Growth and characterization of InAs/GaSb photoconductors for long wavelength infrared range

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In this letter we report the molecular beam epitaxial growth and characterization of InAs/GaSb superlattices grown on semi-insulating GaAs substrates for long wavelength infrared detectors. Photoconductive detectors fabricated from the superlattices showed photoresponse up to 12 μm and peak responsivity of 5.5 V/W with Johnson noise limited detectivity of 1.33 × 10^10 cm Hz^1/2/W at 10.3 μm at 78 K. © 1997 American Institute of Physics. [S0003-6951(97)03236-1]

Infrared imaging in the 8–12 μm wavelength has many medical, industrial, and military applications. After two decades of progress, the currently dominant HgCdTe technology1 still cannot provide detectors with high sensitivity, resolution, and room-temperature operation. The major drawbacks of HgCdTe detectors are the difficulty in growth, nonuniformity due to high sensitivity to the composition, large tunneling currents, and high Auger recombination rate.2 An alternative structure in the 8–12 μm range is quantum well infrared photodetector (QWIP).3 However, high thermal generation rate and short carrier lifetime limits high-temperature operation and quantum efficiency of QWIPs.4 As another alternative for infrared photodetectors, type II superlattices have been studied.5–7 The II–VI, HgTe/CdTe and the III–V, InAs/Ga1–xSb type II superlattices have shown promising results comparable to HgCdTe photodetectors at long wavelengths.6,7 However, it was found that the growth and processing of these II–VI materials are more difficult than the III–V compounds.

Lower dark current and higher operating temperature is expected for InAs/Ga1–xSb superlattices in comparison to HgCdTe, because of the higher effective mass of electrons and holes and slower Auger recombination.8,9 In this letter, we present the results of photoconductive detectors fabricated from InAs/GaSb superlattices.

The superlattices were grown by molecular beam epitaxy on semi-insulating GaAs substrates. A 4 μm GaSb buffer layer was grown directly on 3 in. GaAs substrates. The wafer was then broken into ~1 cm² pieces and indium mounted to molybdenum blocks. Uncracked elemental Ga, In, As, and Sb were used as source materials. InAs is found to have a very narrow window for planar growth, while high quality GaSb can be grown in a wider range of growth conditions. The optimum growth conditions for InAs layers were found to be T = 400 °C according to a pyrometer, V to III incorporation rate ratio ~ 3, and a growth rate of 0.5 monolayer/s. In this condition, reflection high energy electron diffraction showed 2 × 4 reconstruction patterns. The structure consisted of a superlattice with 48 Å InAs, 48 Å GaSb, one monolayer of InSb at the interfaces, and a thin 200 Å GaSb cap layer.

The quality of the superlattices was assessed by structural, electrical, and optical characterization. A high resolution x-ray diffractometer was used to investigate the structure of the material. X-ray diffraction simulation has also been performed to verify the superlattice structures. Figure 1 shows good agreement between the x-ray diffraction spectra of the two 50-period superlattices and the simulated spectra. It also indicates excellent reproducibility and smooth interfaces.

Since electrons and holes are confined in InAs and GaSb, respectively, we could not use the Hall measurement technique on superlattices because of the high sheet density of electrons and holes in InAs and GaSb layers. The overall Hall coefficient for this material, with two dominant channels of electrons and holes can be approximated as10

\[
\frac{\mu_p \sigma_p}{1 + \mu_p^2 B^2} \frac{\mu_n \sigma_n}{1 + \mu_n^2 B^2} + B^2 \left( \frac{\mu_p^2 B^2}{1 + \mu_p^2 B^2} + \frac{\mu_n^2 B^2}{1 + \mu_n^2 B^2} \right)
\]

(1)

FIG. 1. High resolution x-ray diffraction of two samples and the simulation result. Although one of the samples was grown one week after the other, they are almost identical and the simulation is also in good agreement with them.
where \( B \) is the magnetic field in the Hall measurement, and \( \sigma \) and \( \mu \) are the conductivity of each channel and the mobility of carriers. The formula shows clearly that the overall Hall mobility can be much smaller than the real mobility of electrons or holes if the numerator approaches zero. As the transport of electrons is more important for photodetector operation due to its higher mobility, a single quantum well of InAs was grown to examine this property. This provided a simple, fast method for electrical assessment of the interface quality. After the optimization of growth conditions, in-plane room-temperature mobility of electrons in a 75 Å InAs well increased from 5000 to 14 000 cm²/V s which is about half the value of bulk InAs.

A Galaxy 3000 Fourier transform infrared (FTIR) spectrometer was used to obtain the optical characteristics of the superlattices. Figure 2 shows the room-temperature optical absorption spectra of the superlattice. The effect of the substrate and GaSb buffer layer was removed by measuring the background with a substrate and GaSb buffer layer. Fabry–Perot oscillations were reduced by positioning the samples at Brewster’s angle to the direction of incident light. The absorption edge at room temperature. The calculated energy levels are at the value of bulk InAs. 11

The Johnson noise limited detectivity13 was comparable to 2.5 \( \times 10^9 \) cm Hz\(^{1/2}\)/W at 10.3 \( \mu \)m and 78 K. This value is much lower than the InAs/GaSb superlattices. The Johnson noise limited detectivity13 was comparable to 2.5 \( \times 10^9 \) cm Hz\(^{1/2}\)/W, the best reported Johnson noise limited detectivity of InAs/Ga\(_x\)In\(_{1-x}\)Sb superlattices at the same wavelength and temperature. 14 Although the incorporation of In in GaSb should improve the absorption theoretically, it seems that the superior quality of binary compositions compared to the ternary is also an important factor. Also, the sensitivity of the cutoff wavelength of InAs/Ga\(_x\)In\(_{1-x}\)Sb superlattices to the value of \( x \), especially at longer wavelengths, is very high. 15 Therefore, uniformity and reproducibility of the InAs/Ga\(_x\)In\(_{1-x}\)Sb superlattices are lower than the InAs/GaSb superlattices.

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