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In(Ga)As Quantum Rings for Terahertz Detectors

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1. Introduction

Terahertz (THz) radiation covers a broad frequency range from 100 GHz to 40 THz. It can be applied for use in imaging, communication, medical diagnosis, environmental control, health monitoring and biochemical identification [1]. There are few suitable detectors operating in this frequency range. The typical QW detectors using AlGaAs/GaAs heterojunction structures with critical Al fractions aren't suitable to normal incidence and high temperature operation [2]. Recently, the InAs/GaAs quantum dot infrared photodetector (QDIP) has demonstrated the operation in far-infrared (FIR) region [3,4]. But the cutoff frequency is limited to less than 40μm. During the growth of InAs/GaAs quantum dot (QD), it is difficult to control the InAs dot size to a small value uniformly, hence it is hard to achieve the low confined-to-conduction band transition. The growth of InAs/GaAs quantum ring (QR) is similar to that of QD [5]. A thin GaAs capped layer was deposited surrounding the InAs QDs and the sample was annealed at higher temperature to evaporate the central uncovered InAs dot. Finally the edge of the embedded InAs dot and GaAs capped layer is mixed together and leaves an In(Ga)As ring shape structure shown in Fig. 1. The confinement of QR is limited by the capped layer thickness. Therefore, the In(Ga)As provides the smaller confined-to-conduction band transitions that can be applied in detector in THz range. This structure combines the advantages of QW and QD in size controllable and normal incidence available.

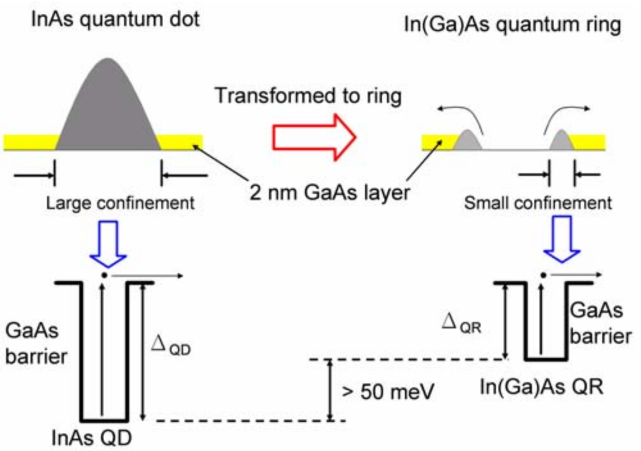

Fig. 1 Model for the transformation from a InAs quantum dot to a In(Ga)As quantum ring and The intraband transitions from different quantum confinements of the ring and the dot.

In this work, we reported a broadband QR terahertz detector, The response is extending from 100 to 3 THz (100μm) which has a spectral detectivity of 2.3×10^{11} $cmHz^{1/2}/W$ at 10 K under 1.2 V bias.

2. Experiments

The In(Ga)As QRs were grown by molecular beam epitaxy (MBE) using the Stranski-Krastanov growth mode, 2.6 ML InAs QDs was first grown on GaAs substrate and covered by 2 nm GaAs partial capping layer and then annealed for 30 sec. at 480 ℃. The atomic force microscopy image of the QDs is shown Fig. 2 (a). The cross-sectional TEM showing the In(Ga)As QR region is really small as shown in Fig. 2 (b).The ten periods of QR are embedded in 50 nm undoped GaAs barrier within top and bottom contact layers. The schematic detector structure is shown in Fig. 2 (c).

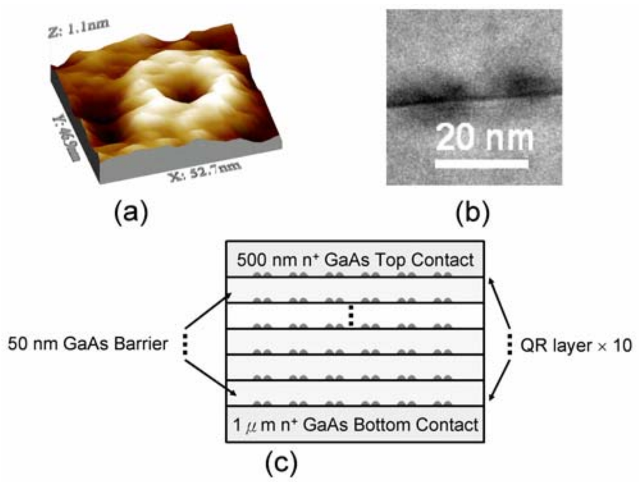

Fig. 2 (a) a three-dimensional AFM image of a single QR. (b) the cross-sectional TEM image of QR. (c) Schematic of the growth and device structure with self-organized In(Ga)As quantum rings.

The detector with an area of 150×150 μm^2 is fabricated after the above two-step process. The device is measured under an edge coupling scheme with a cryostat. The temperature-dependent dark and ambient background irradiation irradiation current-voltage characteristics measured by HP 4156B precision semiconductor parameter analyzer At lower temperature, the dark current is restrained under 2.3×10^{10} A. The BLIP of detector is 40 K as shown in Fig. 3.

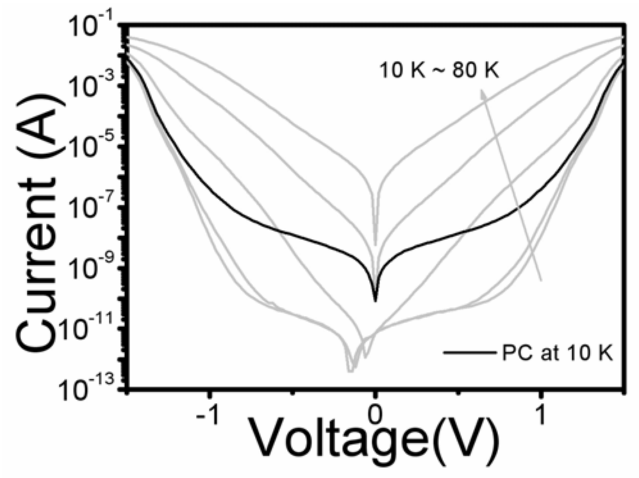

Fig. 3 Dark current as a function of applied voltage of the detector from 10 to 80 K. The bold curve represents the photocurrent measure at 10 K when the device is illuminated from the ambient background radiation through the cryostat window.

The spectral responsivity of the QR detector are measured from 100 THz to 3 THz that high detectivity of 2.3×10^{11} cmHz$^{1/2}$/W is obtained in peak wavelength of 21μm at 10 K under 1.2 V bias. The peak responsivity is observed at 127 mA/W as shown in Fig. 4.

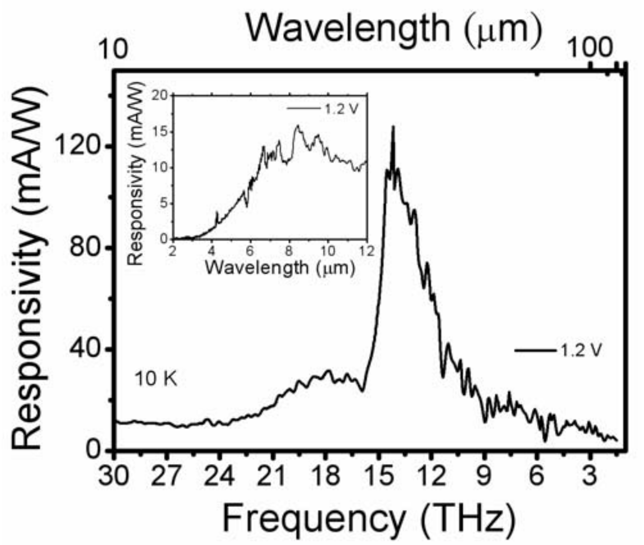

Fig. 4 Experimental responsivity spectra for bias 1.2 V obtained at 10 K. The inset is the MIR responsivity.

3. Conclusions

The normal incidence and broadband terahertz detector is fabricated by In(Ga)As quantum rings. The cutoff response can be operated up to 3 THz (100 μm) at 10 K. Besides, the quantum ring THz detector has potential tailor its cutoff frequency by adjusting the thin GaAs capped layer.

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