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Multi-Pixel Photon Counter (MPPC) for Detection of Scintillation Spectra of Liquid Argon and Xenon

2015.8.31

HAMAMATSU PHOTONICS K.K.

Solid State Division

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Our Motivation for this R&D effort…

- **There remain unexplored frontiers of detecting ultralow levels of light with silicon photodetectors.**
- **One such frontier is the extreme cold of cryogenic physics experiments.**
- **Our goal is to explore this frontier with your help and develop suitable detector technologies for the corresponding physics research and discovery.**
- **We further hope that those technologies shall find other applications in the service of humankind as well.**

Liquefied noble gases in cryogenic physics

- **Dark matter search & Neutrinoless double beta decay**
- Liquid Xenon (LXe)
  - Peak emission wavelength: 175nm
    - **Directly detected by VUV photodetector**
- Liquid Argon (LAr)
  - Peak emission wavelength: 128nm
    - **Directly detected by VUV photodetector or indirectly (after WL-shifter) by UV/blue photodetector (typically ~420 nm)**
- *{Liq. He and liq. Ne are not addressed here…}*

Our Photodetector Solution: The MPPC

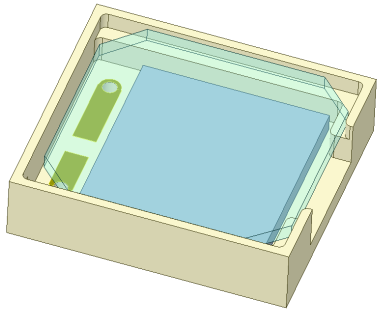
- MPPC Features for Cryogenic Applications
  - **Packaging material**
    - Cryogenic reliability & radioactivity content
  - **Recovery time & temperature characteristics**
  - SNR
    - **Noise (Cross-talk, After-pulsing, etc.)**
    - **Gain**
    - **Photon Detection Efficiency (PDE)**

MPPC Packaging: Ultralow RI materials

For direct detection of VUV (128 or 175nm)

Window material: synthetic silica (quartz) for 175nm | none for 125nm

Package material candidates: ceramic, synthetic sapphire, quartz + TGV, intrinsic silicon, etc.



Example: ceramic package + quartz window

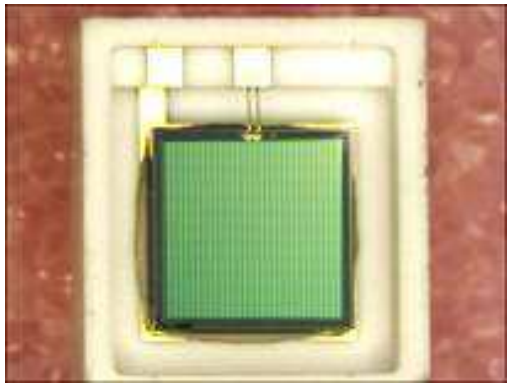
For detection of wavelength-shifted 420nm signal

Window material: various kinds of resin

Package material candidates: various kinds of resin

MPPC Packaging: Cryogenic reliability

- **Reliability test on CERAMIC (alumina) PKG w/ quartz window:**
  - Structure : CERAMIC / conductive glue / MPPC / window
  - LN2 ←→ room temperature, 5cycles
  - 40℃～125℃, 250 cycles
  - 60℃, 90%, 250hr w/ operation (general test)

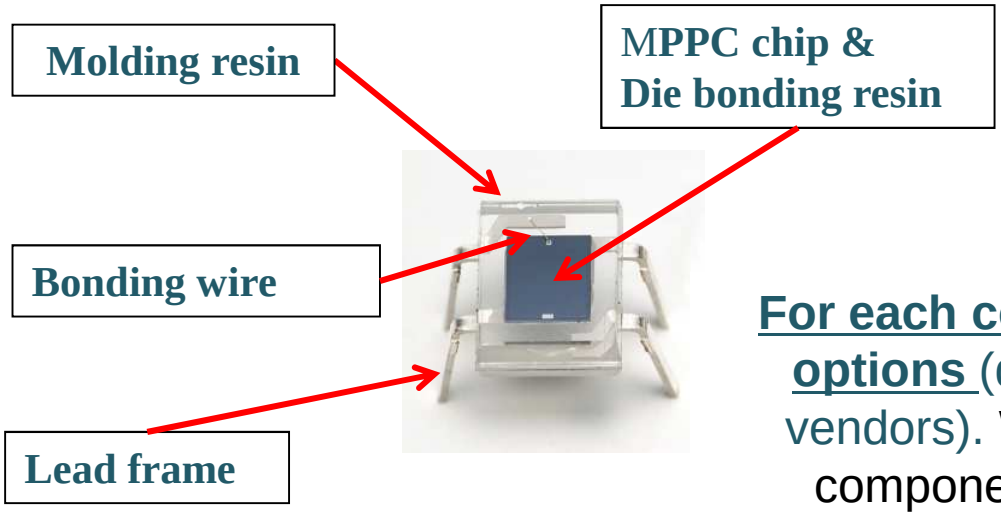


- **No mechanical or electrical problem!**

MPPC Packaging: Ultralow RI materials

Development strategy

Example: plastic-package device



For each component, we have numerous options (different materials and different vendors). We will measure the RI of each component option and identify suitable components for making a low-RI MPPC.

MPPC Packaging: Cryogenic reliability

- **Reliability tests performed on RESIN PKG:**
  - Sample A) Potting: Epoxy | Chip mounting: conductive adhesive glue
  - Sample B) Potting: Silicone | Chip mounting: conductive adhesive glue
  - Sample C) Potting: none (bare) | Chip mounting: conductive adhesive glue
  - Sample D) Potting: none (bare) | Chip mounting: none (fixed by wire bonding)

Temperature: -196℃ (Liquid nitrogen) | **Test cycle:** 20 cycle max.

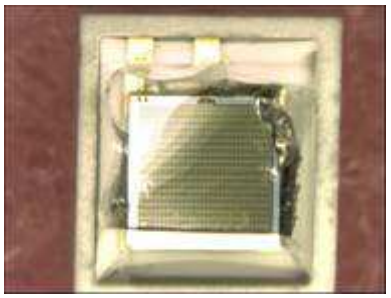
Test Procedure:

1 cycle
- submerge sample in liquid nitrogen (5min.)
- ↓
- expose sample to room temperature (5min.) in dry N2 atmosphere
- ↓
- check conductivity & mech. damage (record pictures in case of crack, etc.)

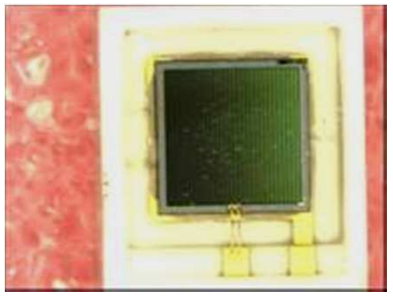
MPPC Packaging: Cryogenic reliability

Results of our reliability tests:

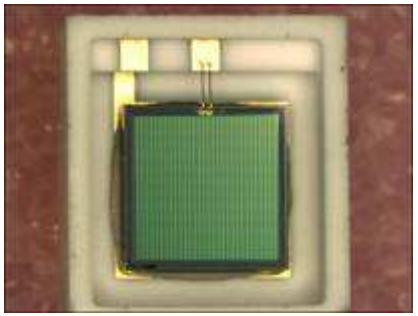
A) cracked at 1cycle | conductivity: good at > 20cycles



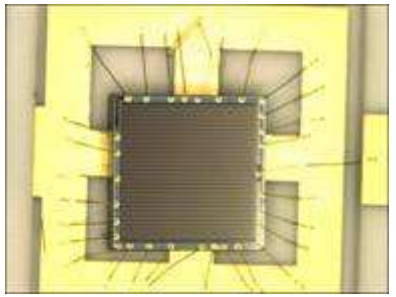
B) small crack at 10cycles | minor detachment at 20cycles | conductivity: good at > 20cycles



C) no damage at >20cycles | conductivity: good at > 20cycles

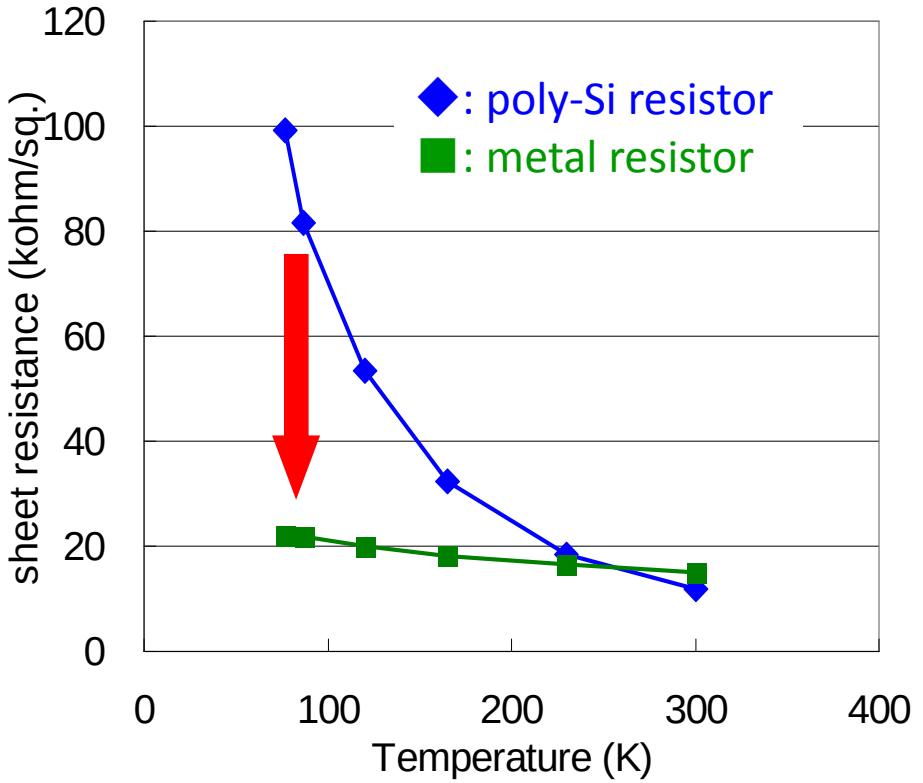


D) no damage at >20cycles | conductivity: good at > 20cycles

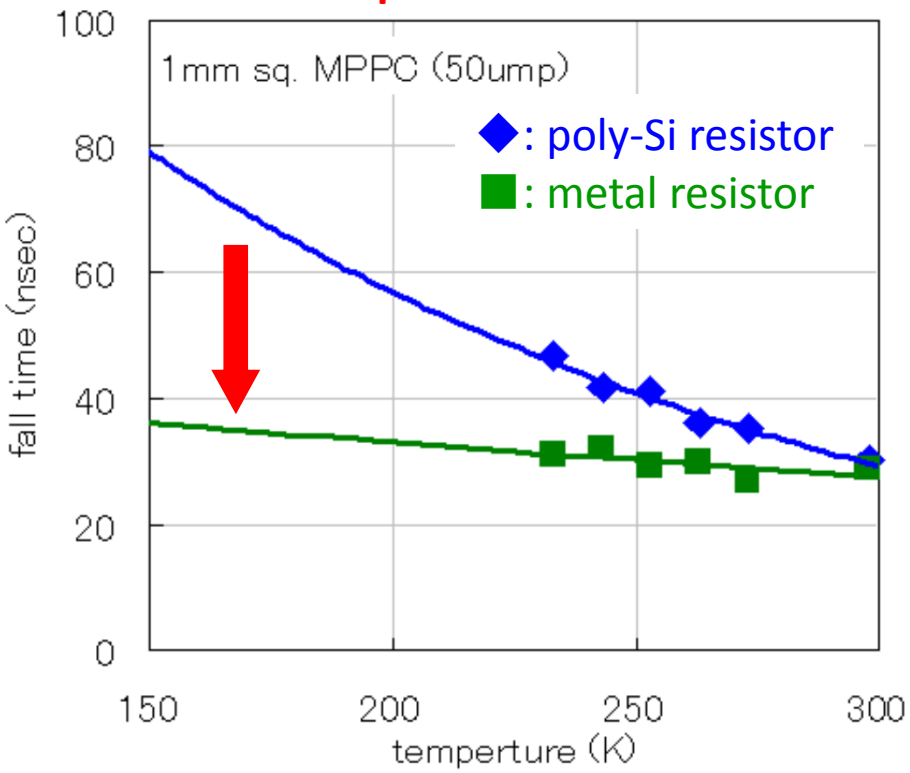


MPPC recovery time at cryogenic temperatures

Temperature dependence of the sheet resistance



Temperature dependence of the pulse fall time



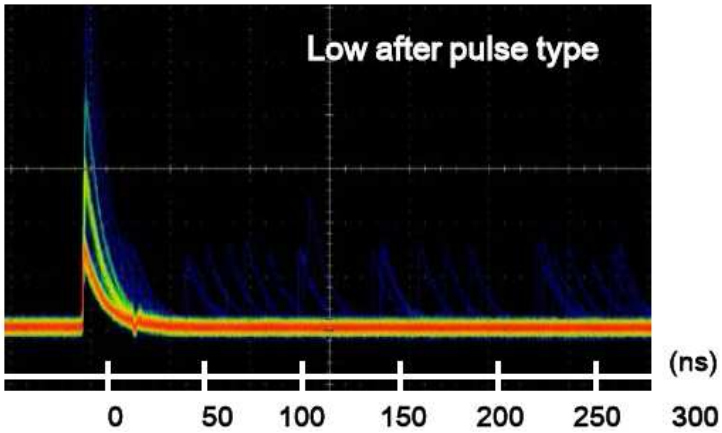
Achieved 1/5th of prior temperature dependence.

For more details, please see:

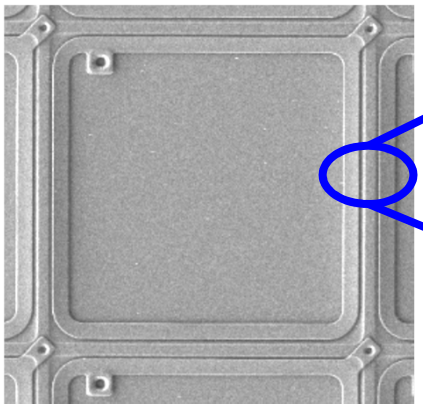
NIM A, Volume 732, Dec. 21, 2013, Pages 427–430, Vienna Conf. on Instrumentation 2013

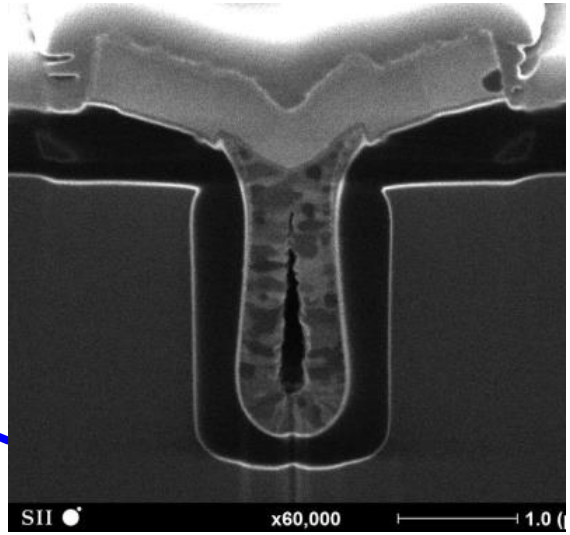
MPPC Noise (Cross-talk & After-pulsing) Suppression

- After-pulsing suppression
  - Ultralow-defect wafer

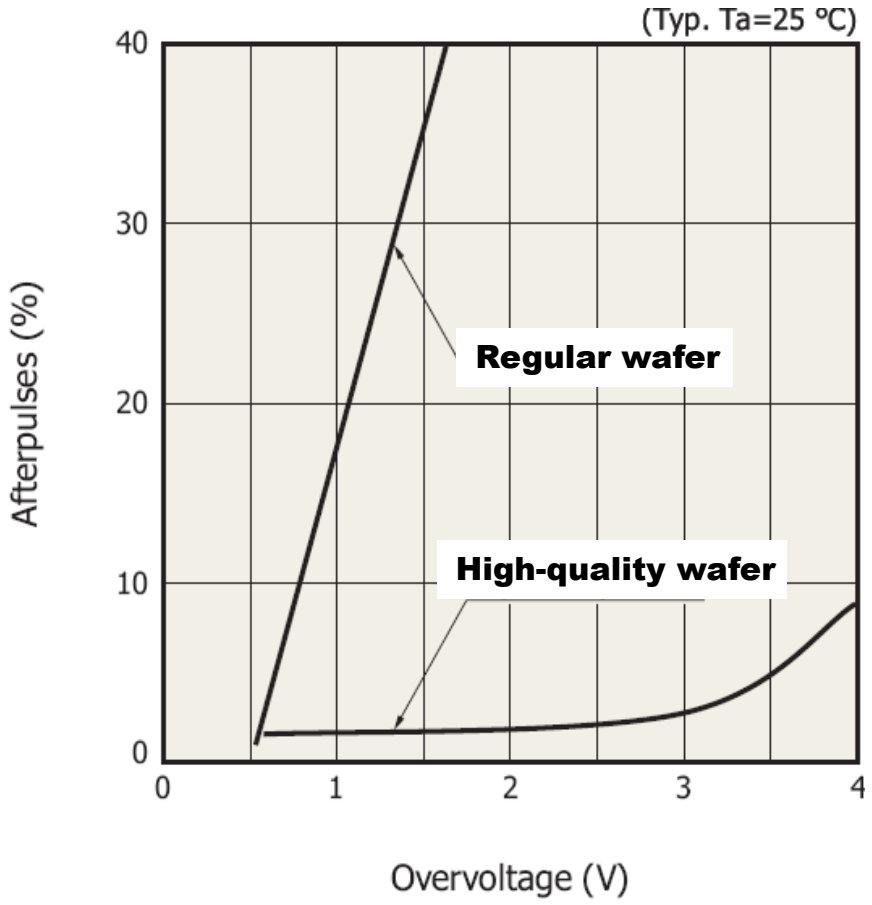


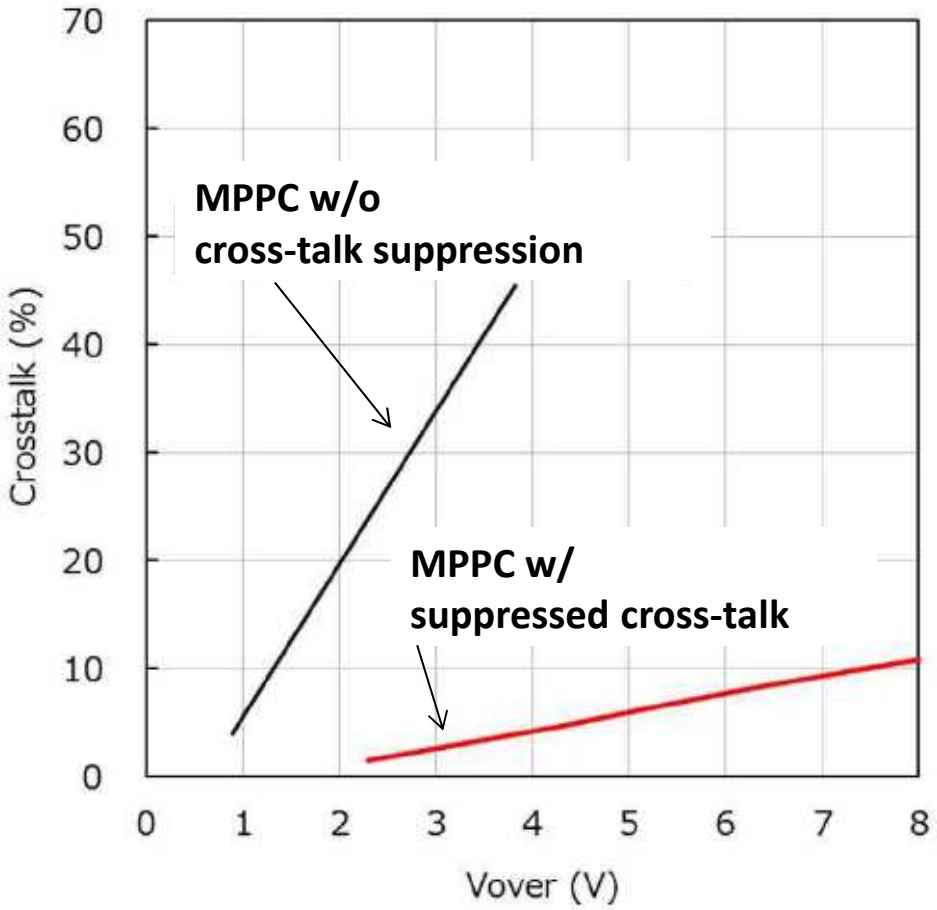
- Cross-talk suppression
  - Optical trench around each μcell





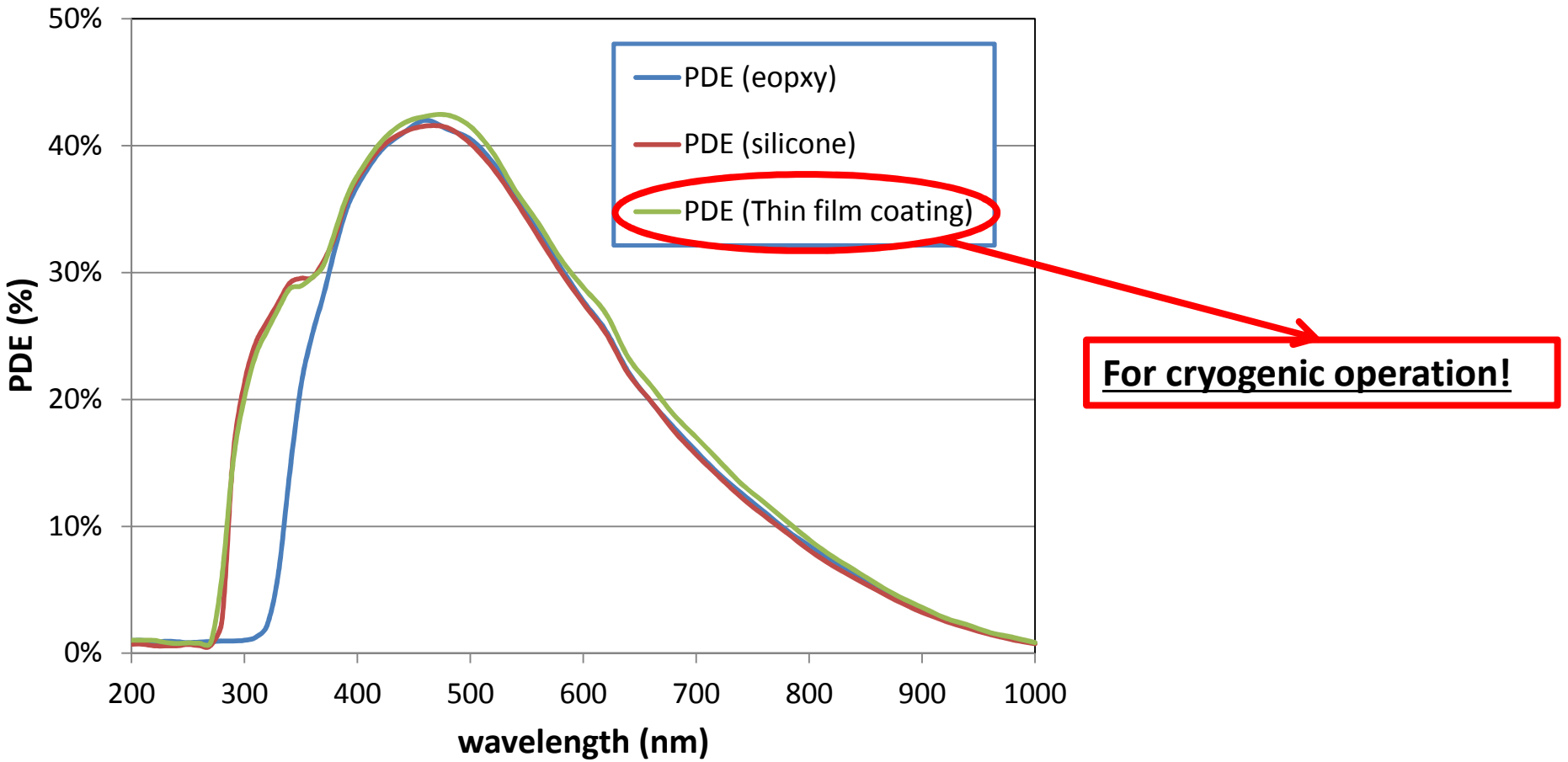
MPPC Noise Suppression





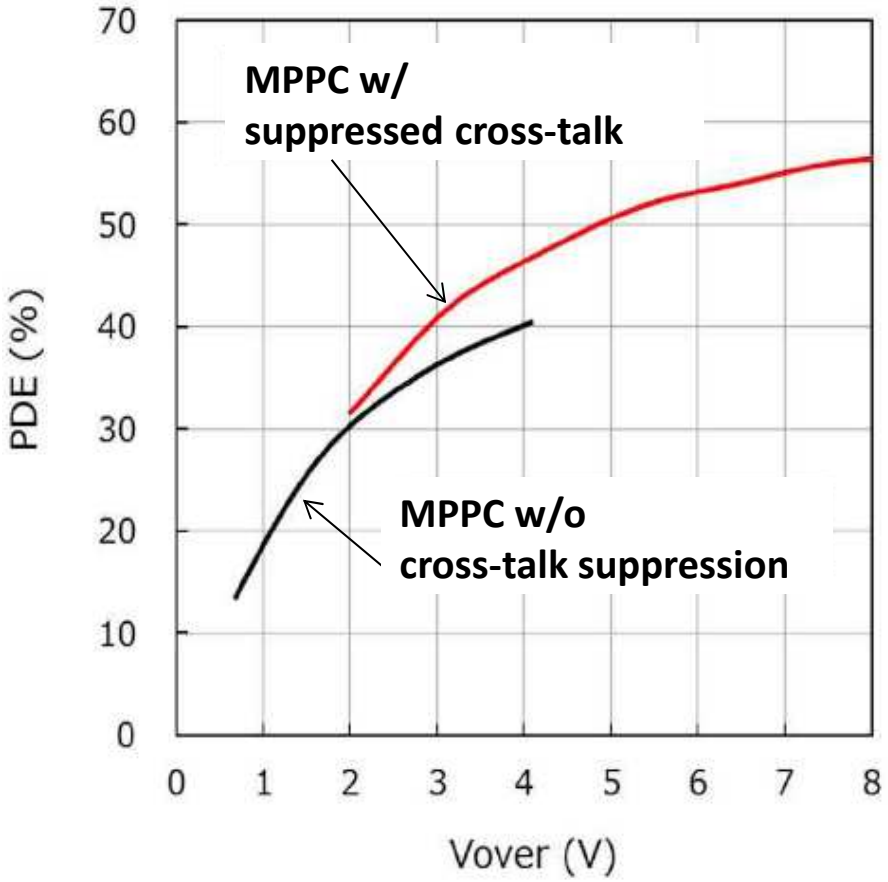
MPPC for detection of 420nm (wavelength-shifted)

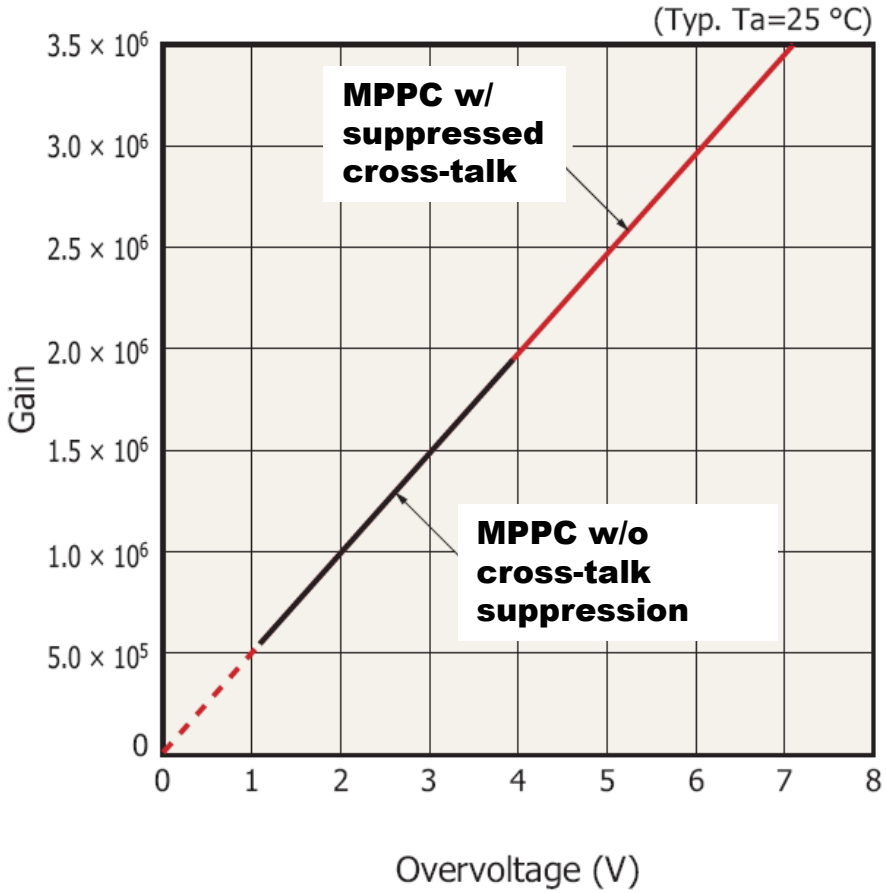
- **MPPC (w/ noise suppression) has remarkable PDE @ 420nm!**
- For comparison with PMT, please note that PDE = QE x CE



MPPC: Gain & PDE

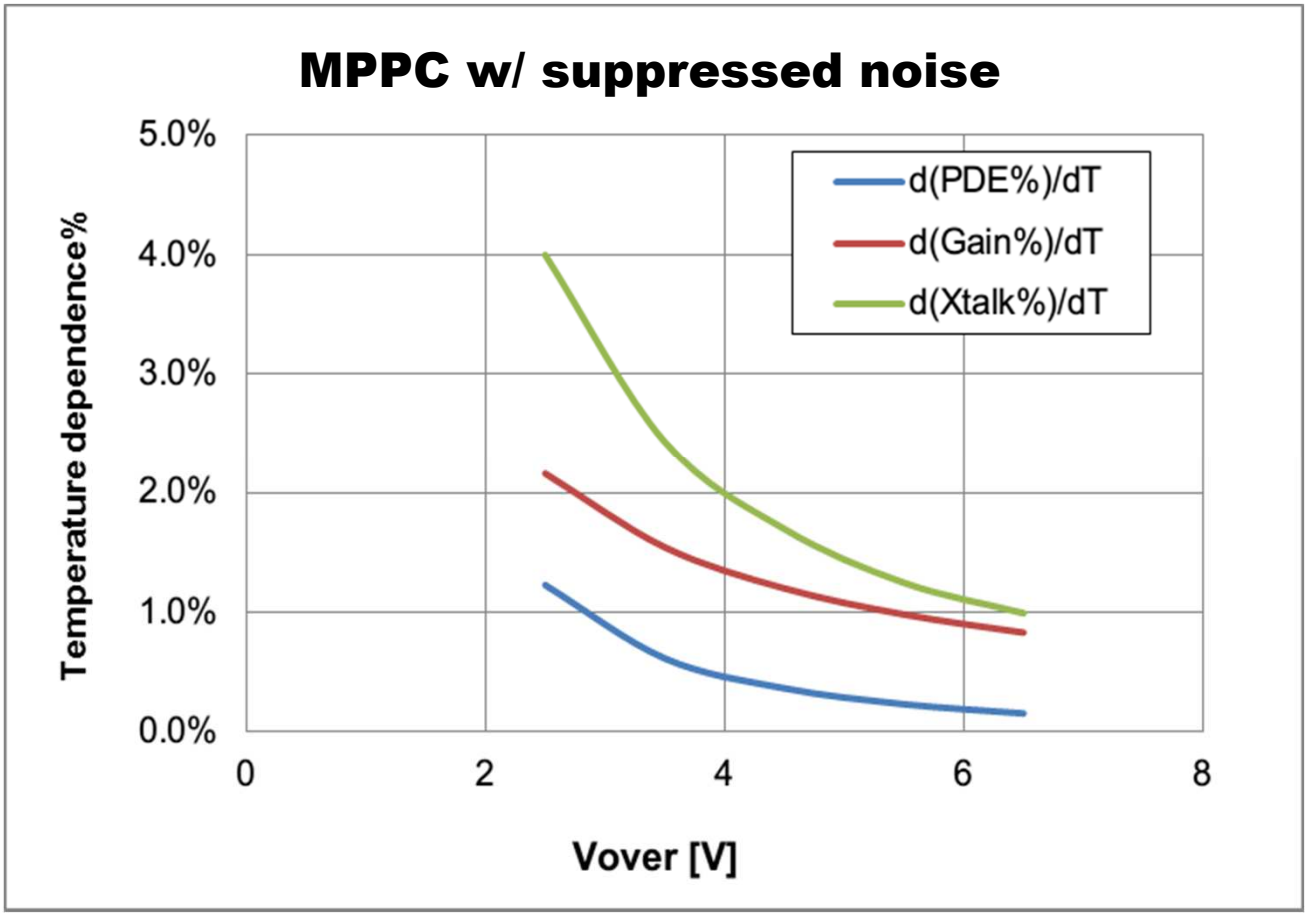
- Diminished cross-talk allows for higher Over-Voltage (= V bias – V breakdown).
- **Higher OV leads to higher gain and PDE (*even compared to last slide*).**





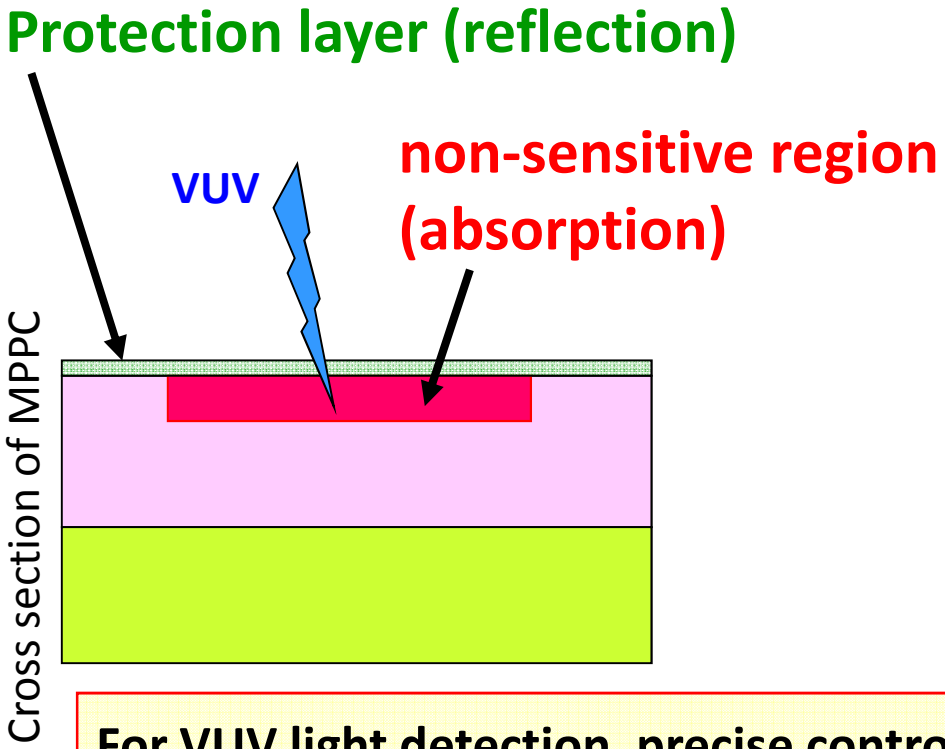
Reduced-MPPC Noise: Temperature Stability

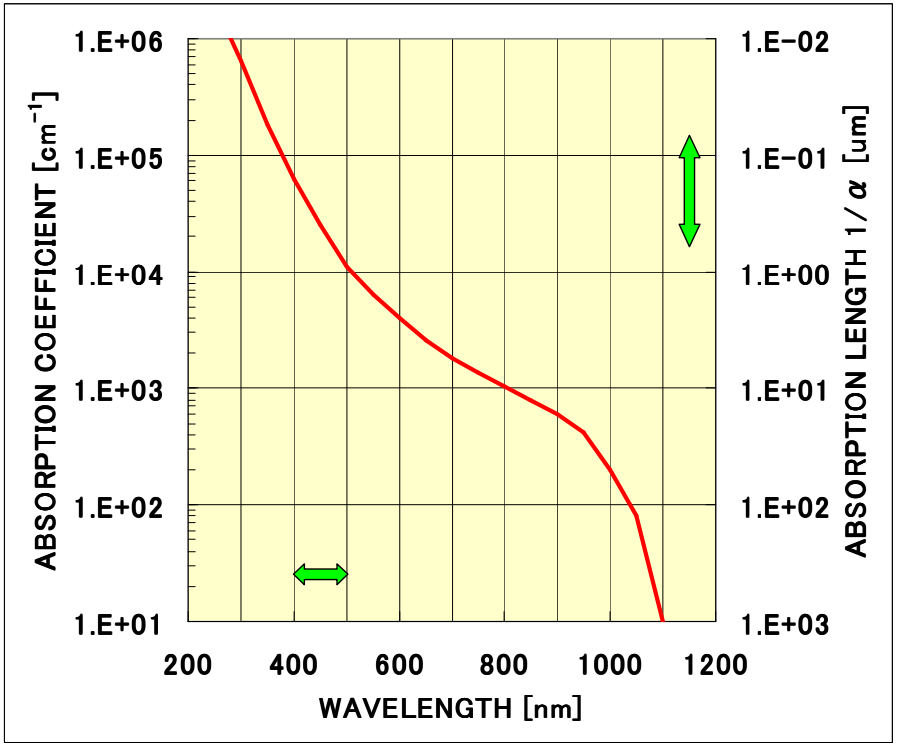
Greater temperature stability is also attained at higher OV.



MPPC's PDE: direct detection of VUV (LAr's 128nm and LXe's 175nm)

- Our solution for direct detection is the "VUV-MPPC" series.

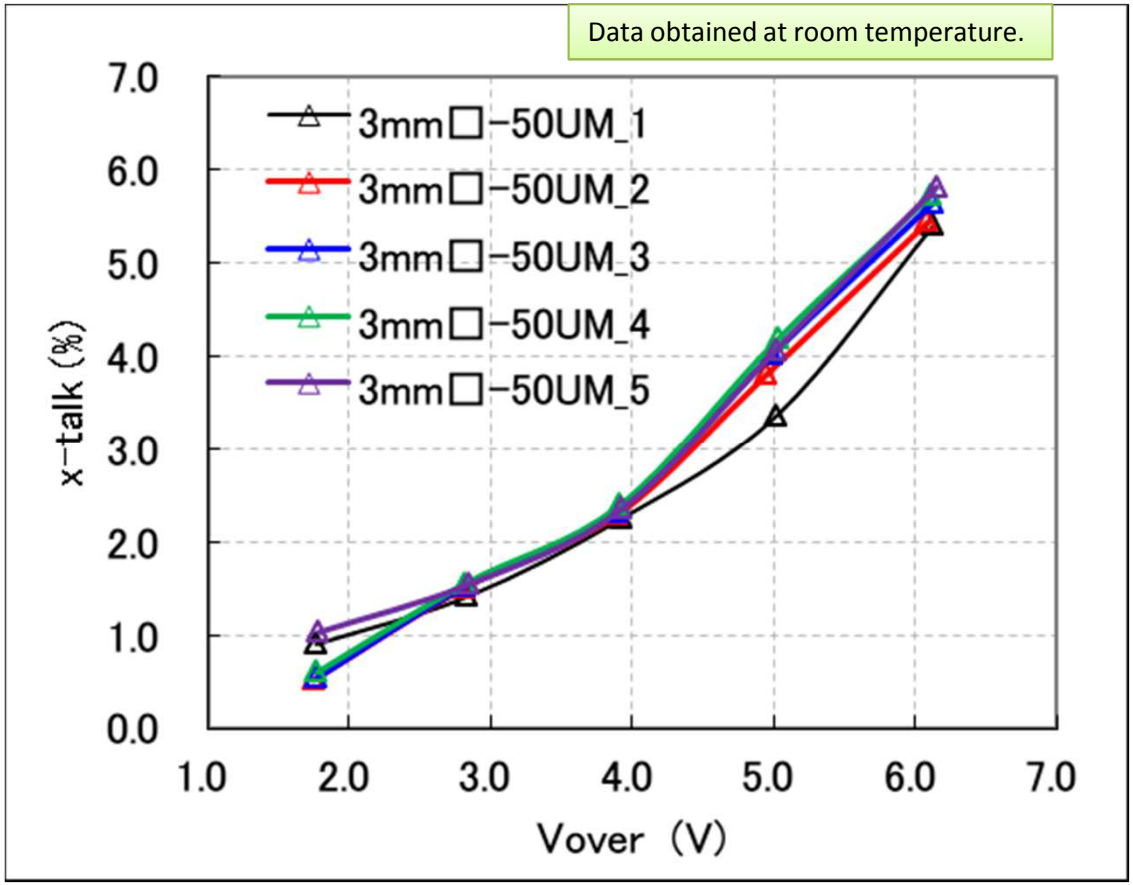




For VUV light detection, precise control of MPPC's protection layer and non-sensitive region is required.

MPPC for direct detection of VUV

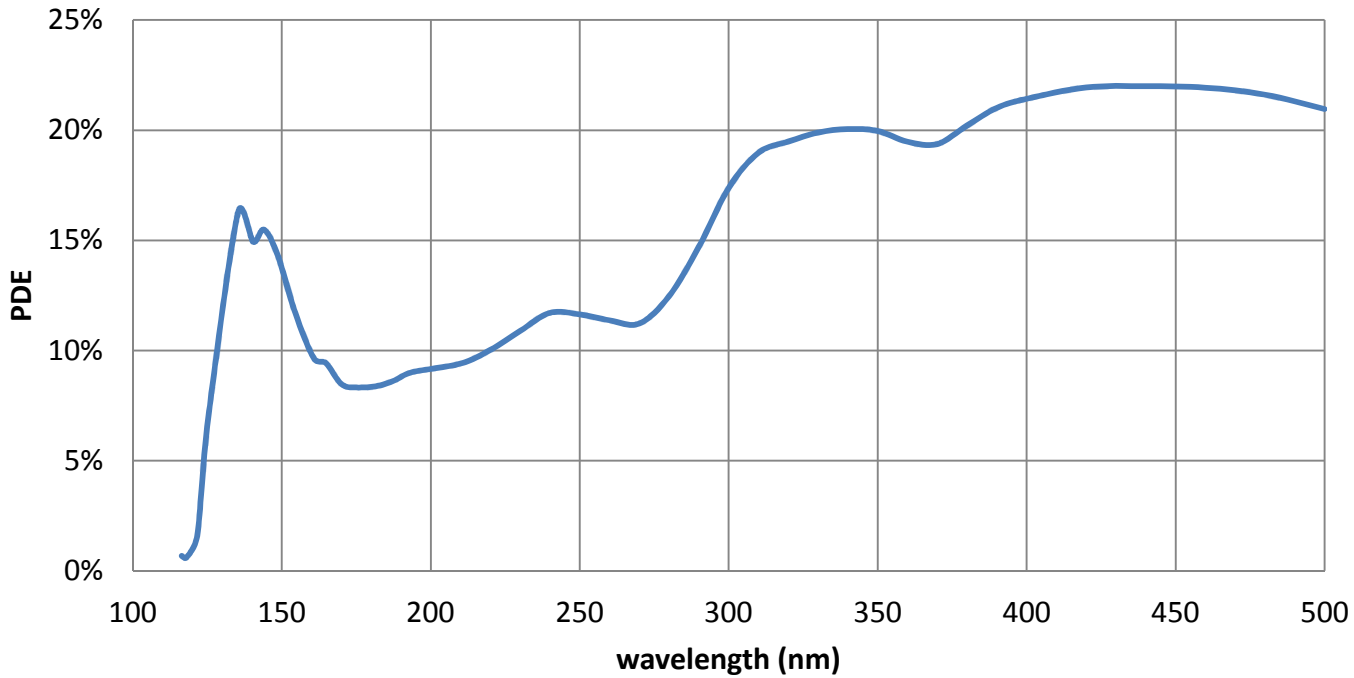
- **Our latest VUV-MPPC model is VUV3 (w/ optical trenches)**



MPPC for direct detection of VUV

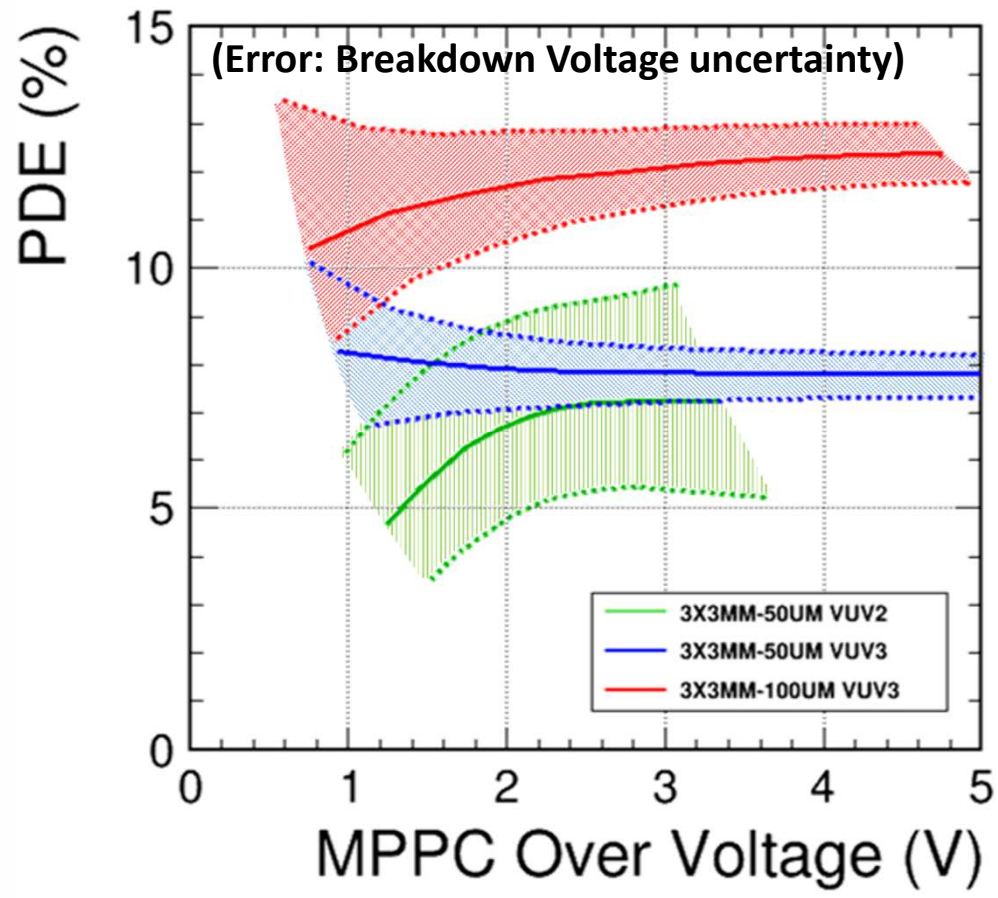
PDE of VUV3 MPPC - 3mm chip w/ 50um pixels

Under vacuum <200nm | In Air >200nm | Gain =1.25x10^6



MPPC for direct detection of VUV

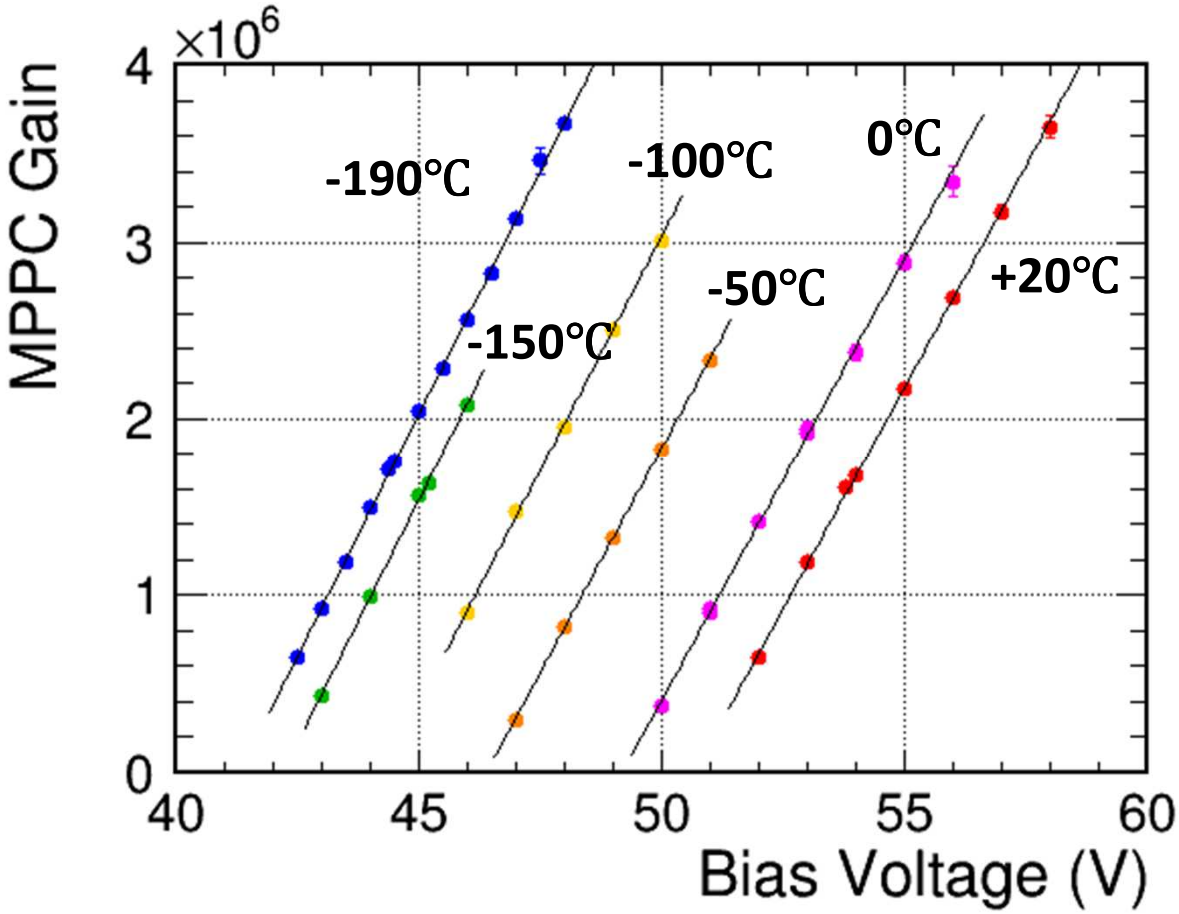
- **VUV3's Absolute PDE (LAr emission)**



Source: Kohei Yorita, Masashi Tanaka, Tatsuki Washimi of Waseda University, LIDINE 2015 presentation (Albany, NY), August 28, 2015

MPPC for direct detection of VUV

- **VUV3's gain characteristics:**



Source: Kohei Yorita, Masashi Tanaka, Tatsuki Washimi of Waseda University, LIDINE 2015 presentation (Albany, NY), August 28, 2015

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Our near-term development objectives…

- VUV-sensitivity improvement
  - Improvement of pixel fill-factor in VUV-MPPC series
  - Evaluation samples will be available in late 2015 as “VUV4”.

- Lower RI
  - Continuation of radioactivity measurements of various materials for development of an optimal ultralow-RI packaging
  - Evaluation samples will be available in early 2016.

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Presentation Summary

- Overview of Hamamatsu's product development
  - For cryogenic physics experiments
    - VUV-MPPC
    - Low-RI packaging

- Communication & Collaboration
  - We'd love to hear your thoughts regarding current product features along with your ideas for improvements.
  - We'd also be interested in collaborating with well-equipped researchers on development of ultralow-RI packaging.
  - So, please feel free to contact us through your local Hamamatsu sales representative.

www.hamamatsu.com

