Two-colour quantum well infra-red photodetector with peak sensitivities at 3.9 and 8.1 μm

K.L. Tsai, C.P. Lee, J.S. Tsang and H.R. Chen

Indexing terms: Infra-red detectors, Infra-red imaging, Image sensors, Semiconductor quantum wells

A two-colour infra-red photodetector using multistacks of GaAs/AlGaAs quantum wells is demonstrated. The response peaks are at 3.9 and 8.1 μm. The peak responsivities of the detector are 0.4A/W and 35mA/W for 8.1 μm and 3.9 μm bands, respectively. The detectivities of the 3.9 and 8.1 μm bands are 7.5×10^9 and 1.5×10^{10} cmHz$^{1/2}$/W. These values are the best reported results for two-colour detectors with peak sensitivities in the spectral regions of 3–5 and 8–12 μm.

Introduction: Quantum well infra-red photodetectors (QWIPs) are currently being developed as an alternative technology to HgCdTe junction diodes. The mature epitaxial growth and the processing technologies of III-V compound semiconductors mean that QWIPs are potentially useful for large area and low cost two-dimensional imaging array applications [1]. The use of quantum wells not only provides the flexibility of tailoring the detectors for a specific spectral window but also allows the possibility for the detectors to operate in two or more spectral windows by proper design of the quantum wells. Several QWIP structures with two or multiple absorption bands have recently been demonstrated [2–8]. The structures of these multicolour QWIPs include multistack structures [2, 3, 7, 8], asymmetric [4], and symmetric [5, 6] quantum well structures. The multistack structure appears to have a better performance than the others because of its large oscillator strength. The most useful two-colour detector would be that with a photoresponse in the 3–5 and 8–12 μm atmospheric transmission windows. However, the requirements on the designs of the quantum wells and the potential barriers are quite different for these two bands. For GaAs/AlGaAs systems, 8–12 μm detectors can be easily designed, but the quantum wells that can absorb 3–5 μm radiation need to have AlGaAs barriers with a very high Al content, which may create potential problems.

To solve this problem, we have previously used strained InGaAs quantum wells instead of GaAs wells to increase the well depth to accommodate the mid-infra-red band [7]. However, because of the strain, the device cannot have a large number of quantum wells. Otherwise, misfit dislocations may develop to degrade device performance. So to have optimum absorption, it is desirable to have both types of quantum well built with the same lattice-matched material system. Recently, there have been reports that the use of thin tunnel barriers beside the quantum wells can raise the transition energy without sacrificing the responsivity [9, 10]. In this study we combine this structure with tunnel barriers for the 3–5 μm band and a conventional GaAs/AlGaAs quantum well structure for the 8–12 μm band. Very good performance has been achieved with this two-colour detector.

Experiment: The QWIP sample was grown at 600°C by an Intervac Gen II molecular beam epitaxy system on a (100) semi-insulating GaAs substrate. The layers, starting from the substrate side, consisted of a 1.4 μm bottom contact layer, two stacks of quantum wells for the two infra-red absorption bands with 25 quantum wells each and a 1.1 μm top contact layer. The first stack was designed as a long wavelength QWIP, with each period of quantum wells in the stack consisting of a 40Å GaAs well and 500Å $Al_{0.27}Ga_{0.73}As$ barriers. The second stack was designed as a middle wavelength QWIP, with each period of quantum wells consisting of a 48Å GaAs well and two types of barrier. The inner barriers were 14Å AlAs and the outer barriers were 280Å $Al_{0.3}Ga_{0.7}As$. The wells and the contact layers were Si-doped with doping concentrations of 1×10^{18} cm^{-3} and 2×10^{18} cm^{-3}, respectively.

After growth, 200 μm square mesas were defined by chemical etching down to the n^+ bottom contact layer. Two-dimensional gratings with a period 2.7 μm were chemically etched through a photoresist mask on top of the mesas. The depth of the grating was ~0.7 μm. The grating period was chosen so that the long wavelength band is coupled into the quantum wells by first-order diffraction and the short wavelength band is coupled by second-order diffraction. Au/Ge was evaporated onto the top of each mesa and the n^+ bottom contact layer for ohmic contacts. The QWIPs were irradiated with IR from the back side with normal incidence. The spectral response of the QWIPs was measured using a current preamplifier and a Nicolet Fourier transform infra-red spectrometer. The responsivity was measured at 77K by the standard lock-in technique using a 800°C blackbody source chopped at 1kHz.

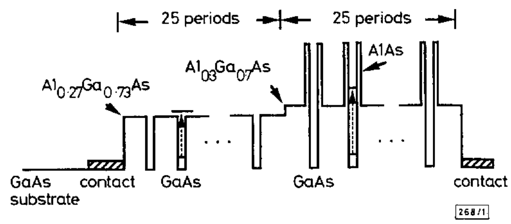

Fig. 1 *Energy band diagram of two-colour QWIP structure*

Results and discussion: Fig. 1 shows the energy band diagram of this structure. It also illustrates the intersubband transition schemes for the two-colour absorption. The intersubband transition of the quantum wells of the first stack is a bound-to-continuum state, but that of the second stack is a bound-to-quasicontinuum state [9, 10]. Because the inner barriers of the second stack are very thin, they act as tunnelling barriers [10], which allow electrical detection of the photoelectrons coming from the GaAs/AlGaAs quantum wells. Fig. 2 displays the spectral response of a two-colour device at 77K at different applied voltages. The absorption peaks of the two-colour QWIPs are near 3.9 and 8.1 μm. The 3.9 μm band turns on first (at low biases) because the quantum wells have high resistance in comparison with those of the 8.1 μm band [7, 8]. The 3.9 and 8.1 μm peak responsivities are 35mA/W measured at 1.5V and 0.4A/W measured at 4V, respectively. Fig. 3 shows the dark current against voltage at 77K, which is lower than the dark current of a conventional 8.1 μm QWIP. This is because the outer barrier of the second stack has a higher aluminium content. The detectivity (D^*) of this QWIP is calculated by using $D^* = R\sqrt{A}/\sqrt{[4egI_d]}$ [11], where R is the responsivity, A is the device area, g is the noise gain and I_d is the dark current. For the 3.9 μm band and the 8.1 μm band, the detectivities obtained are 7.5×10^9 cmHz$^{1/2}$/W (at 1.5V) and 1.5×10^{10} cmHz$^{1/2}$/W (at 4V), respectively. These values are the best reported results for a two-colour quantum well infra-red photodetector with peak sensitivities in the spectral regions of 3–5 and 8–12 μm.

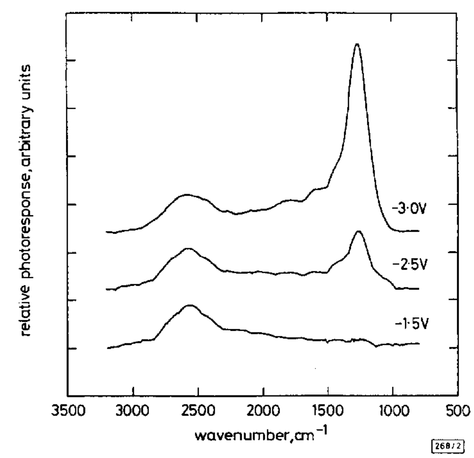

Fig. 2 *Spectral response of two-colour device at 77K at several applied voltages*

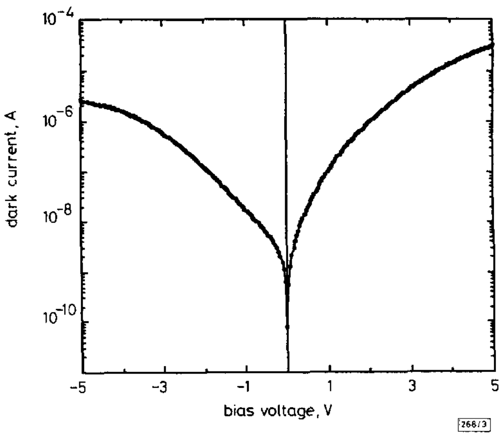

Fig. 3 *Dark current against voltage at 77K*

Conclusion: We have demonstrated a high performance two-colour infra-red detector in a GaAs/AlGaAs system with peak sensitivities at 3.9 and 8.1μm. The responsivity of the detector is 0.4A/W at 8.1μm and 35mA/W at 3.9μm. The detectivities of the 3.9μm and the 8.1μm bands are 7.5×10^9 and 1.5×10^{10}cmHz$^{1/2}$/W. These values are the best reported results for a two-colour quantum well infra-red photodetector with peak sensitivities in the spectral regions of 3–5 and 8–12μm.

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K. L. Tsai, C. P. Lee, J. S. Tsang and H. R. Chen (*Department of Electronics Engineering and Institute of Electronics, National Chiao Tung University, HsinChu, 30050, Taiwan, Republic of China*)

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Optimum design of a Salisbury screen radar absorber

B. Chambers

Indexing terms: Radar, Electromagnetic wave absorption

The author derives expressions for the sheet resistance of a Salisbury screen radar absorber which will yield the maximum bandwidth for a specified level of reflectivity performance, angle of incidence and polarisation. Design curves are also given which relate the maximum absorber bandwidth, reflectivity performance and spacer dielectric constant.

Since it was first described some 50 years ago, the conventional (i.e. passive) Salisbury screen radar absorber has been examined by a number of authors, [1, 2], but it has been superseded for many applications because of its inherently small reflectivity-bandwidth product. However, recent advances in materials technology which point to the feasibility of practical dynamically adaptive radar absorbing materials (DARAMs) [3, 4], have led to a renewed interest in the Salisbury screen because of its physical and electrical simplicity. A search of the literature, however, revealed a surprising lack of detailed information concerning the optimum design of the Salisbury screen and hence this is considered below.

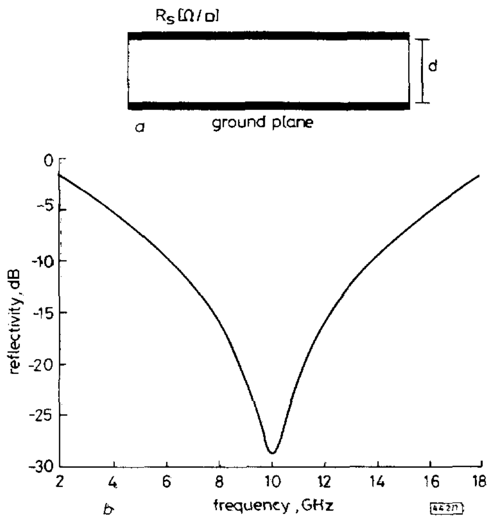

Fig. 1 *Geometry of Salisbury screen and typical Salisbury screen performance*

a Geometry
b Performance : $R_s = 350\Omega/\square$, $\varepsilon_r = 1$, $d = 7.5$mm

The basic geometry of the Salisbury screen is shown in Fig. 1*a* and a typical reflectivity-frequency performance plot is shown in Fig. 1*b*. The electrical thickness of the spacer, $\sqrt{\varepsilon_r}d$, is equal to a quarter-wavelength at the absorber centre frequency, f_c. The starting point for the absorber design is the specification of the required reflectivity performance, r, in dB. Hence

$$r = 10\log_{10}(\rho\rho^*) \quad (1)$$

where ρ is the complex (voltage) reflection coefficient seen by a