# Design consideration for ion-implanted planar GaAs blocked-impurity-band detectors

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*Abstract*

**Design of ion implantation scheme for the planar GaAs blocked-impurity-band (BIB) detectors is performed by numerical simulation. The device structure and the preparation process are presented. It is demonstrated that the implanted Si ion concentration of the absorbing region and the contact region are $5\times10^{15}$ cm$^{-3}$ and $4\times10^{19}$ cm$^{-3}$, respectively, and can be implemented by four-step implantation with different ion energies and doses.**

## I. INTRODUCTION

Blocked impurity band (BIB) detector was first proposed by Petroff and Stapelbroek at the Rockwell International Science Center in Anaheicm, CA [1]. With the improvement of materials and structures, BIB detectors sensitive to radiation range from infrared to terahertz region has been realized. Si BIB detectors are sensitive to a range of wavelength from 5 to 40μm, and have been widely used in spectral measurement and detection in space, such as Si:P and Si:As BIB detectors [2]. A lot of efforts have been made to extend the cutoff wavelength of BIB detectors. For example, Ge BIB detectors can response the wavelength about 250 μm, far beyond the cutoff wavelength of Si BIB detectors. However, the application of Ge BIB detectors is limited because of these challenges: high purity requirements, doping control, passivation and reproducibility [3]. The wavelength coverage can also be significantly extended by GaAs material system, making GaAs BIB detectors much more attractive in far-infrared astronomical application.

GaAs BIB detectors can extend the wavelength response to ~300 $\mu$m with a low binding energy of 5.7 meV. The first effort was done by Stillman, Wolfe and Dimmock in 1970s and the result indicates that N-type GaAs is a promising material for far-infrared and terahertz radiation detection [4]. Then, many efforts were made for GaAs BIB detectors fabrication. For instance, Reichertz *et al.* use liquid phase epitaxial (LPE) technique to fabricate GaAs BIB detectors and find that a high purity blocking layer can be grown by this technique [5]. Katterloher *et al.* use centrifugal system to grow ultra-high purity GaAs that can be used as a blocking layer [6]. However, the determination and control of the doping concentration profile are still difficult not only for stacked Ge BIB detectors but also for stacked GaAs BIB detectors by epitaxial methods. This means that not only the extremely high purity of the blocking layer cannot be achieved, but also the interface sharpness between the absorbing layer and the blocking layer can hardly be guaranteed by epitaxial methods.

In order to solve this problem, the planar structure is proposed, indicating that absorbing region can be formed by implantation together with the pattern transfer [7-8]. Compared with the conventional stacked BIB detectors, there are three advantages of planar BIB detectors: (1) the high purity of blocking region can be ensured and therefore the dark current can be limited strictly; (2) doping concentration profile can be well controlled by ion implantation for improving the device reproducibility; (3) surface defects can be suppressed due to the absence of etching process.

## II. DEVICE STRUCTURE AND PROCESSING TECHNIQUE

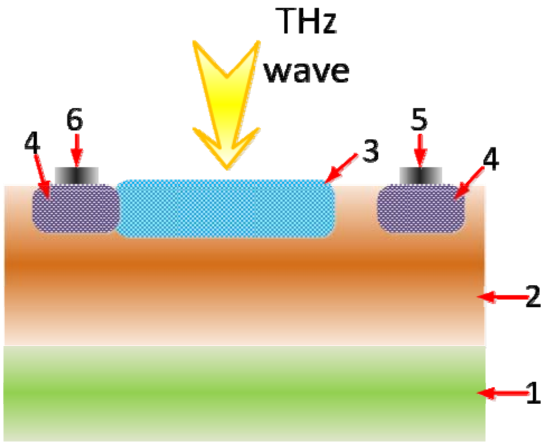

Fig. 1. Schematic cross-section of the planar GaAs BIB detector.

Structure of the planar GaAs BIB detector includes: (1) a high resistance GaAs substrate, (2) a high purity epitaxial layer formed by LPE technique, (3) an absorbing region formed by implanting shallow donors such as Si, (4) the contact layer, (5) an anode formed upon the contact layer adjacent to the high purity epitaxial layer, and (6) a cathode formed upon the contact layer adjacent to the absorbing region. Terahertz radiation is illuminated from the top side of the device and

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absorbed by the absorbing region. The schematic cross-section of the planar GaAs BIB detector is shown in Fig. 1.

The main processing steps are as follows: (1) Growing a high purity GaAs layer on a high resistance substrate by LPE technique; (2) Forming an absorbing region by ion implantation; (3) Forming the contact region by ion implantation; (4) Activating the dopant ions in the contact region by rapid thermal annealing; (5) Depositing anode and cathode on the contact region. In order to form the ohmic contacts, the doping concentration of the contact region is much higher than that of the absorbing region.

## III. RESULT AND DISCUSSION

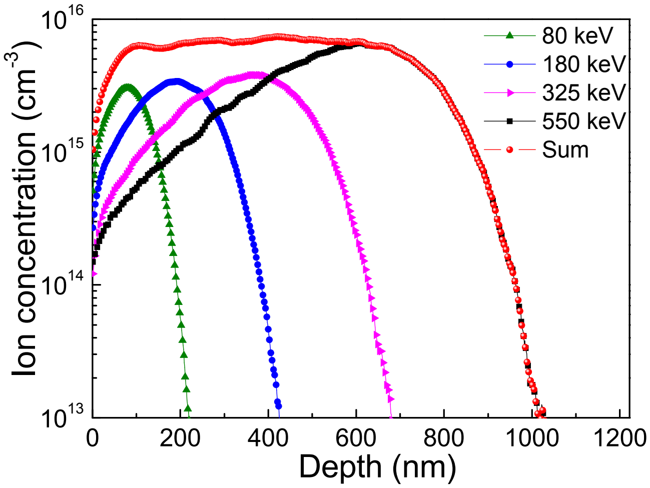

Fig. 2. Doping profile of Si ion in the absorbing region. The implantation doses of the absorbing region are as follows: $3.5\times10^{10}$ cm$^{-2}$ at 80 keV, $7.3\times10^{10}$ cm$^{-2}$ at 180 keV, $1.2\times10^{11}$ cm$^{-2}$ at 325 keV, $2.8\times10^{11}$ cm$^{-2}$ at 550 keV. The total concentration is $5\times10^{15}$ cm$^{-3}$.

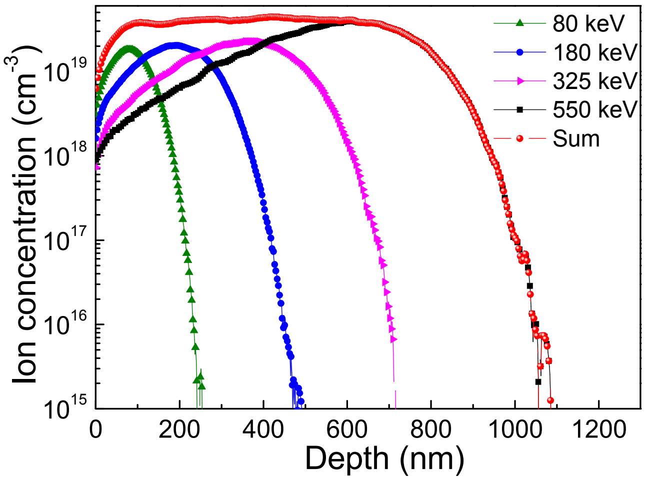

Fig. 3. Doping profile of Si ion in the contact region. The implantation doses of the contact region are as follows: $2.1\times10^{14}$ cm$^{-2}$ at 80 keV, $4.4\times10^{14}$ cm$^{-2}$ at180 keV, $7.3\times10^{14}$ cm$^{-2}$ at 325 keV, $1.7\times10^{15}$ cm$^{-2}$ at 550 keV. The total concentration is $4\times10^{19}$ cm$^{-3}$.

It is known that the higher the dopant concentration, the broader the response spectrum. If the doping concentration is too low, terahertz radiation cannot be absorbed by absorbing layer effectively. However, if the doping concentration is too high, the top of the valence band will overlap with the bottom of the conduction band, resulting in unlimited dark current. So the optimal majority doping concentration of the absorbing layer must be controlled within a reasonable range. It has been discussed that the optimal doping range lies between $1\times10^{15}$ cm$^{-3}$ to $6.7\times10^{15}$ cm$^{-3}$ [9]. In our study, doping concentration of $5\times10^{15}$ cm$^{-3}$ and $4\times10^{19}$ cm$^{-3}$ are chosen for the absorbing layer and the contact layer, respectively.

Figure 2 illustrates the doping profile of Si concentration in the absorbing region. The ion implantation is performed four times with different ion energy and doses. Figure 3 shows that the ion implantation scheme of the contact region is the same as the absorbing region except the doses. According to Fig. 2 and Fig. 3, the doping concentration is uniform and the injection depth is deep enough.

## IV. CONCLUSION

Design of ion-implanted planar GaAs BIB detector is considered and the ion implantation scheme of the absorbing region and the contact region are presented. Our results show that the doping concentration is uniform and the injection depth is deep enough for the absorbing region and the contact region, confirming that the doping concentration profile can be well controlled by ion implantation for improving the reproducibility of device.

## ACKNOWLEDGEMENTS

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