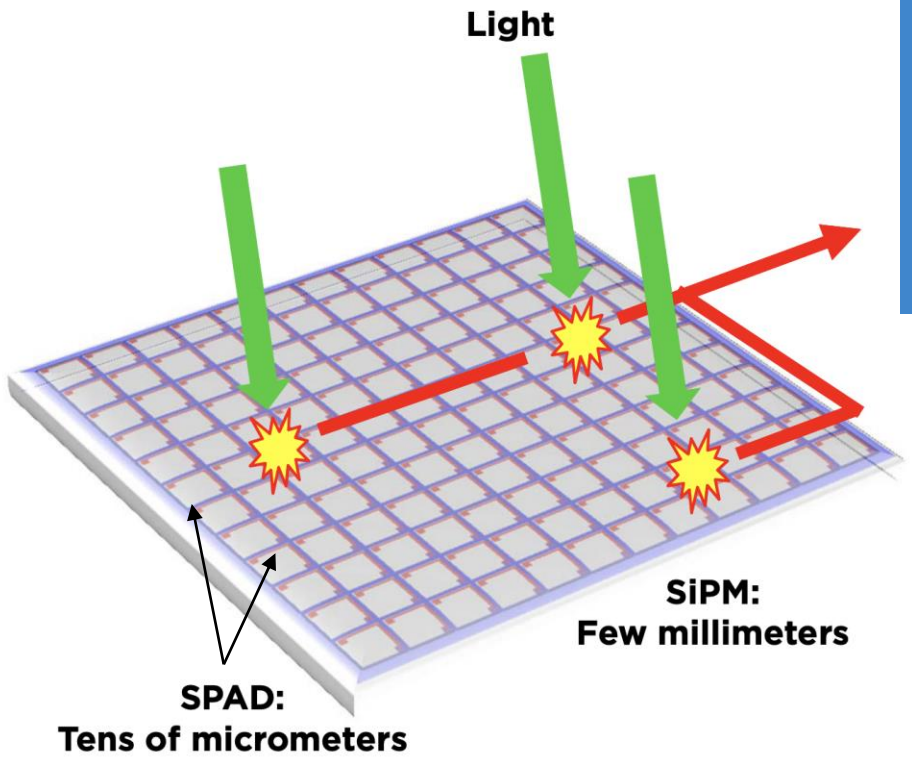
Silicon Photomultiplier (SiPM)

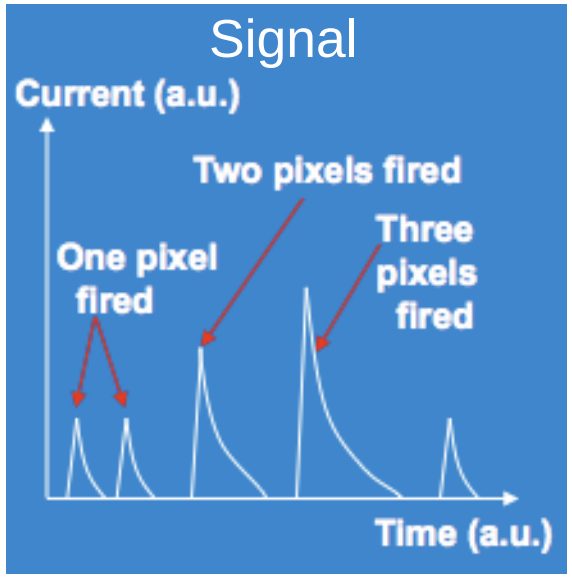
An SiPM is

- an array of single photon avalanche diodes (SPADs)
- sensitive to single photons
- providing very high internal gain → quasi-digital states of SPADs (on/off)
- very fast

An SiPM is NOT

- an imaging/camera sensor!!!





Images: Wikimedia, Politecnico Milano, www.everyphotoncounts.com

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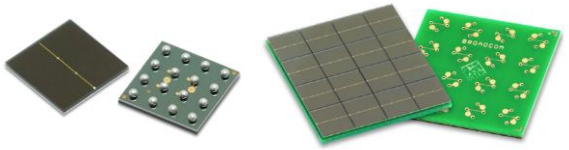
SiPM roadmap



NUV-HD
products released

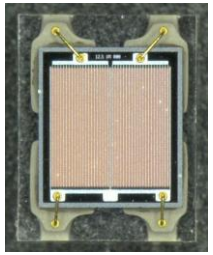
- Acquisition of KETEK SiPM assets

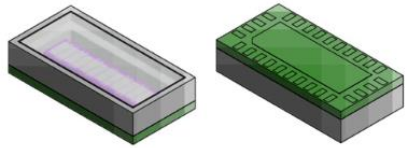
- Technology Upgrade NUV-MT
- Over molded package

New form-factors

AFBR-S4N BLUE/NUV | 2018/19 | 2021 | 2022 | 2023

- Technology development NIR
- Development of NIR packages
- Release of first NIR products





- 1x24 NIR array
- Optimization of 2nd gen NIR-technology

AFBR-S4P RED/NIR | 2022 | 2023

Custom SiPM-ASIC developments ongoing

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AFBR-S4 Silicon Photomultipliers: Applications

SiPM

NUV-SIPM
AFBR-S4N

NIR-SIPM
AFBR-S4P

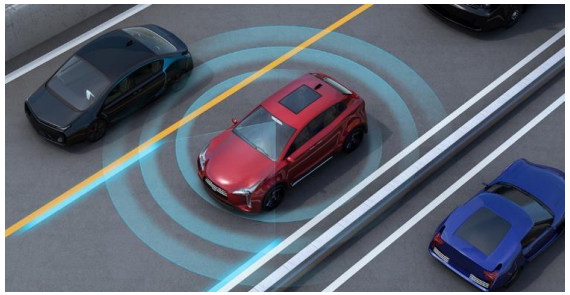
Medical

Industrial

Automotive

Positron Emission Tomography (PET)

Safety / Security
- Border Control
- CBRN defense
- Nucelar decomissioning



Life-Sciences:
- Radon detetection
- Flow cytometry
- Hygiene detectors
- Cell sorting
- Time-corellated fluorescence

Photon-counting CT

Mining / Geology
- Muon Tomography
- Photon Counting X-ray

Data-comm
- Underwater comm.
- Long-distance line-of-sight

LiDAR & Ranging

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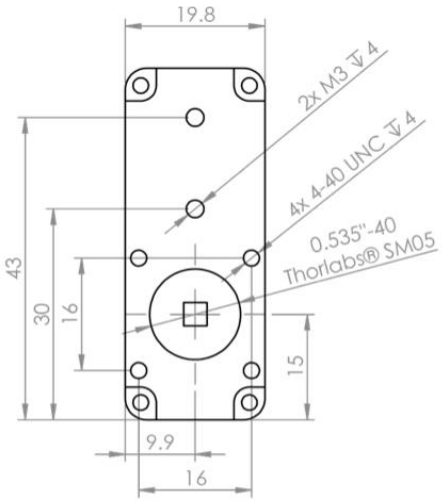
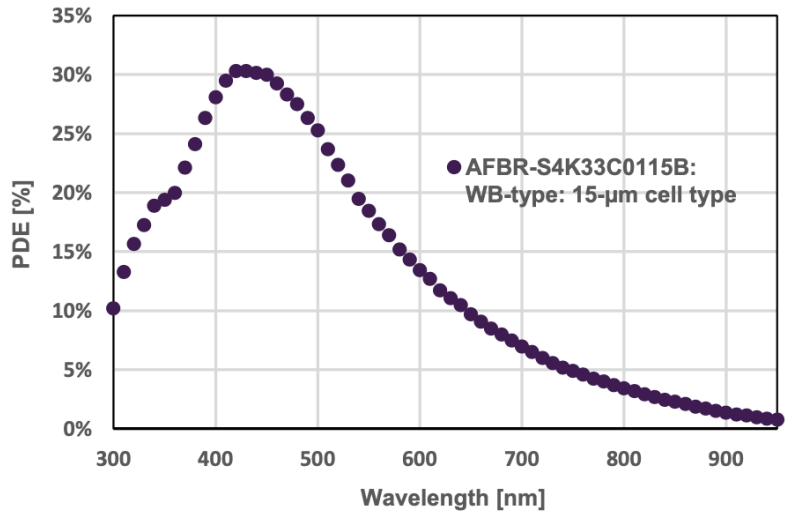
Integrated SiPM TIA modules AFBR-S4KTIA3315B

- Features
  - Integrated TIA
  - Integrated SiPM Bias Supply
  - Adjustable gain
  - Housing compatible with Thorlabs SM05 cage mount
  - Housing compatible with standard PMT-modules
- Connections:
  - Input 1: Bias 5V
  - Input 2: Bias control 0 to 1V
  - Output 1: Analog signal out (coax)
- Applications
  - Flow Cytometry
  - Life Sciences





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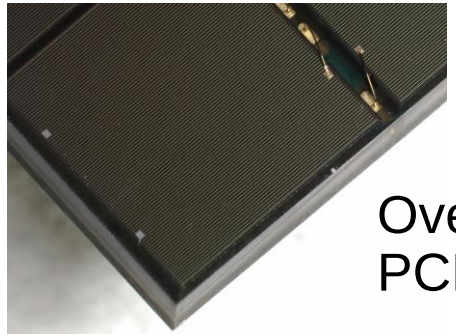
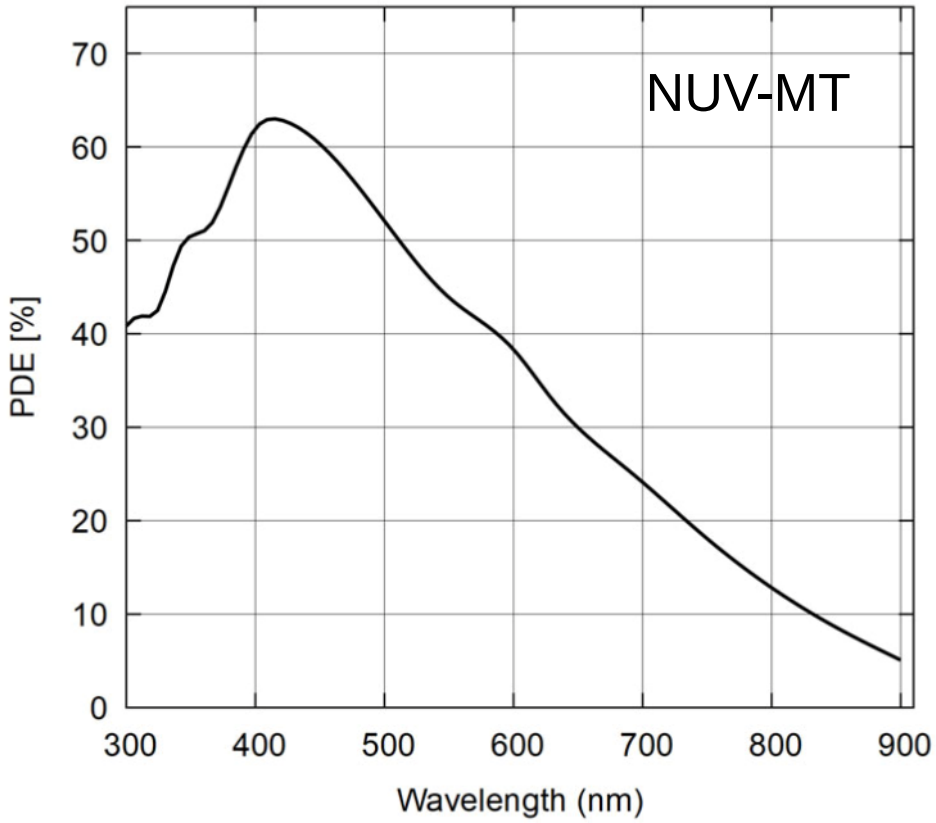
AFBR-S4N: NUV-SiPM Technology

	NUV-HD	NUV-MT
Package	CSP	Overmolded PCB
Sensitivity range (nm)	250 to 900	250 to 900
Peak sensitivity (nm)	420	420
PDE at peak sensitivity (%)	54	63
Gain (M)	3.2	7.3
DCR (kcps/mm2)	270	120
SPAD pitch (µm)	30	40
CT (%)	34	23
AP (%)	1	1
Recharge time constant (ns)	50	55
Typ. OV	7	12
Vbreak (V)	26.9	32.5
Status	Productive	Productive



Overmolded PCB



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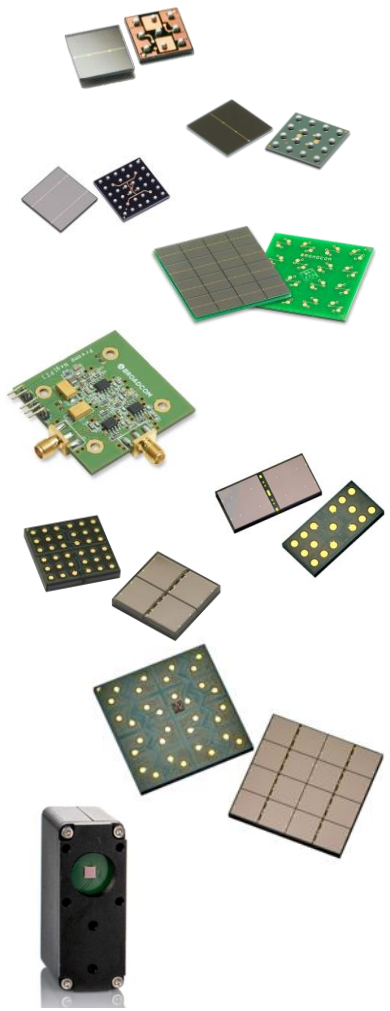
AFBR-S4N: NUV-SiPM Product Summary



Part no	Technology	Size (mm^2)	Channels	Package	Status
AFBR-S4N33C013	NUV-HD	3 x 3	1	CSP	Productive
AFBR-S4N44C013	NUV-HD	4 x 4	1	CSP	Productive
AFBR-S4N66C013	NUV-HD	6 x 6	1	CSP	Productive
AFBR-S4N44P163	NUV-HD	16 x 16	4 x 4	CSP	Productive
AFBR-S4E001	NUV-HD	4 x 4	1	Eval-Kit	Productive
AFBR-S4N66P024M	NUV-MT	13 x 6	2 x 1	Overmolded PCB	Productive
AFBR-S4N44P044M	NUV-MT	8 x 8	2 x 2	Overmolded PCB	E-samples
AFBR-S4N44P164M	NUV-MT	16 x 16	4 x 4	Overmolded PCB	Productive
AFBR-S4N44P014M	NUV-MT	4 x 4	1	Overmolded PCB	E-samples
AFBR-S4N66P014M	NUV-MT	6 x 6	1	Overmolded PCB	E-samples
AFBR-S4KTIA3315B	NUV-B*	3 x 3	1	TIA-module	Productive

*upgrade to NUV-MT planned

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Application Focus: Safety & Security

- Task: detect radiation or high energy X-rays using scintillators and SiPM (scintillators convert radiation to visible light, SiPM detects visible light!)
- Requirements for photodetector in Security Applications:
  - High speed & High sensitivity
- Special advantages of SiPM for Hand-Held devices:
  - **Robust**
  - **Low voltage**
  - **Can be battery powered**
  - **Insensitive to magnetic fields**
- Keywords to watch for:
  Chemical Biological Radiological and Nuclear (CBRN) defense, EHS, portal monitor, cargo screening, scintillation, radiation detection, radiation safety, border control, nuclear instrumentation/ decommissioning /decontamination, dosimetry

PMTs are still state-of-the-art, but SiPMs will replace PMTs, because SiPMs are much smaller, less expensive, more robust and require a much lower operating voltage.

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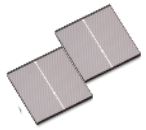
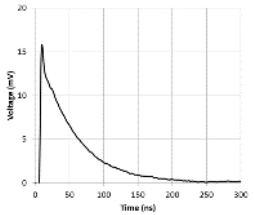
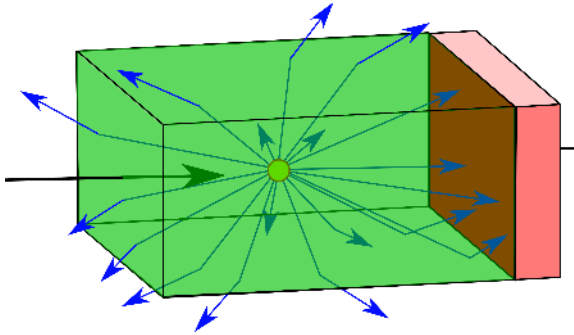
Radiation detection with SiPMs

Radiation (e.g. gamma) → digital signal

Radiation → **Scintillation** (light flash) → **Light detection** (PMT, SiPM,) → **signal**

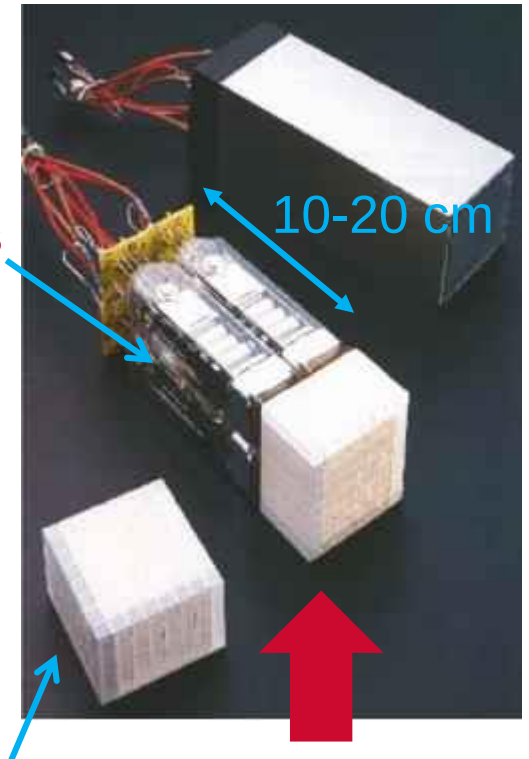


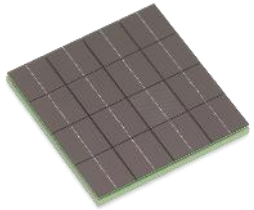




Energy (photon counting)

Time





SiPM thickness:
few mm!

SiPMs are perfectly suited to detect scintillation light!

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Roadmap for NIR SiPMs for Broadcom IFPD

NUV-HD

Medical / PET

Safety & Security

NIR

Automotive Lidar

Industrial / Robotics

2018 → **2023**

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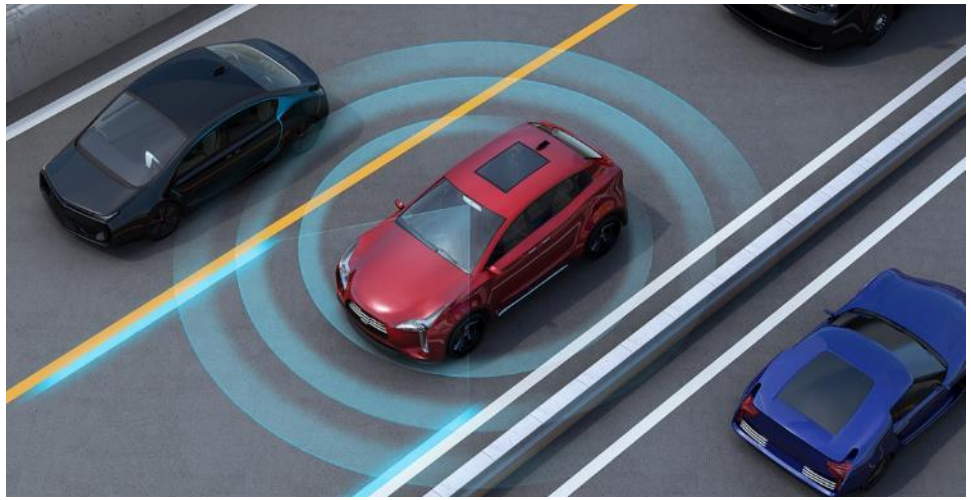
NIR vs. longer wavelength in LiDAR systems

- NIR LiDAR at 905 nm wavelength enables
  - Lower laser and receiver cost
  - Higher robustness of silicon detector
  - Lower power consumption
  - Better scalability for high volume



- NIR LiDAR at 905 nm limitation
  - Lower emitted optical power to meet eye safety
  - ➢ High PDE receivers required

➢ NIR is ideal for high volume LiDAR enabling high performance industrial robotics and automotive ADAS.

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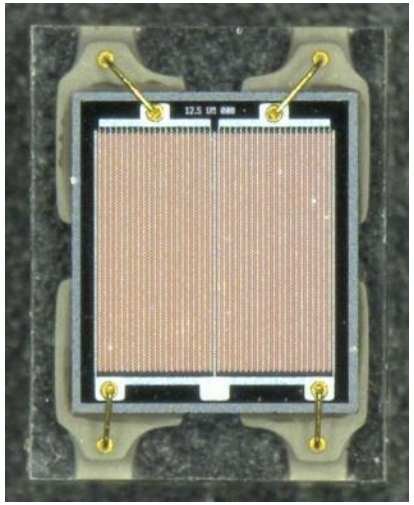
Broadcom's NIR30 SiPM Technology Advantages

- Completely new SPAD structure optimized for LiDAR application
  - **PDE at 905 nm: ~30%**
  - **High dynamic range: > 6000 SPADs / 1 mm²**
  - **Recharge time constant (DC out): < 20 ns**
  - **Optical cross talk: < 5 %**
  - **Bias voltage: < 60 V**



- Engineering samples available
  - Dual Channel: 1 x 1 mm² active area
  - 1x24 Channel Array: 5.6 x 1.1 mm² active area
- Development of custom detectors also with smaller channel size possible

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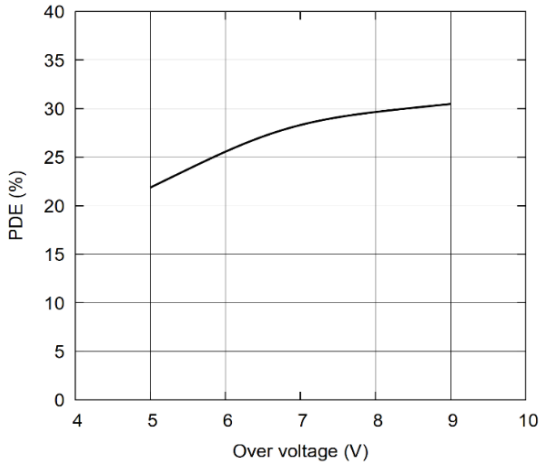
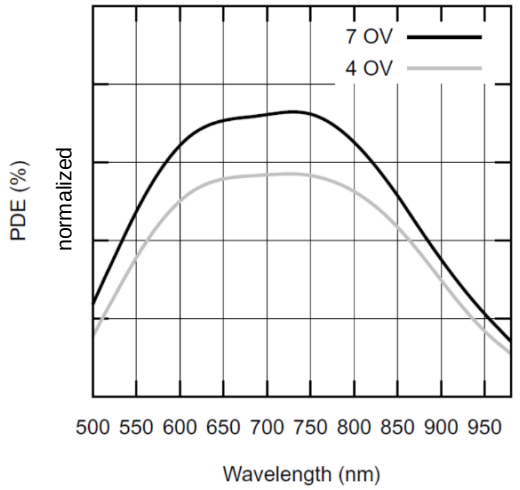
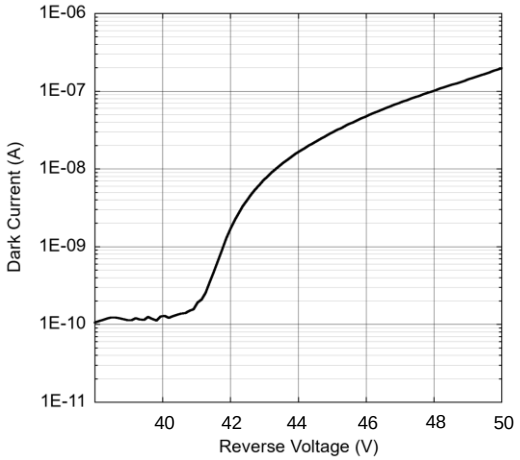
Next Technology Generation NIR30

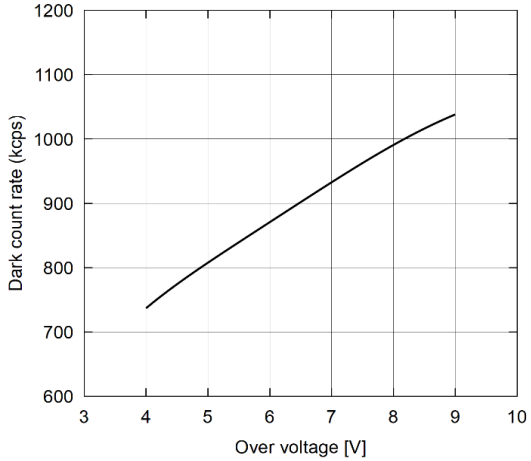
- Higher PDE: about 30% @905 nm
- Low direct cross talk: less than 5%
- Reduced after pulsing and long tail noise

Graphs are exemplary, final performance is under evaluation









➢ Engineering samples available

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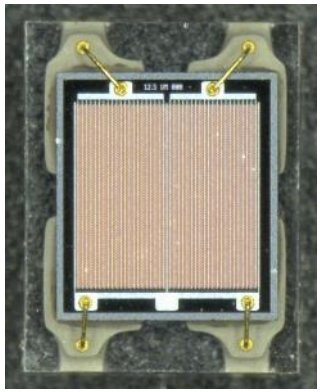
SiPM NIR30 1x2 Channels for Industrial Market



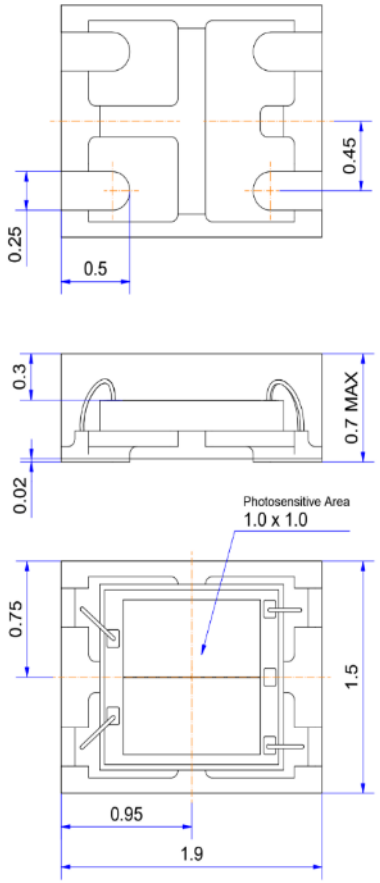
AFBR-S4P11P012R

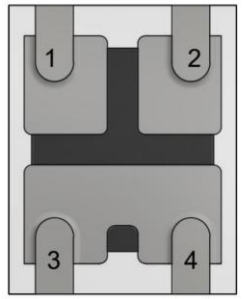
Features

- Active area 1 x 1 mm^2 (can be split in 1x2 array)
- PDE higher than 30% at λ=905 nm
- Wide dynamic range
- Very fast cell recharge time constant (< 15 ns)
- Low bias voltage (< 60 V)
- Compact moulded lead frame package
- Operating temperature range from -40 to +85 °C

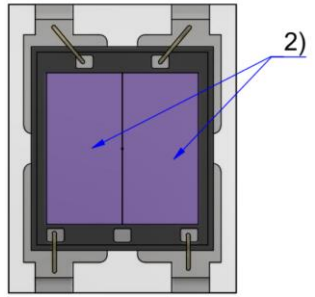
Engineering Samples available

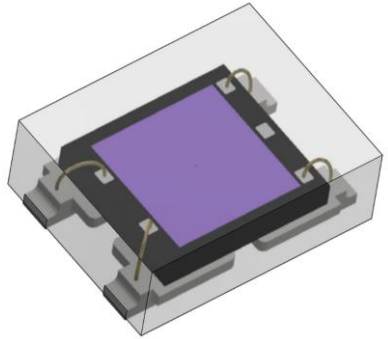
Product Release end Q2 CY23





Pin Assignment	
Pin #	Description
1	Cathode 1
2	Cathode 2
3	Anode
4	Anode





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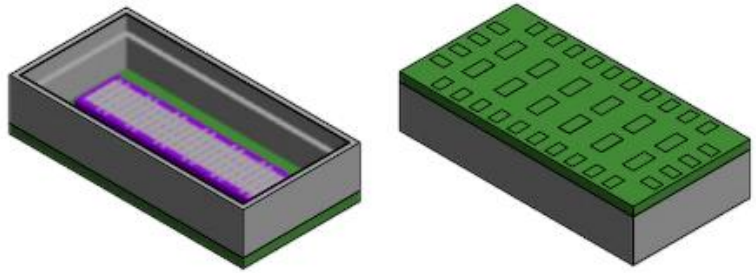
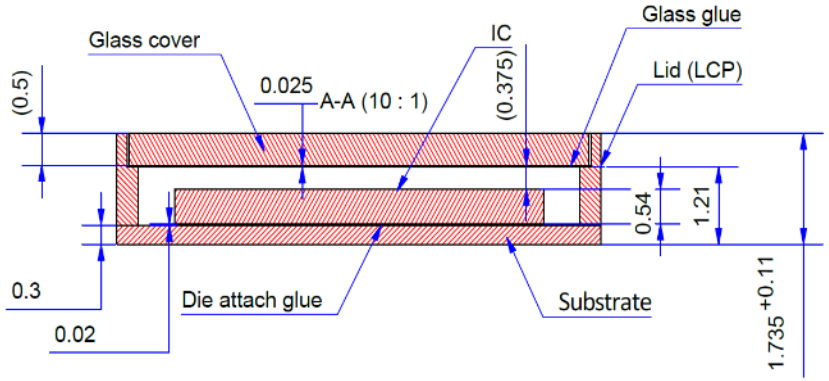
SiPM NIR30 1x24 Array Package Dimensions

AFBR-S4P0124P2RA

Features

- 1x24 Channel Array with ~0.25 x 1.1 mm² active area per channel
- Broadcom NIR30 SiPM Process
- 28-pin 8 x 4 mm² optical quad flat no leads package (OQFN)
- AR Coated cover glass (optimized for 905 nm range)
- AEC-Q102 qualified
- -40 to 105 °C ambient temperature range
- IATF 16949 certified production line





Package cross section

Engineering samples available

SOP Q3 CY23

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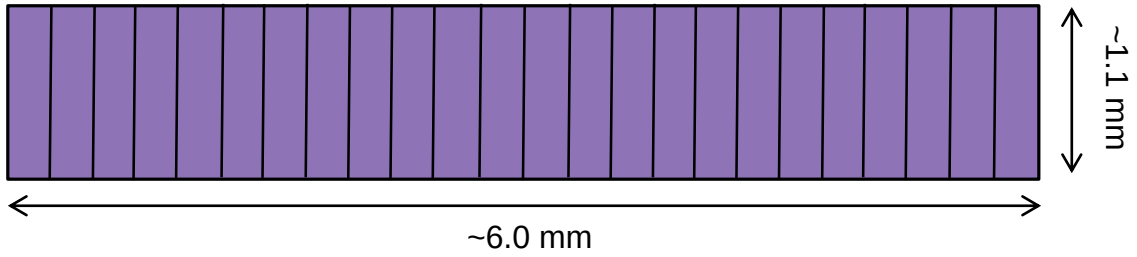
SiPM NIR20 1x24 Array for High Resolution Scanner Application

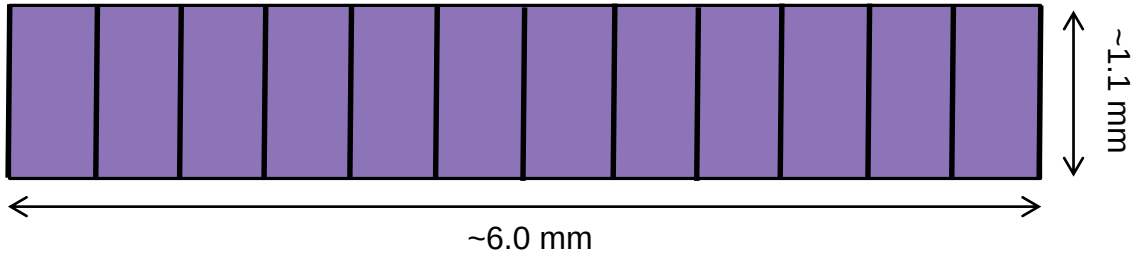
1x24



- channel ~0.25 x 1.1 mm²
- ~ 1:4 aspect ratio
- 12.5 µm SPAD pitch
- ~1600 SPADs / channel

- Adjacent channels can get connected on customer PCB to mimic 1x12 arrays:

1x12



- channel ~0.5 x 1.1 mm²
- ~ 1:2 aspect ratio
- 12.5 µm SPAD pitch
- ~3200 SPADs / channel

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