Spectral Response Modification Of Quantum Well Infrared Photodetector By Quantum Well Intermixing

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ABSTRACT

We have studied the change of the spectral response in a quantum well infrared photodetector (QWIP) by using the impurity-free vacancy disordering (IFVD) to change the bandgap of the GaAs/AlGaAs multiple quantum well absorption layer. IFVD process has been carried out with PECVD-grown SiO_2 capping on the MOCVD-grown QWIP structure, whose absorption region consists of 25 periods of 3.6nm thick Si-doped GaAs well and 50nm thick $Al_{0.24}Ga_{0.76}As$ barrier. The PL peak of MQW decreased with the increase of annealing temperature and time from 802 nm to 700 nm at 15 K. The fabricated QWIP whose absorption region was intermixed at 850 ^oC by IFVD technique showed the maximum change in spectral response from 8 to 10 um when compared to a QWIP without intermixing. This result implies that the intermixing technology can be used to make multicolor QWIP without growing multiple IR absorption regions.

INTRODUCTION

The detection of thermal radiation is very important for the application of Infrared (IR) communication, medical treatment, detecting gas leak and security of industrial equipment [1]. For this purpose, HgCdTe material system has been widely studied and used to detect IR radiation. Though the HgCdTe material system provides high quantum efficiency and detectivity, through a band-to-band transition, in the IR detection, this material system shows low stability and low uniformity in a whole wafer, which gives a limitation to fabricate a stable IR detector array.

Since the bandgap energy of III-V compound semiconductor is larger than the photon energy whose wavelength is longer than 2 μm, IR detection is impossible through band-to-band transition for the wavelength longer than 2 μm with III-V compound semiconductor. However, since the energy difference between inter-subbands of quantum well is well matched to the energy of IR photon, IR detection is possible with III-V compound semiconductor. West at al. has reported first quantum well infrared photodetector (QWIP) utilizing inter-subband transition in GaAs/AlGaAs quantum well (QW) in 1985 [2]. Since QWIP provides high detectivity, quick response, high stability, and cost-effective fabrication with the III-V compound semiconductor device fabrication technology, many researchers have studied QWIP [3-8].

Two-color QWIP for dual band IR detection has wide applications in remote sensing. Recently, Gunaplla et al. proposed two-color QWIP by using stacked two different QW structures for dual band IR detection [8]. But the fabrication of this type of two-color QWIP is not easy, and furthermore this approach causes different detectivity for each IR band and a current leakage in the fabricated devices.

Alternatively we have studied the change of the spectral response in a QWIP for the two-color QWIP by using quantum well disordering technique [9-14] in order to change the bandgap of the GaAs/AlGaAs Multiple Quanum Well (MQW). Since quantum well disordering technique can locally intermix the MQW structure and produce different bandgap regions on the same substrate without any re-growth or selective growth step [9-11], this technique can be used to fabricate two-color QWIP. In this study, we adopted impurity free vacancy disordering (IFVD) technique [9-11, 14] in order to change the bandgap of GaAs/AlGaAs MQW structure.

EXPERIMENT

Figure 1 shows GaAs/AlGaAs QWIP structure used in this study. The QWIP structure has 25 periods of GaAs(3.6nm)/$Al_{0.24}Ga_{0.76}As$ QW which was designed to have only one confined state in conduction band for a bound-to-continuum transition. The GaAs well was doped with Si to $2x10^{18}cm^{-3}$ in order to provide carriers. The thickness of AlGaAs barrier was set to 50nm to prevent carrier leakage and state coupling between adjacent QWs. The GaAs/AlGaAs QWIP structure was grown by a metal organic chemical vapor deposition technique on a semi-insulating GaAs substrate.

A. Quantum Well Disordering

Since SiO_2 film has been known to enhance quantum well disordering [9-11], we adopted it as a capping layer for IFVD process. The SiO_2 capping layer was deposited by the plasma enhanced chemical vapor deposition technique. We used dilute silane (5% SiH_4 in N_2) and N_2O (99.999%) as reactive gases and N_2 gas was used as a buffer gas. The total pressure was maintained at 0.9 Torr and growth temperature was 275°C during the growth with 30 watts RF power. The thickness of SiO_2 capping film was 300nm. Thermal treatment of the SiO_2 capped MQW samples was accomplished in an electrical furnace in the temperature range from 800°C to 950°C for the times from 5 minutes to 15 minutes under N_2 atmosphere. The extent of disordering of MQW absorption region was characterized by photoluminescence (PL) measurement at 15K.

Layer	Materier system		Thickness	
Contact	GaAs	Nd=2×10^{18}cm^{-3}	0.5μm	
Barrier	$Al_{0.24}Ga_{0.76}As$		500Å	
Well	GaAs	Nd=2×10^{18}cm^{-3}	36 Å	×25 Periods
Barrier	$Al_{0.24}Ga_{0.76}As$		500 Å	
Contact	GaAs	Nd=2×10^{18}cm^{-3}	1μm	
Substrate	SI-GaAs			

Fig 1. QWIP structure.

B. PROCESS AND MEASUREMENT OF QWIP

Disordered and non-disordered QWIP substrates were processed to QWIPs by using standard photolithography, etching and metalization. Thermal treatment was done at 850 °C for 10 minutes for the disordered sample. The reason for this condition is following in section 3. A H_3PO_4:H_2O_2:H_2O solution was used as a etchant for a mesa etching and E-beam evaporated Ti/Au was used for contact metal. The pixel size of the QWIP was 200 × 200μm^2. One side of samples was polished at an angle of 45° in order to satisfy the selection rule in the inter-subband transition of the quantum well. The measurement of fabricated QWIPs was performed at 10K.

RESULTS AND DISCUSSION

Figure 3 shows PL spectra disordered and non-disordered sample. The PL peak position of non-disordered sample was a 802 nm. As one can see in Fig. 3, the PL peak position of MQW

IR absorption region was blue-shifted with the increase of annealing temperature and time from 802 nm to 700 nm at 15 K. This result has been explained by the increased Al-Ga inter-diffusion with the increase of annealing time and annealing temperature [9,11,14]. Compared to our previous report [11], the extent of disordering at the temperature range used this study is larger. This would be due to the highly Si-doped GaAs QW which has been reported to enhance the Al-Ga inter-diffusion during the high temperature annealing [12].

As seen also in Fig. 3, there is a decrease in PL intensity, which indicates the introduction of defects after thermal annealing. The defects introduced by high temperature thermal treatment would capture the carriers generated by an IR photo-absorption process and degrade the performance of QWIP. Thus one should find out the experimental condition to reduce the defects in order to keep the device performance high. In our result shown in Fig. 3, the temperature of 850°C gave relatively high PL intensity and a good sample surface after removing SiO_2 capping film. Due to this reason, we used the sample disordered at 850°C for 10 minutes for the fabrication of disordered QWIP. In this case, the PL peak position was located at 740 nm at 15K.

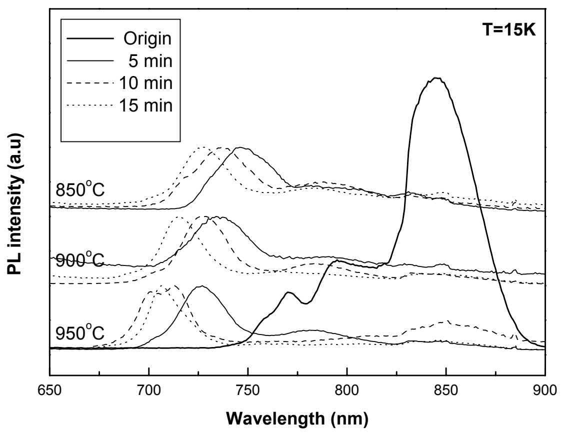

Fig 3. PL spectra of non-disordered and disordered samples

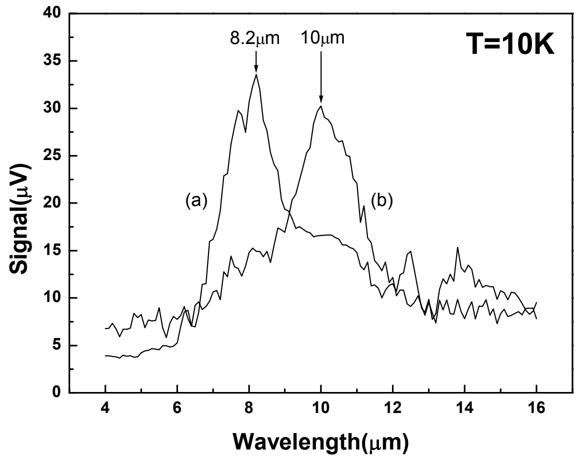

Fig 4. The spectral response of the QWIPs fabricated from (a) non-disordered substrate and (b) disordered substrate

The spectral responses of the QWIPs measured at 10K are shown in Fig. 4. One can see the response peak of disordered sample at 10μm, while that of non-disordered sample is located at 8.2μm. This red-shift of spectral response in disordered QWIP is due to the result of the blue-shift of QW bandgap after disordering. The blue-shift of bandgap energy after disordering has been explained by the increased confined state energy of electron and hole, which can be calculated from the deformed potential profile due to the Al-Ga inter-diffusion in a GaAs/AlGaAs QW structure [9].

There is an increase in electron state energy after the Al-Ga inter-diffusion, and hence a decrease in inter-subband transition from confined electron state to continuum state. Therefore the blue-shift in QW bandgap energy leads to the red-shift in inter-subband transition of disordered QW structure.

As shown in Fig. 4, there is a decrease in the maximum signal amplitude for the disordered QWIP. As discussed above, this may be due to the defects generated by high temperature thermal treatment.

4. CONCLUSION

IFVD process has been carried out with PECVD-grown SiO_2 capping on the MOCVD-grown QWIP structure. The PL peak position of MQW decreased with the increase of annealing temperature and time from 802 nm to 700 nm at 15 K. The intermixed sample and non-intermixed sample were processed to QWIP and tested at 10 K with an illumination at 45^o

angled facet of QWIP. The non-disordered sample showed its maximum response at 8.2 ㎛ but disordered sample, which was annealed at 850 ℃ for 10 minutes, showed its maximum response at 10 ㎛. The red-shift in the spectral response of disordered QWIP has been understood by the increase of electron state energy which leads the blue-shift of QW bandgap in disordered QW structure. The result in this study implies that the disordering technology can be used to fabricate multicolor QWIP without growing multiple IR absorption regions.

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