Semiconductor scintillator for three-dimensional array of radiation detectors

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Scintillators detect high-energy radiation through generation of light that is subsequently registered by a photo-detector that converts light into an electrical signal. An essential advantage of the semiconductor scintillator is that each scintillator slab can be supplied with its own integrated photo-detector. Such slabs can then be stacked up without limit, thus enabling the possibility of three-dimensional (3D) pixellation of Compton scatterings of the incident gamma photon. The 3D pixellation in turn enables rapid simultaneous determination of both the incident gamma-photon energy and the direction to its source. These two tasks – isotope discrimination and directional resolution – are the two most important challenges in the apprehension of evil-doers carrying radioactive materials. Thus, semiconductor scintillators are highly desirable.

However, scintillators are not normally made of semiconductor material. The key issue is how to make the semiconductor essentially transparent to its own infrared light, so that photons generated deep inside the semiconductor slab could reach its surface without tangible attenuation. I will discuss several ways how this can be accomplished, all subject of intense research.

One way is based on heavy doping of bulk semiconductor with shallow donors, so as to introduce the Burstein shift between the emission and the absorption spectra. This approach is actively pursued in our laboratory at Stony Brook with InP used as the scintillator material. It turns out that heavy doping does improve the transparency of a semiconductor slab against interband absorption but it also increases the free-carrier absorption in the doped material. Another way under investigation is to use lightly doped semiconductors and rely on impurity-related radiative recombination, which is red-shifted relative to the fundamental absorption edge.

Still another — tantalizing but not yet realized in practice — possibility lies in employing composite "impregnated" materials. The "host" semiconductor body absorbs gamma rays but itself neither generates nor absorbs scintillating radiation. That radiation is produced by multiple small direct-gap "guest" semiconductor inclusions slightly narrower in bandgap than the host material. In this way it is possible, in principle, to implement a luminescent semiconductor material where the photon mean free path exceeds centimeter dimensions. The key challenge for this approach is to find an appropriate technique that would be capable of producing millimeter-thick impregnated structures. One possible direction is epitaxial growth of the host with periodic interruptions that introduce random guest inclusions that do not obstruct further epitaxial growth. However, the desired thickness is much larger than that commonly used in epitaxial applications. Another possibility for introducing inclusions is to employ the natural tendency of some material systems to phase-separate via spinodal decomposition during the crystal growth. In this way one can envisage impregnated materials produced by bulk growth techniques. Needless to say, the implementation of impregnated scintillator structures is a challenging proposition. Nevertheless, it offers a very high pay-off, especially in homeland security applications, where the development of an efficient semiconductor scintillator offers unprecedented opportunities.