



Noise characteristics investigation in quantum dot infrared photodetectors



Honggang Bai^{a,*}, Jianqi Zhang^a, Xiaorui Wang^a, Yingji Jin^b

^a School of Technical Physics, Xidian University, Xi'an, ShaanXi 710071, China

^b School of Science, Engineering University of Armed Police Force, Xi'an, ShaanXi 710086, China

HIGHLIGHTS

- A noise model of QDIP is further verified at different temperatures.
- The noise characteristics with different performance parameters are investigated.
- The reasons for the influence on the noise of QDIP are analyzed.
- Theoretical guidance for pursuing the higher performance QDIP is proposed.

ARTICLE INFO

Article history:

Received 20 February 2013

Available online 20 May 2013

Keywords:

Noise

Electrons transport

Performance parameters

ABSTRACT

The noise of quantum dot infrared photodetectors (QDIPs) can bring about the degradation on their performance, so keen interest has been paid to research on the noise in recent years. In this paper, a noise model of QDIP including the common influence of the microscale and the nanoscale electron transport to the activation energy is further verified at different temperatures, moreover, with the consideration of the dependence of the drift velocity on the electric field. The main concern is to investigate the influence of QDIPs parameters on the noise characteristics, such as the electric field, temperature, two electrons transport, detector material and structural performance parameters, respectively. The reasons for the influence of main performance parameters on the noise are analyzed and discussed in detail. The calculated and simulated results show that the noise model has a good agreement with the experimental data, and the research can provide the guidance in the optimization of the device design and the pursuit of the higher performance QDIP.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

The quantum dot infrared photodetectors (QDIPs) have recently been the subject of numerous research efforts, owing to their lower dark currents, higher photoconductive gain, increased extraction efficiency, and increased operating temperatures, etc. [1–10]. The noise is one of the most basic and important property because it can lead to the great degradation of sensitivity in QDIP, so more and more attention has been paid to research on the noise to pursue higher performance QDIP [11–17]. For now, people start out investigating the noise from the dark current, which is the main component in the noise. On the one hand, a large number of people investigated the dark current from the perspective of the electronic potential distribution in potential well of quantum dots. For example, a device model for realistic QDIPs in dark condition was proposed. The model accounts for the self-consistent potential

distribution and features of the electron capture and transport [6]. An analytical dark current model for realistic QDIPs including the effect of the space charge, and self-consistent electric potential in QDIP, and the activation character of the electron capture was presented [7]. Meanwhile, the dark current as a function of the structural parameters, and applied voltage and temperature was calculated by using the respective model [6,7]. The algorithm which used to calculate the dark current, photocurrent, responsivity and detectivity as a function of the structural parameters was developed [8]. The dark current [9,10] and the photocurrent [10] were respectively presented by Shekhi et al., in which it is assumed that both thermionic emission and field-assisted tunneling mechanisms determine the dark current, moreover, Richardson effect was considered. Nevertheless, the noise characteristics of QDIP were not further discussed by the relationship between the noise and the dark current [13–17] in these works. On the other hand, from the perspective of the activation energy, an analytical dark current model was presented with only consideration of the contribution of the microscale electron transport to the activation energy

* Corresponding author.

E-mail address: bhg3399@sina.com (H. Bai).

by Liu [18,19], or the dark current was only dependent on the nanoscale electron transport to the activation energy [20–22]. Recently, the noise model has been rapidly developed based on the relationship between the noise and the dark current. Although a noise model was obtained by considering the common influence of the microscale and the nanoscale electron transport to the activation energy on the dark current [5,23–26] by Liu [26], unfortunately, the influence of main performance parameters on the noise was not further investigated, and the noise model was limited in analyzing the performance and guiding the design of QDIP. So it is very necessary for us to investigate the influence of the main performance parameters of QDIP on the noise.

The main concern of this paper is the influence of QDIP performance parameters on the noise characteristics. In this paper, a noise model including the common contribution of the microscale and the nanoscale electron transport to the activation energy is further verified at different temperatures, meanwhile, with the consideration of the dependence of the drift velocity on the electric field. More importantly, the model can be used to investigate the noise characteristics of QDIP by different performance parameters, such as the electric field, temperature, two electrons transport (microscale and nanoscale), detector material performance parameters (mobility of electrons, effective mass of electrons, and saturation velocity of electrons), and detector structural performance parameters (detector area, number of quantum dot (QD) layers, spacing between QD layers, lateral size of QDs, height of QD, density of QD, and capture rate of electrons), respectively. Furthermore, the reasons for the influence of main performance parameters on the noise are analyzed and discussed in detail. The calculated and simulated results show that the noise model has a good agreement with the experimental data, and the research plays an important theoretical role in pursuing higher performance QDIP.

2. Noise model

The QDIP detect infrared radiation through intraband transitions in the conduction band, and the absorption of IR radiation is associated with the electron subband and subband or subband and continuum transitions [9]. It is mainly composed of barrier layers of excited regions and repetitive QDs composite layers [8–10], and the schematic diagram of the QDIP structure is shown in Fig. 1a. The top and the bottom respectively contacts with doped are used as the emitter and the collector, and the QDs layers sandwiched between the emitter and collector are separated by barrier layers. In this paper, each QD layer is composed of many periodically distributed identical QDs with the density $\sum_{QD}$. The lateral size of QDs a_{QD} is supposed so large that each QD has a large number of bound states to accept more electrons. Conversely, the transverse size of QDs is assumed to be relatively small in comparison with the spacing between the QD layers L . h_{QD} represents the height of QD, and M is the number of the QD composite layers in our model. The QDIP active region (the stack of QD arrays) is sandwiched between two heavily doped regions which serve as the emitter and collector contacts.

The dark current is the current that flows even without the presence of incident light [5–7]. The dark current is a source of noise [14–17], which plays an important role in limiting the performance of both devices. Based on these assumptions, the dark current can be obtained by counting the mobile carrier in the barrier [5,19,26–28], and it can be estimated as:

$$I_{dark} = 2e\mu F \left(1 + \left(\frac{\mu F}{v_s} \right)^2 \right)^{-\frac{1}{2}} \left(\frac{m_b kT}{2\pi\hbar^2} \right)^{3/2} \exp \left(-\frac{E_a}{kT} \right) A \quad (1)$$

where e is the electron charge, μ the mobility of electrons, F the electric field, v_s the saturation velocity of electrons, m_b the effective

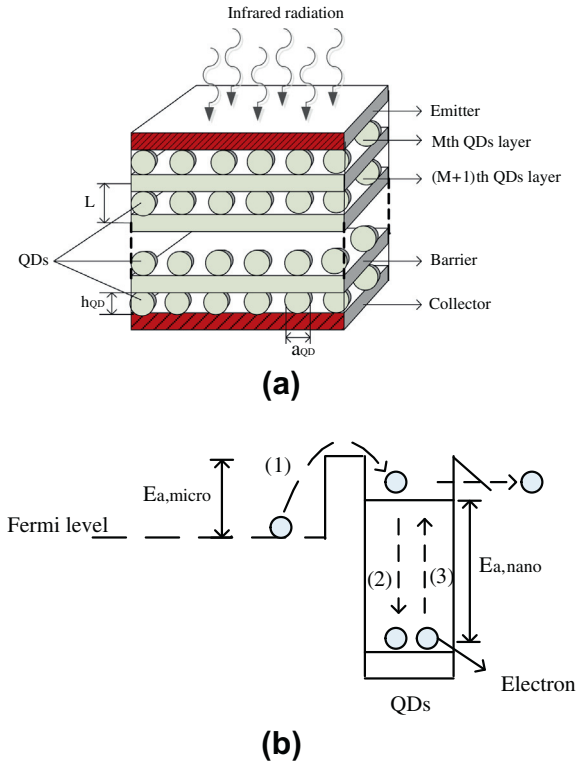


Fig. 1. (a) Schematic diagram of the QDIP structure. (b) Sequential coupling model of two kinds of electron transport in QDIP.

mass of electrons, k the Boltzmann constant, T the temperature, $\hbar$ the Planck constant, E_a the activation energy, and A the area of detector.

Since the electron transport mechanism is characterized by the activation energy in QDIP. In the model, we suppose that the activation energy of QDIP include the common influence of the microscale and the nanoscale electron transport on the dark current [5,23–26]. These processes are shown in Fig. 1b. The total electrons contributing to the dark current should undergo three processes in a sequential way [23,24]: (1) thermal emitting over the effective potential barrier presenting the built-in band profiles (being the microscale effect), (2) being captured by the QD, and (3) escaping out of the QD (as the nanoscale effect). The activation energies of the process (1) and (3) respectively represent $E_{a,micro}$ and $E_{a,nano}$. Based on this consideration, the activation energy E_a can be written as:

$$E_a = E_{a,micro} + E_{a,nano} \quad (2)$$

$$E_{a,micro} = E_{0,micro} \exp(-F/F_0) \quad (3)$$

$$E_{a,nano} = E_{0,nano} - \beta F \quad (4)$$

where $E_{0,micro}$ and $E_{0,nano}$ represent the activation energy for the microscale and the nanoscale mechanism at zero bias ($F = 0$ kV/cm), respectively. F_0 and β are the experimental parameters, which respectively indicate the change rate of the activation energy under the microscale and the nanoscale electron transport with the electric field. The parameter F_0 describes the dependence of the thermal emission over the effective potential barrier on the electric field, and β originates from the correspondence between the electron escaping from the QD (related to tunneling mechanism) and the electric field.

In QDIPs, the noise is mainly from the generation–recombination (G–R) process of carriers, as a good approximation, the photo-

Download English Version:

<https://daneshyari.com/en/article/8147151>

Download Persian Version:

<https://daneshyari.com/article/8147151>

[Daneshyari.com](https://daneshyari.com)