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Evaluation of detector-grade GaAs via alpha and X-ray spectrometry

Although GaAs has been tested as a material for X-ray detectors for more than 50 years, practically significant results have only been achieved in the last decade, when semi-insulating, chromium-compensated single crystals have been employed [1]. This is particularly true for imaging sensors developed for Medipix/Timepix readout ASICs [1, 2].

We demonstrated imaging sensors fabricated by pixel-pattern processing of 500 µm-thick GaAs wafers compensated by post-growth doping with Cr [2]. The sensor parameters depend on the structural and electrical properties, which are determined by the characteristics of the initial commercial n-type wafers grown by the Liquid Encapsulated Czochralski method, as well as the conditions of thermal annealing of Cr-coated wafers, polishing, surface treatment, and subsequent pixel contact deposition. To evaluate the obtained detector-grade Cr-compensated GaAs and study the effect of crystal thickness on sensor spectroscopic properties, the voltage dependences of the alpha (α) particle and X-ray spectra were measured using a 241Am source at room temperature, since it is an efficient commonly used efficient technique for GaAs characterization [3, 4].

Samples with an area of 5 × 5 mm2 and a thickness of 220 µm, 380 µm, and 480 µm were diced from the double-side polished GaAs wafers, which were pretreated with bulk chemical etching for the corresponding thinning. Thin (˜20 nm) Cr electrodes were deposited onto the opposite faces of GaAs samples by sputtering using a metal mask with dimensions of 4 × 4 mm2. The fabricated planar Cr/GaAs/Cr structures with symmetrical contacts exhibited low dark currents of approximately 3 µA, 4 µA, and 9 µA at bias voltage of 500 V for the different crystal thicknesses, respectively. The Cr/GaAs/Cr structures were connected to a measurement holder using clamping contacts with conductive rubber and placed inside a shielding box. A portable ultra-high count rate spectrometer was used. The spectra were acquired without charge-loss correction or rise time discrimination electronics. The spectrum acquisition time was 5 min. The 5.5 MeV α particles from the noncollimated 241Am source, positioned at front of the sample, had to pass through 20 mm of air and the contact metallization to reach the GaAs. The crystal margins were also affected. Certainly, the detected α particle kinetic energy was lower than its nominal one. The X-ray spectra of 241Am (59.5 keV) were measured using a sheet of paper to stop the α particles.

Cr/GaAs/Cr sensors resolved the full energy spectrum for a 241Am radiation source, clearly demonstrating both the dominant high-energy α particles in the high channel-number range and the accompanying low-energy X-ray peak in the low channel range. The α-peak was well distinguished when the sensor front side was negatively biased, while the X-ray peak appeared at both the polarities, however higher detection efficiency was observed with a positively biased front contact. The Cr/GaAs/Cr sensors were capable of clearly resolving α peak under low biasing conditions: 5 V, 20 V, and 40 V for 220 µm, 380 µm, and 480 µm thick GaAs crystals, respectively. The thinnest sensor showed the highest detection efficiency and energy resolution (FWHM ˜ 3%). However, these α-peak parameters did not differ significantly among the samples of different thicknesses, contrary to other studies [3, 4]. Certainly, the highest values were achieved at lower bias voltages for thinner sensors: 300 V, 400 V, and 700 V for thicknesses of 220 µm, 380 µm, and 480 µm, respectively. The features of the voltage dependences of α spectra measured by all three sensor thicknesses over a wide voltage range (up to 1200 V) were analyzed. A typical shift of the peak toward larger channel numbers with increasing bias voltage was observed, and this effect was most pronounced for the thinner sensors. The peak reached the largest channel number, corresponding to the most efficient charge collection, and consequently resulted in the highest peak height and energy resolution [3].

Based on the bias voltage dependences of electrical and spectrometric characteristics, derived from I-V and α particle spectrum measurements of the planar radiation sensors, fabricated using semi-insulating Cr-compensated GaAs crystals with symmetric Cr contacts, the charge transport parameters of the semiconductor were estimated. The α particle response, observed over a wide bias voltage range with high energy resolution at the optimal biases for Cr/GaAs/Cr sensors of different thicknesses, has demonstrated the excellent suitability of the material for imaging detector applications [2]. The consistently high α spectrometric performance across all sensor thicknesses has evidenced the efficient Cr doping of GaAs wafers during thermal annealing, leading to uniformly Cr-compensated detector-grade material.

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Workshop topics

Sensor materials, device processing & technologies

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