Soft X-Ray Silicon Photodiodes with 100% Quantum Efficiency

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Abstract

Silicon p-n junction photodiodes (AXUV diodes) with nearly 100% quantum efficiency (QE) for soft x-ray photons (up to about 6 keV) were recently developed. This implies no recombination of photo-generated charge carriers in the front doped region and at the Si-SiO_2 interface. This work reports fabrication and testing of the AXUV diodes with 100% quantum efficiency for photons with energy up to 10 keV. Response of the new diodes was measured using electron-beam x-ray generators with copper and molybdenum anodes that, when filtered properly, provide K x rays at 8 and 17.5 keV respectively. AXUV photodiodes fabricated on high-resistivity silicon were found to exhibit gain in their response to these x rays. The x-ray signal was observed to increase, by up to a factor of 25, when the bias voltage was raised above the level required for full depletion of the silicon. A similar gain was found in the response to α particles when the diodes fabricated on high-resistivity silicon were operated in pulse mode. A diode fabricated from low resistivity silicon, with low leakage current, did not exhibit any gain in its x-ray response.

I. Introduction

Silicon p-n junction photodiodes (AXUV, absolute XUV diodes) with 100% internal quantum efficiency (no recombination of photogenerated carriers in the doped n^+ region and at the Si/SiO_2 interface) were reported by one of us recently [1, 2] for soft x-ray photons up to 6 keV. Quantum efficiency of these diodes was found to decrease for photon energies greater than 6 keV owing to limited silicon thickness. This paper describes fabrication and testing of AXUV diodes with larger silicon thickness which are expected to have 100% quantum efficiency for photons with energy up to 10 keV.

Fig. 1 shows a schematic of the 1-cm^2 active area AXUV photodiode fabricated on three-inch diameter, high resisitivity ($> 20,000\,\Omega$-cm), 450-μm thick p-type silicon wafers procured from Topsil and Westinghouse. No substantial difference was noticed in the quality of the diodes fabricated on the starting materials from these two manufacturers. After the standard p^+ channel stop and n^+ guard ring diffusion, phosphorous diffusion was carried out to achieve zero surface recombination without a diffused dead region[3]. The passivating silicon dioxide coating was thinned down to 80 Å after completion of the phosphorous diffusion. Subsequent processing involved masking, aluminum metallization, post metal anneal, Cr-Au deposition on backs and sawing. More details on the diode fabrication are available in references [1, 3].

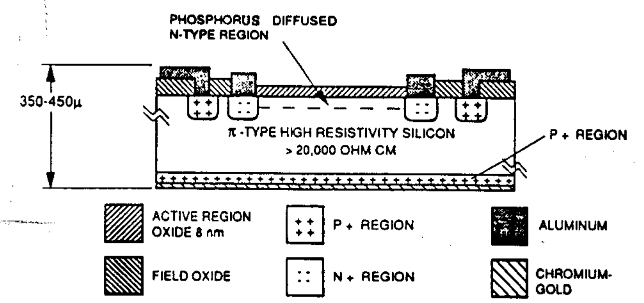

Figure 1: Schematic of the fabricated AXUV photodiode

The fabricated chips were assembled in two-lead International Radiation Detectors (IRD) standard ceramic packages. Response of the diodes was measured using two different electron-beam x-ray generators. In one generator, the x-ray flux to the detectors was mechanically chopped, and in the other generator an AC signal was created by the full-wave-rectification of the accelerating voltage. An AC-coupled transimpedance amplifier was then used to measure the resultant photocurrent (see Fig. 2). For absolute x-ray response measurements, the AXUV signal was compared to the signal from a previously-calibrated silicon surface barrier diode (SBD) [4]. More details on this method are available elsewhere [5].

This paper reports two sets of AXUV response measurements. In the first set, the absolute x-ray response of AXUV detectors was determined by comparing the signals of the AXUV and SBD when they were subjected to the same x-ray flux. In the second set, the relative AXUV and