Study on Noise Behaviors of Epitaxial Si:P Blocked-Impurity-Band Detectors

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Abstract

The noise behaviors of the epitaxial Si:P BIB detectors have been investigated by experimental and theoretical tools. The device structure and testing system are presented in detail. The relationship between the noise spectral density and device temperature is analyzed. It is demonstrated that not only thermal noise but also shot noise are strongly dependent on the device temperature.

I. Introduction

The blocked-impurity-band (BIB) detector consists of a heavily doped absorbing layer in series with a thin high-purity blocking layer. The Si-based BIB detectors can response a wide spectral range from infrared to terahertz (THz) region. The detection mechanism of the Si-based BIB detectors is as follows: (1) the radiations pass through the blocking layer and is absorbed by the absorbing layer; (2) the carriers in the impurity band are excited and transit to the conduction band; (3) the excited free carriers are swept along the conduction band and collected by electrodes. Through the above three steps, the THz optical signal can be transformed into electrical signal, and realize its detection [1]. Generally, the Si-based BIB detectors are operated at temperature below 12K, and possess excellent performances such as high sensitivity, large quantum efficiency, and low dark current [2].

The Si-based BIB detectors have been developed for the optimal choice for astronomical imaging, atmospheric sensing, and spectroscopic applications in spectral range from 5 to 40 micron [3-5]. The first application of Si-based BIB detectors in space was on the Cosmic Background Explorer (COBE) satellite launched by NASA in 1989. There are 16 separate Si-based BIB detector elements carried on the COBE, which were designed and fabricated at Rockwell International Science Center. Before then, the extrinsic Si photoconductive detectors were commonly used in satellite-based far infrared telescope (for instance, the Infrared Astronomical Satellite (IRAS) launched in 1983). In terms of response spectrum range and susceptibility to high energy cosmic rays, the performances of the BIB detectors carried on the COBE are far superior to the extrinsic Si-based photoconductive detectors carried on the IRAS. Therefore, the state-of-the-art Si-based BIB detectors have completely replaced extrinsic Si photoconductors.

Noise behaviors can be used as a baseline for characterizing performance of Si-based BIB detectors. Up to now, most of researchers have focused on the dark current study of Si-based BIB detectors [6]. However, dark current is only one of factors that contribute to the device noise, and other critical noise components also include background noise, $1/f$ noise, and thermal noise. To fill this gap and facilitate device optimization, it is therefore necessary to give a full description of device noise by considering all the related factors.

II. Device Structure and Testing System

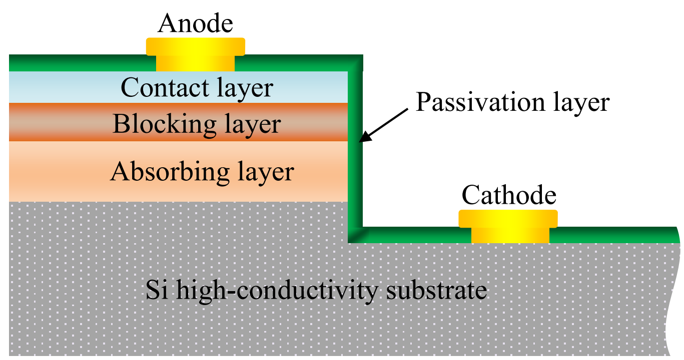

Fig. 1. Schematic of cross-section of epitaxial Si:P BIB detector.

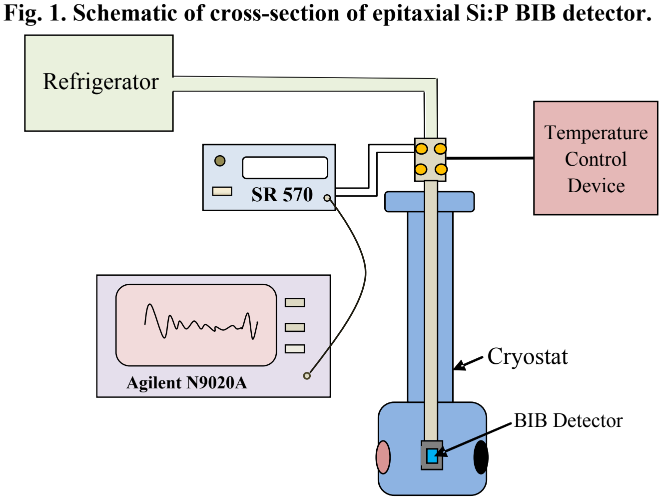

Fig. 2. Schematic of testing system for measuring device noise.

Epitaxial Si-based BIB detectors were fabricated for noise measurement. The cross-sectional structure is shown in Fig. 1, and is sequentially composed of Si high-conductivity substrate,

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absorbing layer, blocking layer, contact layer, and passivation layer. The anode is formed upon the contact layer, and the cathode is formed upon the substrate. As shown in Fig. 2, the measured BIB detector is placed in the cryostat, and device temperature can be adjusted accurately by the refrigerator and the temperature control device. The anode bias is applied by SR570, and device noise is displayed by Agilent N9020A.

III. Result And Discussion

Fig. 3. Measured noise spectrum of the epitaxial Si:P BIB detector enclosed by liquid helium at anode bias of 3V.

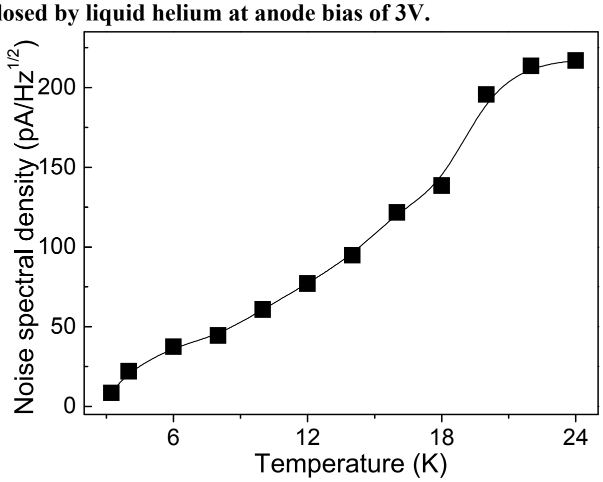

Fig. 4. Dependence of noise spectral density on device temperature at anode bias of 3V.

The noise components of Si-based BIB detectors consist of thermal noise, shot noise, and flicker noise. Among them, thermal noise can be expressed as:

$$I_{\mathrm{T}} = \sqrt{4KT/R} \tag{1}$$

where K is the Boltzmann constant, T is the device temperature, and R is the device output resistance. The shot noise has the following form:

$$I_{\mathrm{S}} = \sqrt{2q(I_{\mathrm{D}} + I_{\mathrm{P}} + I_{\mathrm{B}})} \tag{2}$$

where q=1.6×10^{-19} C, I_{D} is the dark current, I_{P} is the signal current, and I_{B} is the background current. The flicker noise is due to random effects associated with surface traps and generally has $1/f$ characteristics that are important only at lower frequencies, and thus is also commonly known as $1/f$ noise. Figure 1 shows the noise spectrum of Si-based BIB detector enclosed by liquid helium at anode bias of 3V. It is found that current noise has a $1/f$ dependence on frequency at low frequencies, and keeps a constant value of 0.76pA/Hz$^{1/2}$ when the frequency is above 2 KHz. Our results show that the actual device noise level in the liquid helium environment is far below 0.76pA/Hz$^{1/2}$ due to the limitation from electronic noise of the testing system.

Figure 4 shows the dependence of noise spectral density on device temperature at the anode bias of 3V. As observed, the relationship between the noise spectral density and the device temperature is an approximately S-type curve. However, according to Eq. (1), the thermal noise is proportional to the square root of device temperature. Therefore, it can be concluded that the thermal noise is not only component of device noise and the shot noise as one of contributors of device noise is also a strong function of device temperature.

IV. Conclusion

The noise behaviors of the epitaxial Si:P BIB detectors have been investigated by experimental and theoretical tools. Our results show that the actual device noise level in the liquid helium environment is far below 0.76pA/Hz$^{1/2}$ due to the limitation from electronic noise of testing system. It is found that the measured relationship between the noise spectral density and the device temperature is an approximately S-type curve. Moreover, it is demonstrated that not only thermal noise but also shot noise are strongly dependent on the device temperature.

Acknowledgements

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