Recovery Time of Silicon Photomultiplier with Epitaxial Quenching Resistors

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Outline

- **Motivation**
- **Experimental**
- **Results**
- **Discussion**
- **Conclusion**

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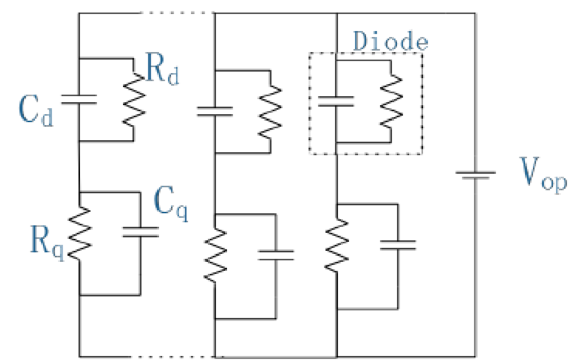
Motivation

Silicon photomultiplier (SiPM) is a new generation of high sensitive semiconductor photodetector, which consists of multiple pixels of avalanche photodiodes operating in Geiger-mode.

- ✓ High gain, high PDE, high time resolution
- ✓ Single photon counting, excellent photon number resolving ability
- ✓ Insensitive to magnetic field, low operated voltage and low cost



It is gradually replacing the traditional PMT in low-level light detection and sensing applications.

Motivation

Analog SiPM:

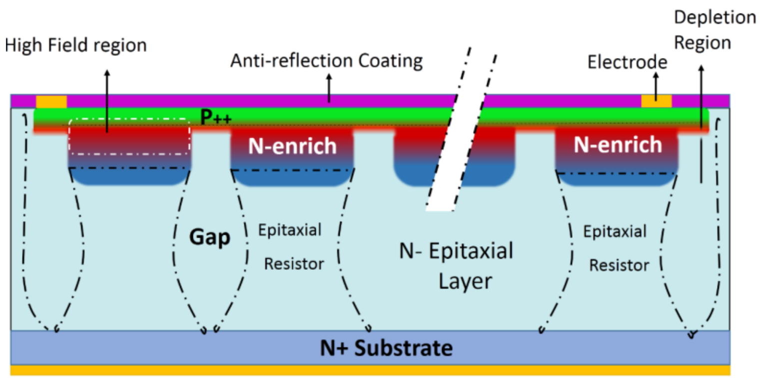
- SiPM with quenching resistors fabricated at the surface using poly-silicon or metal strips (HPK,FBK,ect.)
- SiPM with integrated quenching resistors in epitaxial or bulk silicon

EQR SiPM:

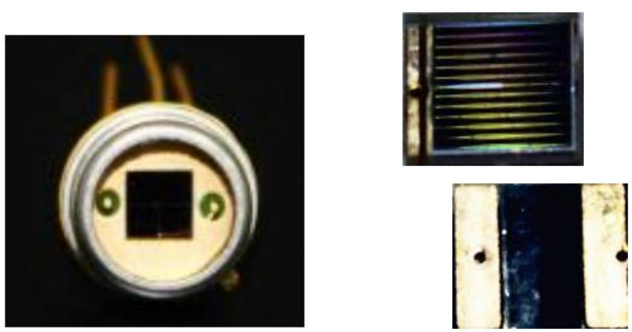
- Epitaxial silicon layer below p-n junction as the quenching resistor
- A large fill factor with small cell size
- High PDE can be obtained while retaining large dynamics range
- The fabrication steps for quenching resistors on the surface are omitted

The EQR SiPM firstly developed by NDL in 2010
(*https://doi.org/10.1016/j.nima.2010.04.040*)

Motivation



Schematic structure of EQR SiPM



3×3mm^2 EQR SiPM

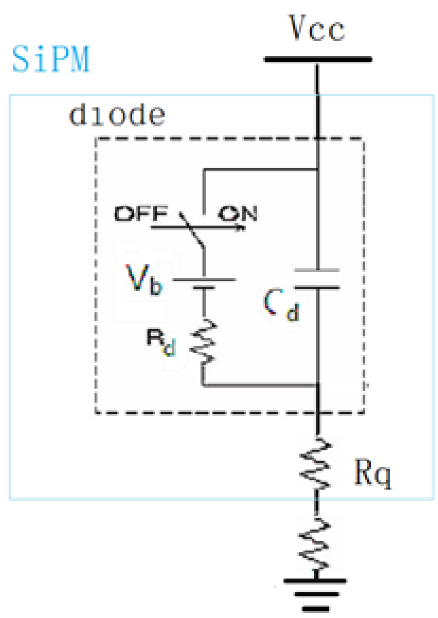
- Device type：P-on-N
- Active area ：3×3mm^2
- Pixel size：10μm
- Charge time constant：~3ns
- Number of microcells：~9× 10^4
- Gain：~2×10^5
- Dark count rate：7MHz
- Crosstalk：8%
- Peak PDE：31% at 420nm

Small RC time constant for the APD cells, short recovery time and fast time counting rate can be expected.

Motivation

Recovery time of SiPM

Definition : The time needed to recharge a pixel after a breakdown has been quenched due to the finite time taken to quench the avalanche then reset the diode voltage to its initial bias value.



Motivation

Shortening recovery time for the high flux photons detection and fast photon counting applications

Photon counting CT

- ✓ **multicolor imaging**
- ✓ **Reducing Radiation dose**
- ✓ **Reducing exposure time**

If the counting rate of SiPM is increased to hundreds MHz or GHz, it would be expected to be applied to photon reflectometry, quantum random number generators, etc.

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Experimental

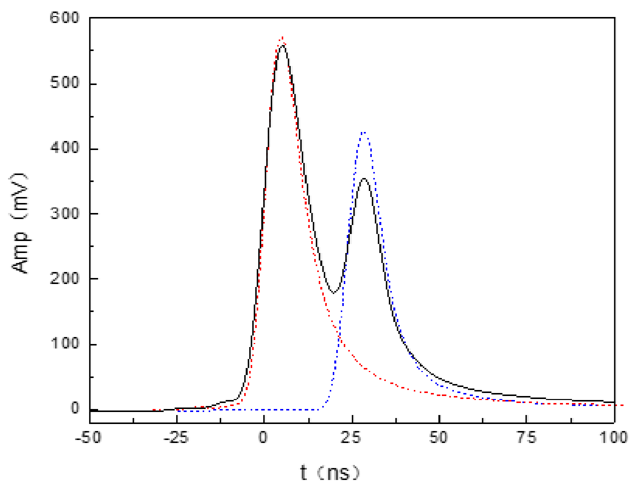
Method: **Double light pulse method:** for measuring Overall recovery time and partial recovery time

Waveform analysis method: for recovery time of Single photon pulse

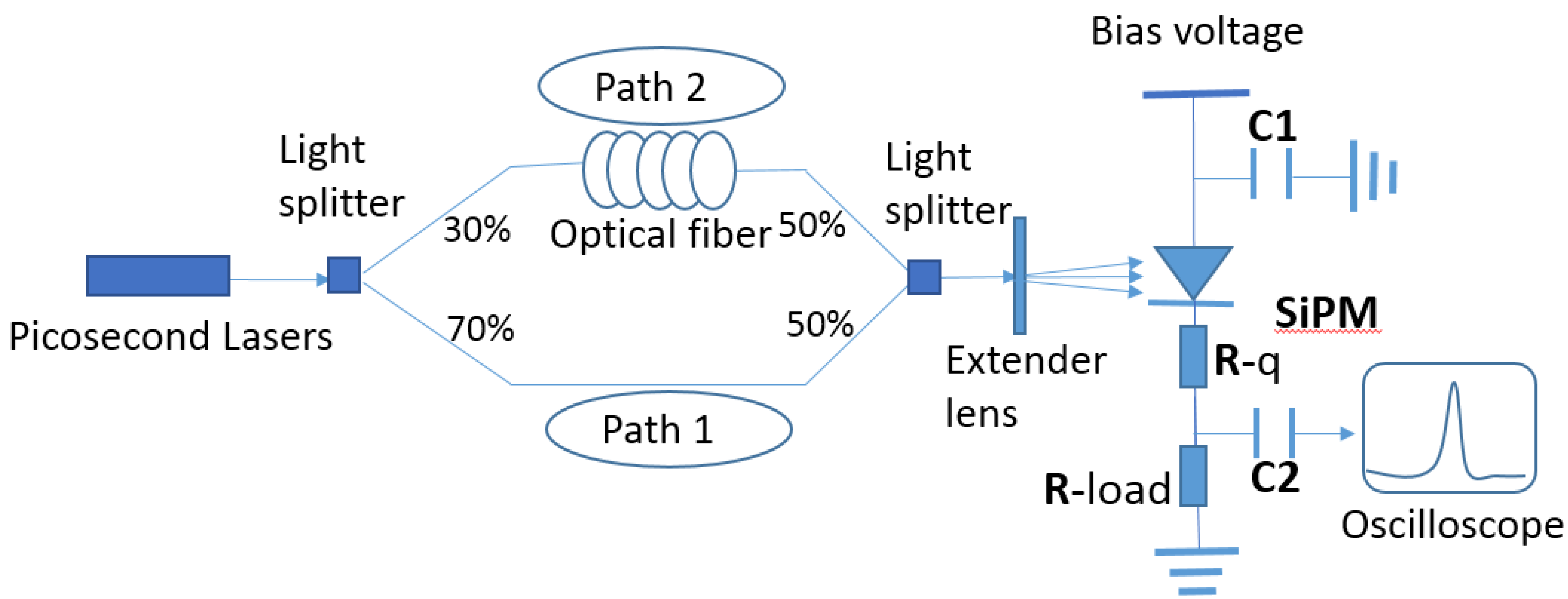
Principle: Photon reach to detector surface during voltage recovery process, its signal amplitude is reduced.

$$A_2/A_1 = y_0 + A * \exp\left(-x/\Delta t\right)$$

Red dashed lines shows the signal when the 2 path is blocked, blue dashed lines shows the signal when the 1 path is blocked, black line the signal when both paths are connected.

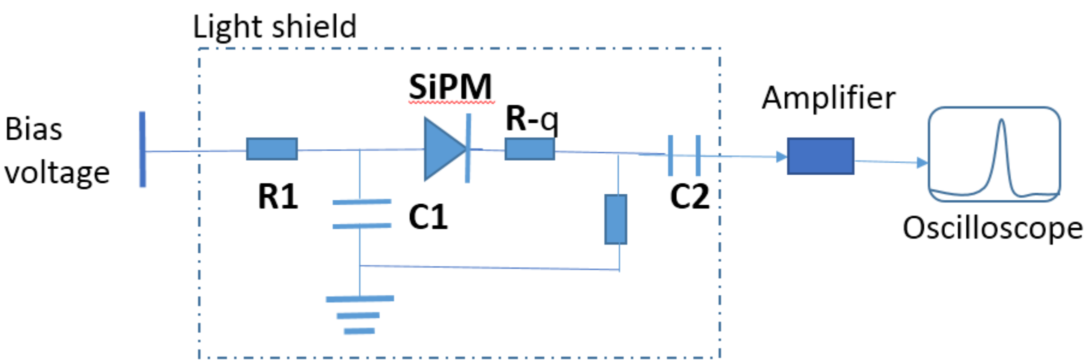


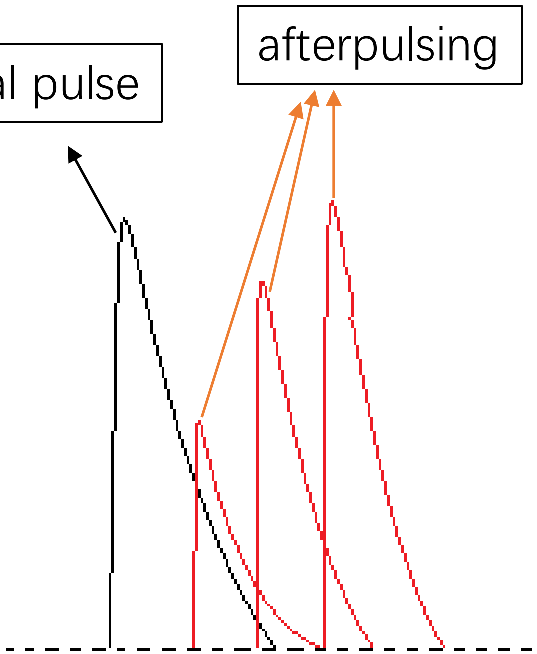
Double light pulse method



Picosecond pulsed with pulse width of 32 ps
Lecroy oscilloscope: waverunner 610zi, with a bandwidth of 4 GHz

Waveform analysis method





If an afterpulse is caused during this recovery time, as the bias voltage is lower than V_{op}, its pulse height is less than 1p.e. should be observed. Thus, by tracing the interval time and the amplitude of afterpulsing, recovery curve can be obtained.

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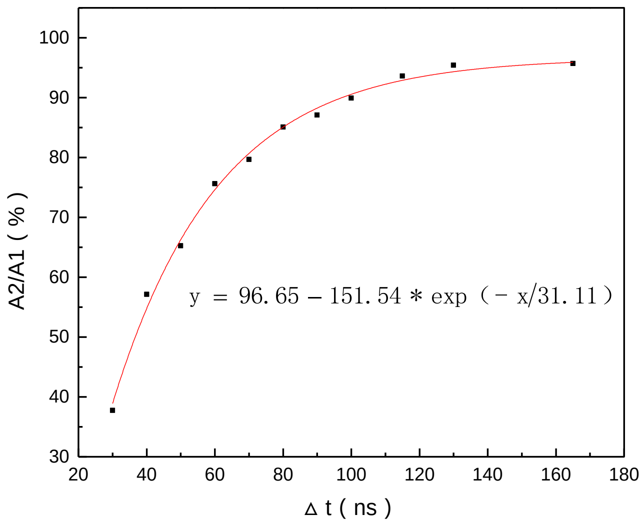
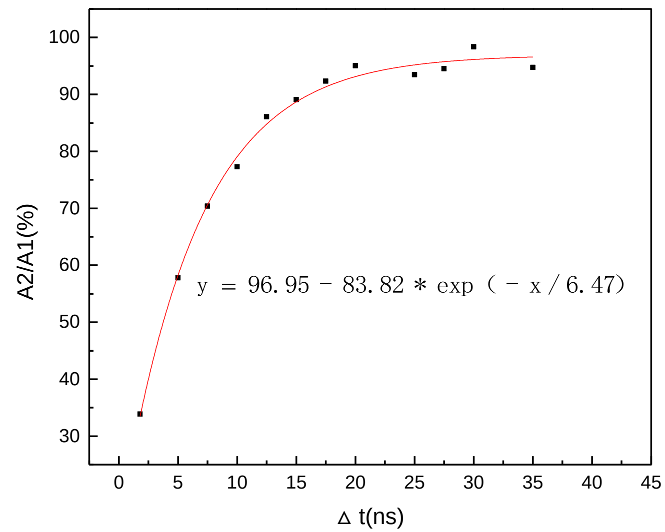
Results

Recovery time of 3mm device

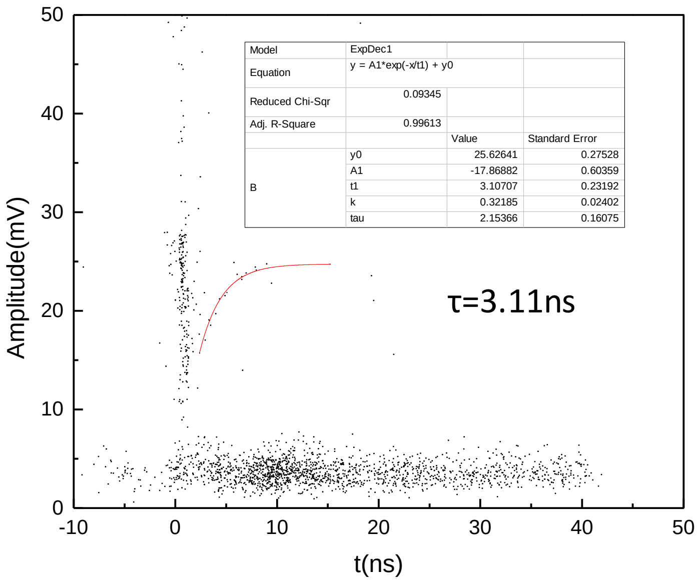




Total ~**90000 pixels** were fired, the overall recovery time of the device was ~**31ns**; the number of fired pixels were controlled to be about **2000**, the device recovery time was decreased greatly to ~**6.5ns;**

Results

Recovery time of 3mm device

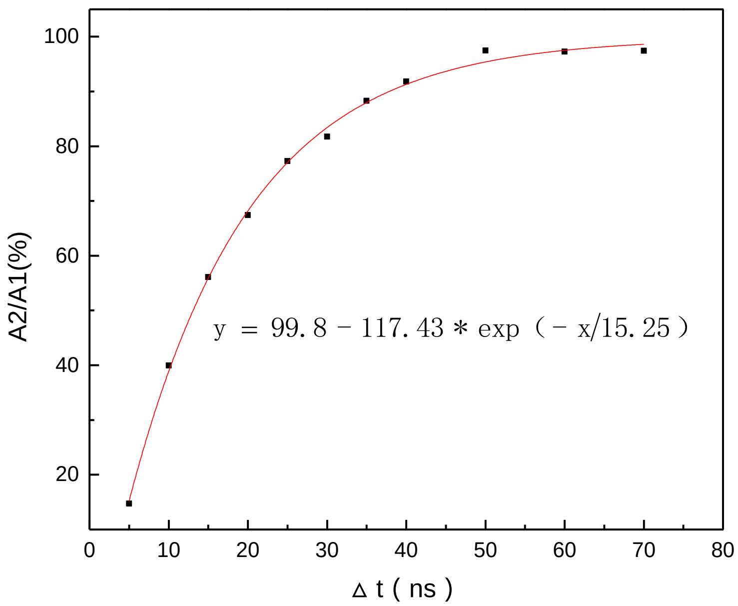


The recovery time of **one fired pixel** obtained by extracting afterpulsing under dark conditions and fitting out the recovery curve was ~ **3ns**

The recovery time increases with the number of fierd cells.

Results

Recovery time of 1.4mm device



The device with 1.4×1.4mm^2 active area and 10μm pixel size, the device recovery time was ~15ns while total ~20000 pixels were fired

The recovery time increases with the device area.

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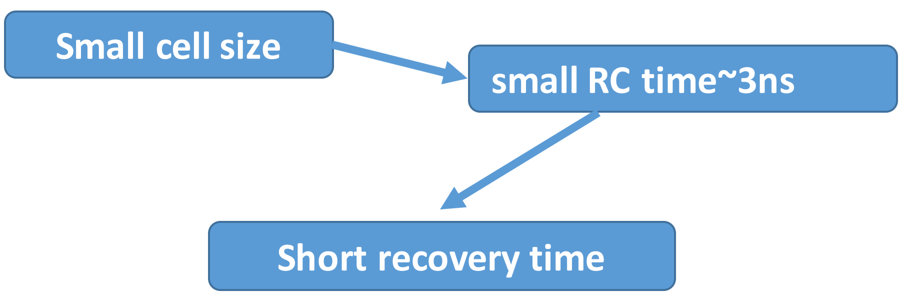
Discussion

The recovery time of the device is strongly dependent on the active area of device and the number of fired pixels, the recovery time increases with the number of fierd cells and device area.



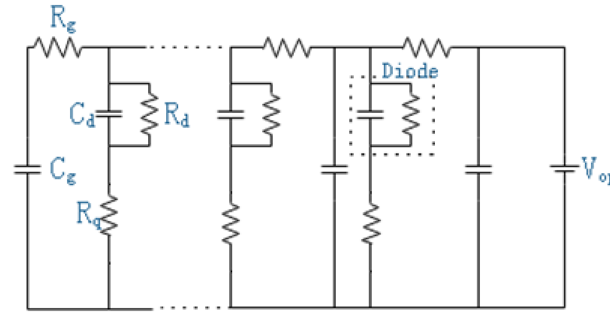
Discussion

Reason 1 ： signal transmission time delay

RC transmission line:

P++⟶Rg

total C⟶Cg

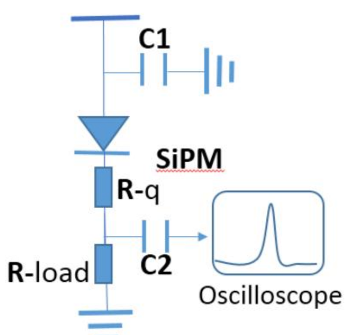


equivalent electrical mode of EQR-SiPM

Reason 2 ： readout electronics

Impedance matching

The value of signal capacitance and load resistors



Reason 3 ： pixels can't possibly be fired synchronously when they are bias on

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Conclusion

- Recovery time of EQR-SiPM is increasing with the increase of the number of fired pixels.
- The device with same microcell size, its overall recovery time increases with the device area.
- Signal circuit, RC transmission line and charge transport mode affect the pulse waveform.
- Improve direction: reduce RC transmission lines and Optimized readout circuit

Thank you for your attention!

Development of P-on-N Type Silicon Photomultiplier with Epitaxial Quenching Resistors

Type: Poster **Track:** Photon detectors

Silicon photomultiplier (SiPM) is alternative to conventional PMT in various applications due to its high photon detection efficiency (PDE), excellent resolution for single photon detection, insensitivity to magnetic field, low operating voltage and convenience for integration, etc. SiPM with epitaxial quenching resistor (EQR SiPM) is one of the main SiPM technologies, which can effectively reduce … More

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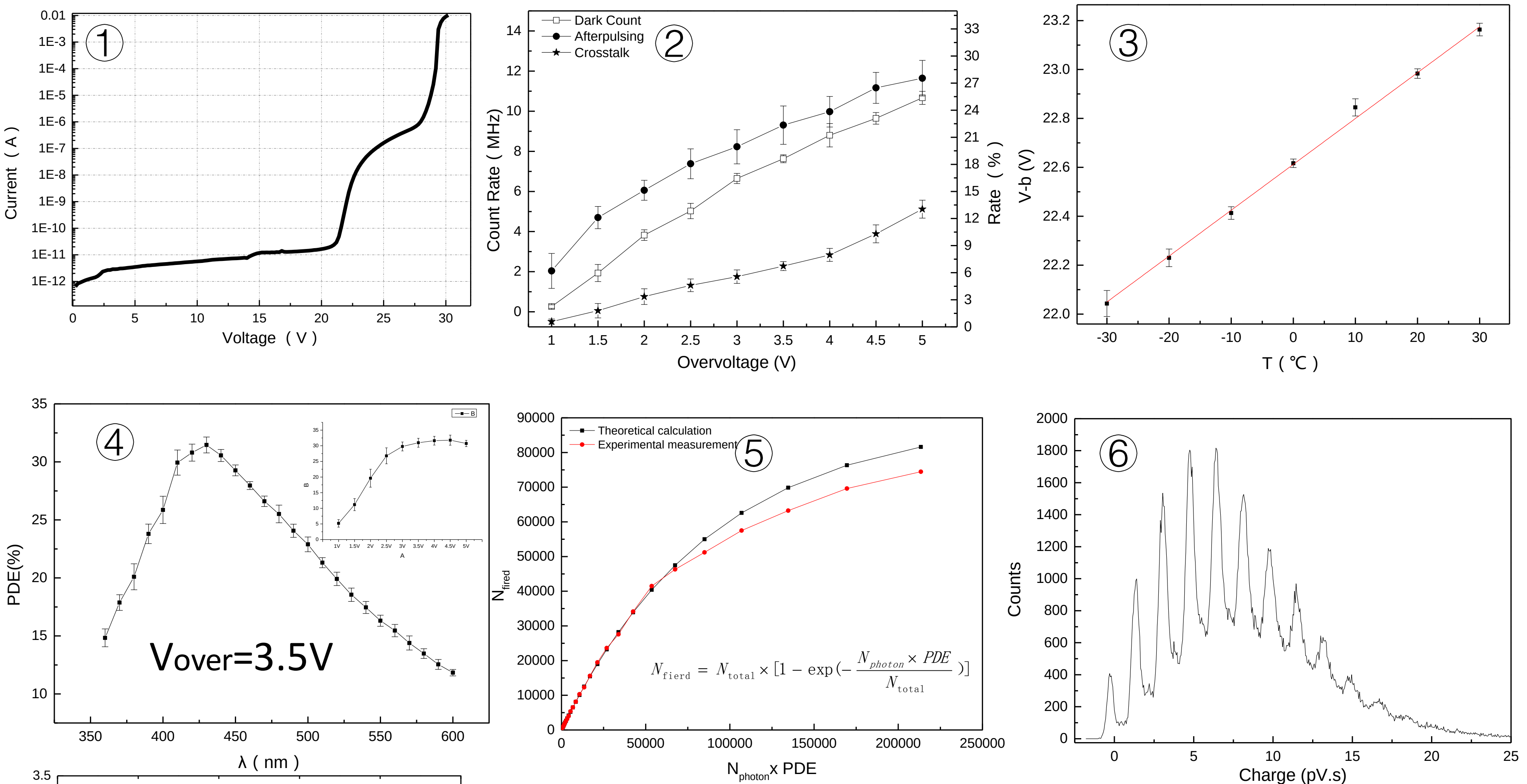

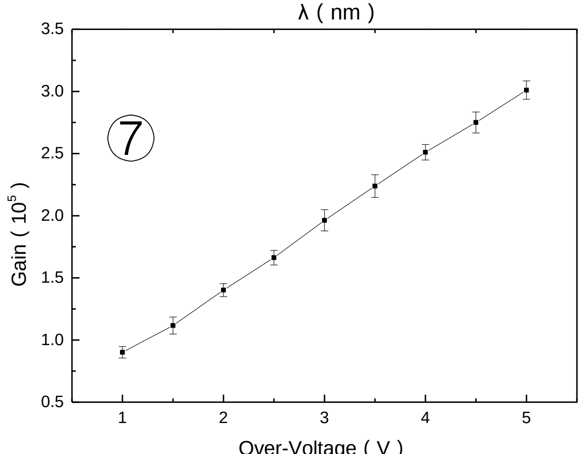

①Device I-V characteristic curve

②Noise characteristics

③ Vb –Over biased diagram

④The relation of PDE with the optical wavelength

⑤Dynamic range map of 3mm SiPM device

⑥Single photon resolved spectrum

⑦Gain –Over biased diagram