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Strained and Unstrained InGaAs/InP Quantum-Well Infrared Infrared Photodetectors Prepared by Metal Organic Chemical Vapor Deposition

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1. Introduction

Due to the mature epitaxy technology and the increasing requirement for infrared photodetecctors, a lot of reports about quantum-well infrared photodetectors (QWIPs) have been published [1]-[3]. Among which, most of the devices are fabricated based on GaAs/AlGaAs material system. Compared with GaAs-based materials, InP-based materials are considered to be of higher gain and lower dark currents due to their lower effective masses and the Al-free barriers, respectively [4]-[6]. Unlike GaAs-based QWIPs, most of the InP-based QWIPs are fabricated by metal organic chemical vapor deposition (MOCVD) instead of molecular beam epitaxy (MBE). The reason lies on the abrupt interfaces and easy-to-control layer compositions of epiwafers prepared by MOCVD and therefore, the method is especially advantageous for the fabrication of InP-based hetero-structures. In this report, ten-period InGaAs/InP quantum-well infrared photo- detectors (QWIPs) with and without compressive strain at the quantum-well region prepared by MOCVD are investigated. With detection wavelength at 8 μm, high responsivity of 20 A/W is observed for the unstrained device. Along with the increase of photocurrents, increasing dark currents are also observed. To depress the dark currents, InGaAs/InP QWIP with 1 % compressive- strain (CS) quantum wells is prepared. With over three order of magnitude dark current depression, higher peak detectivity of 2.9×10^{10} cm·Hz$^{1/2}$/W at 1.3 V is observed for the 1% CS strained QWIP. The similar normalized responsivity curves over incident light polarization have indicated a low influence of strained wells on the enhancement of normal incident absorption.

2. Results and Discussions

The samples discussed in this report are prepared by 6x2" ThomasSwan MOCVD system on (100) semi- insulating InP substrates. The sample structures are shown in Table. 1. With 500 nm n-type 3×10^{18} cm^{-3} InGaAs layers as top and bottom contacts, 10x QWIPs with lattice-matched QW and 1% CS QW are referred to as samples A and B, respectively. The samples are fabricated into 100x100 μm^2 devices using standard photolithography techniques, contact metal evaporation, and wet chemical etching. The spectral response is measured using a Perkin-Elmer precisely spectrum One (FT-IR spectrometer) [3]. The dark current-voltage characteristics are measured using a Keithley 236 analyzer.

Table I. Sample parameters of the InP-based QWIPs.

QWIP	A	B
Barrier material	InP	InP
Barrier width	30 nm	30 nm
Well material	$In_{0.533}Ga_{0.467}As$	$In_{0.656}Ga_{0.344}As$
Well width	6.6 nm	5.6 nm
QW doping	5×10^{17} cm^{-3}	5×10^{17} cm^{-3}
QW Periods	10	10
Quantum-well Strain	Lattice matched to InP	1 % CS

The 10 K spectral responses of Devices A and B are shown in Fig. 1. As shown in the figure, 8 and 8.6 μm peak detection wavelengths with responsivity values of 20 and 0.73 A/W are observed for Devices A and B at 2.0 V, respectively. Compared with the values of 0.4-0.5 A/W of GaAs-based QWIPs, the one-order-of-magnitude higher responsivity of Device A is attributed to the higher gain of the InP-based materials resulted from their lower effective masses. As for the case of Device B, with additional 1% CS added in the quantum-well region, reduced responsivity is observed, which is attributed to CS-induced increase of the conduction band discontinuity at the InGaAs/InP interfaces.

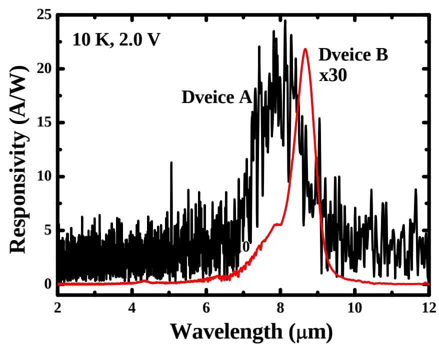

Fig. 1 10 K spectral responses of Devices A and B at 2.0 V.

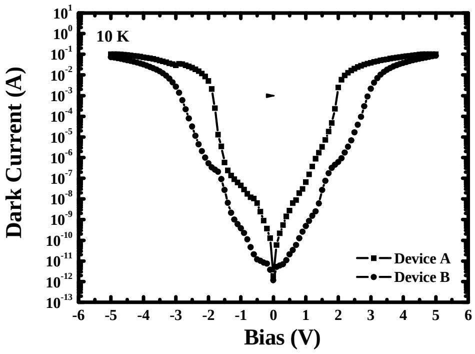

Fig. 2 10 K dark currents of Devices A and B.

In this case, the recombination possibilities for the photo-excited electrons would increase due to the higher barrier height electrons experienced in the device structure. Also observed in the figure is the less noisy spectral response curve for Device B, which indicates lower dark currents are for Device B. The mechanism responsible for the phenomenon is the same for the reduction of photocurrents for Device B.

The dark current-voltage characteristics of device A and B at 10 K are shown in Fig. 2. As shown in the figure, over three order of magnitude dark current depression at 2.0 V is observed for device B. By fitting the temperature-varying dark currents for the two devices, the zero-voltage activation energies obtained for both devices are 171 and 300meV, respectively. Due to the activation energies values are defined as ΔE_C-E_F, the results suggest a lower energy barrier electrons experienced in the unstrained QW of Device A. The results are consistent with previous attributions that lower barrier heights are responsible for the high photocurrents and dark currents for Device A.

With the measured dark currents, the peak detectivities (D*) are calculateed through the equation $D^* = R_p(A\cdot\Delta f)^{1/2}/i_n$, where R_p is peak responsivity, , i_n is noise current, A=100x100 μm^2 to be the illuminated detector area and Δf=1Hz the noise bandwidth [8]. The noise currents can be derived through the equation $i_n^2 = 4\ e\ g_{noise} I_{dark} \Delta f$, where g_{noise} is the noise gain, e is the electron charge and I_{dark} is the dark current. It has been shown that $g_{noise} = g_{photo}$.

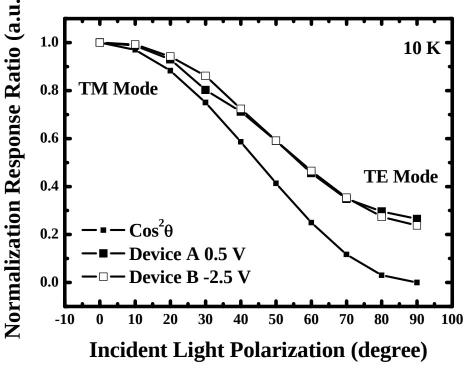

Fig. 3 The response ratio over incident light polarization for Devices A and B.

The peak detectivities thus obtained are 1.5 and 2.9 x10^{10} cm·$Hz^{1/2}$/W for Devices A and B at 1.8 and 1.3 V, respectively. The results suggest that although reduced photocurrents are observed, the more reduced dark currents would result in a enhanced peak detectivity for Device B.

To investigate the influence of QW strain on the spectral responses over incident light polarization, the response ratio under different incident polarizations are shown in fig. 3. As shown in the figure, the curves are almost identical for both devices. The results suggest that the QW strain is of no influence on the normal incident absorption of QWIP devices. Also observed is the ~25 % normal-incident absorption for both devices, which is attributed to the device mesa scattering for the incident TE-mode light.

3. Conclusions

In this report, ten-period InGaAs/InP quantum-well infrared photo- detectors (QWIPs) with and without compressive strain at the quantum-well region prepared by MOCVD are investigated. With detection wavelength at 8 μm, high responsivity of 20 A/W is observed for the unstrained device. Along with the increase of photocurrents, increasing dark currents are also observed. To depress the dark currents, InGaAs/InP QWIP with 1 % compressive-strain (CS) quantum wells is prepared. With over three order of magnitude dark current depression, higher peak detectivity of 2.9x10^{10} cm·$Hz^{1/2}$/W at 1.3 V is observed for the 1% CS strained QWIP. The similar normalized responsivity curves over incident light polarization have indicated a low influence of strained wells on the enhancement of normal incident absorption.

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