A Strain-compensated Mid-infrared Quantum Well Photodetector Operating at Zero Bias up to 250 K and in Photoconductive Mode up to 300K

Stephanie K. Haywood, *Member, IEEE,* Rita Gupta, Khue T. Lai, Weng K. Chee, Ahmed H. Mohamed, *Student Member, IEEE* and Mohamed Missous, *Senior Member, IEEE*

I. Introduction

Quantum well infrared photodetectors (QWIPs) operating in the 6-18 µm spectral range have been widely studied because of their potential for low cost and high yield imaging array applications [1]. Compared to InSb and MCT bulk devices, the QWIPs can provide flexibility to tailor the energy band to different spectral ranges simply by varying the well width/barrier height in a given material system. The 2-5 µm spectral range is of great interest for pollution monitoring, as many pollutant gases such as CO, CH_4, and hydrocarbons have strong vibrational absorption bands in this region. Double-barrier quantum well (DBQW) structures (e.g. Figure 1) are one way to achieve shorter wavelength transitions [2,], [3]. Additionally, the high thin, inner barriers (AlAs) help reduce the dark current [4], while allowing the photo-electrons to tunnel through. A number of authors have also associated a significant photovoltaic (PV) response with these DBQW structures [3], [5]. This PV response has been interpreted as arising from the migration of dopants [5]. Although the precise mechanism for the PV effect is still uncertain, the PV mode of operation is promising for practical applications since the dark current is suppressed and hence the background noise is reduced.

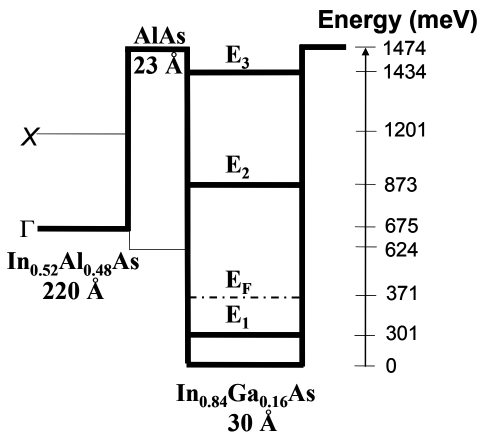

Fig. 1. Modelled conduction band profile of sample 1723.

Stephanie Haywood, Rita Gupta, Khue Tian Lai and Weng Keen Chee are with the Department of Engineering, University of Hull, Cottingham Road, Hull, HU6 7RX, UK (e-mail: S.K.Haywood@hull.ac.uk).

Ahmed Hamed Mohamed and Mohamed Missous are with the Microelectronic and Nanostructures Group, School of Electrical and Electronic Engineering, University of Manchester, Manchester M60 1QD, U.K. (m.missous@manchester.ac.uk)

Here, we present a study of two InGaAs/AlAs/$In_{0.52}Al_{0.48}As$ DBQWs grown on InP substrates with varying InGaAs composition and well width (1723: 84% 3nm and XMBE45: 75% and 4nm). These structures take advantage of strain balancing due to the opposing strain of AlAs and InGaAs layers relative to the substrate. The wavelength of operation for the two samples is 2.1µm (590meV) for 1723 and 2.9µm (428meV) for XMBE45.

II. Experiment and Results

Sample details are shown in Table 1 and the band structure of 1723 calculated using a ***k.p*** model taking into account the strain is shown in Figure 1. For this sample, the energy level E_2, to which electrons are excited on absorption of a photon, is well above the Γ-level of the thick outer barrier. Hence carrier escape should occur even at very low applied bias. Figure 2 shows the photocurrent for 1723 at zero bias and various temperatures; a strong photovoltaic response is seen up to 270 K. Figure 3 shows the peak photoresponse versus applied external voltage at 77K. As can be seen from curve A (1723), there is a measurable photocurrent even at zero bias, and an increasing positive bias reduces the photocurrent to zero at about 0.7V; however, increasing negative bias causes only an increase in signal. This is indicative of a built-in electric field.

Table 1: Modelled subband energy levels in the Γ band and material parameters

				Energy Levels (meV)				
Sample No	L_w (Å)	Indium (%)	Net Strain (%)	E_1	E_2	E_3	E_1+E_F	L_d^A
1723	30	84	-1.3	301	873	1434	371	304
XMBE45	45	75	-1.0	211	644	1123	253	361

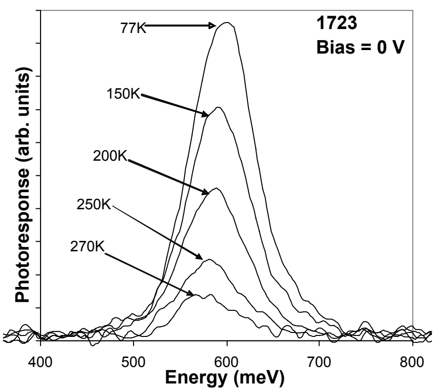

Fig. 2. Photoresponse of sample 1723 for various temperatures.

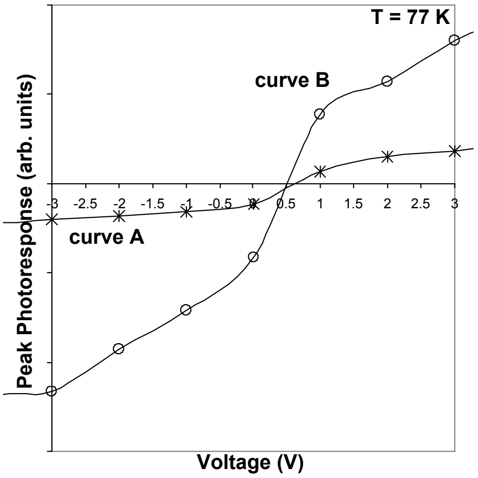

Fig. 3. Peak photoresponse vs external applied bias for samples 1723 (curve A) and XMBE45 (curve B).

Using 1723 as a basis, an optimised QWIP with transition at 2.86μm (XMBE45) was designed with a view to achieving room temperature operation. To do this, the structure was designed to have an E_2 level closer to the conduction band edge of the wide outer barrier and, therefore, a larger separation between the barrier Γ-band and the Fermi level in the well. This results in a higher dark current activation energy for sample XMBE45, compared to 1723 (I_d^A in Table 1). Figure 4 shows the photo-response measured close to zero bias for XMBE45 at various temperatures. It can be seen that this sample can operate up to 250K at zero bias (photovoltaic mode) and up to 300 K at -0.2V (photo-conductive mode).

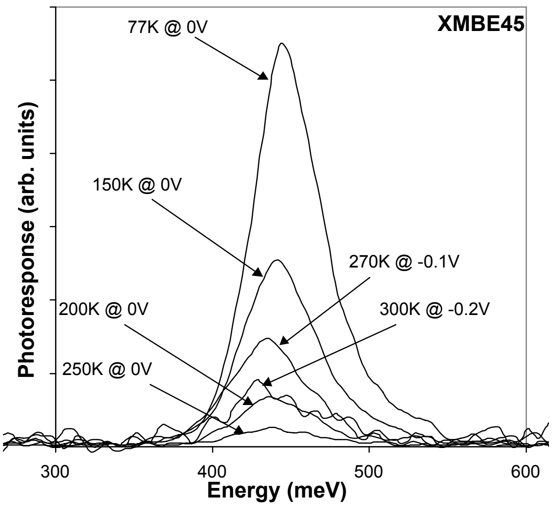

Fig. 4. Photoresponse of sample XMBE45 for various temperatures and close to zero bias.

Curve B in figure 3 shows the 77K photo-response versus applied external bias for XMBE45. The photo-response drops to zero at a lower voltage than for 1723 indicating a lower built-in electric field. Nevertheless, the zero bias photo-response is three times higher for XMBE45 than for 1723 and for all applied voltages and temperatures the detectivity is greater.

III. CONCLUSIONS

In conclusion, we have grown two InGaAs/AlAs/$In_{0.52}Al_{0.48}As$ DBQWs, on InP substrates. QWIP devices fabricated from sample 1723 exhibit a strong zero bias response at 2.1 μm/590 meV (77 K) which persists to up to 270 K. An optmised sample at 2.86μm (XMBE45) shows increased photoresponse at zero bias and can operate up to 300K at –0.2 V.

REFERENCES

[1] B. F. Levine, "Quantum-well infrared photodetectors," *J. Appl. Phys*., vol. 74, pp. R1, 1993.

[2] K. T. Lai, A. H. Mohamed, M. Missous, R. Gupta, and S. K. Haywood, "Photovolatic operations up to 270K of a strain-compensated AlAs/$In_{0.84}Ga_{0.25}As$/AlAs/InAlAs quantum well infrared photodetector," *Appl. Phys. Lett*., vol. 87, pp. 192113, 2005.

[3] H. Schneider, P. Koidl, F. Fuchs, B. Dischier, K. Schwarz, and J. D. Ralston, " Photovolatic intersubband for 3-5μm using GaAs Quantum Wells sandwiched between AlAs tunnel barriers," *Semicond. Sci. Technol*., vol. 6, pp. C120, 1991.

[4] H. C. Liu, P. H. Wilson, M. Lamm, A. G. Steele, Z. R. Wasilewski, J. M. Li, M. Buchanan, and J. G. Simmons, "Low dark current dual band infrared photodetector using thin AlAs barriers and Γ-*X* mixed intersubband transition in GaAs quantum wells," *Appl. Phys. Lett.*, vol. 64, pp. 475, 1994.

[5] E. Luna, A. Guzmán, J. L. Sánchez-Rojas, E. Calleja, and E. Muñoz, "Modulation-doping in 3-5μm GaAs/AlAs/AlGaAs double-barrier quantum-well infrared photodetectors: An Alternative to achieve high photovoltaic performance and high temperature detection", *Infrared Phys. & Technol.*, vol. 44, pp. 383, 2003.