The Dependence of Dark Current on Temperature in Epitaxial Si:P BIB Detector

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Abstract

The dependence of dark current on temperature has been investigated for epitaxial Si:P blocked-impurity-band (BIB) detector. For this purpose, an experimental testing system was constructed. The dark-current behavior of epitaxial Si:P BIB detector in the temperature range from 9.2K to 24.3K and the bias range from -3V to 3V has been obtained. It is shown that the detector exhibits low dark current at the bias voltage of 0.2V and temperature below 20K.

I. Introduction

The Blocked Impurity Band (BIB) detector was first proposed and developed by Petroff and Stapelbroek at the Rockwell International Science Center [1]. Since the 80's of the last century, the detector with blocked-impurity-band structure has been extensively reviewed [2-8]. BIB detectors possess good performances such as high sensitivity and large quantum efficiency in the long wavelength infrared spectral region, wide frequency response, low optical crosstalk, and so on [2]. By employing different materials of substrates and dopants, and changing doping concentration, devices can response a spectrum range from infrared to terahertz region. In extrinsic photoconductors, the absorption coefficient is directly proportional to the concentration of the primary dopant [3]. This implies that we can improve absorption coefficient by increasing doping concentration, however, the impurity band will be formed and significant hopping conduction will occur, which results in a substantial increase in dark current of the detector [9]. The BIB detector is a modification of the extrinsic photoconductive detector. It consists of a heavily doped absorbing layer in series with a thin high-purity blocking layer [10]. Compared with the extrinsic photoconductive detector, a more heavily doped absorbing layer means greater absorption efficiency. Meanwhile, the high-purity blocking layer disposed on the absorbing layer blocks dark current associated with hopping and impurity band conduction. For the ion-implanted Si:P BIB photodetector, the absorbing layer was formed by implanting phosphorus ions, and the thin high-purity blocking layer is obtained from a high resistivity single crystal silicon substrate. The device exhibits good blocking characteristics with low dark current density under 10^{-4} A/cm^2 under the operating temperature of 5K and the bias voltage of 1V [11].

In this paper, the dependence of dark current on temperature has been investigated for epitaxial Si:P BIB detector. The absorbing layer and the blocking layer were sequentially grown by Chemical Vapor Deposition (CVD). Unavoidably, the introduction of impurities in the process of epitaxial growth can result in a low resistivity of the blocking layer. Thus, the appropriate increase in thickness of blocking layer to 8 microns has been employed to reduce the dark current.

II. Device Structure And Testing System

The epitaxial Si:P BIB two-layer structure was sequentially grown on a 4 inch silicon substrate. After a series of preparation processes including lithography, ion implantation, etching, evaporation, annealing, etc., the final structure was established. The silicon substrates were heavily doped with a low resistivity of 0.002~0.004Ω·cm. The doping concentration of phosphorus ion in the absorbing layer is approximately 5×10^{17} cm^{-3}. The thickness of blocking layer is about 8 microns. The contact region is formed by phosphorus ions implantation and rapid thermal annealing. The anode and cathode are deposited by electronic beam evaporation.

In order to measure the current–voltage behavior of the epitaxial Si:P BIB detector in the dark environment, an experimental testing system was set up. The system consists of a cryostat, a refrigerating apparatus, a temperature control device, a YOKOGAWA 7651 DC Source, a SR570 low-noise current amplifier, an Agilent 34401A Digital multimeter, and a computer, as shown in Fig. 1.

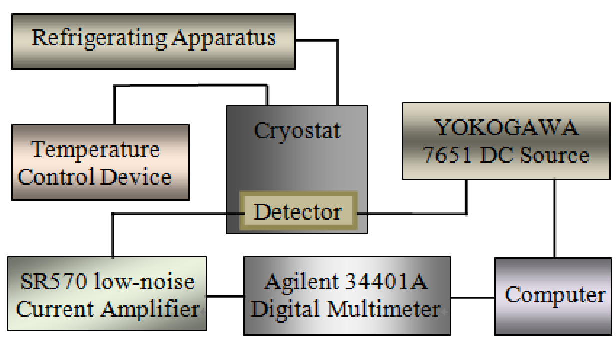

Figure1. Schematic of the experimental testing system for the measurement of dark current.

Before the measurements were taken, the detector was placed in the cryostat. The temperature in the cryostat can be adjusted by the refrigerating apparatus and temperature control

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device. The bias voltage of the detector was provided by the YOKOGAWA 7651 DC Source.

III. Result And Discussion

Temperature-dependent Current-voltage (*I-V*) behavior of the epitaxial Si:P BIB detector has been measured. The results shown in Fig. 2 indicate that there are more charge carriers excited from the impurity band with the increase of the temperature and bias voltage. Consequently, the dark current increases as well.

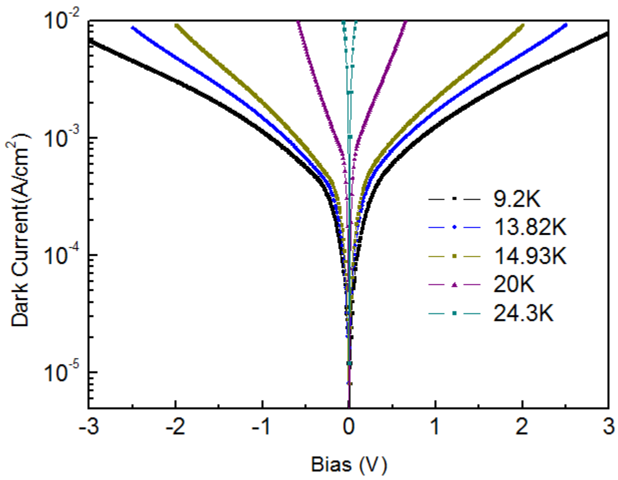

Figure 2. Dark current versus bias of the epitaxial Si:P BIB detector measured in the temperature range from 9.2K to 24.3K and the bias voltage range from -3V to 3V.

In order to obtain the dependence of dark current on temperature, dark-current density at 0.2 V versus the reciprocal of temperature is shown in Fig. 3. As observed, a low dark-current density on the order of 10^{-4} A/cm^2 can be achieved in a large temperature range. If the resistivity of the blocking layer is further increased, and surface passivation of our detector is employed in our following study, a lower dark-current density will be obtained. It needs to be emphasized that the actual temperature of the detector is almost 3K higher than that displayed by temperature control device. Therefore, the dark-current density shown in Fig. 3 is overestimated.

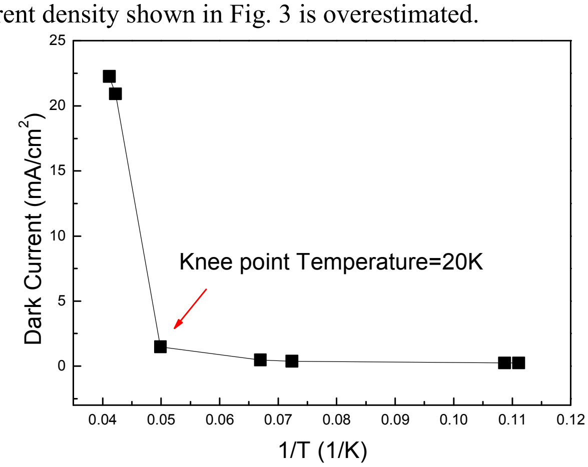

Figure 3. Dependence of dark-current density on the reciprocal of temperature at the bias of 0.2 V.

Additionally, there is a clear knee point in Fig. 3 at the temperature of 20K, which implies that electrons are nearly frozen out in the impurity band below the temperature of 20K. When the temperature exceeds 20K, the dark current increases rapidly for the thermal generation of charge carriers across the impurity band gap [12].

IV. Conclusion

Temperature-dependent dark current behavior of the epitaxial Si:P BIB detector has been investigated. It is found that electrons are nearly frozen out in the impurity band below the temperature of 20K at the bias voltage of 0.2V. The dark-current density can be further suppressed by growth of a high-purity blocking layer and deposition of a suitable passivation layer on the device surface.

Acknowledgements

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