Numerical simulation on the effect of the working temperature on the response sensitivity for GaAs-based blocked impurity band (BIB) terahertz detectors

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***Abstract*—working temperature is a critical parameter to evaluate the performance of Gallium Arsenide (GaAs) blocked-impurity-band (BIB) terahertz detector. An optimal device temperature can ensure the best response sensitivity. Therefore, we analyze the effect of device temperature on the response sensitivity characteristics of GaAs-based BIB detector by numerical simulation. The simulated result shows that the optimal device temperature is nearly 6K.**

Keywords—Numerical simulation, Gallium Arsenide (GaAs), Blocked-impurity-band (BIB), Terahertz detector, Response sensitivity

I. INTRODUCTION

Terahertz (THz) radiation is the electromagnetic wave whose wavelength (frequency) is between 30μm-1000μm (0.3THz-10THz). It has the characteristics of strong penetration, good safety and high resolution[1],which make the terahertz detection technology possess a broad application prospect in the fields of human security inspection, nondestructive testing, astronomical observation, and biomedicine. In terms of human security screening, compared with the conventional X-ray scanning, metal detectors and manual inspection, terahertz human security technology has the advantages of no radiation, no contact and no stop. In the field of nondestructive testing, terahertz detection technology has unique advantages in the detection of internal defects in nonmetallic materials. In deep space exploration, the blackbody radiation peaks of various planets, cosmic dust and newborn stars are all in the terahertz frequency. In the field of biomedical science, the vibration and rotation frequencies of biological macromolecules such as nucleic acids and proteins are just in the terahertz band, which can facilitate the detection of the biological macromolecules[2].

The terahertz detector is the core of terahertz detection technology. At present, it mainly includes electronic type, photon type and thermal radiation type, etc. [3-4]. The uncooled electronic devices such as schottky diode and field effect tube have problems with low sensitivity and narrow detection spectrum. For the refrigerated terahertz detector, like the earliest bolometer, can provide high sensitive detection. However, the long response time of this detector limits its development. The superconducting technology (such as thermo electron radiometer (HEB), superconducting insulator superconducting (SIS) mixer, etc.) have extremely high device response speeds while maintaining high sensitivity. However, it require complex refrigeration to achieve extremely low temperatures (below 1K).

Blocked-impurity-band (BIB) detector is a new type of terahertz detector that can realize detecting by constructing impurity band in semiconductor energy gap and making electrons transition between impurity band and conduction band. It has the characteristics of high sensitivity, large array size and wide detection spectrum. The BIB detector can be classified into three types (i.e., Si-based, Ge-based, and GaAs-based).Among them, Si-based and Ge based BIB detectors started to develop earlier and have been successfully applied in many space missions internationally .As Si, Te and other elements in GaAs single crystal have low activation energy (6MeV), GaAs based BIB detector can achieve the detecting frequency from 0.5-4.6THz(65-600μm)[5].The working temperature is a sensitive parameter which can influence the response sensitivity of GaAs-based BIB detector to a large extent, and the different working temperature corresponds to the different physical mechanism. Therefore, in this work, the comprehensive analysis of temperature-dependent response sensitivity characteristics has been made to provide a good insight into the response sensitivity mechanism.

II. STRUCTRAL AND PHYSICAL MODELS

A typical GaAs-based BIB detector structure is shown in

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Figure 1. The conducting GaAs substrate, back contact, cathode, absorbing layer, blocking layer, and anode form the structure. As the terahertz radiation exposure on the device, the electron will bring transition from impurities to the conduction band. The electrons after the transition are collected by the anode and the detector is converted from optical signal to an electrical signal.

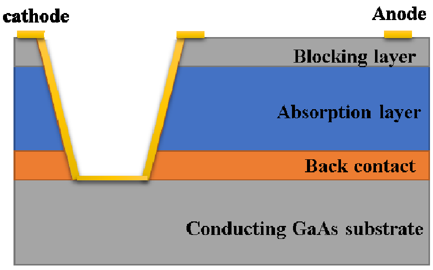

Fig. 1. The structure of GaAs-based BIB terahertz detector.

Key physical models include the carrier recombination model, the carrier generation model, and the carrier low-temperature freeze-out model. Among them, the carrier recombination model includes Shockley-Read-Hall recombination model, Radiative recombination model, and Auger recombination model; the carrier generation model adopts ray-tracing model; the carrier low-temperature freeze-out model adopts incomplete ionization model.

III. Results and Discussions

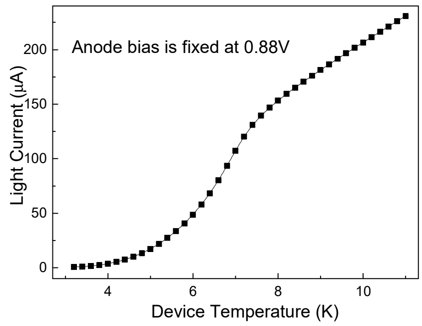

Fig. 2. Temperature-dependent light current characteristics with device temperature decreasing from 11K to 3K in 0.2K steps.

The temperature-dependent response sensitivity characteristics of the GaAs BIB terahertz detector was investigated. Fig. 2 shows the light current as a function of the device temperature in the fixed anode bias of 0,88V with a temperature range of 11–3K and a drop precision of 0.2K. As it can be observed from the results, the light current yielded a positive correlation response over the entire device temperature range .

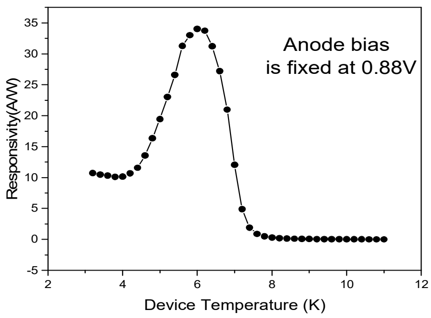

Fig. 3. Characteristic curve of responsivity as a function of device temperature

Figure 3 plots the responsivity curves of the GaAs BIB terahertz detector. It is demonstrated that for a fixed anode bias the relationship between responsivity and device temperature can be classified into four phases: (1) responsivity is independent of device temperature(>7.8K); (2) responsivity increases rapidly with device temperature(7.8-6K) ; (3) responsivity decreases rapidly with device temperature(6-4K); (4) responsivity increases slowly device temperature(<4K). Thus, we can obtain the optimal device temperature of the GaAs BIB terahertz detector. Similar conclusion is also presents in Figure 4, which plots the detectivity of the GaAs BIB terahertz detector as a function of the device temperature. Based on the fitting of the data, the optimal device temperature is 5.6K with a detectivity of 4.76×10^{10}cmHz$^{1/2}$/W in 4-11K. Though we can obtain a better detectivity under 4K, the high costs and the complex refrigerating system is undeserved.

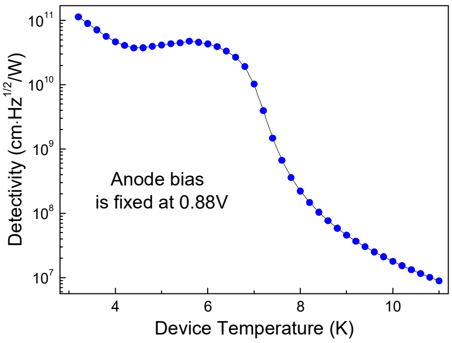

Fig. 4. Characteristic curve of the detectivity of GaAs BIB terahertz detector as a function of device temperature

IV. Conclusion

In this work, the effect of device temperature on the response sensitivity characteristics of GaAs-based BIB detector has been studied. It is found that the optimal device temperature is nearly 6K.

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