Numerical simulation on the effect of operation temperature on noise characteristics for GaAs-based blocked impurity band (BIB) far-infrared detectors

Xiaodong Wang
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
wxd06296@163.com

Yulu Chen*
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
yukiylc@163.com

Bingbing Wang
The 50t Research Institute of China Electronics Technology Group Corporation
Shanghai, China
wbb0308201@163.com

Chuansheng Zhang
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
cszhang519@163.com

Xiaoyao Chen
Laboratory of Advanced Material Fudan University
Shanghai, China
chenxiaoyao@fudan.edu.cn

Haoxing Zhang
The 50th Research Institute of China Electronics Technology Group Corporation
Shanghai, China
13022125120@163.com

***Abstract*—noise level as a critical parameter to evaluate the performance of Gallium Arsenide (GaAs) blocked-impurity-band (BIB) far-infrared detector has attracted a lot of attentions from academic and technological researchers. In this work, the effect of operation temperature on the noise characteristics of GaAs-based BIB detector has been studied by numerical simulation for suppressing device noise.**

Keywords—Numerical simulation, Gallium Arsenide (GaAs), Blocked-impurity-band (BIB), Far-infrared detector, Noise

I. INTRODUCTION

Far-infrared wave band is commonly known as wavelength range covering 25~500μm. In this wave band, radiation exhibits distinct heating effects and capabilities of penetrating cloud and mist, and thus has the extraordinary application potential in the areas of astronomical observation, atmospheric monitoring, and contraband detection. In the area of astronomical observation [1], almost all kinds of planets and cosmic dusts have the characteristic absorption peaks in the far-infrared wave band, and gaseous nebulas can emit far-infrared radiation by internal molecular rotation and vibration. Thus, high-performance deep space exploration can be realized by exploiting far-infrared detectors. In the area of atmospheric monitoring [2], compared with the conventional near-infrared and mid-infrared technologies, far-infrared detection can not only collect the information of stratosphere but also extend detection coverage to the troposphere. Thus, environmental monitoring and atmospheric analysis can both be promoted by exploiting far-infrared detectors. In the area of contraband detection [3], explosive and drug possess plenty of absorption peaks in the far-infrared wave band, which can be used as fingerprint characteristics for explosive and drug inspection. Thus, a new generation of public safety monitoring and forecasting technology can be developed by exploiting far-infrared detectors.

A variety of detectors can operate in the far-infrared wave band, such as bolometer, HEB, SIS mixer, STJ detector, TES, and BIB detector, and different detectors have different advantages. For example, the advantage of the bolometer is its wide spectral response range covering the entire far-infrared wave band; the advantage of the superconductor detector (i.e, HEB, SIS mixer, STJ detector, TES) is the extremely high speed and sensitivity; the advantage of the BIB detector is the feasibility of large scale focal plane array. Blocked-impurity-band (BIB) detectors can be classified into three types (i.e., Si-based, Ge-based, and GaAs-based), and Si-based BIB detector is the most mature and widely used in the three types of BIB detectors because the material quality of Si is markedly superior to that of Ge and GaAs. Although different Si-based BIB detectors can be realized by doping various group-III or group-V elements (e.g., P, B, Ga, etc.) in Silicon, Si:As and Si:Sb BIB detectors are still the most advanced and widely used Si-based BIB detectors, and have been successfully applied into space science missions many times. The response wavelength of Ge-based BIB detector is much longer than that of Si-based device due to the binding energy of shallow impurity level formed in Ge is generally less than that formed in Si.

GaAs-based BIB detector can further extend response wavelength beyond 500μm, and thus has attracted a lot of attentions from far-infrared technology researchers. However, the research and development of GaAs-based BIB detector is still on the initial stage due to the restrictions from the poor crystalline quality and immature processing technique, which directly gives rise to large dark current and noise level. The temperature-dependent dark current transport mechanisms have been investigated in our previous work, and have shed light on the source of excess dark current [4]. In this work, the effect of operation temperature on the noise characteristics of GaAs-based BIB detector has been studied by numerical simulation for suppressing device noise.

II. STRUCTRAL AND PHYSICAL MODELS

Figure 1 presents the cross-sectional schematic of GaAs-based BIB far-infrared detector. As shown in Fig. 1, From the bottom to the top, the device structure consists of conducting GaAs substrate, cathode, absorbing layer,

*Corresponding author: Yulu Chen

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blocking layer, contacting layer, and anode. Additionally, the anode is formed upon the contacting layer, and the cathode is formed upon the conducting GaAs substrate.

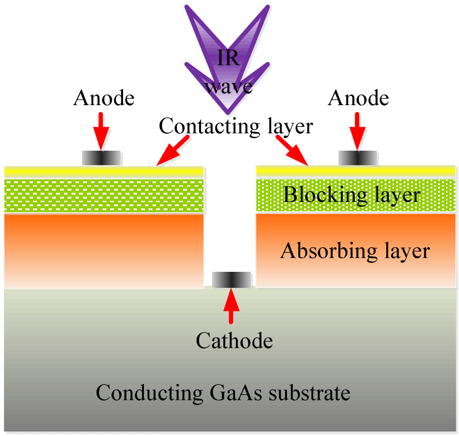

Fig. 1. Cross-sectional schematic of GaAs-based BIB far-infrared detector.

Key physical models adopted in the numerical simulation of GaAs-based BIB far-infrared detector is composed of drift-diffusion model, generation-recombination model, high-field saturation model and incomplete ionization model. Among them, the drift-diffusion model take simultaneously Poission equation, the carriers' continuity equations, and the current transport equations into consideration.

III. Results and Discussions

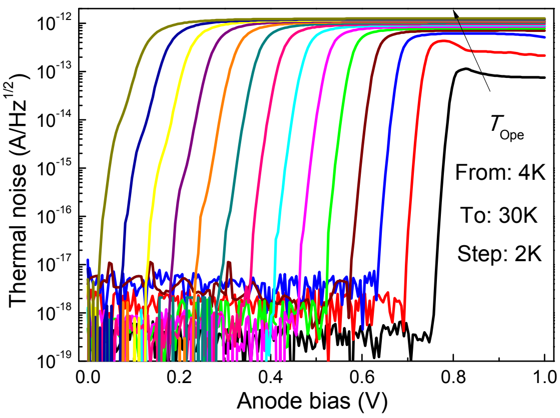

Fig. 2. Temperature-dependent thermal noise characteristics with operation temperature (T_{Ope}) increasing from 4K to 30K in 2K steps.

The device noise level is a critical parameter to evaluate the performance of GaAs BIB far-infrared detector. From the measurement point of view, the primary noise source of GaAs-based BIB far-infrared detector includes 1/f noise, thermal noise, shot noise, readout noise, and system noise. Among them, readout noise and system noise are introduced by readout circuit and testing system, respectively. While, 1/f noise, thermal noise, and shot noise correspond to the intrinsic noise of GaAs-based BIB far-infrared detector, and can be characterized by numerical simulation. In this work, 1/f noise is not considered because 1/f noise can only be observed at low frequency (generally less than 100Hz), and the typical band width of frequency spectrum for GaAs-based BIB far-infrared detector is larger than 1MHz. Temperature-dependent thermal noise characteristics with operation temperature (T_{Ope}) increasing from 4K to 30K in 2K steps are shown in Fig. 2. According to Fig .2, thermal noise is a monotonically increasing function of T_{Ope}.

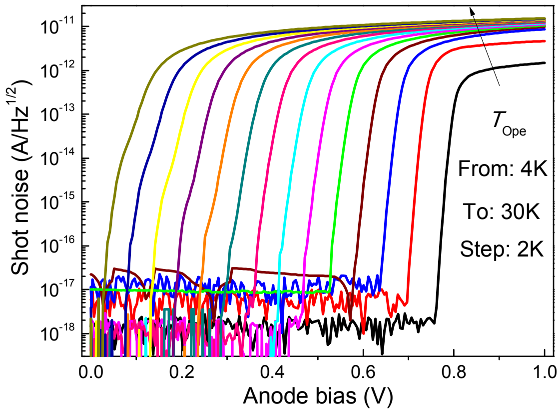

Fig. 3. Shot noise versus anode bias (V_{Anode}) with operation temperature (T_{Ope}) increasing from 4K to 30K in 2K steps.

Figure 3 presents shot noise versus V_{Anode} with T_{Ope} increasing from 4K to 30K in 2K steps. It is demonstrated that the shot noise is approximately one order of magnitude larger than thermal noise when T_{Ope} and V_{Anode} are both fixed. According to Fig .4, it is found that the total noise is dominated by the shot noise.

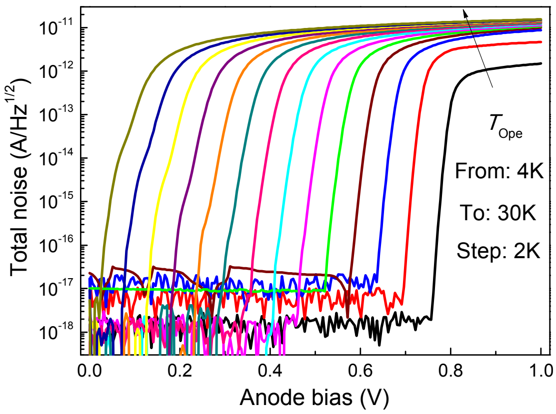

Fig. 4. Total noise versus anode bias (V_{Anode}) with operation temperature (T_{Ope}) increasing from 4K to 30K in 2K steps.

IV. Conclusion

In this work, the effect of operation temperature on the noise characteristics of GaAs-based BIB detector has been studied. it is found that the total noise is dominated by the shot noise.

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