Numerical simulation on temperature-dependent spectral responsivity characteristics for GaAs-based blocked-impurity-band (BIB) far-infrared detectors

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***Abstract*—GaAs-based BIB far-infrared detector can response optical wavelength beyond 500μm, and had thus attracted a lot of attentions since the first successful realization. However, the issue of low responsivity has dramatically restricted the further development of GaAs-based BIB detector. In this work, numerical simulation on temperature-dependent spectral responsivity characteristics for GaAs-based BIB detector has been performed for shed light on response mechanism exploration.**

Keywords—Numerical simulation, operation temperature, Gallium Arsenide (GaAs), Blocked-impurity-band (BIB), spectral responsivity, detector

I. INTRODUCTION

The concept of blocked impurity band is proposed based on the extrinsic photoconductor, which can enhance the absorption efficiency of the target radiation and extend response wavelength into far-infrared domain compared with the intrinsic photoconductor. However, large dark current and shot noise are still encountered by the extrinsic photoconductor because a conducting impurity band is formed between the conduction band and the valance band, which can extremely restrict further improvement of optical response and device noise. In order to solve this problem, Petroff and Stapelbroek first invented the blocked-impurity-band (BIB) detector in 1977. The unique feature of BIB detector is the addition of the blocking layer upon the absorbing layer in comparison with that of extrinsic photoconductor. The existence of the blocking layer can effectively suppress the contribution of impurity band to the dark current, and thus the doping concentration of BIB detector can be much higher than that of conventional extrinsic photoconductor. It is known that the increased doping concentration can further enhance the absorption of far-infrared wave, which implies that the required size of photodetector for absorbing the equivalent incident photons can thus be substantially reduced. Therefore, BIB detector present a better impact resistance to cosmic rays and a longer life span.

There are three types of BIB detectors, which are Si-based, Ge-based, and GaAs-based, respectively. The academic research on Si-based BIB detector had always been active, and several new structures and new mechanisms had been emerging. For example, Martin et al. [1] from Lake Forest replaced the ohmic contact with PtSi Schottky contact, which had significantly suppressed the dark current, and the maximum applied bias can be increased up to 10V; Garcia et al. [2] from physics department naval postgraduate school proposed an alternate operating mode for Si- BIB detectors, allowing for growth of significantly thicker blocking layers and overcoming growth issues associated with the blocking layers. Wang et al. [3] from the 50th research institute of china electronics technology group corporation analyzed the dark current and spectral response mechanisms for Si-based BIB detectors, and demonstrated that a trade-off between dark current and peak responsivity has to be made for the optimal thickness of the blocking layer. The state-of-the-art Ge-based BIB detector had been developed by Japan aerospace exploration agency for natural background-limited observations with cryogenic cooled infrared space telescopes. GaAs-based BIB detector can response optical wavelength beyond 500μm [4], and had thus attracted a lot of attentions since its first successful realization.

However, the research and development of GaAs-based BIB detectors lag well behind that of Si-based and Ge-based devices, and no focal plane array has been reported for GaAs-based BIB detector. The reason can be attributed to the poor material quality and immature processing technique, contributing to unacceptable reliability, large dark current, and low responsivity. Especially, the issue of low responsivity has dramatically restricted the further development of GaAs-based BIB detector, and it is pressing to the explore the internal response mechanisms and improve the detector response level. Operating temperature (T_{Ope}) as a critical parameter can determine the working condition of GaAs-based BIB detector to a large extent, and thus numerical simulation on temperature-dependent spectral responsivity characteristics can pave the way for response mechanism exploration. In this work, it is demonstrated that

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the critical T_{Ope} and the optimal T_{Ope} both exist for GaAs-based BIB detector. Our results reveal that optical response occurs only when the operation temperature is less than the critical T_{Ope}, and the maximum responsivity can be obtained only the operation temperature is close to the optimal T_{Ope}.

II. Structral and Physical Models

Figure 1 presents the schematic cross-sectional view of GaAs-based BIB detector. From the top to the bottom, the structure of GaAs-based BIB detector consists of anode, contacting layer, blocking layer, absorbing layer, cathode, and conducting GaAs substrate. The far-infrared wave is front-illuminated on the device. In this structure, the contacting layer is thin enough to avoid the strong absorption of the incident far-infrared wave, and is commonly formed by ion-implantation or epitaxial growth.

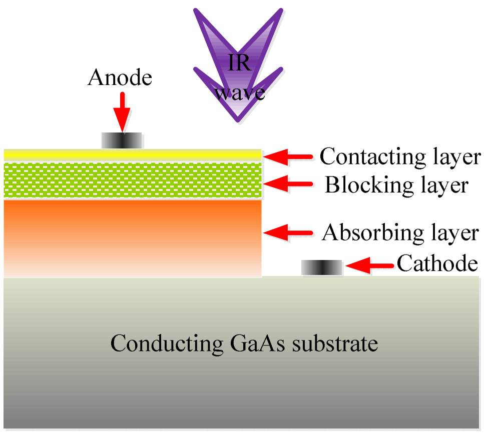

Fig. 1. Schematic cross-sectional view of GaAs-based BIB detector.

The key physical models adopted in this numerical simulation include drift-diffusion model, generation-recombination model, ray-tracing model, high-field saturation model, and incomplete ionization model. It is worthwhile to note that drift-diffusion model couples the Poission equation, the carriers' continuity equations, and the current transport equations. Generation-recombination model considers the Shockley-Read-Hall recombination, the Radiative recombination, and the Auger recombination.

III. Results and Discussions

Figure 2 shows the Temperature-dependent spectral responsivity characteristics with operation temperature (T_{Ope}) increasing from 3.8K to 7.5K and the anode bias fixed at 0.9V. According to Fig. 2, the photoresponse spectrum of GaAs-based BIB detector can cover 170~500μm, which belongs to the far-infrared wave band. The peak response wavelength is approximately 263μm, regardless of the operation temperature. Additionally, the responsivity is a strong and complex function of T_{Ope} for the entire spectral coverage range. For better illustrating the relationship between the responsivity and T_{Ope}, Responsivity at 263μm versus operation temperature (T_{Ope}) with the anode bias fixed at 0.9V is presented in Fig. 3. As observed, the responsivity slowly increases first with the increased T_{Ope}, and markedly increases then, after attaining a maximum value, responsivity starts to decrease rapidly, and eventually tends to be zero.

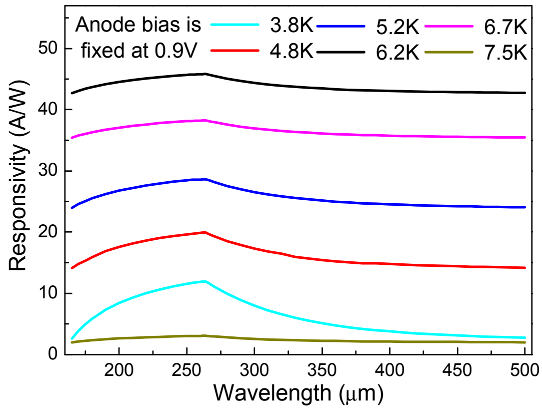

Fig. 2. Temperature-dependent spectral responsivity characteristics with operation temperature (T_{Ope}) increasing from 3.8K to 7.5K .

It should be noticed from Fig. 3 that the critical T_{Ope} and the optimal T_{Ope} both exist for GaAs-based BIB detector. it is demonstrated that optical response occurs only when the operation temperature is less than the critical T_{Ope}, and the maximum responsivity can be obtained only the operation temperature is close to the optimal T_{Ope}.

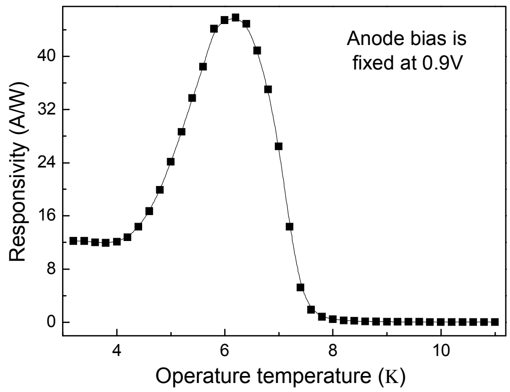

Fig. 3. Responsivity at 263μm versus operation temperature (T_{Ope}) with the anode bias fixed at 0.9V.

IV. Conclusion

In this work, numerical simulation on temperature-dependent spectral responsivity characteristics for GaAs-based BIB detector has been performed for shed light on response mechanism exploration. It is demonstrated that the critical operation temperature and the optimal operation temperature both exist for GaAs-based BIB detector.

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