Development of novel semiconductor detector towards high-rate heavy RI beam counting

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The precise measurement of heavy ion track and energy loss is important for the identification of projectile fragments with a fragment separator such as BigRIPS at RIBF. As the intensity of the primary beam increases, a stronger radiation-resistant detector is required to realize a high-rate (≥1 MHz) RI beam experiment. A Si detector has the characteristics of high-resolution energy measurement, but it is weak in a high-radiation environment. In order to realize a radiation-resistant semiconductor detector, we have examined several types of novel semiconductors that were developed for other purposes. Table 1 lists the semiconductors we are testing. The chalcopyrite compound Cu(In,Ga)Se_2 (CIGS) is well investigated as it has potential for use as a semiconductor in thin-film photovoltaic devices, such as solar cells.[1] CIGS can recover from radiation damage through the annealing of CIGS crystals. This characteristic is advantageous for a radiation detector since we often encountered the damage to semiconductor detectors by high-rate ion beams. GaN is one of the wide-bandgap semiconductors that are expected to be suitable for radiation detectors with long-term stability due to a small intrinsic carrier density and large threshold displacement energy.

We performed a detector test experiment at HIMAC in Chiba, where a highly intense 400 MeV/nucleon Xe beam was irradiated on semiconductor samples: CIGS and GaN. Figure 1 shows the sample of the CIGS detector, the thickness and effective area of which are 2 μm and 0.5 mm^2, respectively. This is thick enough to observe the signal with a 400 MeV/nucleon Xe ion, which loses an energy of 3.5 MeV in the semiconductor. This beam test was the first time a heavy-ion signal was observed from those semiconductors.

Table 1. Specifications of modern semiconductor candidates for radiation detection.

	Bandgap energy (eV)	Density (g/cm^3)	Normalized number of e-h pairs to Si
Si	1.1	2.33	1
CIGS	1.2	5.7	2.93
SiC	3.2	3.21	0.64
GaN	3.4	6.15	1.07
Diamond	5.5	3.50	0.45
AlN	6.1	3.26	0.33

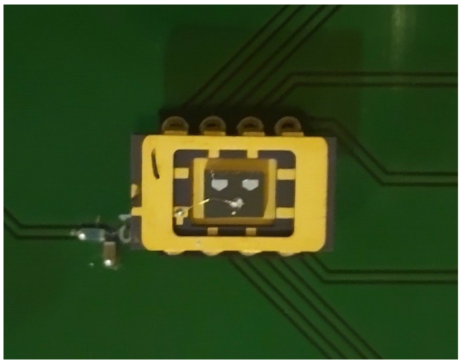

Fig. 1. CIGS samples (two pentagons shown at the center of the photograph) tested at HIMAC.

In addition to checking the signal from CIGS and GaN, we tested the hardness of each semiconductor against radiation damage by a Xe beam. Figure 2 shows the CIGS pulse height as a function of the irradiated Xe beam yield. During the irradiation of a high-rate (10^6 pps) Xe beam on CIGS, the pulse height decreased down to 60% of the original pulse height. After annealing the CIGS semiconductor (130°C, 5 h), we could observe the recovery of the pulse height to ∼85% of the original pulse height.

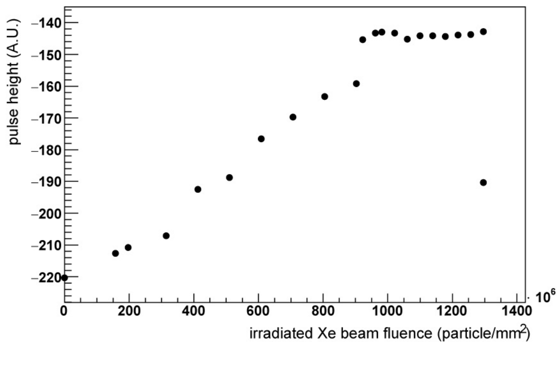

Fig. 2. CIGS negative pulse height as a function of irradiated Xe beam yield. A 400 MeV/nucleon 10^6 pps Xe beam was irradiated on a CIGS sample. After annealing the CIGS sample, the recovery of the pulse height was observed as shown by the rightmost point.

We will continue to develop the next generation of semiconductor detectors by employing a novel type of semiconductor.

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Reference
1) J. Nishinaga *et al.*, Appl. Phys. Exp. **10**, 092301 (2017).