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# Far-infrared absorption spectra measured in InAs/$Al_{0.36}Ga_{0.64}Sb$ quantum wells

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Far-infrared absorption spectra have been measured for molecular beam epitaxial InAs/$Al_{0.36}Ga_{0.64}Sb$ multiquantum wells by Fourier transform infrared spectroscopy using light incident normal to the layers. The special band lineup for this heterostructure system causes an overlap of the electron and hole states. The measured absorption peak varies in the wavelength range of 5–10 $\mu$m in the temperature range of 100–300 K.

Detectors capable of detecting radiation in the far infrared (5–20 $\mu$m) are important for a variety of applications. Traditionally HgCdTe detectors using band-to-band absorption have been used,[1,2] and these detectors still have the highest detectivities. Based on the same principle InAsSb and InAsSb/InSb multiquantum wells (MQWs) have also been realized.[3,4] The MQW devices provide a larger degree of spatial uniformity due to a lesser dependence of the bound-state energies on position. However, these small band-gap materials tend to be "soft" and are hence not very suitable for application to large arrays. An important alternative is provided by utilizing transitions between bound states in a quantum well, where the oscillator strength and dipole moment of the intersubband transitions, involving envelope states, are very large. Instersubband absorption has been demonstrated in both lattice-matched[5-8] and pseudomorphic quantum wells.[9] However, an inherent drawback in such systems is that the selection rules only allow absorption of electromagnetic radiation when the incident polarization is parallel to the confinement direction. Hence, a waveguide geometry needs to be used, which precludes such detectors to be used in large arrays. There is therefore a need to investigate other kinds of materials and mechanisms which overcome the two limitations mentioned above.

We have recently reported calculations on excitonic and band-to-band spectra for vertical incident radiation on InAs/AlGaSb multiple quantum well structures.[10] It is clear that in this case, due to the special band lineup of this heterostructure,[11] there is absorption due to the overlap of the electron and hole bound-state wave functions. This is shown in Fig. 1. The peak of the absorption can be tuned in the wavelength range of interest by changing the Al content in the AlGaSb layer and the strength of the absorption peak can be enhanced by applying an electric field. In this quantum well structure, an applied electric field brings the electron-hole pair closer together resulting in increased absorption and a blue shift in the transition energies.

The experimental samples were grown on (100) GaSb substrates by molecular beam epitaxy. It has been established by us and previous workers[12] that the band gap of the type II InAs/$Al_xGa_{1-x}Sb$ superlattice becomes greater than zero for $x \geqslant 0.30$. We chose a value of $x = 0.36$. Therefore, after initial heating of the substrate in the growth chamber at 550 °C for 30 s, 0.1 $\mu$m of $Al_{0.36}Ga_{0.64}Sb$ was deposited at 500 °C at a rate of 1.5 $\mu$m/h. A good surface reconstruction pattern was observed by reflection high-energy electron diffraction (RHEED) during the growth of this layer. 24 periods of (124 Å) $Al_{0.36}Ga_{0.64}Sb$/(100 Å) InAs MQWs were then grown after lowering and stabilizing the substrate temperature at 380 °C. The growth rate of InAs was 0.8 $\mu$m/h.

Temperature-dependent absorption measurements were made by Fourier transform infrared (FTIR) spectroscopy using a MATTSON Cygnus 100 system consisting of a Hg arc lamp source and a wideband HgCdTe detector. The resolution of the measurement is $\sim 4\ \text{cm}^{-1}$. For the absorption experiments, the experimental sample surface of size $1 \times 1\ \text{cm}^2$ was illuminated and the transmitted light was measured by a detector. The sample was mounted in a liquid He cryostat with appropriate windows and measurements were made in the temperature range 15–300 K.

The transmission spectra of InAs and GaSb substrates at 300 K were first measured. The room-temperature spectra are dominated by absorption due to interband transitions which are at 3.45 and 1.75 $\mu$m for InAs and GaSb, respectively. The data for InAs are shown in Fig. 2. A large peak at $\sim 15$ $\mu$m in the spectra of both materials is due to free-electron absorption. This mode of absorption results from phonon- and impurity-assisted transitions, with the latter being more dominant. With lowering of temperature, the peak resulting from the free-electron absorption remained

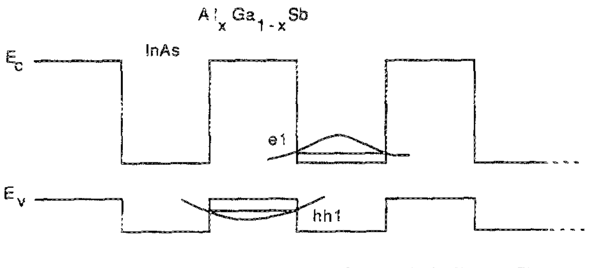

FIG. 1. Equilibrium band diagram of InAs/$Al_xGa_{1-x}Sb$ superlattice for $x \geqslant 0.3$.

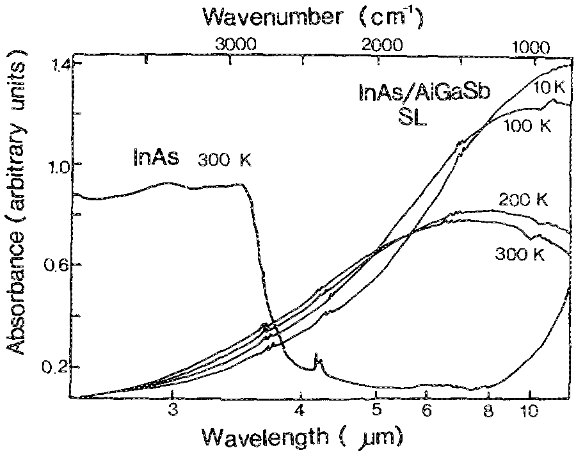

FIG. 2. Temperature-dependent infrared absorption spectra of InAs/$Al_{0.36}Ga_{0.64}Sb$ superlattice and 300 K spectra of bulk InAs measured by Fourier transform infrared spectroscopy. The optical excitation is incident normal to the layers.

invariant in wavelength (energy), while the interband transition peak (or edge) moved to lower wavelengths, as expected.

The absorption spectra of the InAs/$Al_{0.36}Ga_{0.64}Sb$ MQW structure were next measured at various temperatures. The measured data are shown in Fig. 2. The absorbance is quoted in arbitrary units, where the unit 1 approximately represents $10^3$ $cm^{-1}$. The peaks observed at different temperatures are distinctly different from those for InAs and GaSb. From our growth conditions we conclude that the observed linewidth of the peaks primarily results from structural and/or compositional fluctuations across the size of the excitation beam. Also, the absorbance peaks increase in height and move to longer wavelengths with lowering of temperature. From our recent theoretical calculations[10] it is clear that the exciton binding energies are ~2.5 meV for zero applied bias and therefore the peaks in Fig. 2 result from interband transitions. They increase in strength with lowering of temperature due to increased occupancy in the respective wells. However, the shift to longer wavelengths is not so well understood. In a type I superlattice (SL), the well and barrier region band gaps increase with lowering of temperature, and all transition energies move to higher energies. In the case of the InAs/AlGaSb MQW, although the band gaps of InAs and AlGaSb increase, the transition energy resulting from the overlap of the electron and hole states may actually be reduced, as observed experimentally. In fact, FTIR measurements, such as the one described here, may be an appropriate technique to study the band structure in such MQWs. From our measurements it is clear that the electron affinity rule is invalid in this system and the results appear to verify the band lineups used in our earlier publication.[10] It may also be noted that infrared photoluminescence and absorption spectra, indicating similar type II behavior in InAsSb/InSb SLs, have reported by Kurtz *et al.*[13] However, the well and barrier regions of this SL system are made up of low-band-gap materials, which will present problems as mentioned earlier.

In conclusion, we have measured temperature-dependent infrared absorption spectra in InAs/$Al_{0.36}Ga_{0.64}Sb$ quantum wells with normal incidence, resulting from a real-space overlap of the electron and hole states. This confirms earlier theoretical calculations made by us and makes this a viable material for the design of infrared detectors in the form of junction diodes for focal plane arrays. The devices will obviously have to be operating at cryogenic temperatures to minimize thermal noise.

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