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Scintillation properties of n-type GaAs at cryogenic temperatures

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We describe the scintillation properties of n-type GaAs at cryogenic temperatures for the detection of sub-GeV dark matter particles. The density of dark matter in the galactic halo is about 0.6 GeV/c2/cm3, they have average velocities of about 0.001 c in random directions as they orbit the galaxy, and have not been detected by large-scale experiments designed for the GeV/c2 mass range. Dark matter particles in the unexplored 1-1000 Mev/c2 mass range only carry kinetic energies of 1-1000 eV and a scintillator with high efficiency and very low background will be required to detect them. Detection of single photons in the near infrared with high efficiency and low background at cryogenic temperatures is a challenge, but this technology is under active development using transition edge sensors and microwave kinetic inductance detectors. Anti-reflection coatings can be used reduce internal trapping of the scintillation light.

GaAs has a density of 5.32 gm/cm3, a refractive index of about 3.5 in the near infrared, and a direct band gap of 1.52 eV. When doped with silicon to provide a population of shallow donor electrons and boron to provide acceptor sites for ionization holes the luminosity is above 30,000 photons per MeV. Boron is naturally introduced during the crystal growth process. The silicon donor level is only a few meV below the conduction band minimum and the Mott transition concentration is about 2E16 per cm3. The boron acceptor level is about 0.19 eV above the valence band maximum and the donor-acceptor emission peaks at about 930 nm (1.33 eV). This emission is thermally quenched above 120K with a thermal barrier of about 12 meV. Single 1.33 eV photons can be produced with high quantum efficiency by excitation energies above the 1.52 eV band gap.

After prolonged exposure to a 50 keVp X-ray beam at 10 K we are unable to detect any thermally stimulated luminescence during an increase in temperature to 400 K. This is in contrast with NaI(Tl), which has more than six strong thermally stimulated emission peaks. The apparent absence of metastable radiative states in n-type GaAs can be explained by the efficient annihilation of metastable holes by the delocalized n-type donor electrons that fill the crystal when their concentration is above the Mott transition. An important consequence is the apparent absence of afterglow that produces single photon emission over long time spans. No other available scintillator allows the detection of dark matter particles at the single photon level.

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