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Photoresponse improvement of InAs/GaAs quantum dot infrared photodetectors using $GaAs_{1-x}Sb_x$ overgrown layer

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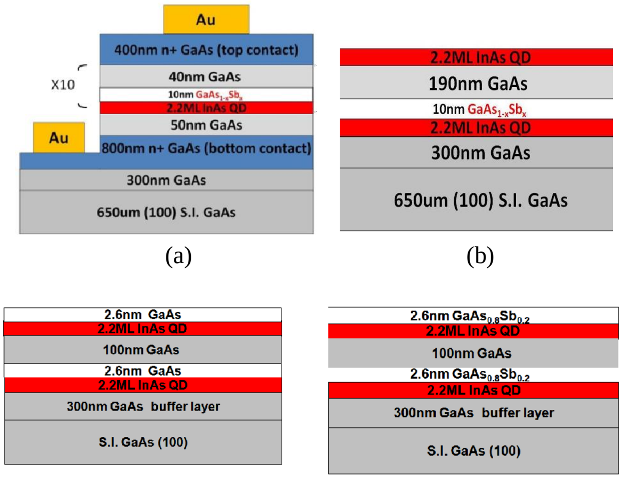
1. Introduction

In the past two decades, different types of quantum dot infrared photodetectors (QDIPs) have been widely investigated owing to their wide range of applications in medical diagnosis and environmental monitoring [1,2]. QDIP has the great potential to operate at higher temperature and is able to detect the light normaly incident to detector surface while compared to quantum-well infrared photodetector(QWIP) [3]. In particular, it was found that using InGaAs capping layer on InAs quantum dots (QDs) not only reduces lattice strain, but also increases the spectral response. AlGaAs-capped QDIPs provide higher barrier to enhance the carrier confinement in the QD, which increase both the quantum efficiency and operation temperatures [4,5]. In this paper, the effect of $GaAs_{1-x}Sb_x$ strain reducing layer on the performance of InAs/GaAs QDIPs is investigated. It was found that the InAs/$GaAs_{1-x}Sb_x$ QDs exhibit a type-II band structure when Sb composition x exceeds 0.15 [6,7]. This transition provided a relative high barrier as well as improved reduction of strain for QDIP. In addition, the $GaAs_{1-x}Sb_x$ layer has the capacity to suppress the intermixing between In and Ga atoms [8,9], thus can reduce the band width of the responsivity curve even with only 1% of Sb [10].

2. Experiments

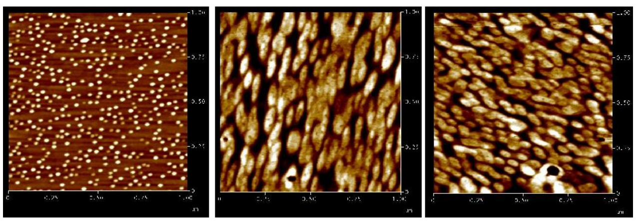
The samples were grown on (100) semi-insulating GaAs substrate using VG 80H gas-source MBE at 490 ℃. The schematic device structure is shown in Fig. 1(a). Sandwiched between top 400 nm and bottom 800 nm n+ GaAs contact layers with Si doped to $2X10^{18}$ cm^{-3}, ten periods of a 2.2 ML InAs QDs capped with 10 nm $GaAs_{1-x}Sb_x$ strain reducing layer and a following 40 nm undoped GaAs barriers were grown on 50 nm undoped GaAs buffer layer. The Sb compositions of the 10 nm thick $GaAs_{1-x}Sb_x$ strain reducing layer were changed with five different values, i.e., x=0, 0.01, 0.03, 0.06, and 0.2 which were denoted as device A, B, C, D and E, respectively. In addition, another five samples A', B', C', D' and E' were grown for PL measurement based on the similar growth parameters of the previous five devices. The structure is shown in Fig. 1(b). Same growth parameters were chosen to grow InAs QDs capped with 10 nm $GaAs_{1-x}Sb_x$ layer on 300 nm undoped GaAs buffer layer, followed by 190 nm undoped GaAs on top. Finally, another InAs QDs layer without $GaAs_{1-x}Sb_x$ capping layer is grown on the top for atomic force microscopy (AFM) measurement. AFM image



(c)

Fig. 1 Device structure of (a) QDIP with GaAs1-xSbx strain reducing layer. (b) Sample structure grown for AFM and PL measurement. (c) Sample structure of R1 (left) and R2 (right).

of the InAs QDs is shown in Fig. 2(a). For qualitative investigation of alloy intermixing between In and Ga atoms, another two samples R1 and R2 as shown in Fig. 1(c) with different partial capping layer were grown. Same conditions were chosen to grow InAs QDs on 300 nm undoped GaAs buffer layer and covered by a 2.6 nm GaAs (R1) or $GaAs_{0.8}Sb_{0.2}$ (R2) partial capping layer and then annealed for 10 s at 460 ℃. This satisfies the conditions for QD transformation into quantum ring (QR). The AFM image of the QRs is shown in Fig. 2(b) and (c). Sample R1 have more elongation on [110] direction than R2 because the $GaAs_{0.8}Sb_{0.2}$ partial capping layer decreases migration length of In atoms. It provides evidence that $GaAs_{0.8}Sb_{0.2}$ suppress alloy intermixing between In and Ga atoms.



(a) (b) (c)

Fig. 2 AFM image of (a) InAs/GaAs QD. (b) Sample R1. (c) Sample R2.

The PL spectra of samples A' to E' measured at 10 K are measured and shown in Fig. 3. An obvious red shift is observed starting from sample C'. It can be clearly seen that sample E' with the highest Sb composition x=0.2 displays the broadest spectra and longest wavelength which can be attributed to three factors. First, the reduction of strain lower the energy level inside the InAs QDs. Secondly, energy band structures transit to type II band gap when the concentration of Sb exceeds 15%, the electrons in QDs recombine with the holes in GaAsSb layer emitting PL spectra with longer wavelengths [7]. The third reason is because Sb suppresses the alloy intermixing between In and Ga atoms, allowing the QDs under the capping layer with more In atoms to form larger QDs [9].

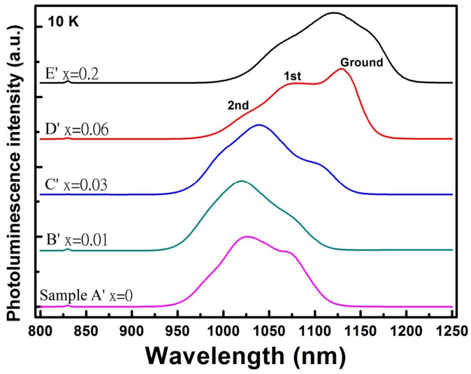


Fig. 3 The PL spectra of five samples A' to E' at 10 K.

The normalized spectral response of different devices are shown in Fig. 4. Spectral curve of device A exhibits the broadest full width at half maximum (FWHM) with 3.3 μm. The most pronounced band shrinkage is observed for device E, which has the narrowest FWHM of spectral response of 1.5 μm. The bottom contact is defined as the ground when applying voltage to all devices. The absolute peak responsivity under different biases for each device are shown in Fig. 5. The best responsivity for device A merely reaches 1.4 mA/W. On the contrary, the maximum responsivity was measured for device E at 533 mA/W. The responsivity was increased to 380 times larger. However, device D performed better below 2 V bias. This phenomenon is the result of the type-II transition in device E, therefore, higher barrier is formed on the conduction band. When the applied forward bias was increased, the energy band of device D was over bent. Hence the device D cannot work above 1.2 V. However, device E has the ability to operate under higher bias voltage because of the higher conduction band barrier.

3. Conclusions

The effect of $GaAs_{1-x}Sb_x$ strain reducing layer on the performance of InAs/GaAs QDIPs has been investigated. It is demonstrated that the additional $GaAs_{1-x}Sb_x$ capping layer enhanced the spectral responsivity to a factor of 380 and pronounced narrowing of the responsivity peak.

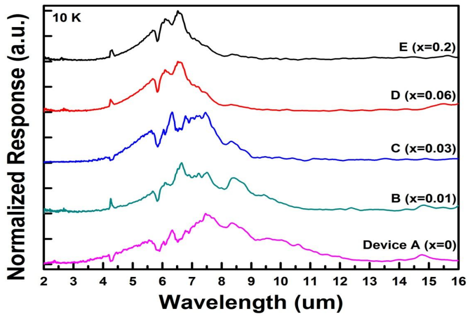


Fig. 4 Normalized spectral response of different devices A to E.

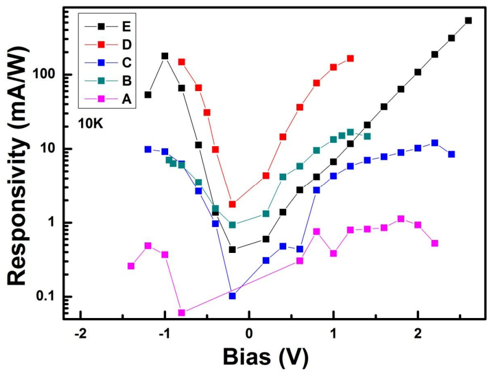


Fig. 5 Absolute peak responsivity under different biases for devices A to E.

Acknowledgements

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REFERENCES:

1. V. Ryzhii, Semicond. Sci. Technol. **11** (1996) 759.
2. H. Lim, W. Zhang, S. Tsao, T. Sills, J. Szafraniec, K. Mi, B. Movaghar, and M. Razeghi, Phys. Rev. B **72** (2005) 085332.
3. S. F. Tang, S. Y. Lin, and S. C. Lee, Appl. Phys. Lett. **78** (2001) 2428.
4. S. F. Tang, S. Y. Lin, and S. C. Lee, IEEE Trans. Electron Devices **49** (2002) 1341.
5. H. S. Ling, S. Y. Wang, C. P. Lee, and M. C. Lo, IEEE Photon. Technol. Lett.**21** (2009) 118.
6. T. S. Wang, J. T. Tsai, K. I. Lin, J. S. Hwang, H. H. Lin, L. C. Chou, Materials Science and Engineering B 147 (2008) 131.
7. P. Klenovský, V. Křápek, D. Munzar, and J. Humlíček, Appl. Phys. Lett. 97 (2010) 203107.
8. J. M. Ulloa, I. W. D. Drouzas, P. M. Koenraad, D. J. Mowbray, M. J. Steer, H. Y. Liu, and M. Hopkinson, Appl. Phys. Lett. **90** (2007) 213105.
9. J. M. Ulloa, R. Gargallo-Caballero, M. Bozkurt, M. del Moral, A. Guzmán, P. M. Koenraad, and A. Hierro, Phys. Rev. B 81 (2010) 165305.
10. P. C. Chiu, W. S. Liu, M. J. Shiau, J. I. Chyi, W. Y. Chen, H. S. Chang, and T. M. Hsu, Appl. Phys. Lett. **91** (2007) 153106.