Semiconductor Scintillators and Three-Dimensional Integration

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There are two large groups of solid-state radiation detectors, the scintillation detectors and semiconductor diodes. Scintillators detect high-energy radiation through generation of light which 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 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 angular resolution — are the two most important challenges in the apprehension of evil-doers carrying radioactive materials.

However, scintillators are not normally made of semiconductor material. The key issue in implementing a semiconductor scintillator 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 Moss-Burstein shift between the emission and the absorption spectra. This approach is actively pursued in our laboratory with InP used as the scintillator material.[1]

Another — tantalizing but not yet realized in practice — possibility lies in employing composite "impregnated" materials.[2] 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 of bandgap slightly narrower than that of the host material. If the typical distance between these impregnations is shorter than the diffusion length of carriers in the host material, most of the radiative recombination will occur inside the inclusions and produce scintillating radiation to which the wide-gap body is essentially transparent. The key challenges for this approach are in material preparation. One has to find an appropriate technique that would be capable of producing millimeter-thick impregnated structures. Implementation of such structures is a challenging proposition. Nevertheless, it offers a very high pay-off, especially in homeland security applications. In my opinion, the search for the right material combination and sound fabrication technology merits a concerted effort in several directions.

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[1] A. Kastalsky, S. Luryi, B. Spivak, *Nucl. Instr. and Meth. in Phys. Research* **A 565**, pp. 650-656 (2006).

[2] S. Luryi, *Int. J. High Speed Electronics and Systems* **18**, No 4, pp. 973-982 (2008).