Solar-blind photodetectors with AlGaN photocathodes for light registration in UVC range

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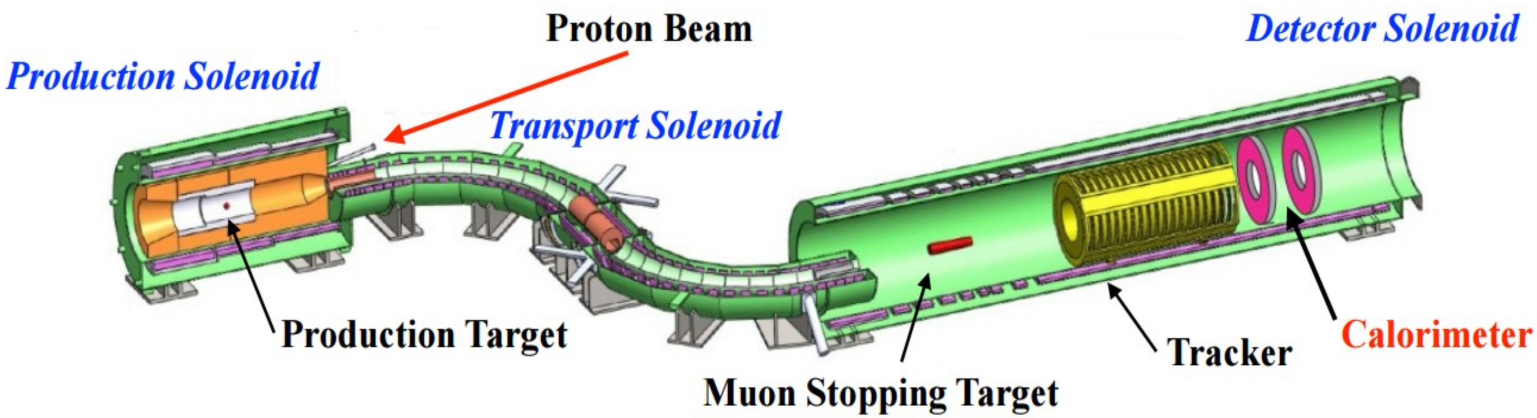
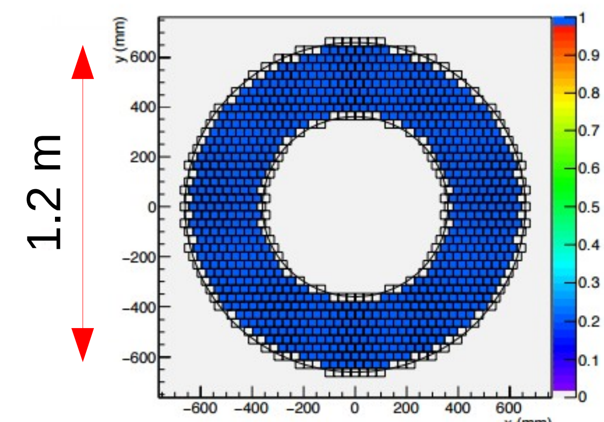
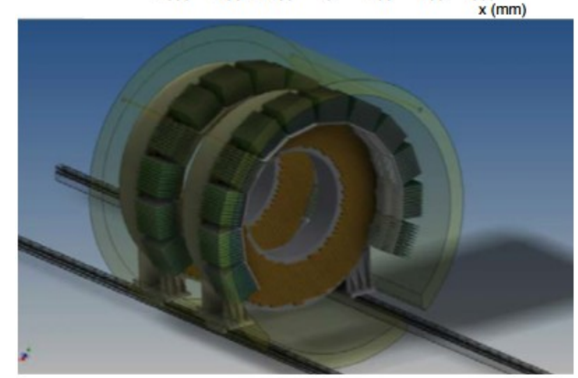
Mu2e electromagnetic calorimeter



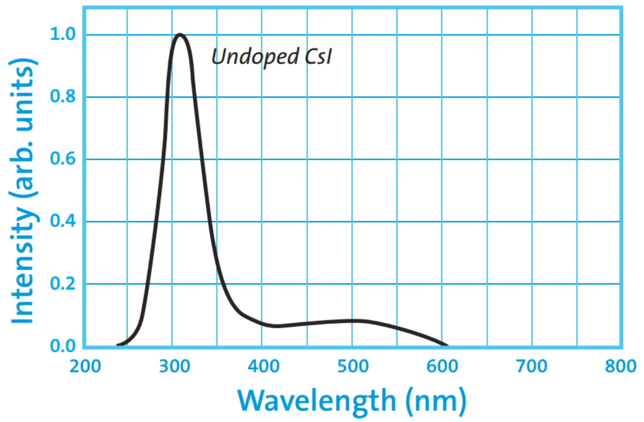




- Two disks with inner radius 35.1 cm and outer radius 66 cm
- ~700 crystals per disk
- Square crystals (34x34x200 mm3)

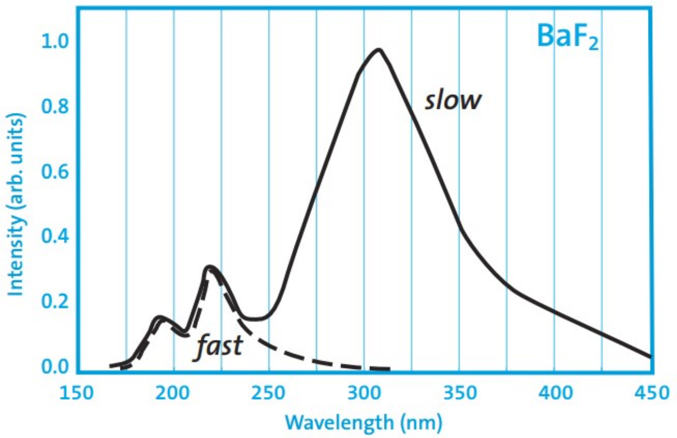
CsI and BaF_2 scintillators for the Mu2e electromagnetic calorimeter

Stage I. CsI(undopped) scintillators
- emission peak ~310 nm,
- decay time 16 ns
- radiation hardness up to 100 krad



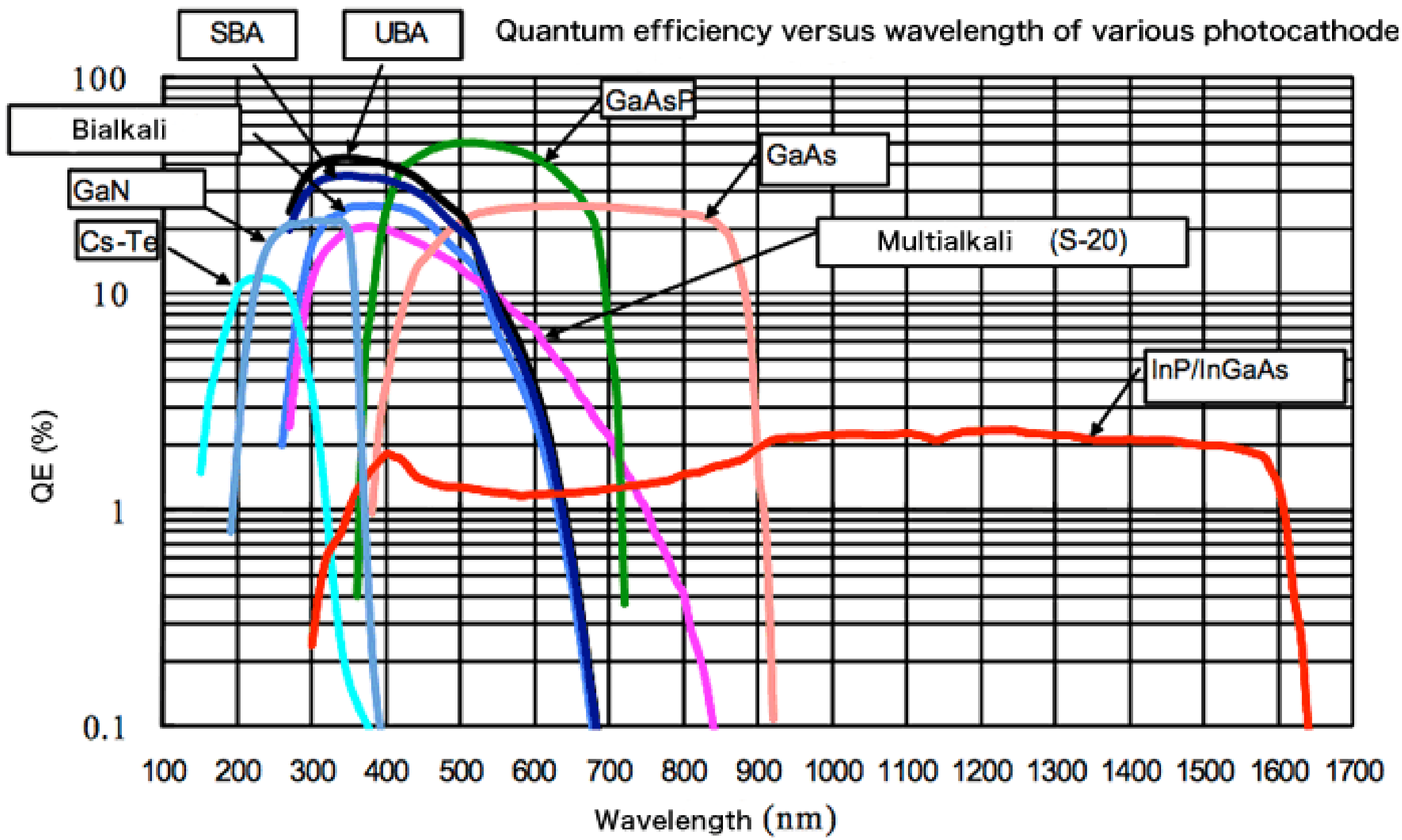
Stage II. BaF_2 scintillators
- emission peaks fast ~220 nm, slow ~310 nm
- decay time 0.8 ns (fast), 600 ns (slow)
- radiation hardness up to 10 Mrad*

*for Saint-Gobain BaF_2 crystals



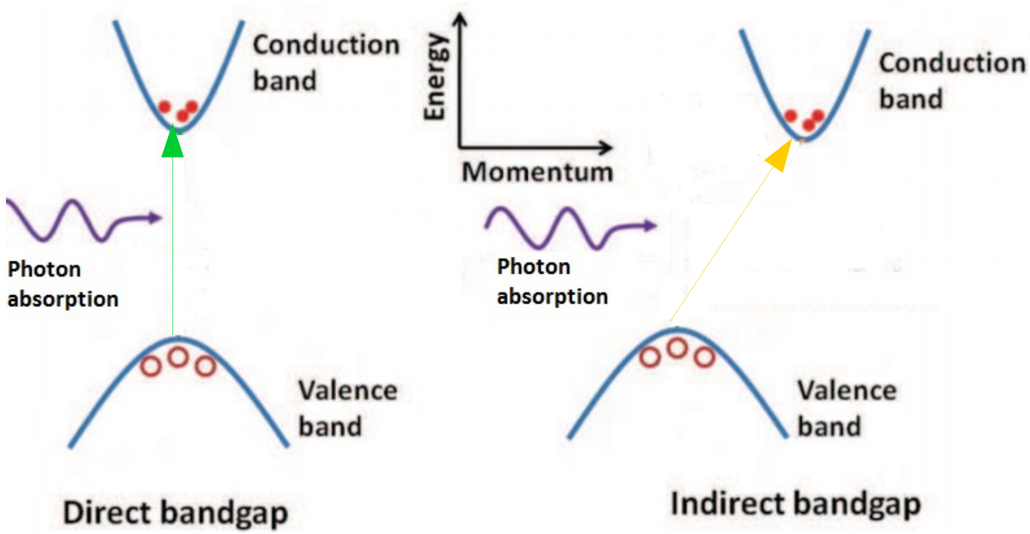
Both crystals have middle UV range emission spectrum. Fast component of BaF_2 is emmited in UVC (< 280 nm) range.

UVC range photocathodes

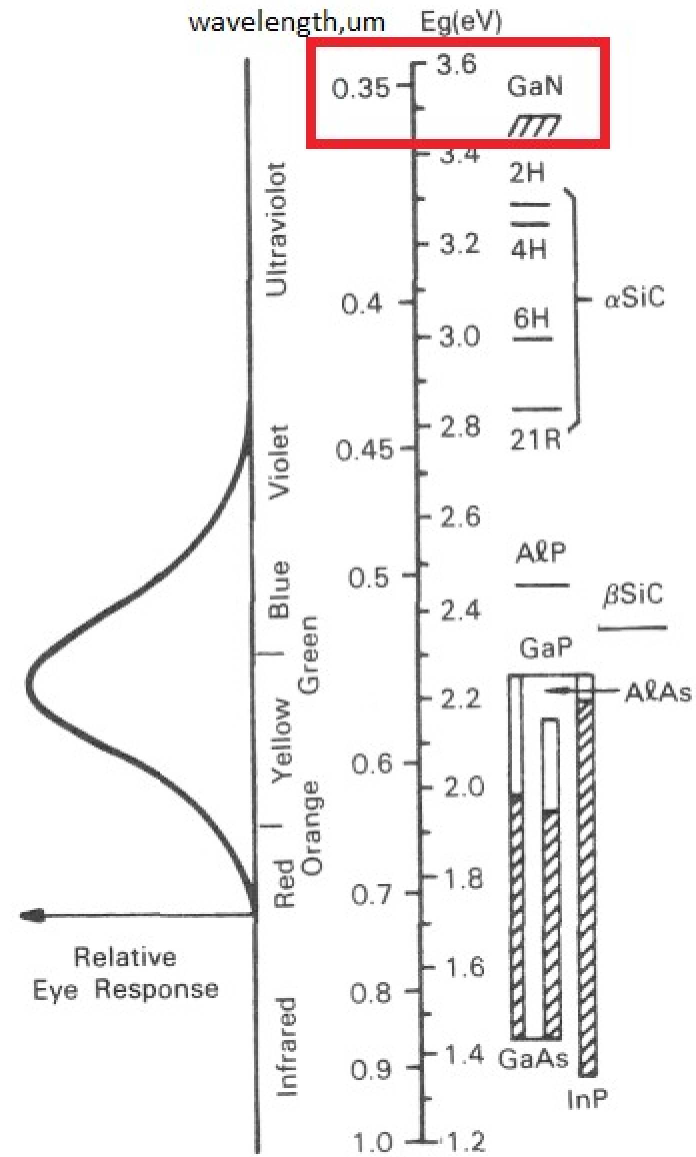


Cs-Te, GaN/AlGaN, Bialkali photocathodes are suited for UV range.
QE is the question.

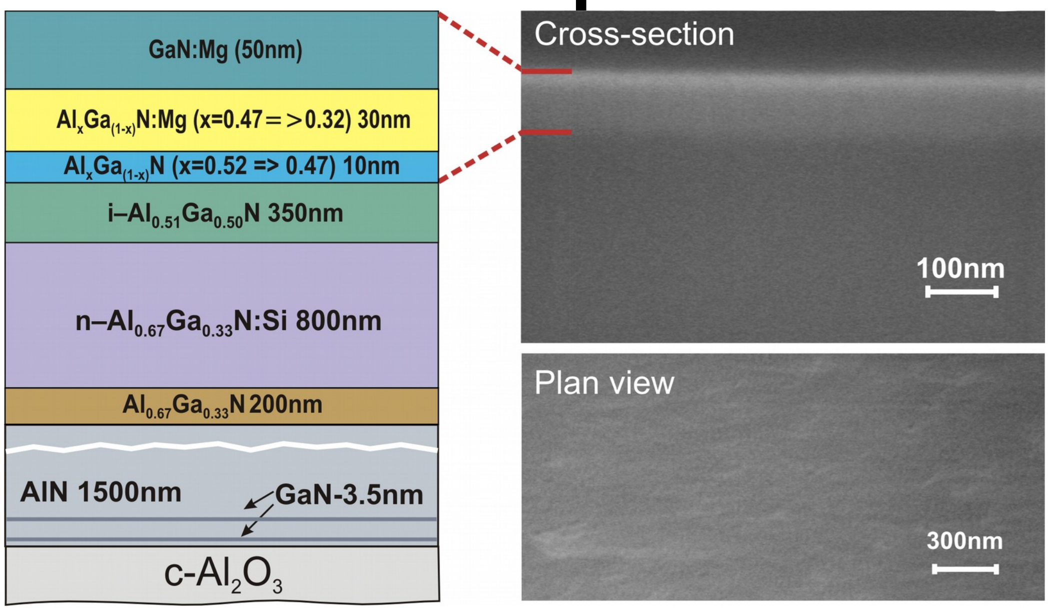
Semiconductor's band gap



Energy spectrum of absorption in semiconductor layer is mainly defined by band gap - energy difference (in electron volts) between the top of the valence band and the bottom of the conduction band.



GaN/AlGaN heterostructures for photodetectors

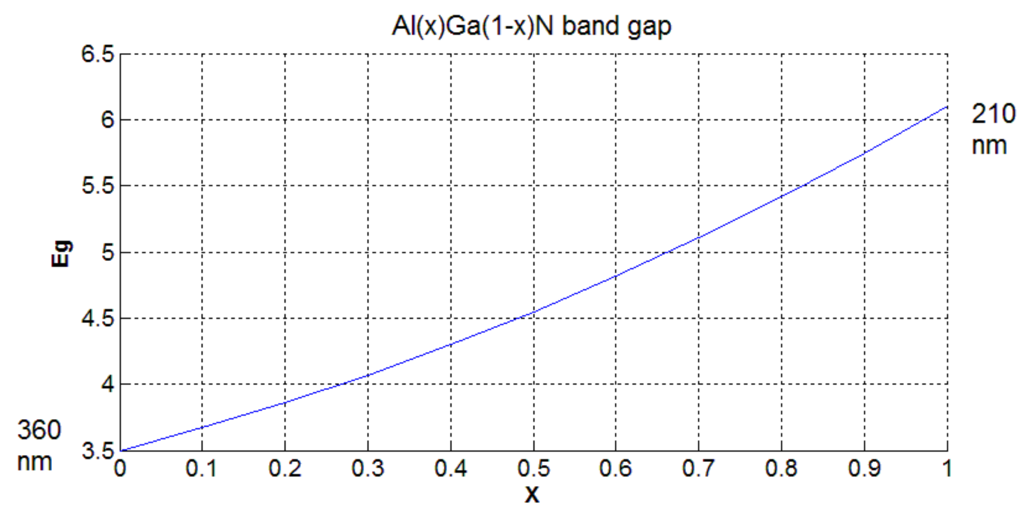


The most promising material for UV photodetecting devices is AlGaN alloy, because

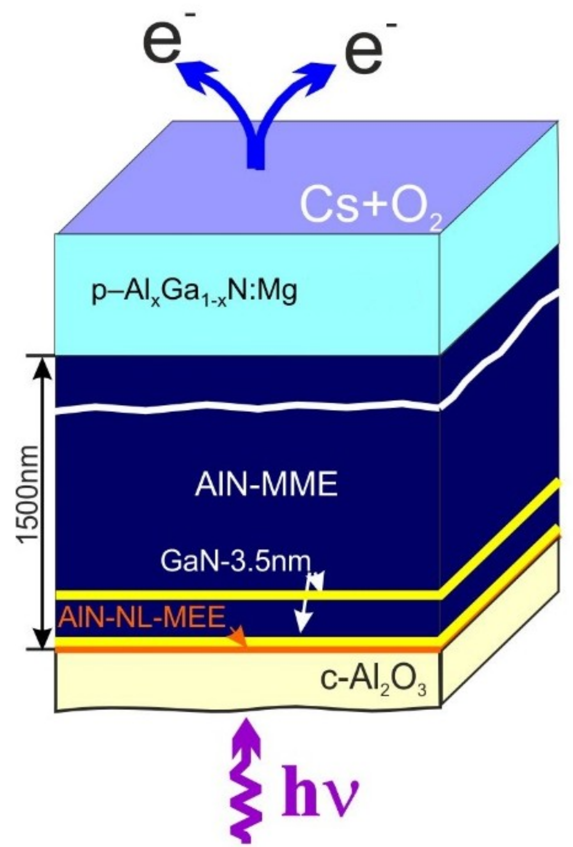
- It is direct band gap semiconductor
- High chemical resistance
- High radiation resistance
- Developed production methods of complex structures for semiconductor devices

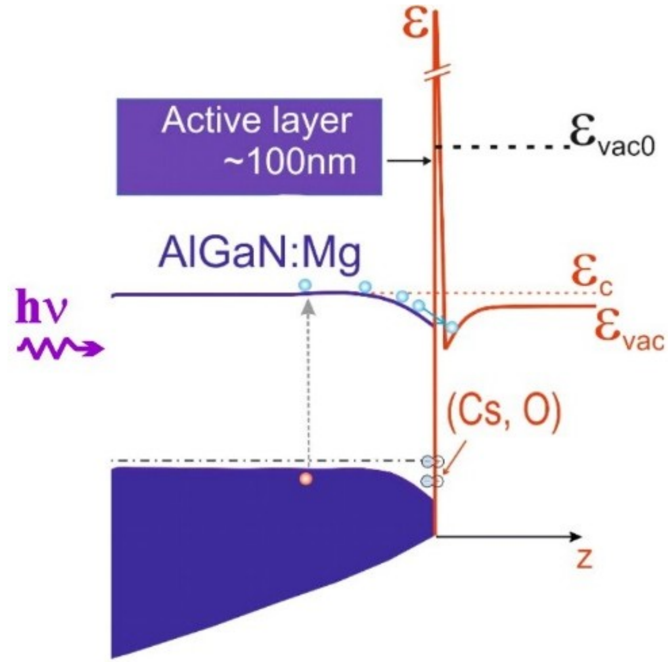
One can change band gap of $Al_xGa_{1-x}N$ alloy by varying Al mass fraction. The band gap behavior is described by equation:

$$Eg = (1 - x)*Eg(GaN) + x*Eg(AlN) - b*x*(1 - x)$$



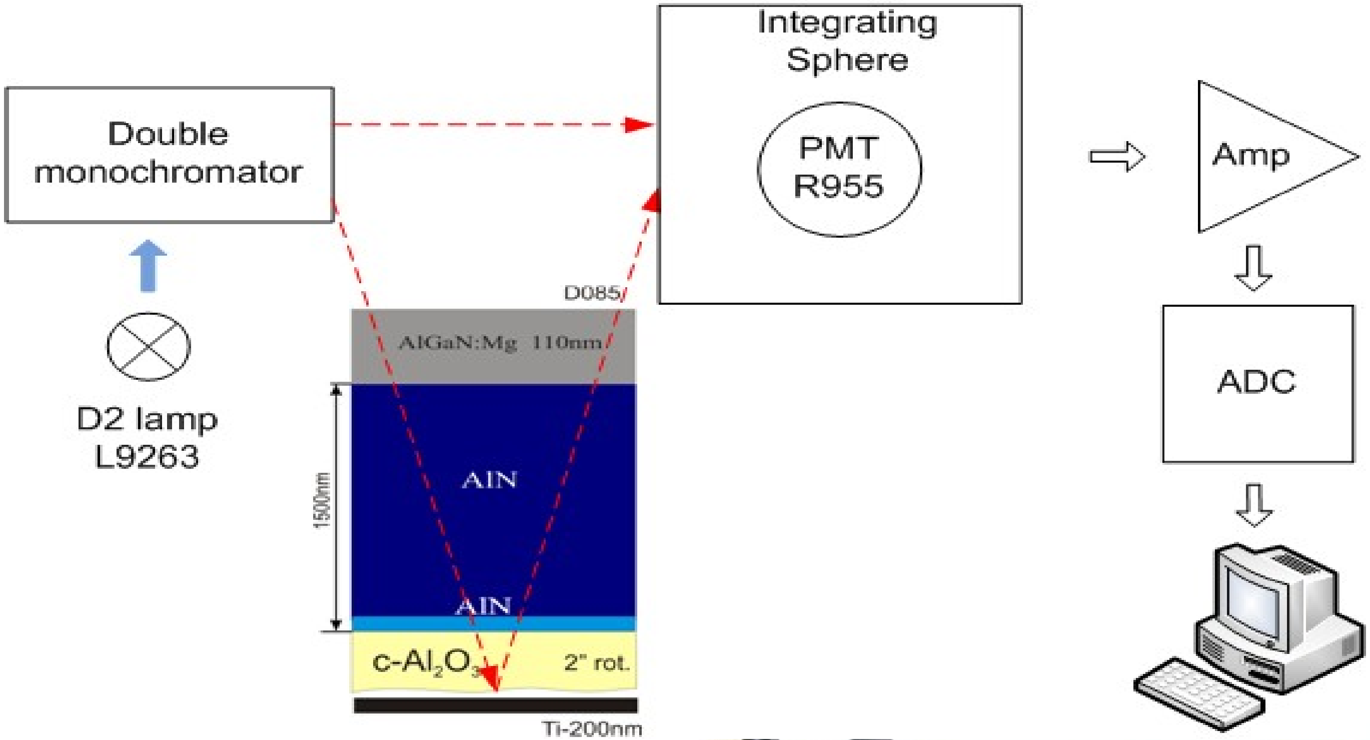
$Al_xGa_{1-x}N:Mg$ structures for photocathodes with negative electron affinity

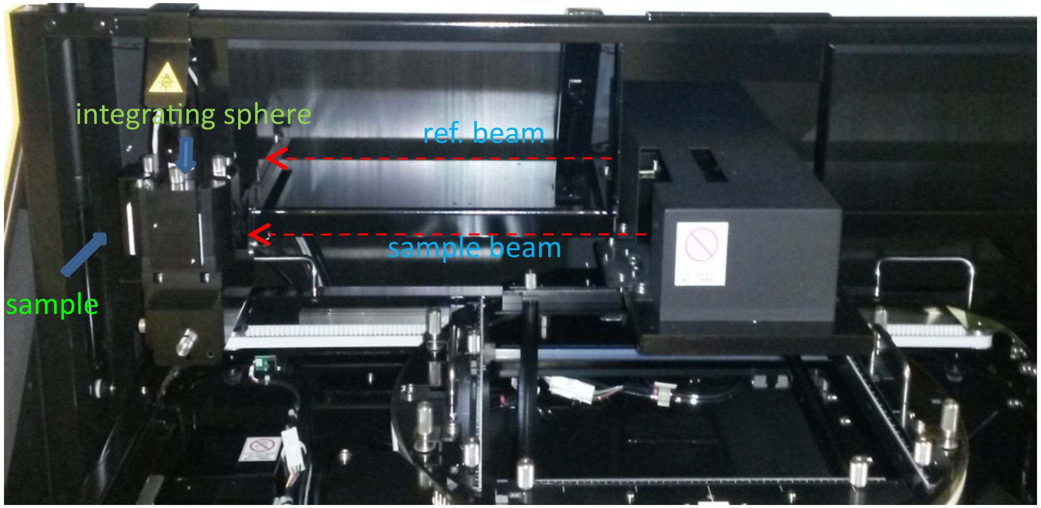




Structures are grown with Al fraction gradient in top layer. To get negative electron affinity structures should be activated with Cs after grow procedure. Three structures for cathodes with 260 nm, 280 nm and 320 nm long-wavelength edge were produced.

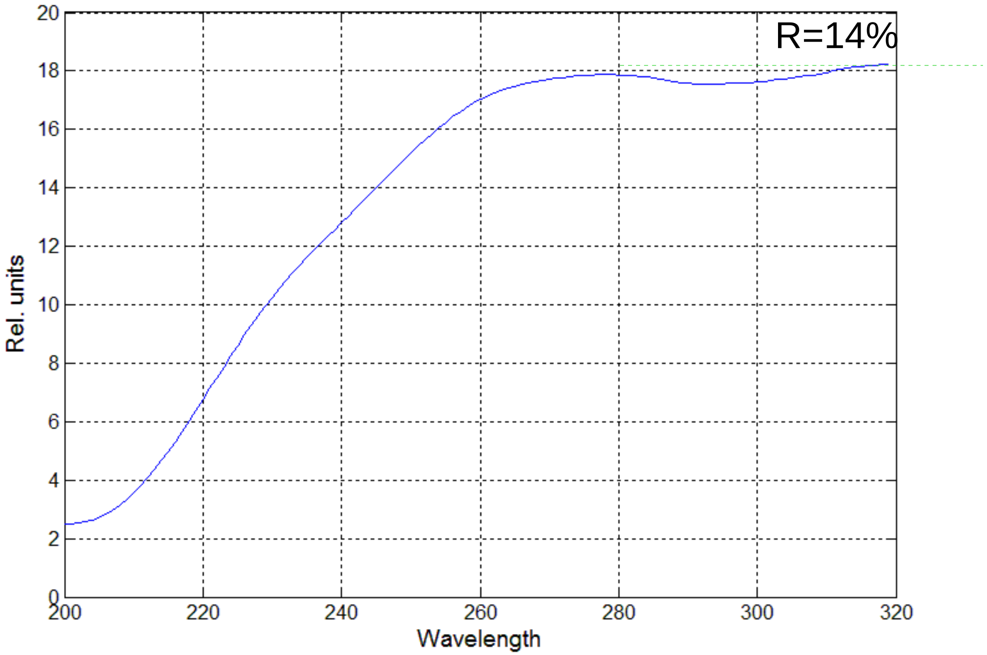
Cathodes light absorbption spectrum measurement. Experimental setup



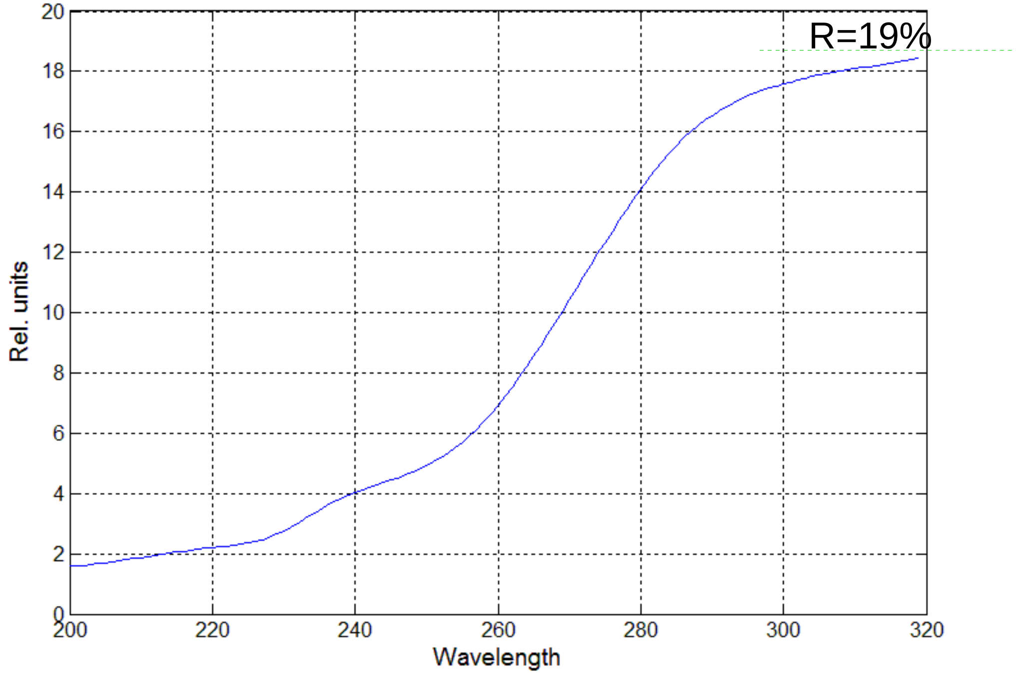


We used double beam spectrophotometer to measure spectrum of light passed through structure and reflected from metallic titan layer.

Cathodes absorption measurement. Results



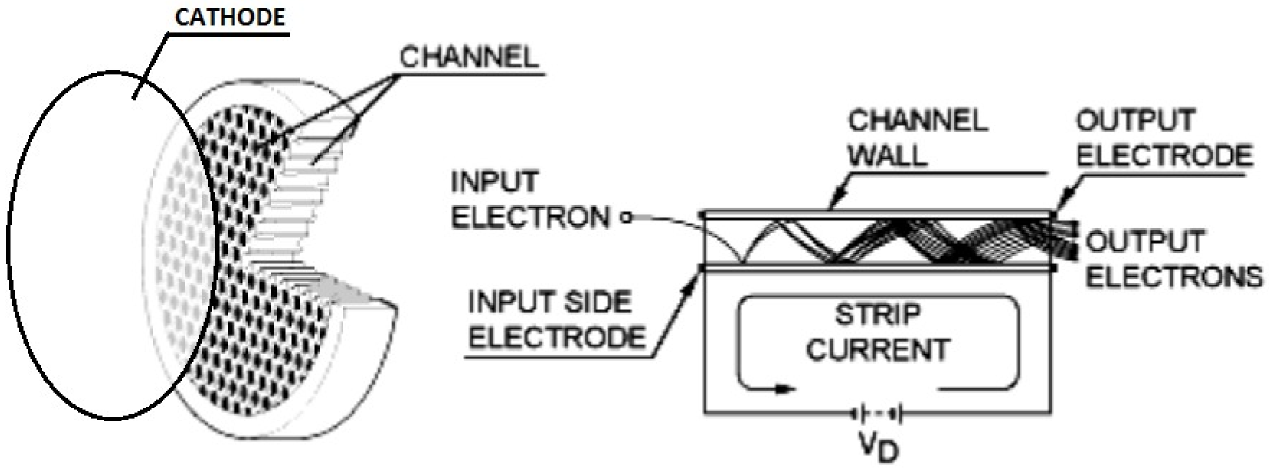
a) AlGaN structure with edge ~260 nm

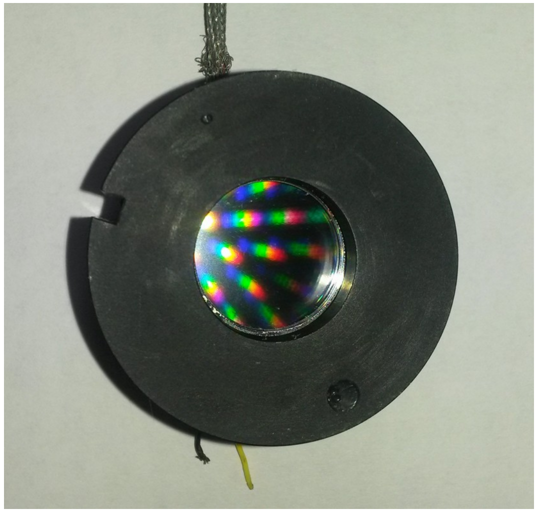


b) AlGaN structure with edge ~280 nm

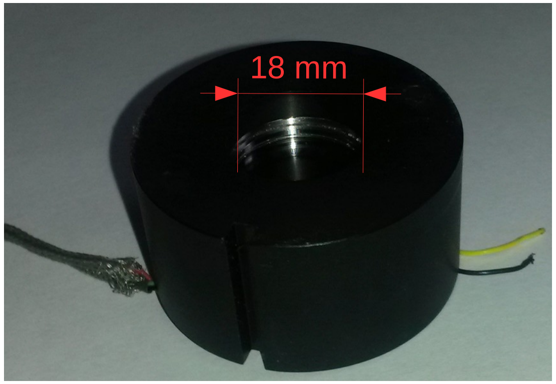
The long-wavelength edge of absorption spectrum is succesfully controlled by changing Al mass fraction in AlGaN alloy. Wavelength decreases when Al fraction is grown.

Photomultiplier based on microchannel plate (MCP) with AlGaN-based photocathodes with a negative electron affinity



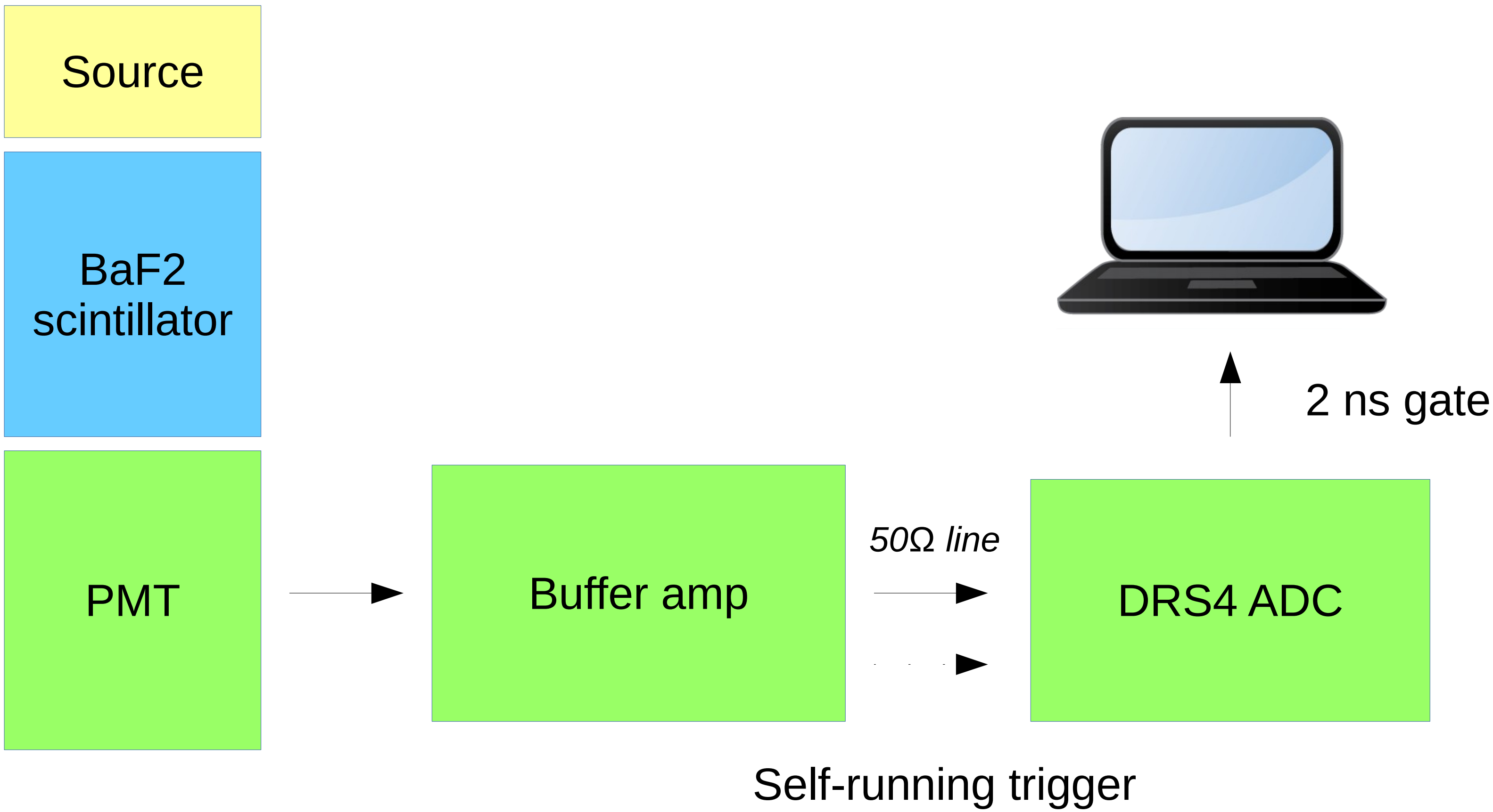


MCP consists of a two-dimensional periodic array of very-small diameter glass capillaries (channels) fused together and sliced in a thin plate. A single incident particle enters a channel and emits an electron from the channel wall.



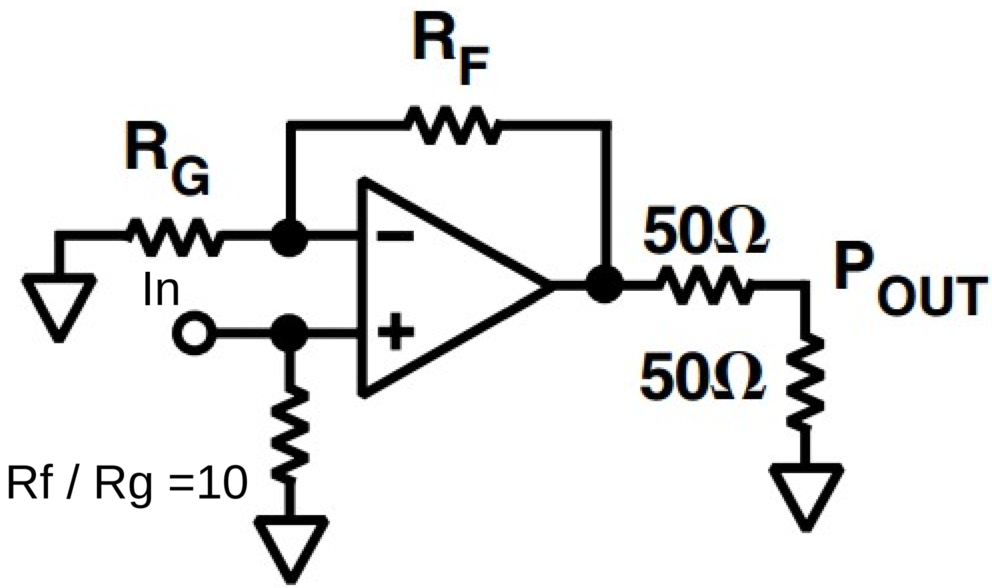
AlGaN photocathode with 320 nm long-wavelength edge was combined with MCP in a single device with 18 mm window diameter.

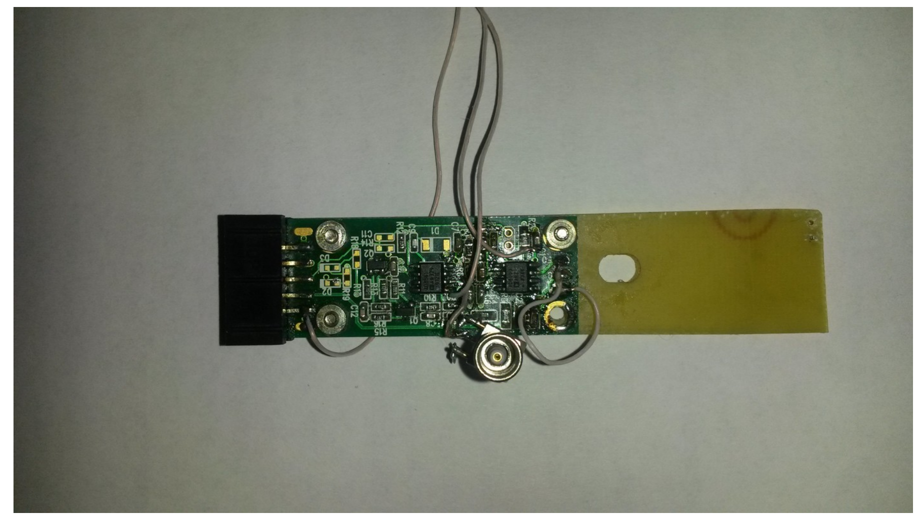
Radiation spectrum measurement. Experimental setup



To estimate photodetector efficency a simple experiment was proceeded. We used small BaF2 scintillator to measure a gamma radiation spectrum of weak radiactive Co60 source. With 320 nm cathode we still have high level for slow component, so one need use 2ns gate to supress it.

Spectrum measurement. Experimental setup. Amplifier

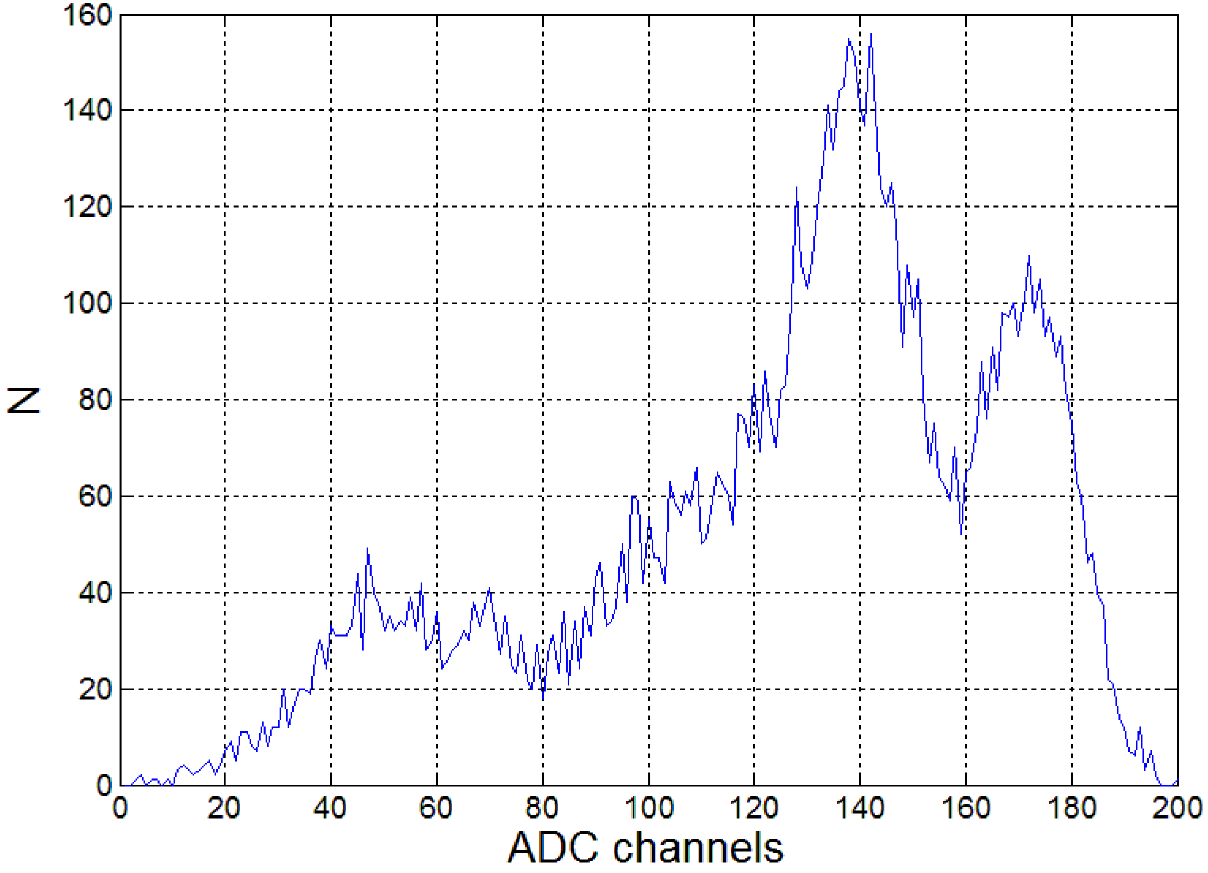




Tranceimpedance amplifier

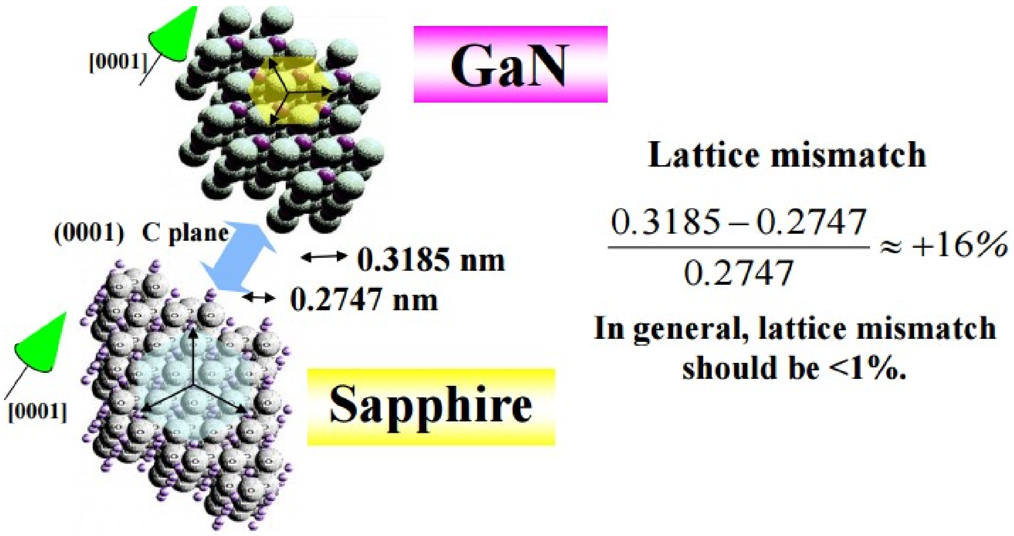
We used buffer trancimpedance amplifier to balance 50 Om line that connect photomultiplier to an ADC. The ADC is DRS4 chip based board with bandwidth of 700 MHz and sampling speed 5 GSPS.

Spectrum measurement. Results.

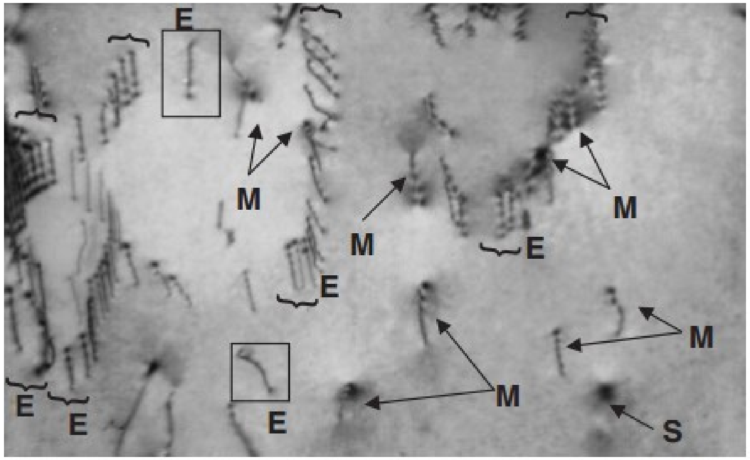


Photomultiplier with BaF_2 crystal was used to measure Co60 spectrum. For mixed signal (fast + slow component, 2 ns gate) we can obtain energy resolution ~10% FWHM.

GaN/AlGaN photodetectors. Dislocations and quantum efficency



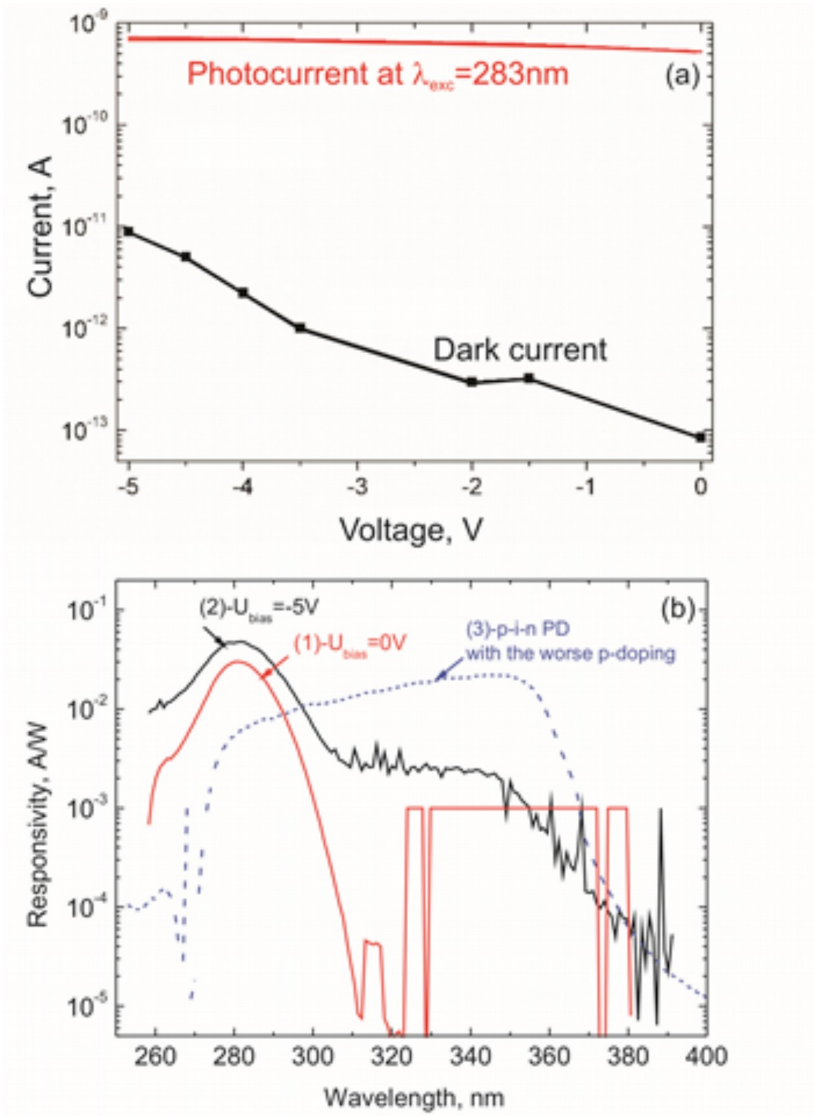
GaN and Al_2O_3 lattice mismatch

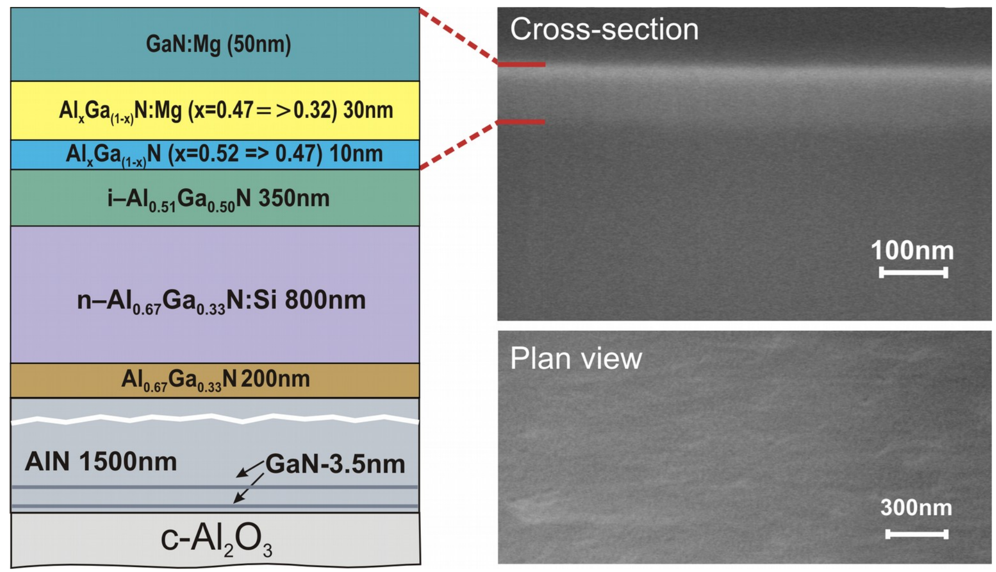


Plan-view images of AlGaN layer grown on saphire. Dislocations of different types: S — screw, E-edge, M — mixed. *Imura et al. 2007, JJAP, 46 1458*

The growth of AlGaN/GaN on sapphire substrates is a big challenge due to the large lattice mismatch and thermal expansion mismatch. The typical threading dislocation density in the AlGaN layers grown on the sapphire template with buffer layers is still as high as 10^{8}-10^{9} cm^{-2}. Treading dislocations act as non-radiative recombination centers, thereby resulting in low quantum efficiency (QE).

Future plans. P-i-n photodiodes





Heterostructure for p-i-n photodiode and (a) sensitivity of p-i-n photodiodes, measured without reverse bias (1), with bias -5V (2), with the worse p-doping quality (3)

V.N. Jmerik, N.V. Kuznetsova, D.V. Nechaev et al. Tech. Phys. Lett. (In print)

Conclusion

- We proposed complete photomultiplier device based on AlGaN photocathode with long-wavelength edge 320 nm, suited for spectrometry tasks with BaF_2 fast emission component and with CsI crystals
- Solar-blind photocathodes with long-wavelength edge 260 nm and 280 nm, regulated by Al mass fraction in AlGaN alloy, were succesfully tested. One should build photomultipliers with these photocathodes to exploit time resolution of fast BaF_2 component
- We have got technology of semiconductor UVC-range photodetectors production on cheap sapphire substrate

Thank you for your attention !