L.1: Development of GaAs detectors for fast response hard X-ray detection

High-speed detection of hard X-rays requires higher-Z materials such as GaAs to meet the competing demands of high X-ray absorption and fast response. Owing to its higher absorption coefficient, GaAs requires a much smaller thickness than silicon for the same absorption, reducing carrier transit time and enabling faster response. Figure L.1.1(a) shows the electron transit times in Si and GaAs for X-ray energies from 10 to 30 keV, assuming 90% absorption, justifying GaAs-based hard X-ray detectors with nanosecond response. In this context, the Semiconductor Lasers and Devices Division, RRCAT, has already demonstrated GaAs p-i-n X-ray detectors, where the X-ray response is maximum at around 12 keV. [1] At higher energy, the response falls because of decrease in absorption coefficient. Thus, to extend the measurable X-ray energy range, a thicker absorption region is required. Accordingly, detectors based on a 350 µm-thick semi-insulating (SI) GaAs have been developed with optimized planner Ohmic contact and circular Schottky contact of diameter 2 mm on either side of GaAs. Prior to metallization the semiconductor is thoroughly cleaned chemically. Ohmic contact is made with sequential deposition of Au-Ge/Ni/Au followed by rapid thermal annealing at 450 °C. On the other hand, Schottky contacts of diameter 2 mm are made using Ti/Au metallization through a shadow metal mask. [2] Figure L.1.1(b) shows the detector mounted on a custom-designed printed circuit board. Reverse-bias measurements up to 100 V yield a leakage current of 15 nA at room temperature, which reduces to 0.8 nA at 280 K (Fig. L.1.2c and inset). A total of six such detectors are made with all of them showing room temperature leakage current below 15 nA.

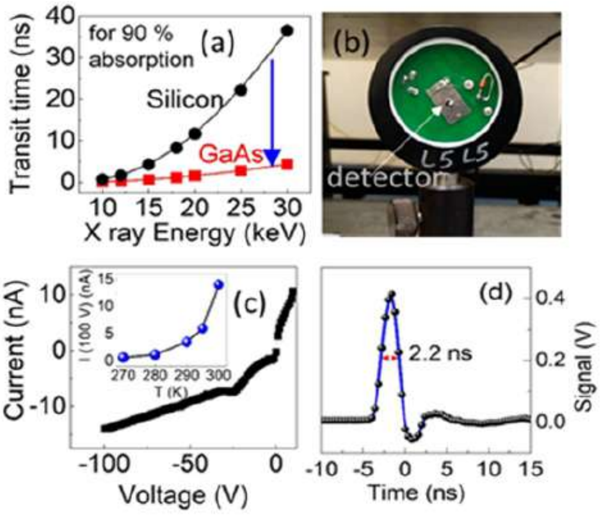

Fig. L.1.1 (a) Electron transit time in Si and GaAs Vs X-ray energy, (b) Photograph of mounted detector, (c) Room temperature I-V of the detector and leakage current as a function of temperature, (d) Temporal response of the detector

The detector operational properties are readily assessed using visible and near-IR illumination. A peak responsivity of 0.15 A/W at 870 nm, along with a spectrally flat response in the 600–800 nm range, is observed, which is typical for GaAs-based photodetectors. To measure the temporal response of the detector, a readout circuit is developed and the voltage signal is measured across 100 Ω resistance using a fast oscilloscope following incidence of Ti:Sapphire femtosecond laser pulse (pulse duration ~35 fs). The detector response was measured to be 2.2 ns, as shown in Fig. L.1.1(d), validating the fast carrier extraction capability of the device. The temporal response for X-ray detection is expected to be similar.

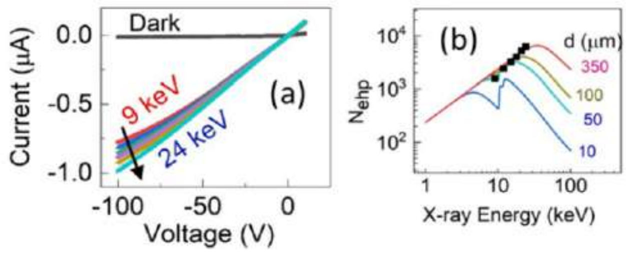

Fig. L.1.2 (a) I-V in dark and in presence of X ray with increasing energy, (b) Comparison of normalized current (black dots) with calculation (solid lines), N_{ehp} is the total number of electron hole pair created under x-ray illumination.

The detector response in the 9–24 keV range was measured in 3 keV steps at beamline-4 (imaging beamline) of Indus-2. A key observation is that at 9 keV the signal magnitude saturates at high bias, whereas at 24 keV it increases linearly with voltage. This is explained by invoking the partial absorption of 24 keV X–ray within the depletion region. [2]

The spectral response of the detector is estimated by normalizing the current at 100 V for each X-ray energy with respect to the measured flux at that energy. In Fig. L.1.2b, these normalized results are shown and the magnitude of signal is observed to increases with X-ray energy. The calculated spectral responses for detector with different thickness are also plotted as solid lines for direct comparison. [2] In summary, we have developed and characterize GaAs based hard X-ray detector operating in the energy range of 9 to 24 keV, which has a time response of 2.2 ns. Cooling of the device by ~30 °C is shown to further improve the device performance.

References:

1. Geetanjali et al., Nucl. Inst. Meth. Phys. Res. A, 1084, 171184 (2026)
2. Harsh Tiwari et al., Proceedings of Solid-State Physics Symposium, IIT Roorkie-2025, p-74

Reported by
Shailesh K. Khamari (shaileshk@rrcat.gov.in)