Conclusion: We have demonstrated the use of Al_2O_3 as a gate insulator for GaAs based MISFETs. More importantly, we show that hydrogenation could be a useful tool in reducing the interface state density in this system. Forming a defect free oxide on GaAs is an extremely valuable pursuit. It will reduce leakage current in FETs at a minimum, leading to improved reliability power amplifiers and low phase noise oscillators. Finally, with reduction in the interface state densities to levels that would allow inversion, Al_2O_3 formed by the wet oxidation of AlAs is a very promising insulator for GaAs based MOS and CMOS electronics.

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Normal incident infrared absorption from InGaAs/GaAs quantum dot superlattice

D. Pan, Y.P. Zeng, M.Y. Kong, J. Wu, Y.Q. Zhu, C.H. Zhang, J.M. Li and C.Y. Wang

Indexing terms: Infrared detectors, Semiconductor quantum dots, Semiconductor superlattices

The authors report for the first time, normal incident infrared absorption around the wavelength of 13–15µm from a 20 period InGaAs/GaAs quantum dot superlattice (QDS). The structure of a QDS has been confirmed by cross-section transmission electron microscopy (TEM) and by a photoluminescence spectrum (PL). This opens the way to high performance 8–14µm quantum dot infrared detectors.

Zero-dimensional (0D) quantum dot (QD) structures have attracted much interest in recent years due to their δ function-like density-of-states, strong carrier localisation, increased excitation binding energies, and enhanced oscillator strength [1 – 7]. High quality QDs can be self-formed *in situ*, in the Stranski-Krastanow growth-mode, without any substrate patterning process [2 – 4].

The potential for quantum dot device applications has also been of much interest. It was shown that the discrete levels in QDs hinder carriers relaxing into the ground state, this is known as the 'phonon bottleneck' [5 – 7]. Although it is inappropriate for laser application, slow carrier relaxation is very useful for application to intersub-band absorption infrared photodetection. Unlike the conventional GaAs/AlGaAs quantum well infrared photodetector (QWIP) that requires a coupler (e.g. grating) to couple the normal incident radiation [8], the intersub-band transition in quantum dot structures can be induced by the normal incident radiation due to the localised state in quantum dots. Hence, the intersubband absorption quantum dot infrared photodetector (QDIP) has a great advantage over the conventional GaAs/AlGaAs QWIP.

This Letter describes an experiment in growing high quality 20 period InGaAs/GaAs quantum dot supperlattice (QDS) with a standard QWIP structure. The normal incident infrared absorption can be observed around the 13–15µm point.

Experimental details: The InGaAs/GaAs QDSs were grown by molecular beam epitaxy Riber-32P on a semi-insulting GaAs (100) substrate. The structure of InGaAs/GaAs QDS is very similar to that of the conventional QWIP. The layers consisted of, from the substrate side, a 1.0µm buffer layer, a 1.0µm n^+ contact layer, a 20 period InGaAs/GaAs quantum dot array, and a top contact layer consisting of 0.5µm GaAs and 2000Å AlGaAs (x = 0.04). The InGaAs layers and the contact layers were Si-doped with concentrations of $1 \times 10^{18}cm^{-3}$, and δ-doping for the InGaAs layer. The quantum dots were self formed by their coherent relaxation into islands of tens of monolayers of $In_{0.3}Ga_{0.7}As$ between undoped GaAs layers ~300Å thick. The actual amount of indium incorporated in the dots is difficult to measure or calculate due to the complex dynamics of the adatoms during island formation.

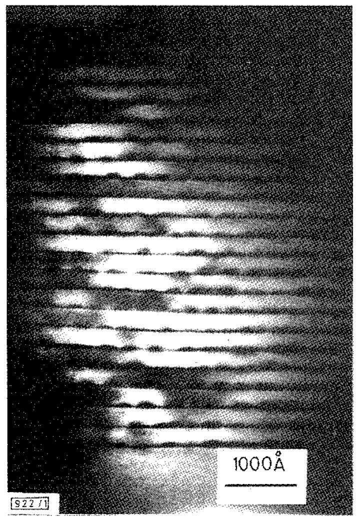

Fig. 1 *Cross-sectional view of quantum dot superlattice*

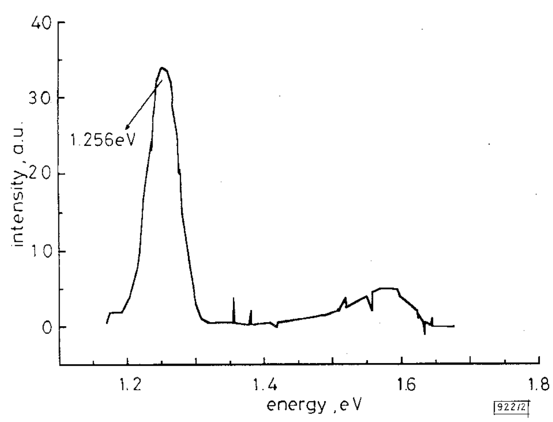

Fig. 2 *Low temperature photoluminescence spectrum of sample*

10K, 10mW, InGaAs/GaAs
FWHM = 53meV, δλ/λ = 4.2%

Result and discussion: Fig. 1 shows the cross-section TEM micrograph of the quantum dot array. A 20 period defect free quantum dot array is clearly shown. It is estimated that the average size of quantum dots is 300Å (diameter) and 60–70Å (height). It is worth noting that the actual size of a quantum dot is less than that measured by TEM due to the distributions measured by TEM being affected by strain, which tends to overestimate the size. Fig. 2 shows the low temperature (10 K) Photoluminescence (PL) spectrum of QDS. A strong luminescence peak around 1.25eV is noted. The dot peaks have a full width at half maximum of ~53meV, which is due to the size fluctuation of quantum dots.

These results concur well with current results from quantum dot experiments [2 – 4].

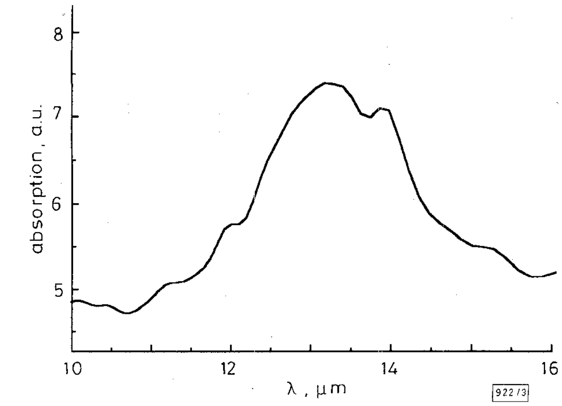

Fig. 3 *Measured infrared absorption in multipass 45° waveguide configuration*

FWHM = 2μm (= 13meV)
$\delta\lambda/\lambda$ = 15%

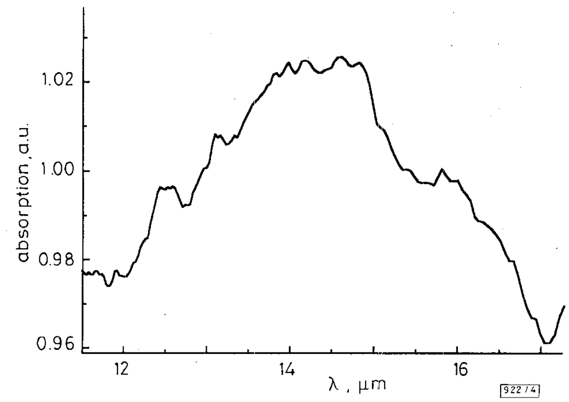

Fig. 4 *Measured infrared absorption under normal incident radiation*

FWHM = 2.1μm (= 11meV)

The infrared absorption was measured for QDS using a Fourier transform infrared (FTIR) spectrometer at room temperature. Fig. 3 shows the measured infrared spectrum of a quantum dot array using a Brucker IFS-120HR FTIR in a multipass 45° waveguide configuration [8]. It is found that the absorption peaks are ~13–14μm with a 13MeV FWHM. Fig. 4 shows the measured infrared absorption spectrum under the normal incident radiation. The obvious absorption peaks around 14–15μm with a 11MeV can be observed. Compared with that measured in a multipass 45° waveguide configuration, the peaks are shifted to the lower energy, which is similar to the de-polarisation effect in a normal incident absorption InGaAs/GaAs quantum well [9]. The measured multi-peak structure may be due to the different size of quantum dots, as seen in PL.

The intersub-band absorption is due to either quantum dots or quantum wells (wetting layer), since the normal incident intersub-band transition is possible with InGaAs/GaAs QWs [9]. However, the narrow absorption linewidih suggests that the absorption takes place between the bound levels. Based on the normal growth parameters, it is impossible to find the intersub-band transition from bound level to bound level in a quantum well (the bound-to-continuum can be found instead) [10]. In particular, the normal infrared absorption can be directly observed without using a multipass 45° waveguide and polarisation configuration. In the case of a quantum well, the normal incident absorption is so weak that it is difficult to observe without using a waveguide [8, 9]. Hence, the 13–15μm infrared absorption results from the intersub-band transition from quantum dots. To the authors' knowledge, this is the first report of the normal incident infrared absorption being observed from the QDS.

Conclusion: The experiments reported in this Letter described the growth of a high quality 20 period InGaAs/GaAs quantum dot superlattice with the structure of a standard quantum well infrared photodetector. The normal incident absorption can be observed around the 13–15μm point. The results are particularly applicable to the fabrication of quantum dot infrared detectors.

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Optical beat frequency generation up to 40.6THz by mode-locked semiconductor lasers

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Indexing terms: Laser mode locking, Semiconductor junction lasers, Optical control of microwaves

Optical beat frequency generation up to 40.6THz is achieved by beating two mode-locked semiconductor lasers optical pulses using a wavelength division multiplexing fibre coupler. To the author's knowledge, this is the fastest amplitude modulated signal observed so far.

Introduction: Recently, ultrahigh repetition frequency (more than several hundred gigahertz to terahertz repetition rate) optical pulse train generation has been investigated [1, 2]. Such pulses are attractive not only in high-speed optical communication, but also for the generation of THz region electromagnetic waves (submillimetre waves) from optical switch elements such as GaAs photomixers. For example, 350GHz optical pulse train generation was reported by Y.K. Chen *et al.*, using colliding-pulse mode-locked