Progress on the SiPM with bulk quenching resistor at NDL

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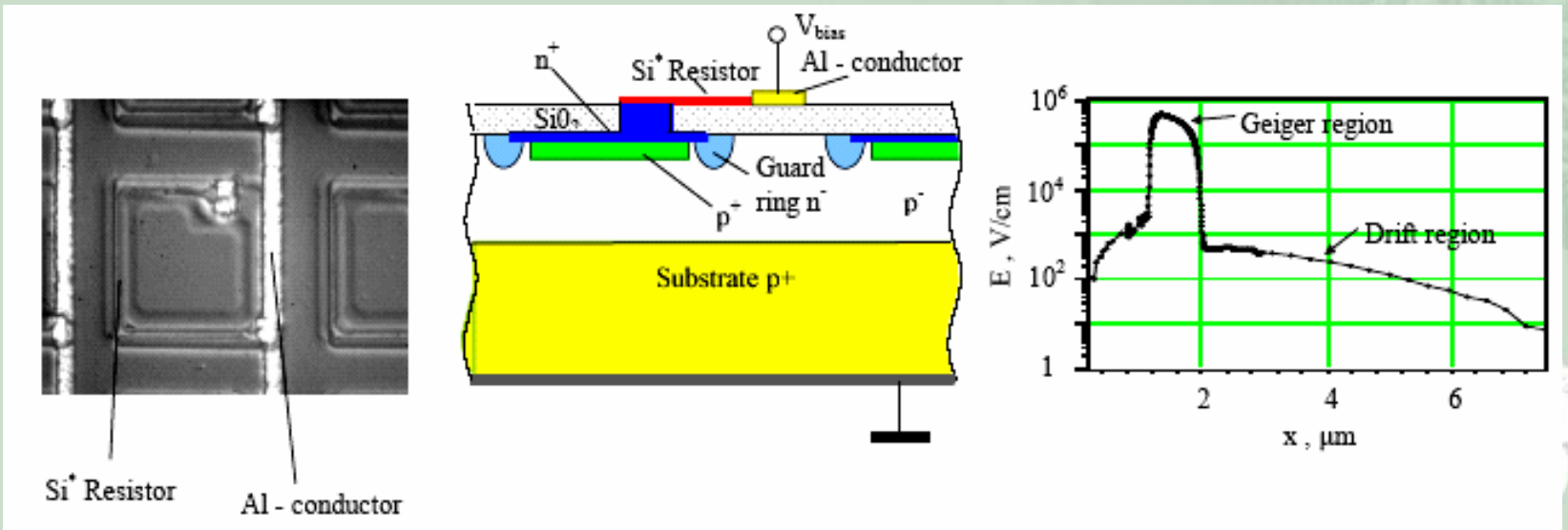
A Problem of SiPM

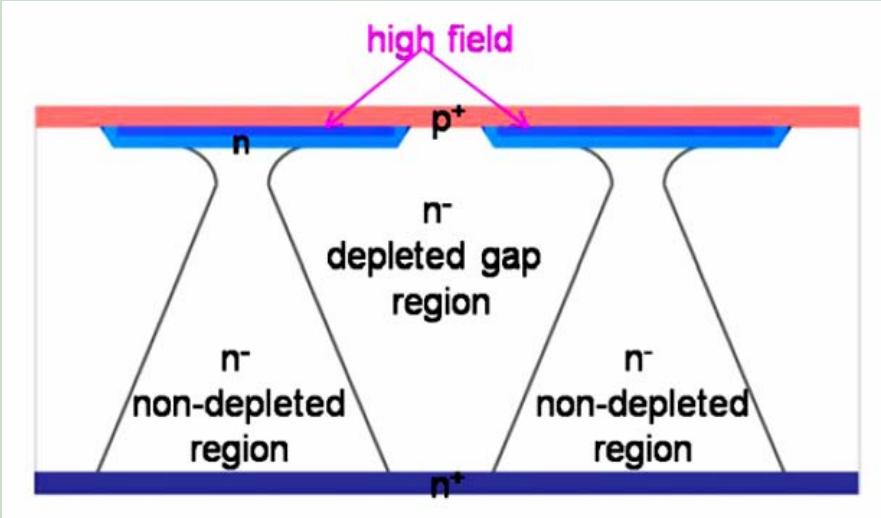
- SiPM is a promising silicon photon counting sensor alternative to conventional PMT in HEP, astrophysics and PET etc.
- Polysilicon is used as the quenching resistor for most SiPMs, the strip resistor, interconnecting Al electrodes and the guard ring of each APD cell limit the geometrical factor
- A conflict between high dynamic range and large PDE!



(Drawing taken from P. Buzhan, et al., ICFA (Fall, 2001), http://www.slac.stanford.edu/pubs/icfa/)

Bulk resistor type SiPM (MPI-HLL)

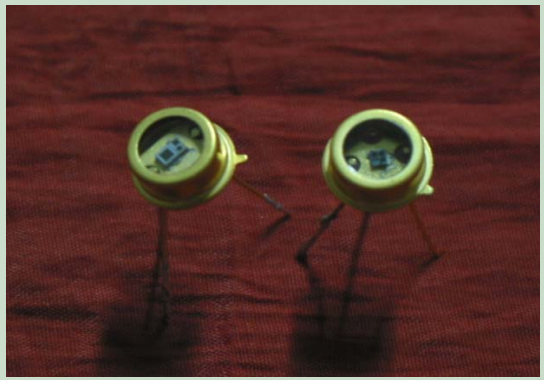
- MPI first reported a new SiPM concept： bulk resistors replace polysilicon resistors on surface
- Aims for astroparticle physics experiments which need possible highest PDE but don't need a large APD cell density
- Big APD cell (100~150 μm pitch and 10~20 μm gap) with limited cell density (<100 cells/mm^2)
- SOI wafer along with wafer bonding technology
- Demonstrated quenching mechanism and photon counting capability at -20 ° C

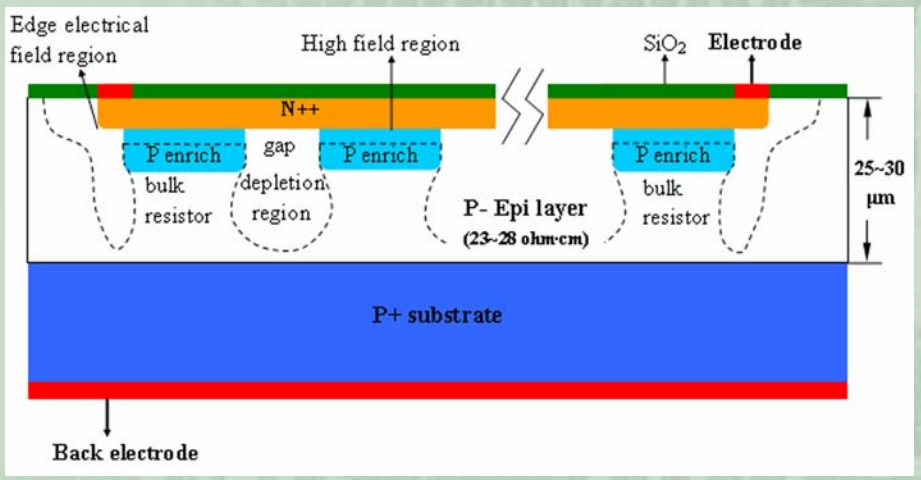


- *11th Pisa Meeting, La Biodola, Isola d'Elba, 24th-30th May 2009*
- *Nucl. Instr. and Meth. A 610 (2009) 142-144*
- *Nucl. Instr. and Meth. A, 628 (2011) 407-410*
- ***Ninkovic's presentation at this conference***

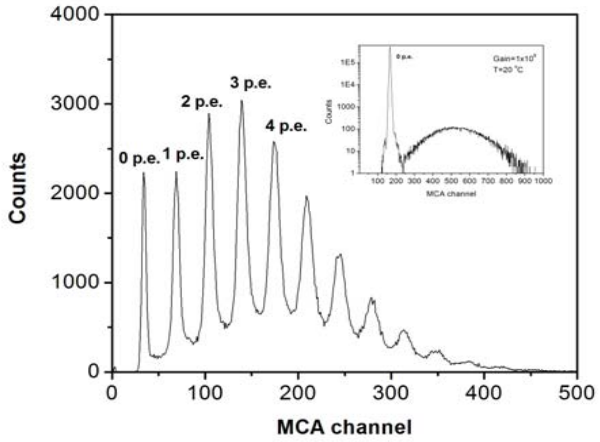
Bulk resistor type SiPM (NDL)

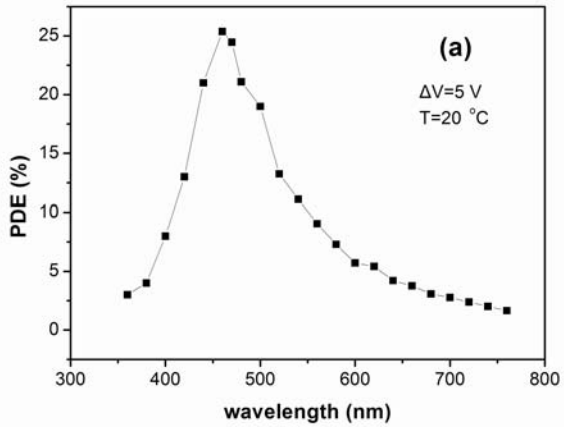
- NDL proposed and investigated the bulk resistor type SiPM on epitaxial silicon independently *["Research on a new type silicon photomultiplier", a proposal to the National Nature Science Foundation of China (NSFC) in March, 2007. Executive period was from January 2008 to December 2010 under Grant number 10775016]*
- To make SiPM having high dynamic range while retain large PDE
- **0.5 mm × 0.5 mm** SiPMs with 10 μm pitch, 4 μm gap and $10^4/mm^2$ density were fabricated in October, 2009
- P-type epitaxial Si wafer with high energy ion implantation up to 480 keV were employed

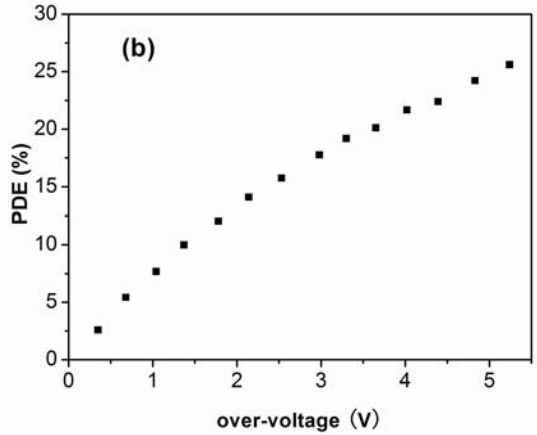




"Demonstration of a silicon photomultiplier with bulk integrated quenching resistors on epitaxial silicon", Nuclear Instruments and Methods in Physics Research A, 621 (2010) 116-120

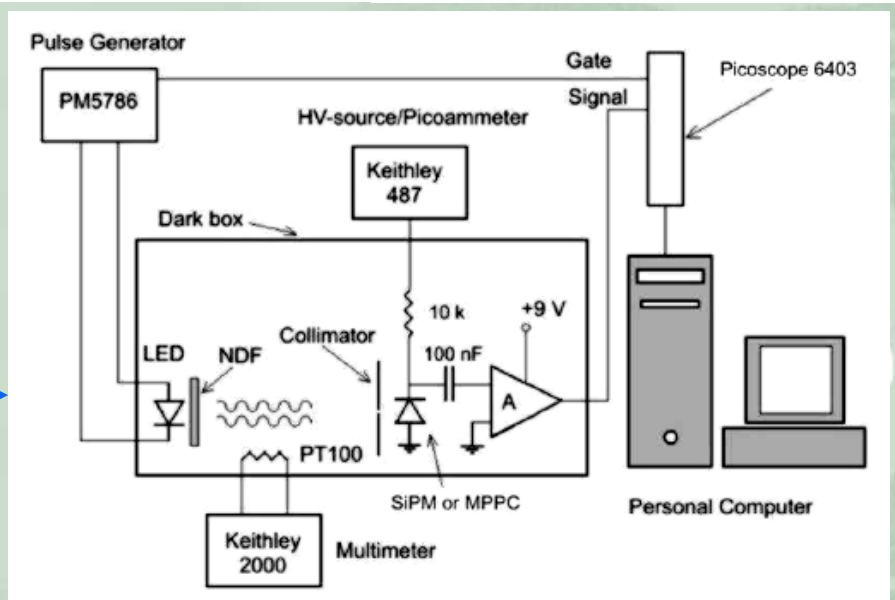


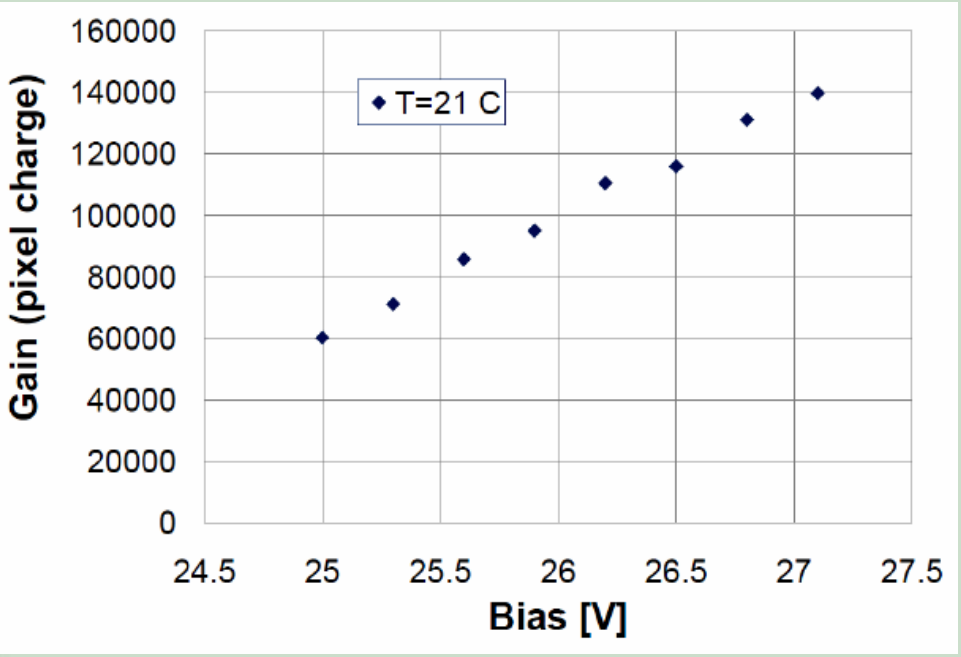


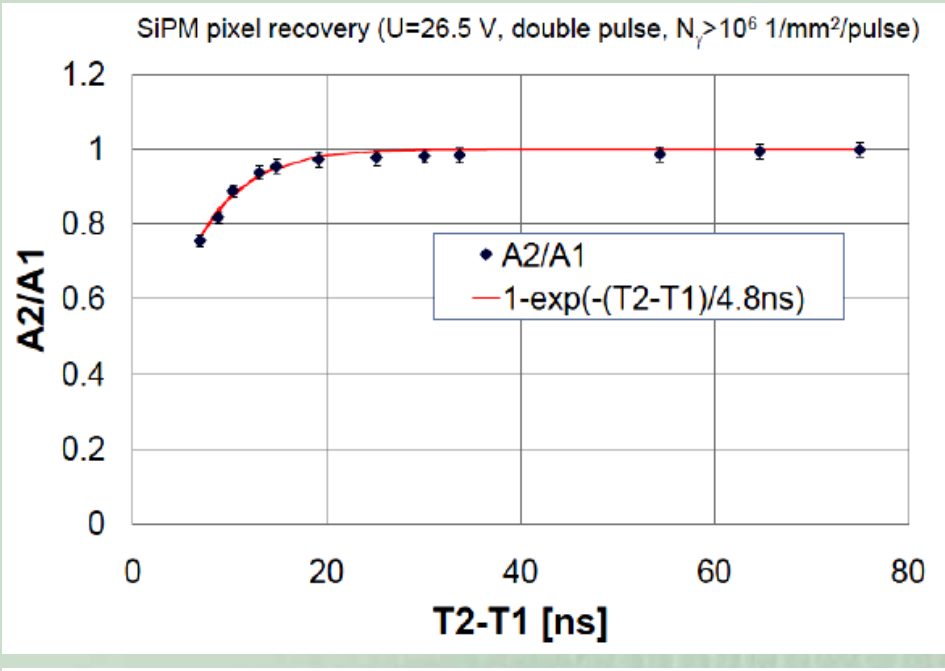


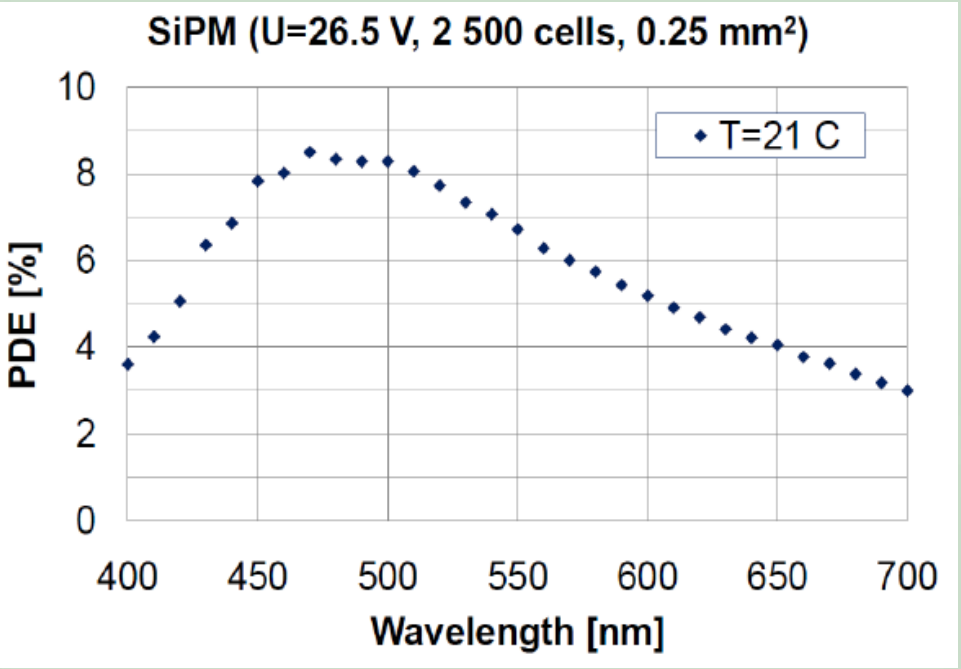
Several devices were sent to Dr. Yuri Musienko (APDlab at CERN) for evaluations

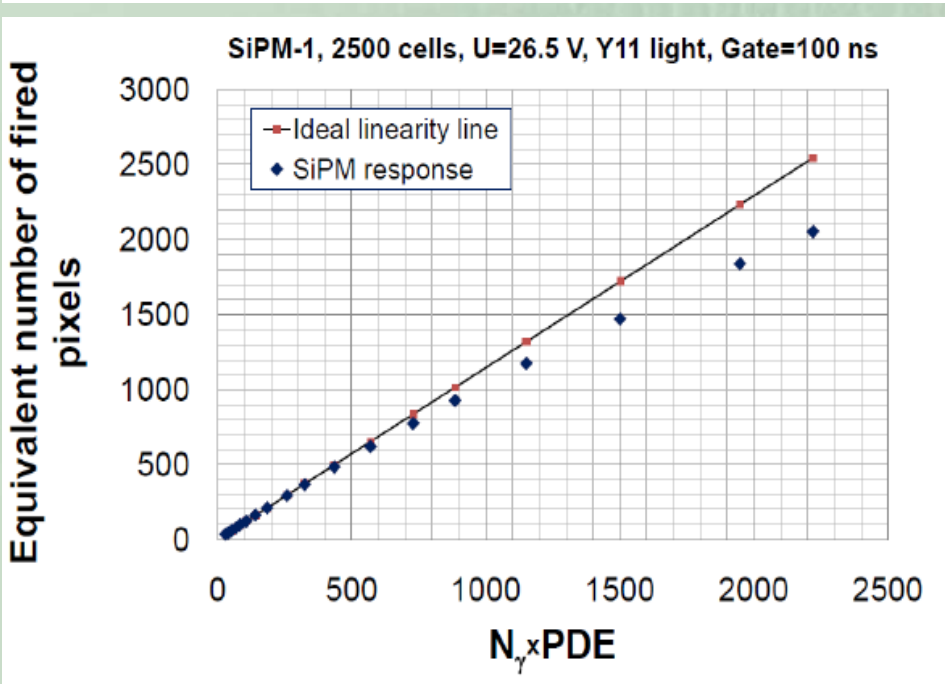
Setup for Gain and PDE measurements at CERN →



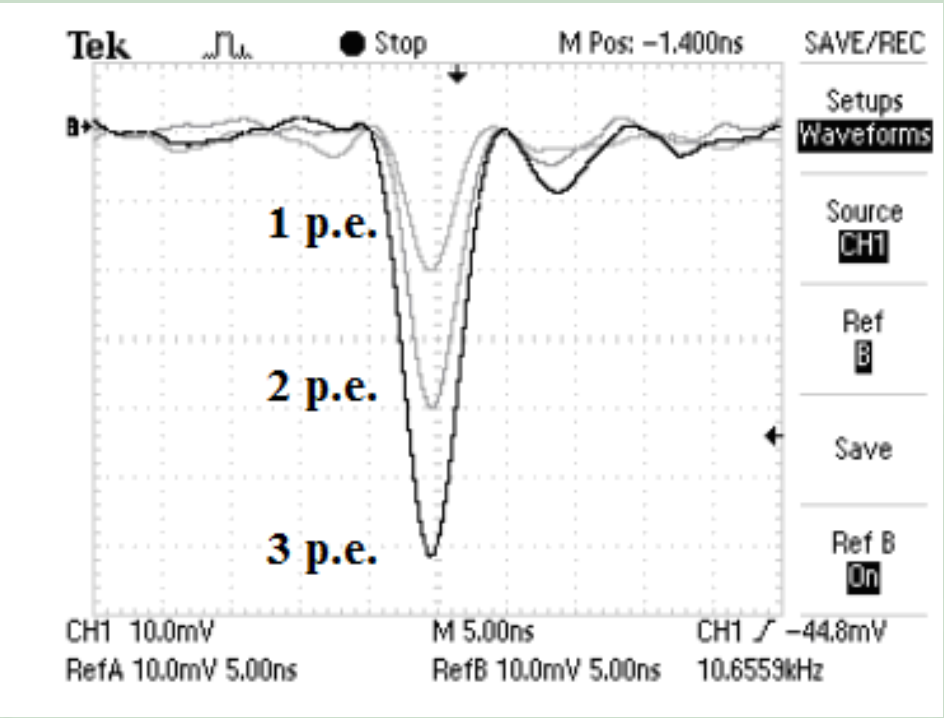

Gain (pixel charge)
160000
140000
120000
100000
80000
60000
40000
20000
0
T=21 C
24.5
25
25.5
26
26.5
27
27.5
Bias [V]

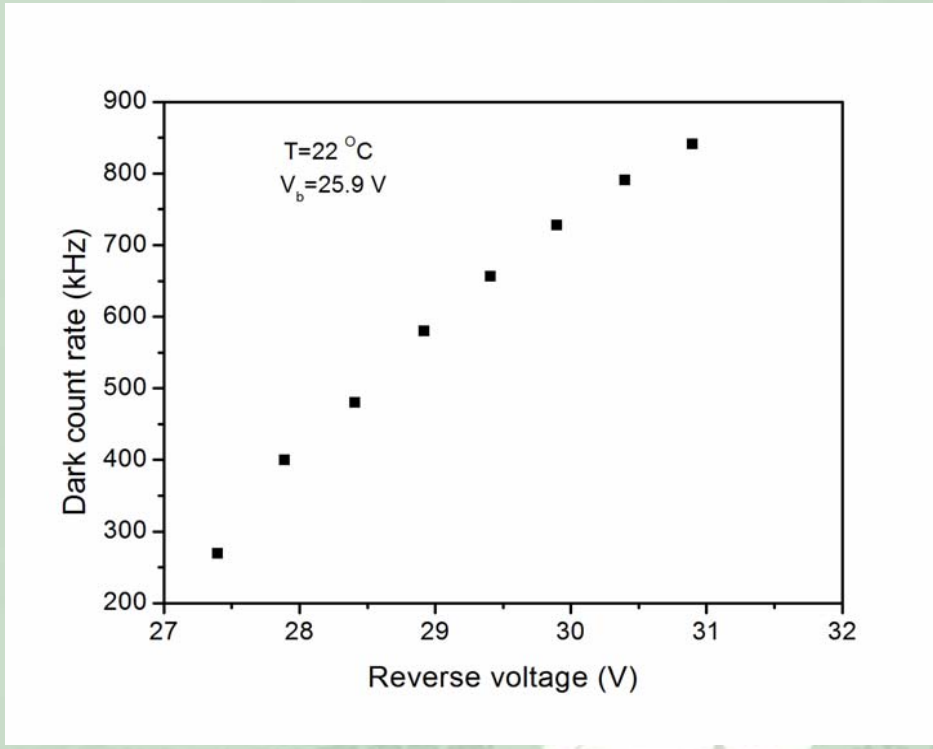

SiPM pixel recovery (U=26.5 V, double pulse, N$_\gamma$>10^6 1/mm^2/pulse)
A2/A1
1.2
1
0.8
0.6
0.4
0.2
0
A2/A1
1-exp(-(T2-T1)/4.8ns)
0
20
40
60
80
T2-T1 [ns]

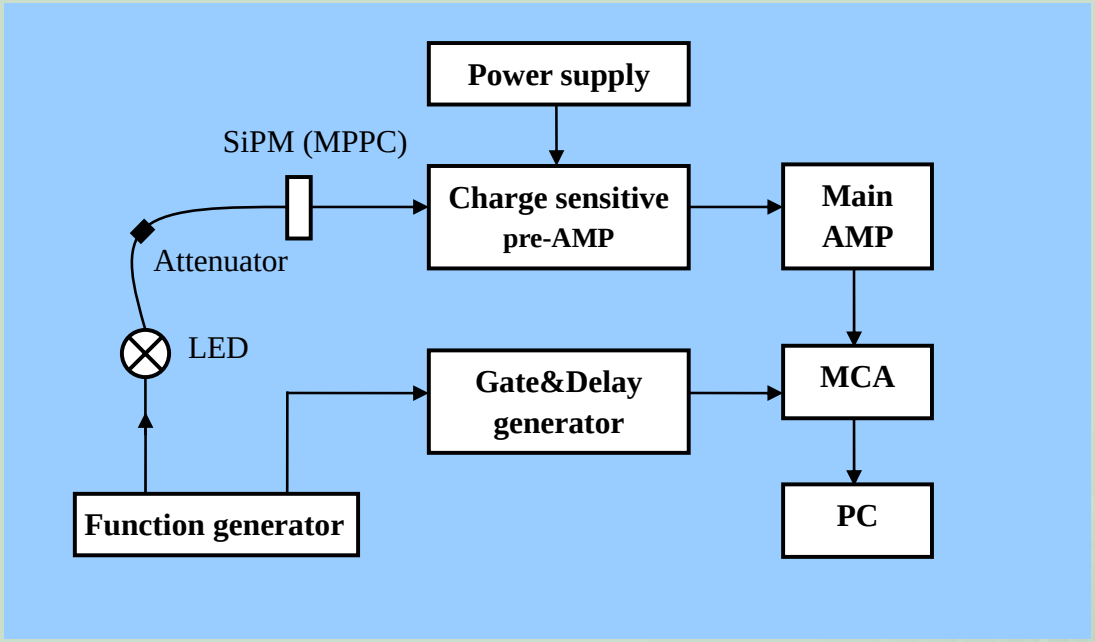

SiPM (U=26.5 V, 2 500 cells, 0.25 mm^2)
PDE [%]
10
8
6
4
2
0
T=21 C
400
450
500
550
600
650
700
Wavelength [nm]

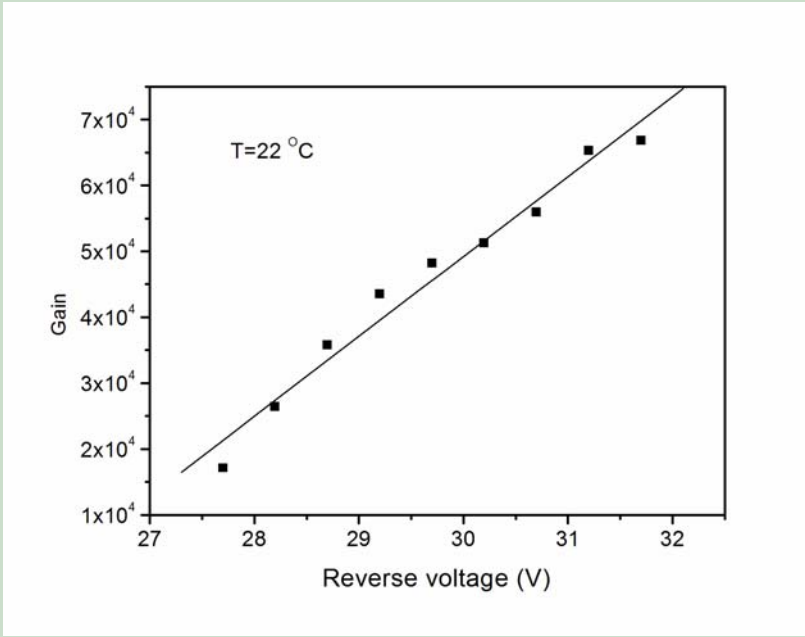

SiPM-1, 2500 cells, U=26.5 V, Y11 light, Gate=100 ns
Equivalent number of fired pixels
3000
2500
2000
1500
1000
500
0
Ideal linearity line
SiPM response
0
500
1000
1500
2000
2500
N$_\gamma$xPDE

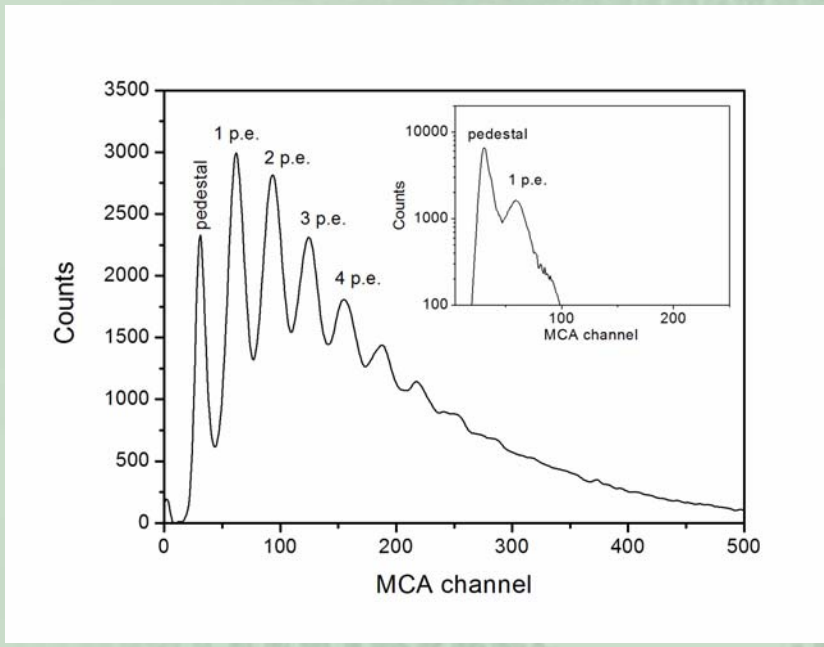
- **1 mm × 1 mm** SiPMs with 10μm pitch and $10^4/mm^2$ density were fabricated in April, 2010, and characterized at NDL
- a p-stop layer around the active area of the device was introduced

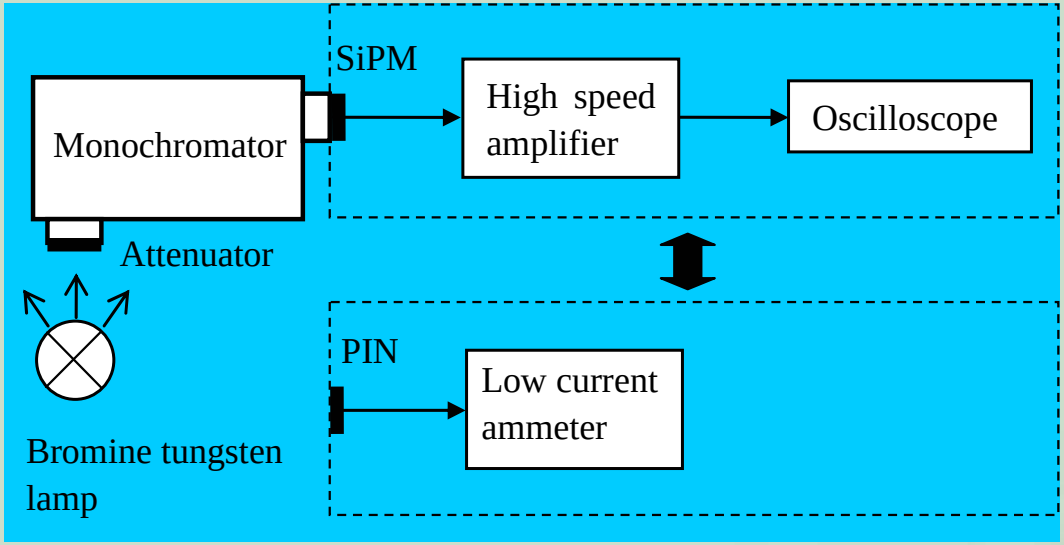


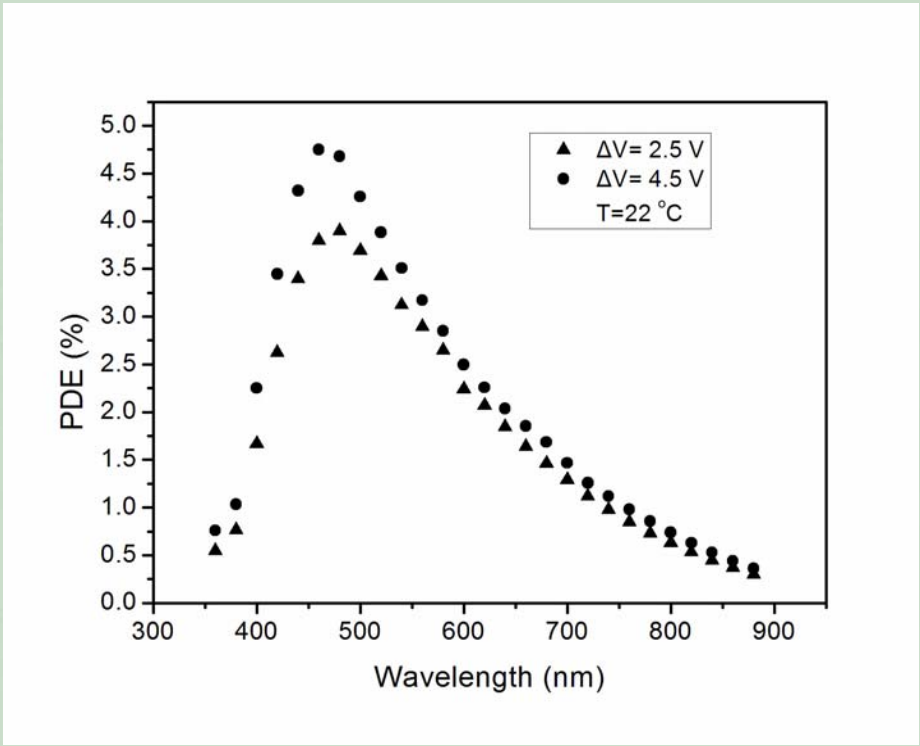


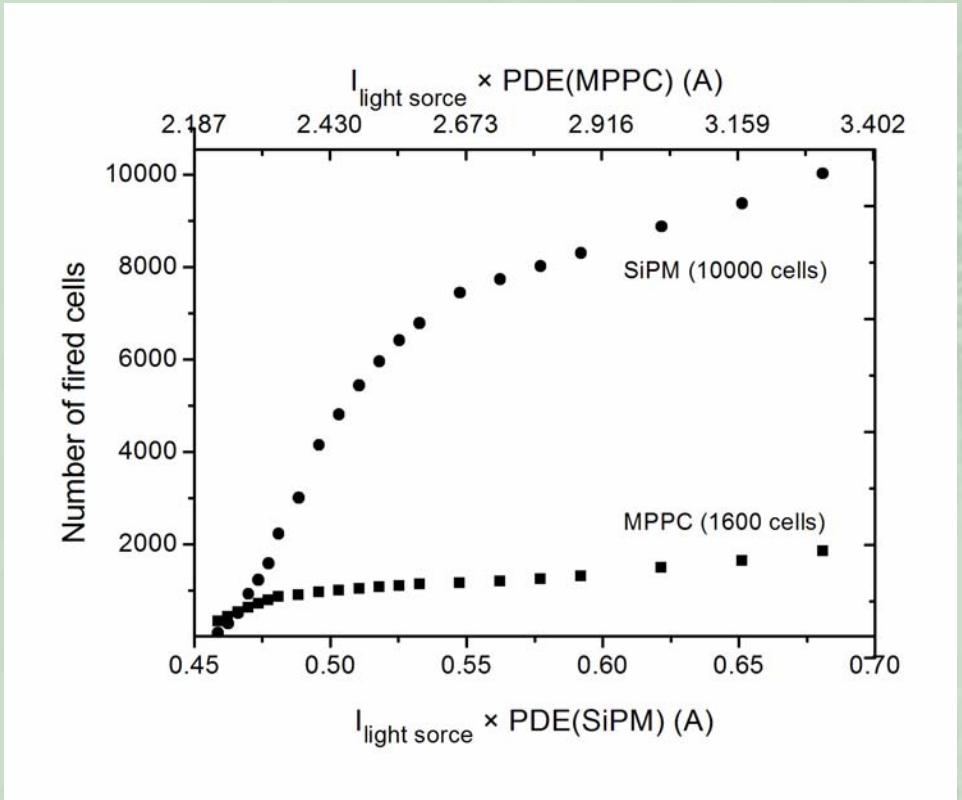

Power supply
SiPM (MPPC)
Charge sensitive pre-AMP
Main AMP
Attenuator
LED
Gate&Delay generator
MCA
Function generator
PC


T=22 °C
Gain
Reverse voltage (V)


pedestal
1 p.e.
2 p.e.
3 p.e.
4 p.e.
Counts
MCA channel

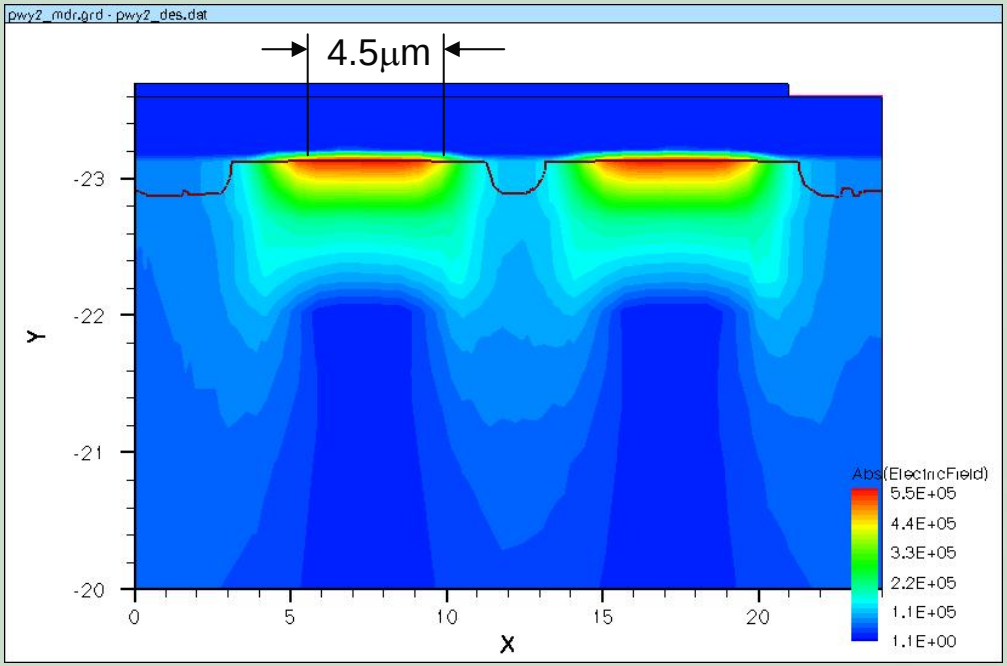

SiPM
Monochromator
High speed amplifier
Oscilloscope
Attenuator
PIN
Low current ammeter
Bromine tungsten lamp


ΔV= 2.5 V
ΔV= 4.5 V
T=22 °C
PDE (%)
Wavelength (nm)


I light sorce × PDE(MPPC) (A)
Number of fired cells
SiPM (10000 cells)
MPPC (1600 cells)
I light sorce × PDE(SiPM) (A)

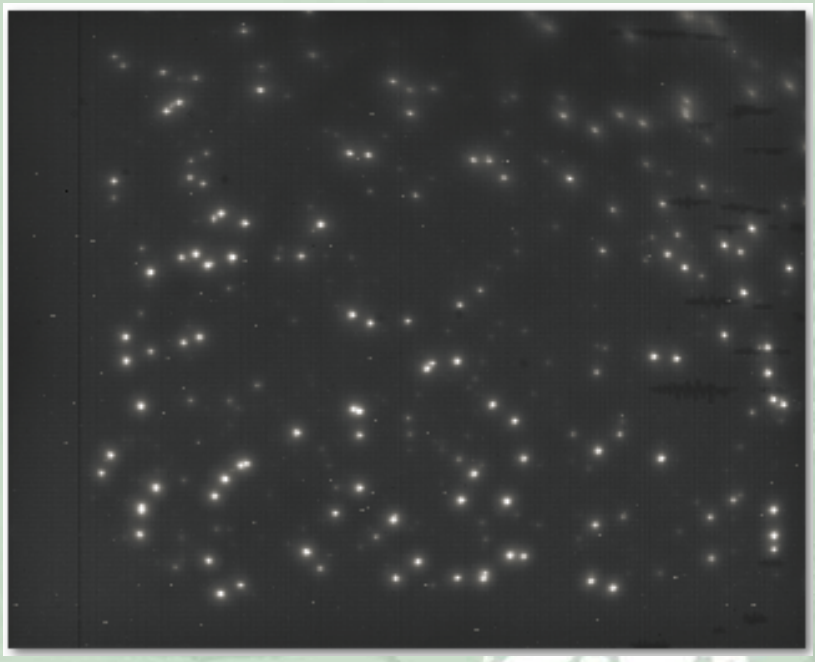
Why the PDE is lower than expectation?

Electrical field by TCAD



high field region shrink by Gap extruding: 6 μm → 4.5 μm

IR emission microscopy



Non-uniform high field region

Conclusion

- The bulk resistor type SiPM fabricated at NDL on epitaxial silicon with features high micro-cell density of $10^4/mm^2$, fast recovery time of 4.8 ns, low optical crosstalk, reasonable large gain and good resolution for single photon detection
- The devices have potential advantage of high PDE and large dynamic range simultaneously
- The actual area or high field region of the micro cells for the devices is smaller than expectation and design

Thanks for Your Attentions!

Comments and Suggestions are Highly Appreciated!

X. B. Hu[1)], C. Z. Hu[1)], D.P. Yin[1)], L. Y. Zhang[1)], C. N. Zhang[1)], Y. Chen[1)], G. Q. Zhang[1)], Ru Yang[1)], Kun Liang[1)], Yu. Musienko[2)], D. J. Han[1)]

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