硅光电倍增器（SiPM）研究进展

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主要内容

1、单光子探测器研究进展
2、SiPM现状及问题
3、0.5mm×0.5mm SiPM及特性
4、 1mm×1mm SiPM特性
5、结论与展望

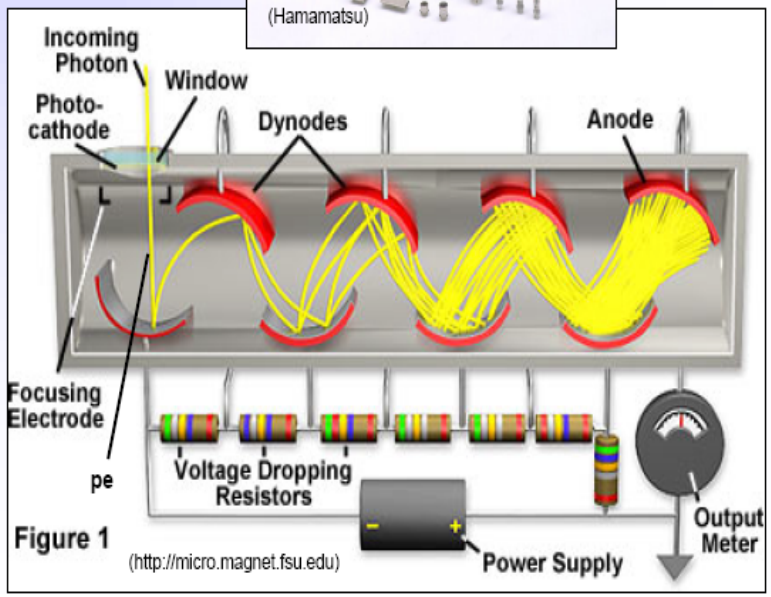
Evolution of Single photon detectors

Basic principle:

- Photo-emission from photo-cathode
- Secondary emission (SE) from N dynodes:
  - dynode gain g≈3-50 (function of incoming electron energy E);
  - total gain *M*:

$$M = \prod_{i=1}^{N} g_i$$

- Example:
  - 10 dynodes with g=4
  - $M = 4^{10} \approx 10^6$

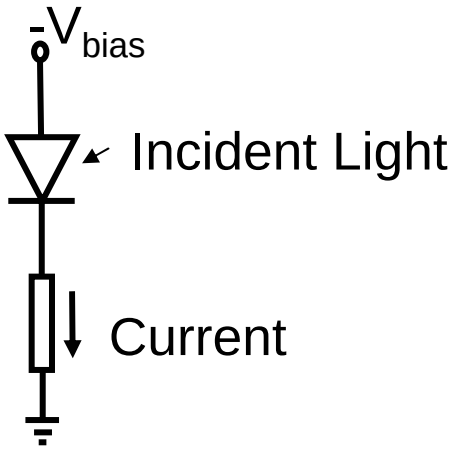


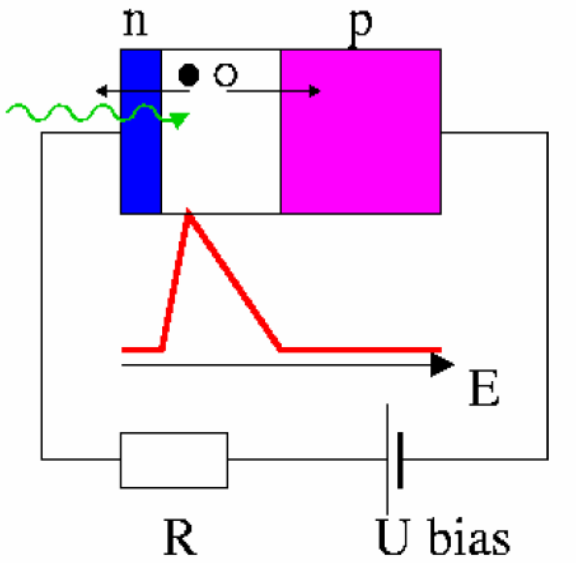
CERN Academic Training Programme 2004/2005

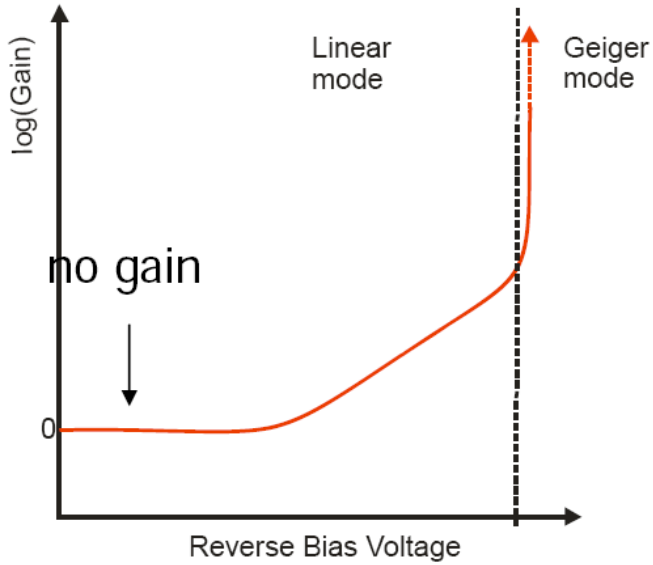
PMT was invented and commercialized in 1936

SPADs or G-APD

Single Photodiode





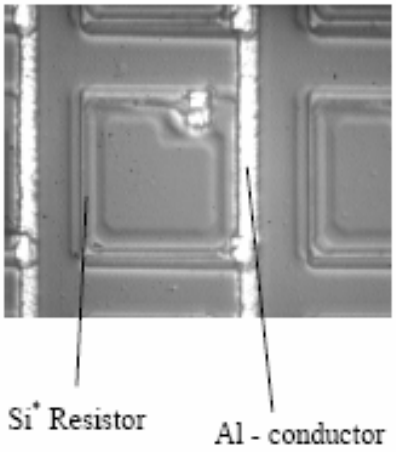


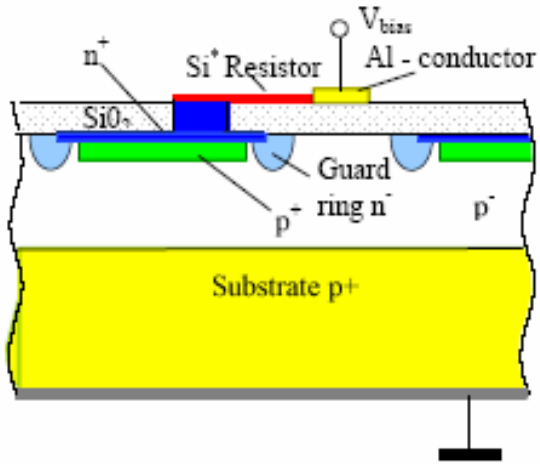
Features

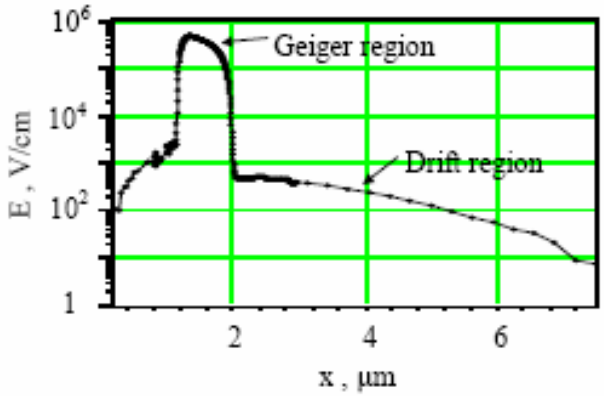
- Gain: "*infinite*"
- Geiger Mode needs quenching
- Fast response: ~ ps levels
- ***BINARY*** device→ **SiPM**

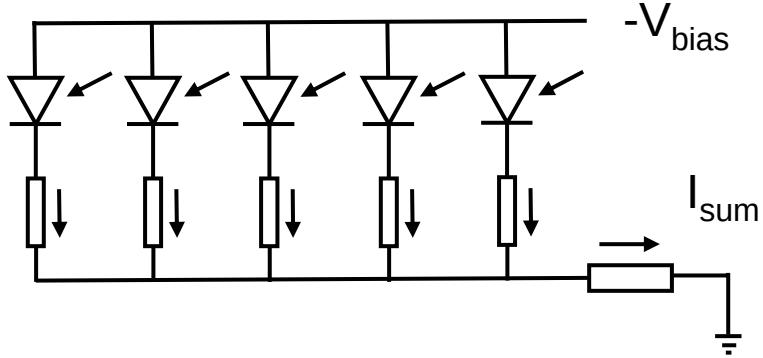
Silicon Photomultiplier（SiPM）

- SiPM (Silicon Photomultiplier) was originally developed in Russia around 1990





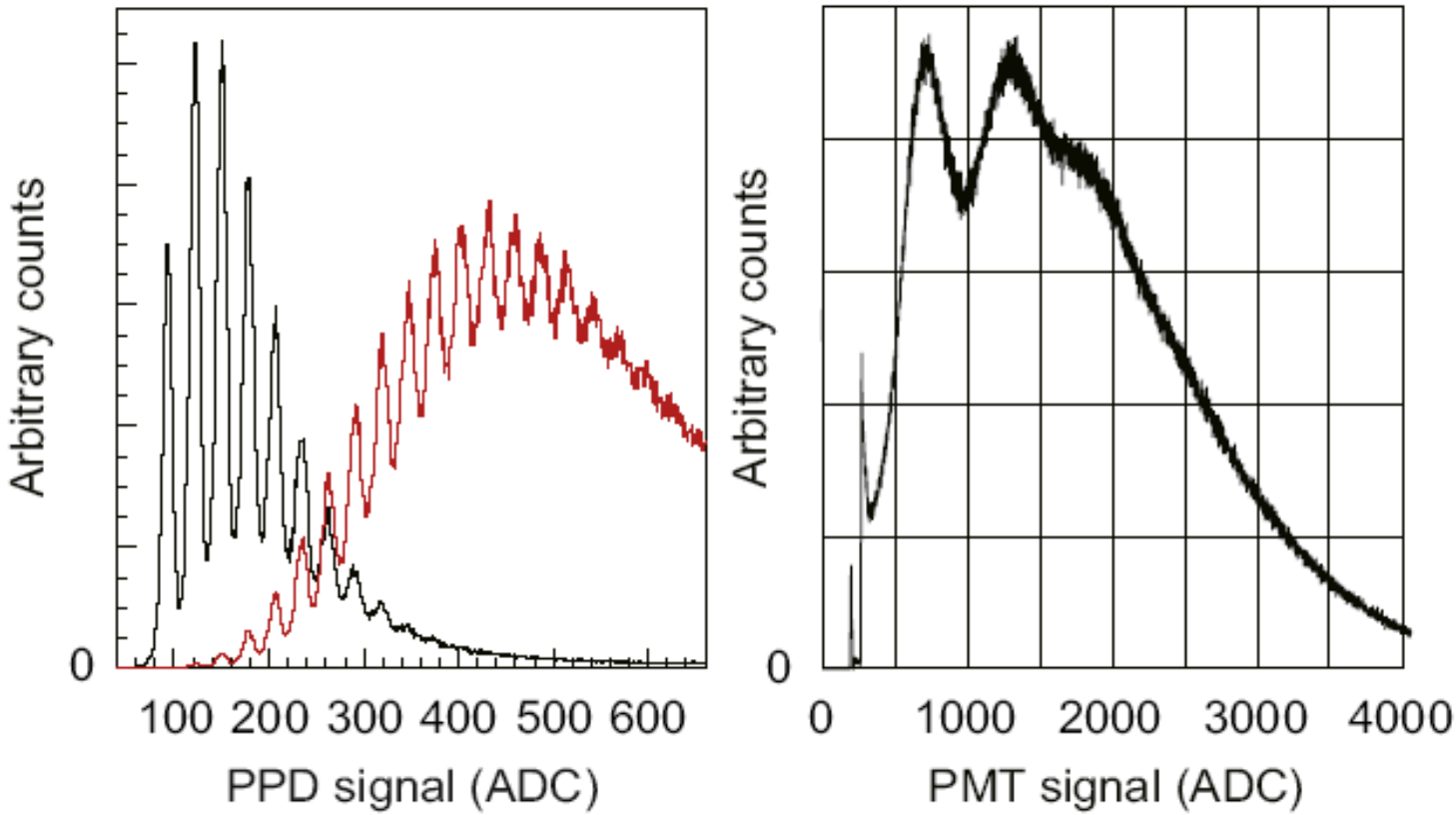




G-APD Array – Sum Individual Pixels

Features

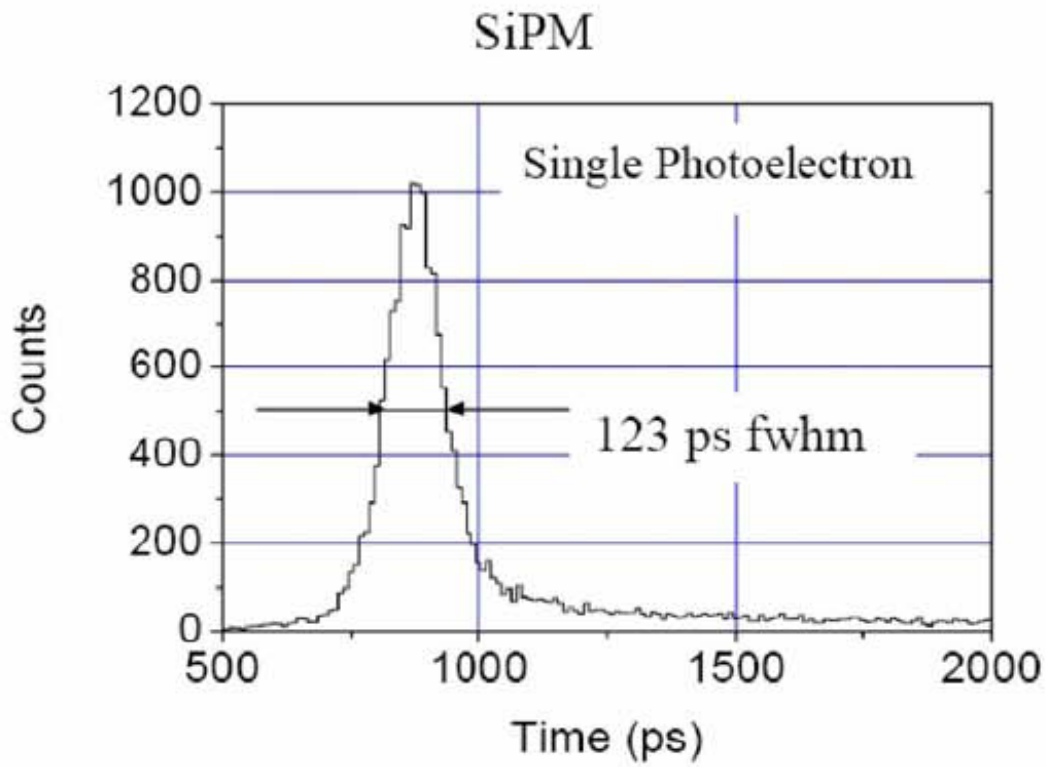
- Composed of many G-APDs in parallel output
- Poly Si used as quench R
- Ultra-high single photon resolution



- SiPM can discriminate the number of incident photons as discrete levels on the output node
- The ability to measure the single-photoelectron spectrum is a feature of the SiPM that is not possible with PMT detectors !

Timing of SiPM

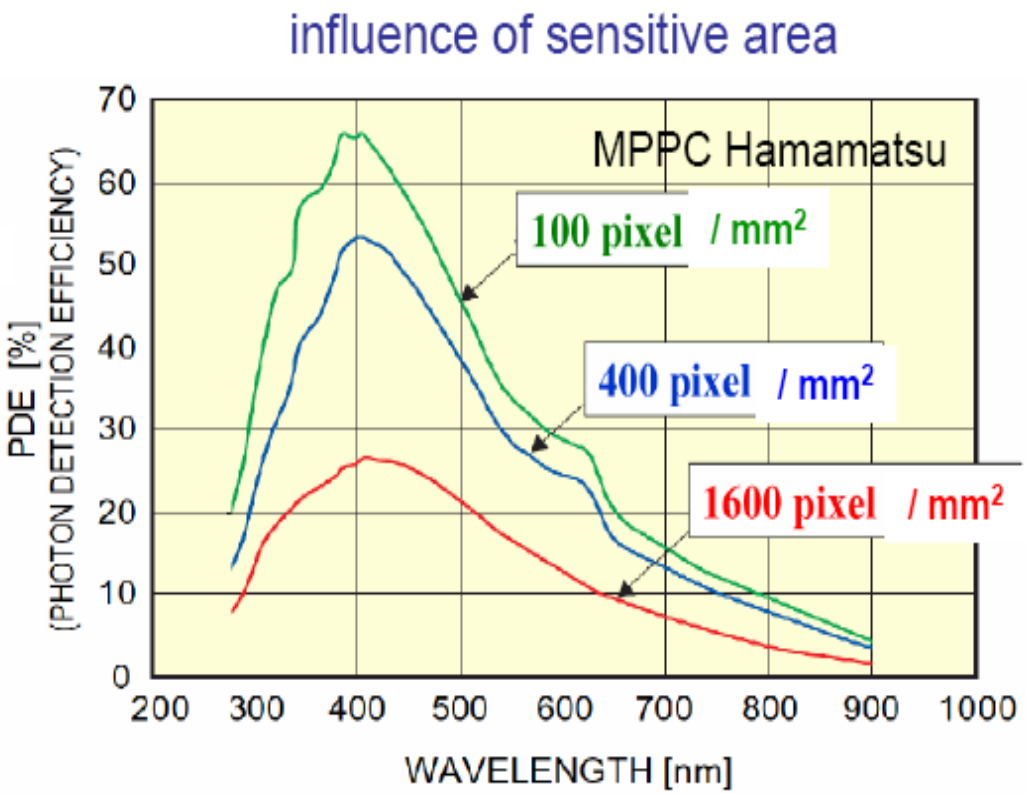
- The avalanche breakdown process is fast (~ps)
- Very good timing properties are expected even for single photons



Contribution from the laser and the electronics is 40 ps each. → time resolution 100 ps FWHM

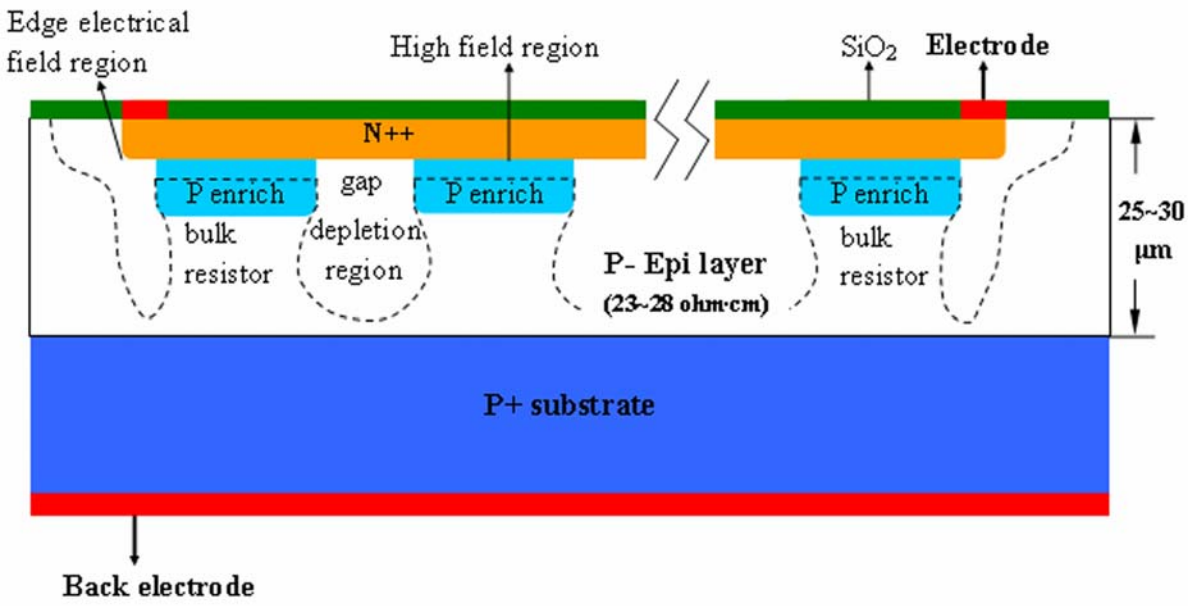
SiPM现状及问题

- 主要研机构MEPhI、DUBNA和CPTA，MPI、ITC-irst以及SensL、滨松、Zecotek等公司



- 面积较小：1mm×1mm -- 3mm×3mm
- 暗计数率较高：400-1000kHz/mm^2
- 动态范围小：10^2-10^3/mm^2
- 探测效率与动态范围之间存在矛盾关系!

0.5mm×0.5mm SiPM及特性

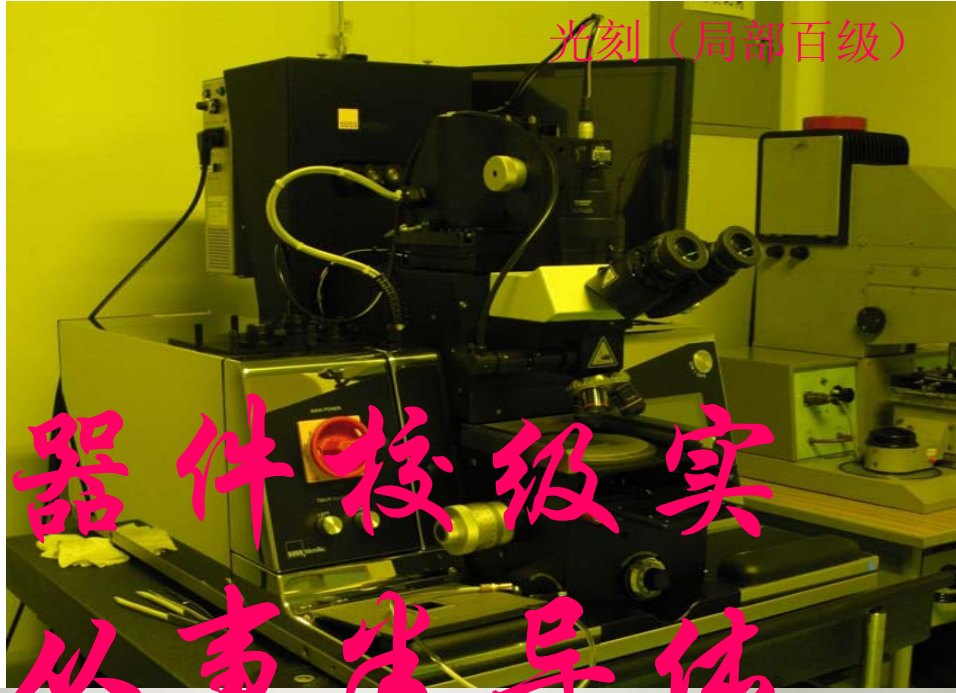


体电阻淬灭 SiPM结构示意图

管芯照片

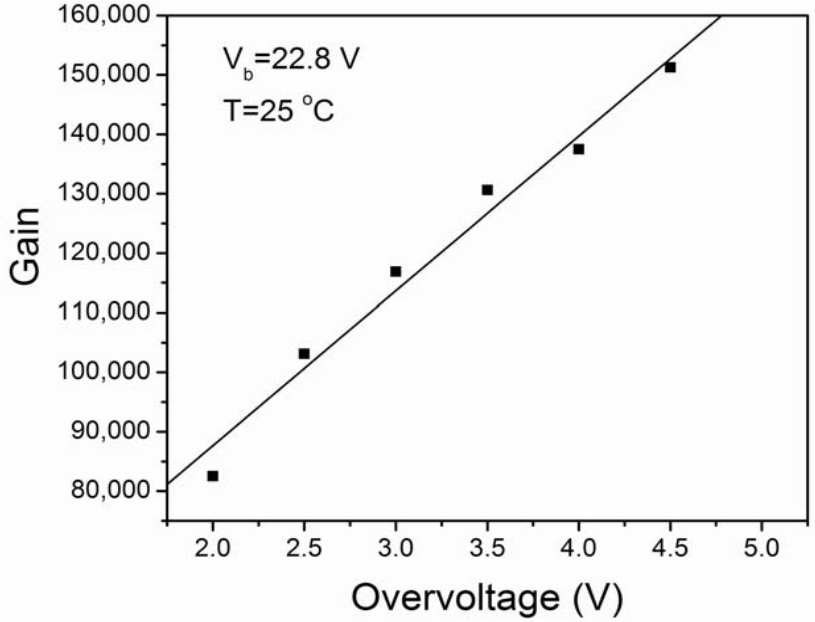
2500个APD单元，密度$10^4/mm^2$

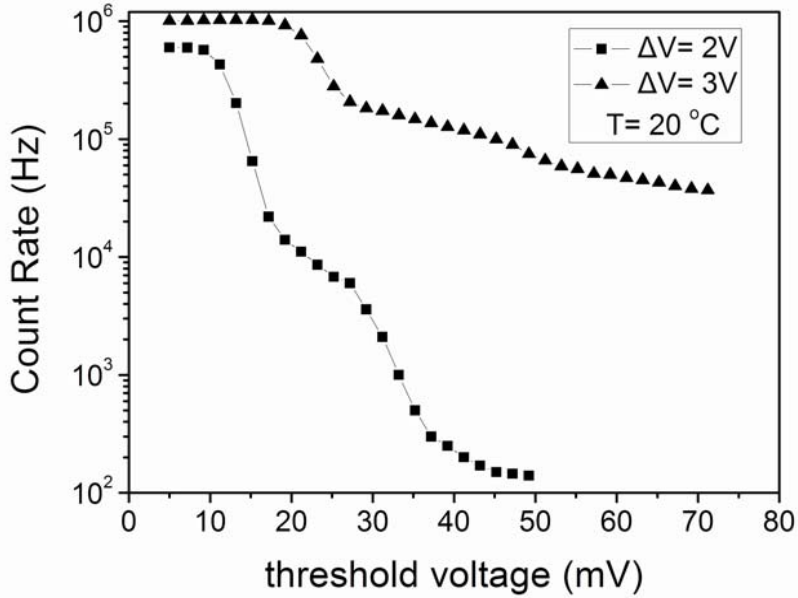
光刻（局部百级）

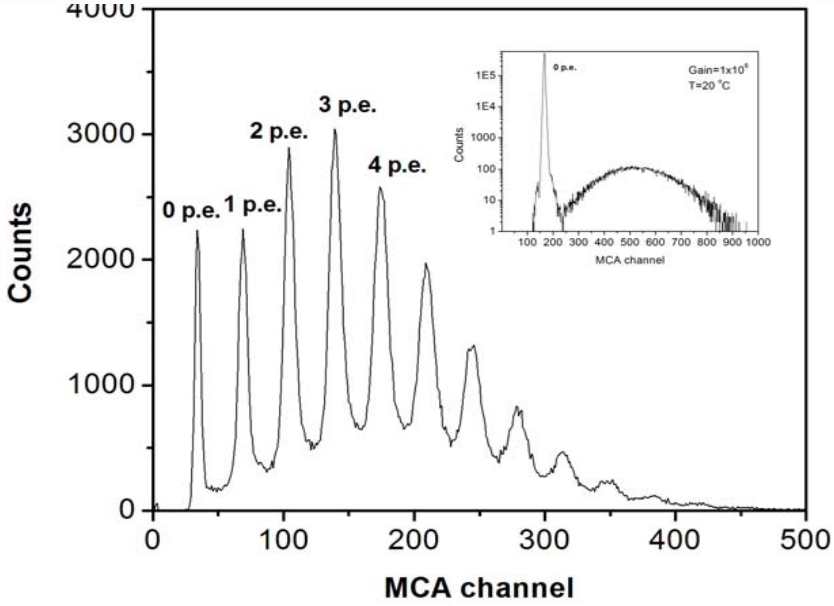


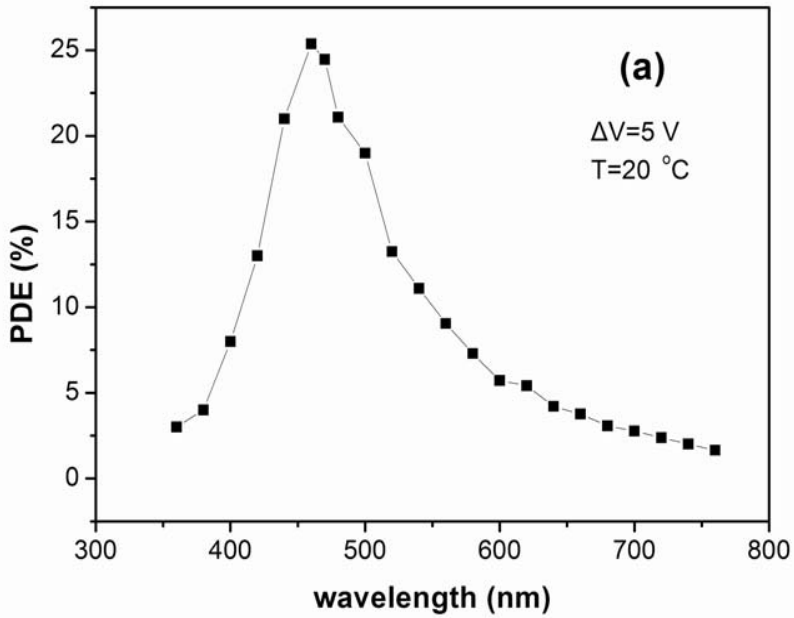
北师大新器件核级实验室专门从事半导体辐射探测器研制工作

PECVD

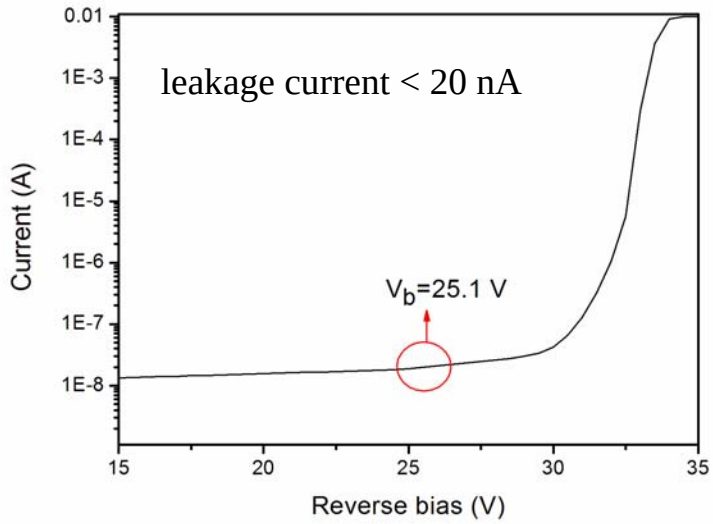

V_b=22.8 V
T=25 °C
Gain
Overvoltage (V)

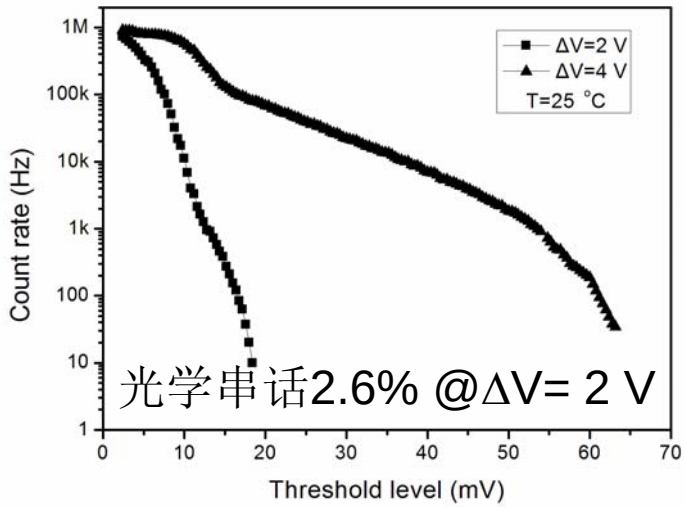

ΔV= 2V
ΔV= 3V
T= 20 °C
Count Rate (Hz)
threshold voltage (mV)

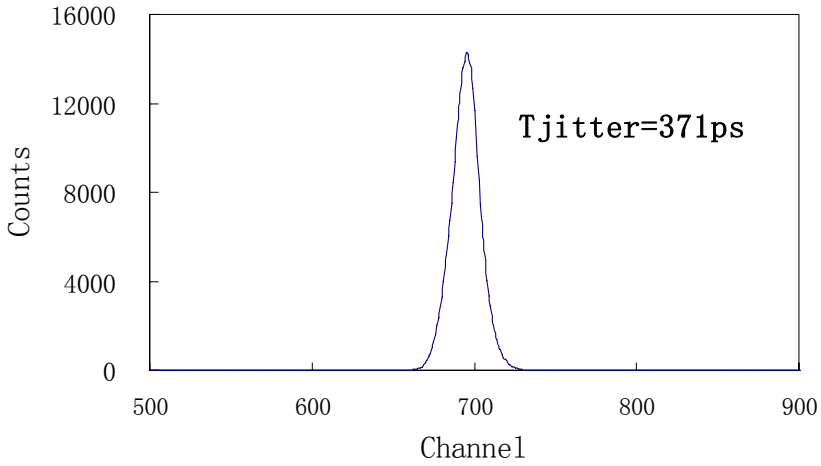

0 p.e.
1 p.e.
2 p.e.
3 p.e.
4 p.e.
Counts
MCA channel
Gain=1x10^6
T=20 °C

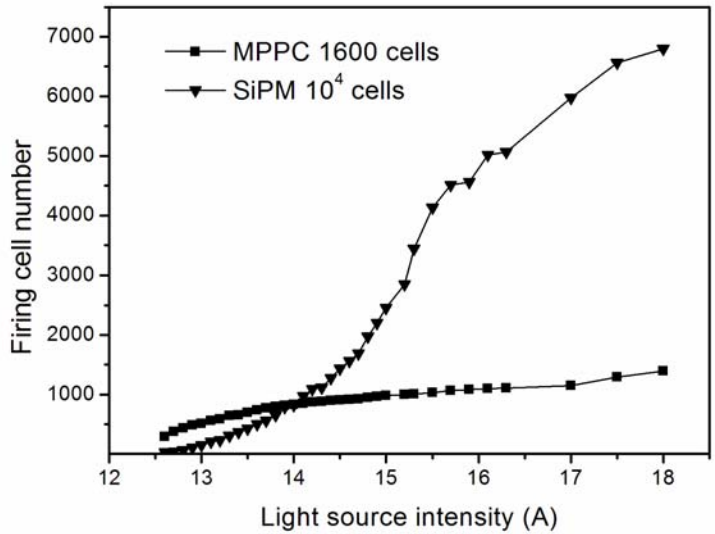

(a)
ΔV=5 V
T=20 °C
PDE (%)
wavelength (nm)

1mm×1mm SiPM特性（10000APD单元）









结论与展望

- 迄今为止没有一个研究机构或公司能够制作出所有主要特性参数都是最好的SiPM，一般只能根据需要优化其关键特性参数，折衷其它特性参数
- 采用衬底体电阻作为雪崩淬灭电阻的新结构SiPM具有较高的填充因子和APD单元密度，同时具有较高的探测效率。其光学串话较低，器件制作工艺较为简单，适合用于同时需要高的光探测效率和大的动态范围的场合
- 若要在更多应用场合替代PMT，除动态范围外，SiPM还需克服暗计数率较高、面积较小的缺点

谢谢！