Optimization of InAs Quantum Dots for Scintillation Applications

M. Yakimov[1], V. Tokranov[1], K. Dropiewski[1], A. Minns[1],
P. Murat[2], and S. Oktyabrsky[1]
[1] *SUNY Polytechnic Institute, Albany NY 12203 USA*
[2] *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*

Use of semiconductors as scintillators for particle detection is limited by self-absorption in material bulk. Introducing below-bandgap transitions – e.g. by doping (ZnS:Cu) is a way to address absorption. A scintillation medium utilizing heterostructures was proposed [1] and GaAs with artificial luminescent centers, InAs quantum dots (QD) was demonstrated [2].

A prototype scintillation device is grown by MBE and consists of 20 um thick GaAs layer with 50 sheets of embedded self-assembled InAs QDs. A metamorphic p-i-n detector with InGaAs absorber is grown on top of the structure for high-speed integrated photo-detection. Overall structure and measurement diagram is shown in Fig 1. After detector fabrication, the epi layer is separated from GaAs by epitaxial lift-off to form a scintillation waveguide and bonded to glass for testing; cross-sectional TEM of top layers is shown in Fig 2.

We use elevated QD growth temperature of 520 ^{0}C to reduce native defect density and associated recombination. Indium surface evaporation is addressed with high indium flux. Modulation p-doping and potential profile engineering was employed to achieve 60% luminescent efficiency at room temperature with low excitation level. This enables observations of single-particle events in QD medium, reduced self-absorption and scattering on structural defects. Shape engineering of QDs and barrier shape using thermal cycling, AlAs capping layers on QD for preserving shape and InGaAs barrier engineering to reduce carrier thermal escape rate from QDs were further optimized. We demonstrate a prototype scintillator in the form of a free-standing 20 um GaAs waveguide impregnated with InAs QDs with self-absorption in the range of 1-5 cm^{-1}, and its operation by detection of alpha particles using integrated InGaAs photodetector with time resolution of 60ps. (Fig. 3)

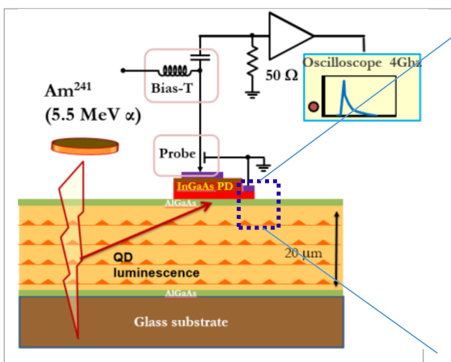

Fig. 1. Fig. 1. Schematic diagram of scintillator operation with excitation of GaAs:QD scintillator using alpha-particles and light detection system

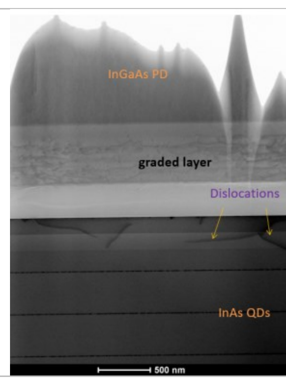

Fig. 2. TEM of low-dislocation density top QD layers with integrated photodetector in a 20 um thick, 50 QD scintillator stack with integrated photodetector.

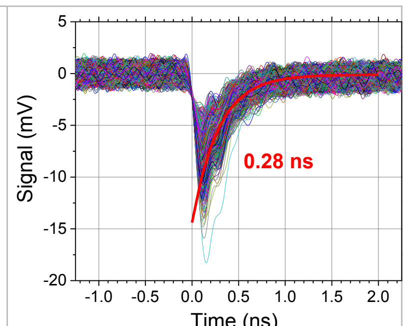

Fig. 3. Recorded pulses showing ~100 ps risetime and 0.28 ns decay time from alpha particles incident on scintillator as shown in Fig 1.

[1] Kastalsky, A., Luryi, S. and Spivak, B., *Nucl. Inst. Methods Phys. Res. Sect. A*, **565**(2), 650. (2006).
[2] Oktyabrsky, et al, *IEEE Trans. on Nuclear Sci.*, **63**(2), pp.656-663, (2016).