Young Scientist

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In the autumn of 1995, when I was 19 years old, I first visited Prof. Shoji's laboratory at the Tohoku Institute of Technology. Afterwards, I started to study room-temperature semiconductor X- and gamma-ray detectors, and after finishing my Doctorate of Engineering in the spring of 2001, I became a post-doctoral fellow at his laboratory. For these past six years, I have worked on the development of TlBr semiconductor detectors. I was honored to receive the Radiation Award (encouragement Award) awarded by the Radiation Science Division of the Japanese Society for Applied Physics for my research into TlBr detectors.

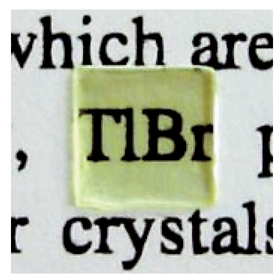
The room-temperature semiconductor X- and gamma-ray detector is a device in which X- and gamma-rays are converted into electronic pulses. By analyzing the pulses, one can obtain information on the incident photons, particularly the energy, the number of incidences, and the photon arrival time. Semiconductor X- and gamma-ray detectors that can operate at room-temperature are now being increasingly applied in medicine, industry, astronomy, and nuclear science. Conventional semiconductor X- and gamma-ray detectors based on Ge and Si are well established and widely used in various fields. They offer considerable advantages over other kinds of radiation detector, such as scintillation detectors and gas counters, especially their high energy resolution. The application of these detectors, however, has been somewhat restricted since Ge detectors provide high-resolution capabilities only at a cryogenic temperature (77 K) because of their low resistivity at room temperature, and Si detectors exhibit sufficient detection efficiency for only low energy X-rays (less than 20 keV) because of their low photon stopping power at higher energies. Thus, there has been a strong interest in developing semiconductor detectors that have high photon stopping power and can operate at room temperature, without sacrificing the advantages of Ge and Si detectors. The main physical semiconductor properties requisite for fabrication of room-temperature semiconductor detectors are

1. high atomic number and density for high photon stopping power,
2. a bandgap large enough to keep leakage currents low at room temperature,

and

3. large electron and hole mobility-lifetime products for efficient charge collection.

The compound semiconductors CdTe, CdZnTe (CZT), and HgI_2 have been investigated as detector materials that meet these requirements. Although devices and instruments based on CdTe, CZT, and HgI_2 detectors are commercially available, widespread use of these devices is limited because of drawbacks such as their small sizes, insufficient energy resolution, or high cost. Therefore, research into other semiconductor materials for use in X- and gamma-ray detectors continues. Although many semiconductor materials have been promising or were expected to show suitable physical properties, none of these have been established as practical X- and gamma-ray detector materials. At the start of my research, I selected a compound semiconductor, thallium bromide, from among the candidate materials because it has a high atomic number (Tl: 81, Br: 35), high density (7.56 g/cm^3), and a wide bandgap (2.68 eV). Because of its high atomic number and density, TlBr has greater photon stopping power for hard X- and gamma-rays than other semiconductors commonly used for detector fabrication (e.g., Ge, Si, CdTe, and HgI_2). Also, the wide bandgap of TlBr implies a low intrinsic carrier concentration −i.e., low leakage currents− and accordingly permits low-noise device operation at and above room temperature. Because of these attractive properties, TlBr has been studied as a detector material by several groups. However, the TlBr detectors reported so far have exhibited satisfactory detector performance only for low energy X-rays because of their low mobility-lifetime products for electrons (1.3×10^{-5} cm^2/V) and holes (1.5×10^{-6} cm^2/V).[1)]



The development of semiconductor X- and gamma-ray detectors requires extensive work that extends into many fields involving material science, crystal growth, electronics, and nuclear science. I have continuously worked on the development of a TlBr detector from the initial crystal growth through to detector evaluation. In this work, the first step of TlBr detector fabrication was further purification of the TlBr starting material for crystal growth using the conventional zone refining method. The traveling molten zone (TMZ) method was used to grow TlBr crystals. To fabricate detectors, the as-grown crystals were then cut into several wafers whose surfaces were treated mechanically and chemically. The resultant wafers were transparent and had a good surface finish (see the **photograph**). The treated wafers were characterized in terms of their structural properties, stoichiometry, and surface properties. Finally, TlBr detectors with a planar structure were fabricated by depositing gold electrodes on both surfaces of the wafers. Electrical properties of the TlBr, including the resistivity and the charge transport properties for electrons and holes, were measured using the fabricated detectors. The performance of the TlBr detectors was characterized by acquiring X- and gamma-ray energy spectra and coincidence timing spectra. By continuously repeating the processes from crystal growth to detector evaluation, I improved the detector performance step by step. Finally, I obtained TlBr crystals exhibiting mobility-lifetime products for electrons (2.6×10^{-4} cm^2/V) and holes (3.7×10^{-5} cm^2/V) that were about one order of magnitude greater than previously reported values. With these crystals, I was able to fabricate TlBr detectors that could adequately detect high energy photons as well as low energy X-rays (see the **figure**).[2] These TlBr detectors can be applied, for example, as flux detectors for X-ray computed tomography and photodetectors for scintillation detection.[3, 4]

The performance of our TlBr detectors is close to that of commercially available CdTe, CZT, and HgI_2 detectors, and this makes the TlBr detector a promising candidate for X- and gamma-ray applications. We foresee potential applications in various fields. However, further investigation regarding the crystal growth, semiconducting properties, and long- term stability is needed to permit practical use of these TlBr detectors.

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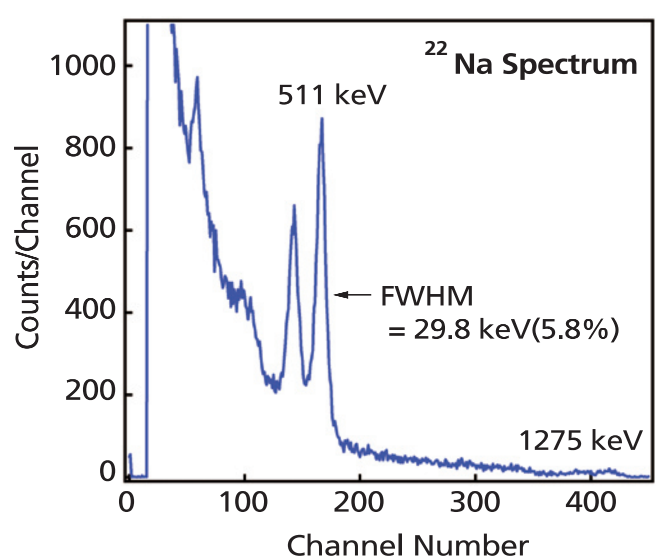

References

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