The sensitivity and the dark current on InAs quantum dots detector with adjustable wavelength

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Abstract- This paper designs and simulates the quantum effects optoelectronic device on the sensitivity, low dark current and wavelength range. The simulation result shows that changing the density of the quantum dots and the quantum well width respectively when the voltage is 0.1 V, the dark current is as low as 0.05 fA at room temperature. It is also indicated that the photo-detector has a broad response spectrum with wavelengths ranging from 100 to 950 nm. By changing the asymmetry structure of the quantum dots in the quantum well can adjust response wavelength.

Introduction

Recently, The low dimensional nano-scaled narrow band gap III-V semiconductor devices have received great attentions for their applications in photodetector, solar cells, light emitting diodes, and so on[1]. The quantum structures based on GaAs have been successfully used for infrared detection, especially after having succeeded in the transition from pure quantum physics to the system engineering of the photon detection process involving quantum coherence [2]. The underlying quantum structures are quantum dots (QDs) and the dots-in well (DWELL) structure. As a basic device characteristic, the dark current properties of the quantum dot infrared photo-detectors (QDIPs) based on the DWELL structure have been investigated many years. One relevant issue in the optimization photodetectors is to control or suppresse the dark current [2]. Being a fundamental source of electronic noise, it ultimately limits the sensitivity of the optoelectronic device, setting the achievable signal to noise ratio (SNR). Moreover, high dark current can negatively affect the detectivity by increasing the recombination losses and the power consumption. On this basis, we research quantum dots and quantum well structure for influence of the dark current, and temperature how to influence on the dark current for quantum detector.

Modeling

The sample in use was simulated by Apsys on an n+-type (1 0 0) GaAs substrate and the model of photoelectric detector shown in Fig.1. After the growth of a Si-doped ($10^{18}cm^{-3}$) 1mm GaAs buffer layer and an undoped 30 nm GaAs spacer, the undoped double barrier structure was deposited in the sequence of the first 25nm AlAs barrier, a 3nm GaAs interlayer, a 6 nm $In_{0.15}Ga_{0.85}As$ QW, a 45 nm GaAs well, a 1.8 ML self-assembled InAs QD layer with a 5nm GaAs overlayer, and the second 25nm AlAs barrier [4-5]. On the top, an undoped 30nm GaAs spacer and a Si-doped (($10^{18}cm^{-3}$) 30nm GaAs capping layer were overgrown [4-5].And ohmic contacts were separately made to the top and back contact layers [4-5]. We systematically study the response wavelength and sensitivity when detecting weak light on double-barrier InAs QDs and InGaAs QW hybrid structure. The structure's I–V and C–V properties are calculated numerically.

Result and Discussion

By changing the component of the In to change the width of the quantum well is a way for reducing the dark current. It is found that both the quantum well and quantum dot suppressing dark current. This is because the quantum well energy levels can be reduced by the introduction of the electronic energy levels of the quantum dot, thereby reducing dark current. When the composition of the In is bigger, the higher the quantum well height, then lower the tunneling chance, thus reducing the dark current. From Fig.2, when the bias is 0.1 V, the dark current is only 0.05 fA. The I–V characteristics of the photoelectric device are simulated at room temperature. From 613 nm wavelength to 910 nm, the response of the current is gradually increasing. But from 910 nm to 1.3 um, the result is opposite. The best response wavelength is about 875 nm at 300 K, but at 77 K about 950 nm. Using three different kinds to scan the device shown in Fig.3, the rate maybe affect the current shifting, and we obtain a lower dark current in a normal model, which is about 0.8 pA at 0.4 V at 77 K. We explain the shift value due to the QD storage. The scan rate can reduce or increase the number of QD capturing holes and electrons. So the dark current is lower on the special structure. This fact implied that the double-barrier InAs QDs and InGaAs QW hybrid structure enhanced the detection efficiency at low temperature. It also indicated that the photodetector has a broad response spectrum with wavelengths ranging from 100nm to 950 nm by changing the asymmetry structure of the quantum dots in the quantum well. By changing the In component change the quantum well width, when In component x=1, the response wavelength is up to about 2.2 um in Fig.4.

Conclusion

The simulation found that the dark current of the quantum well is more obvious than the quantum dot at low temperature. By changing the quantum well width can suppress dark current. This is because the quantum well which is introduced in wide GaAs well can reduce quantum dot internal electronic energy levels, thereby reducing dark current. By changing the asymmetry structure of the quantum dots in the quantum well can be adjusted in response to the wavelength.

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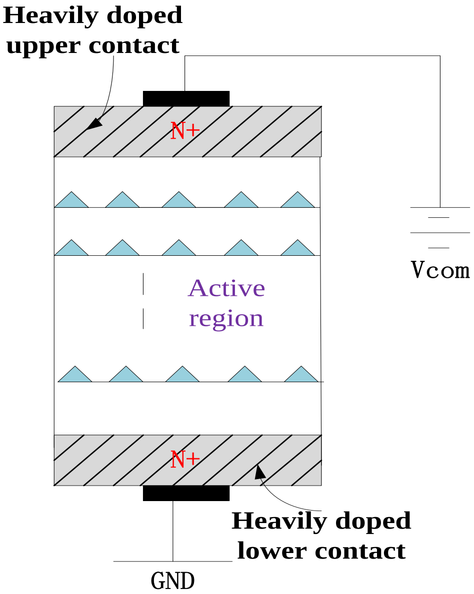

Fig. 1 The schematic structure of self-assembled QDIPs showing the active regions and the top and bottom contacts.

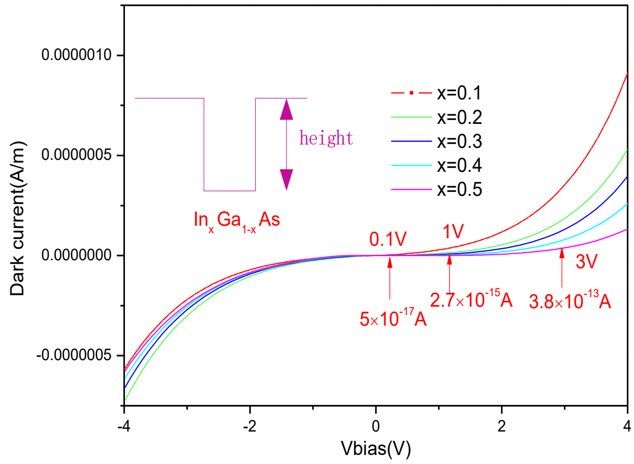

Fig.2. The different dark current at the width quantum well

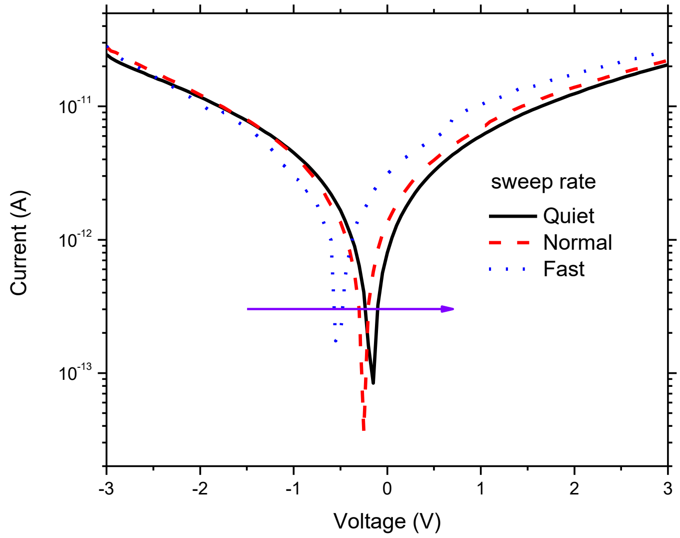

Fig.3 dark current test with three scan rate—quiet, normal, fast

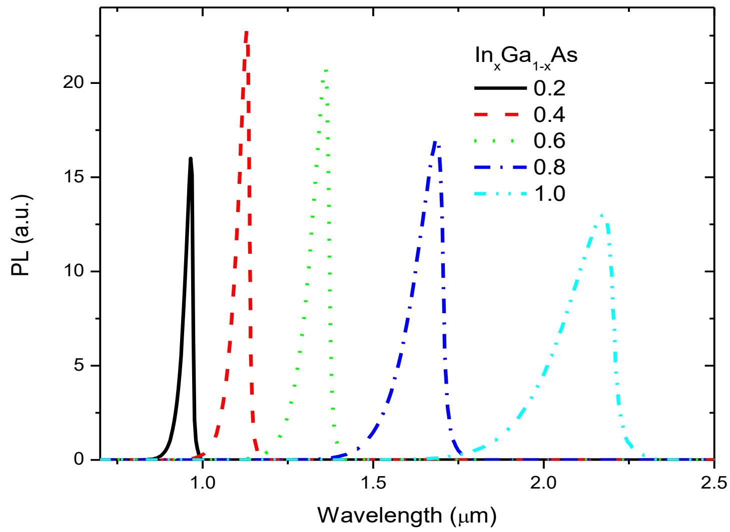

Fig.4. Photoluminescence spectra simulated under different the component of the In. (x=0.2, 0.4, 0.6, 0.8, 1)