Cryogenic GaAs(Si,B) Scintillator for Transition Edge Sensor Readout

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n-type GaAs has recently been identified as a promising target material for detecting electron recoils from DM interactions. GaAs has a density of 5.32 g/cm^3 and a direct gap of 1.52 eV. Large (15 cm) crystals are commercially grown for electronic circuits. Si doping provides n-type donor electrons and boron is intrinsic to the growth process. It has a strong luminescence band centered at 1.33 eV (930 nm) that arises from silicon donor to boron acceptor transitions. A DM particle scattering off a valence-band electron can excite this electron to the conduction band and a boron atom can capture the valence band hole. Excitations as low as the band gap produce 1.33 eV photons with high efficiency, and these can be detected by transition edge sensors attached to an absorber. While available crystals have not been optimized for scintillation efficiency, their measured luminosity is 30 photons/keV. This project first plans to find the Si and B concentrations that optimize scintillation performance and use anti-reflective coatings to approach the theoretical limit of 200 photons/keV. Commercial GaAs is highly purified and the background from radio-impurities can be estimated because their energy spectra extend well above the DM-electron recoil energies of interest. Unlike NaI and CsI, n-type GaAs has delocalized electrons at the top of the forbidden band that annihilate metastable radiative states that could cause afterglow, as evidenced by the lack of thermally stimulated emission after cryogenic x-ray bombardment. When used with transition edge sensor readout this target material promises a remarkable combination of large target mass, low backgrounds, and sensitivity to electron recoils of a few eV that would be produced by DM particles as light as a few MeV.

The figures below show the possible projected sensitivity (Fig. 1), a large GaAs crystal (Fig. 2), emission spectra (Figs. 3 and 4), and the absence of any observed afterglow (Figs. 5 and 6). Figs. 3 to 6 show data to be published by Derenzo et.al.

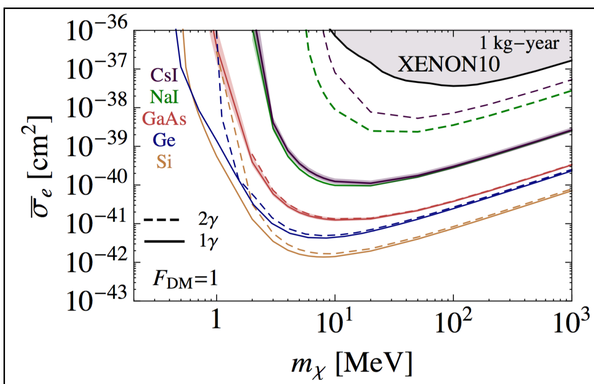

Fig. 1. DM-electron-scattering-cross-section (σ_e) versus DM mass (m_χ) for F_{DM} (q) = 1, assuming an exposure of 1 kg for 1 year and a radiative efficiency of 1. Solid (dashed) lines show 3 events for a threshold of one (two) photons in CsI (purple), NaI (green), and GaAs (red). [Plot from arXiv: 1607.01009]

Fig. 2. 10 cm GaAs crystal grown at the Leibniz Institut für Kristallzüchtung (IKZ), Berlin, Germany

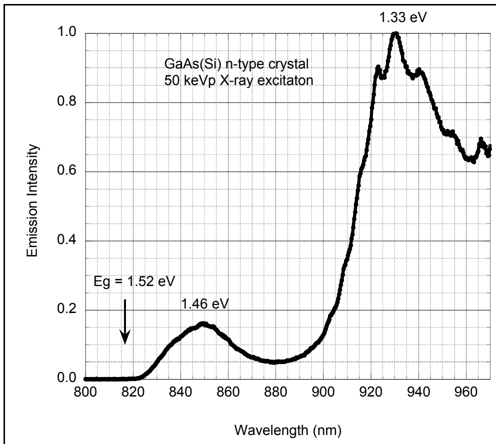

Fig 3. Emission spectrum for 50 keVp X-ray excitation. Scintillation emission band peaking at 930 nm is due to silicon donor-boron acceptor recombination. [Plot from Derenzo et.al, to appear]

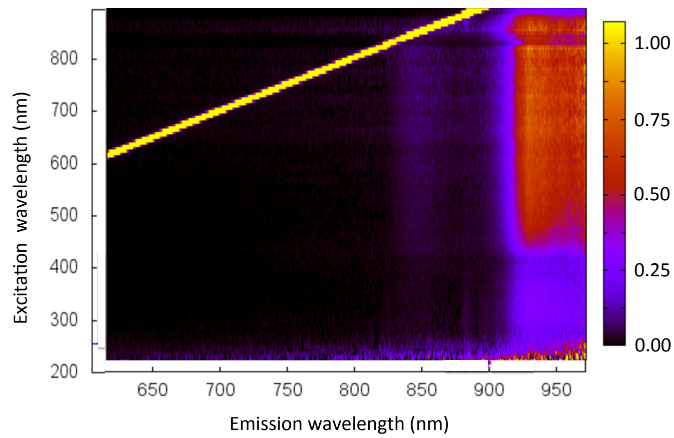

Fig. 4. Emission spectra at different optical excitation wavelengths. The 930 nm (1.33 eV) band is produced for all excitation energies above the 1.52 eV band gap. [Plot from Derenzo et.al, to appear]

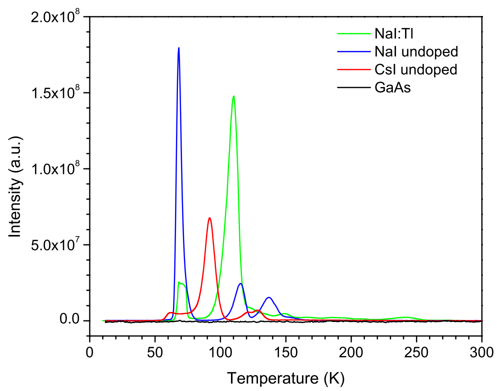

Fig. 5. Thermally stimulated emission as a function of temperature after 30 minutes of 50 keVp cryogenic X-ray bombardment. GaAs shows no emission, indicating the absence of metastable radiative states that could cause afterglow background. [Plot from Derenzo et.al, to appear]

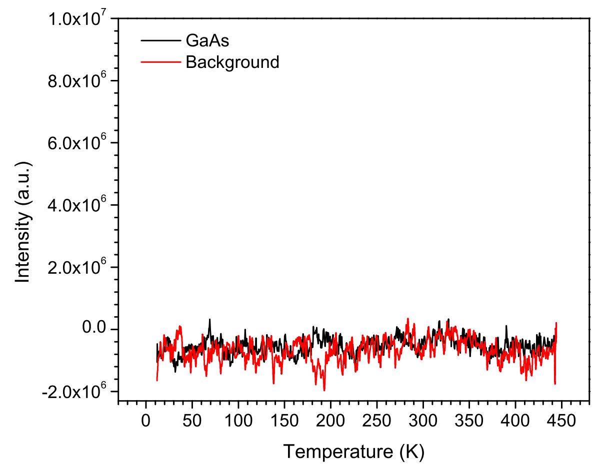

Fig. 6. Enlargement of Fig 5., showing that the GaAs curve is not statistically different than the background. [Plot from Derenzo et.al, to appear]