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UNCOOLED GaInAsSb INFRARED DETECTORS GROWN BY METALORGANIC CHEMICAL VAPOR DEPOSITION *

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The GaInAsSb as one of the most important semiconductor alloy systems for infrared detectors is well established. Samples of GaInAsSb alloys have been grown by atmospheric pressure metalorganic chemical vapor deposition on n-GaSb (Te-doped) substrates. The properties of GaInAsSb layers were characterized by single-crystal X-ray diffraction, double-crystal X-ray rocking curve and scanning electron acoustic microscopy. The spectral responses of p^+-GaInAsSb/p-GaInAsSb/n-GaSb detectors showed cut-off wavelength at 2.4 μm, detectivity $D^* = 1.2\times 10^9$ $\mathrm{cmHz^{0.5}/W}$ at room temperature, and quantum efficiency 40%.

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I. INTRODUCTION

New trends in semiconductor infrared detector research have been directed toward improving the performance of single-element devices, large electronically scanned arrays, and higher operating temperature[1]. HgCdTe is the most important semiconductor alloy system for making infrared detector, but there exist the most serious technological problems[2]: the material is difficult to grow, and devices are expensive and power-consumptive for cryogenic systemf. Cooling requirements add considerably to the cost, bulk, weight, power consumption, and inconvenience. Uncooled and near-room-temperature semiconductor infrared detectors have the current privileged position. The quaternary GaInAsSb alloy is potentially a very important material for the fabrication of detectors designed for middle-wavelength infrared applications at room temperature. This system with direct band gaps adjustable in wavelength from 1.7 to 4.3 μm was grown lattice-matched on GaSb, InP and InAs substrates, which may provide the basis for detectors over this entire region. Tournie *et al*.[3] and Bowers *et al*.[4] reported GaInAsSb/GaSb photodetectors by liquid phase epitaxy (LPE) for the atmosphere and lightwave communication systems using fluoride glass fibres. However, most recent efforts in the technology of infrared detectors have been on large electronically focal plane arrays.[1] It is difficult to grow GaInAsSb alloys in miscibility gap and with large epitaxial surface by LPE. The metastable large epitaxial surface of GaInAsSb alloys with compositions in the miscibility gap can be grown by using non-equilibrium techniques, such as molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD). The studies reported here focused on the characterization and structure of the p^+-GaInAsSb/p-GaInAsSb/n-GaSb heterostructure. It is a preliminary study for the large electronically focal plane array infrared detector of this structure at room temperature. These layers have

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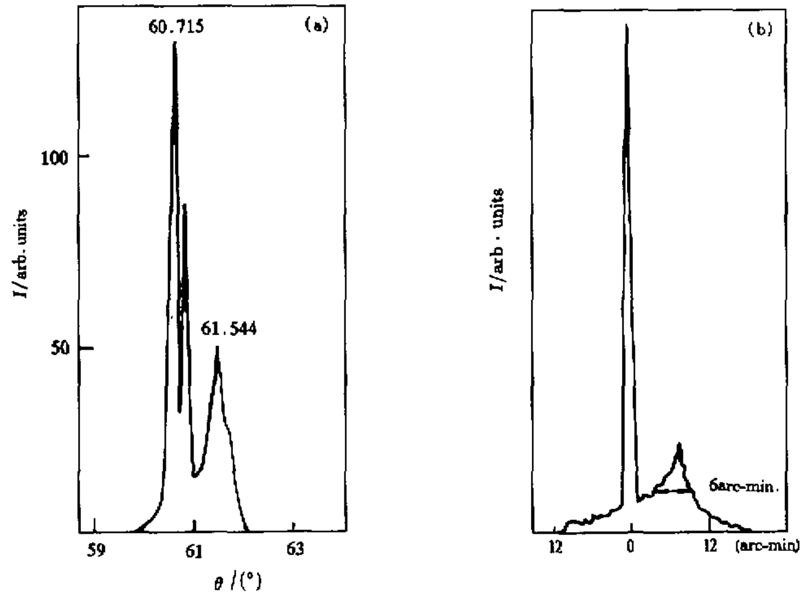
been characterized by single-crystal X-ray diffraction, double-crystal X-ray rocking curve and scanning electron acoustic microscopy. The details of growth conditions and characterization are described in this paper.

II. GROWTH AND CHARACTERIZATION

The alloys of GaInAsSb were grown on GaSb substrates by MOCVD using a conventional atmospheric pressure horizontal reactor. The sources of Ga, In, Sb and As were trimethylgallium (TMGa), trimethylindium (TMIn), trimethylantimony (TMSb) and arsine (AsH_3) diluted to 10% and were carried by Pd-diffused hydrogen into the reactor, separately. The substrates were n-GaSb (Te-doped) oriented 2 - 3° off (100) towards <110>. Before being put into the reactor, the GaSb substrates were chemically etched. The growth temperatures were between 560 ℃ and 640 ℃.



(a) The single-crystal X-ray diffraction pattern.

(b) The double-crystal X-ray rocking curve.

Fig. 1

Compositions of GaInAsSb epilayers were determined by electron probe microanalysis. According to the energy-composition relation of $Ga_xIn_{1-x}As_{1-y}Sb_y$ $E(x, y) = 0.359 + 0.48x - 0.78y - 0.398xy + 0.6x^2 - 0.596y^2 + 0.185x^2 + 0.054xy^2$ (Ref. [5]). The X-ray diffraction pattern of $Ga_{0.79}In_{0.21}As_{0.14}Sb_{0.86}$ epilayer on GaSb substrate in Fig. 1(a) indicates good crystallinity. Figure. 1. (b) shows the double-crystal X-ray rocking curve of the (400) diffraction of GaInAsSb epilayer on n-type GaSb substrate. A full width at half maximum (FWHM) of 6 arc-min shows a high crystalline quality of the GaInAsSb epilayer.

Photoluminescence measurements of GaInAsSb epilayers were carried out at 72 K excited by the 514.5 nm line from an argon ion laser with a power of 100 mW. The peak wavelengths of the photoluminescence spectra of two GaInAsSb epilayers are at 1.966 and 2.136 μm, and the FWHM are 26 meV and 30 meV, respectively. This indicates that the epilayers show high quality. The energy gap of the GaInAsSb alloy was obtained from infrared absorption spectrum of a GaInAsSb epilayer at 300 K. It is seen that the values of E_g calculated according to the composition are in good agreement with the measured E_g using PL and infrared absorption.

III. SEAM EXPERIMENT OF p^+-GaInAsSb/p-GaInAsSb/n-GaSb

Scanning electron acoustic microscopy (SEAM) was developed in 1980[6,7] and has been mainly used in the last few years in the characterization of thermal, elastic and pyroelectric properties on a microscale resolution. SEAM observation was performed in a system modified from a KyKy-1000B microscope made by a China-USA joint-venture Company. It has been reported as a new experimental tool for the study of polarization distribution, phase transtion, subgrain boundaries and domain structure in polar materials and nondestructive observation of internal phenomena in many other materials and devices. SEAM was constructed using conventional scanning electron microscope, to which several newly designed parts, a flexible plug-in beam blanking system, an opto-electric coupler and a spring-loaded and metal-shielded PZT electron-acoustic signal detector were attached. Figure 2 shows the SEAM image of p^+-GaInAsSb/p-GaInAsSb epilayer. The acoustic waves produced by the electron-beam-induced heat distribution carry subsurface information of epilayer to be imaged by SEAM. It is the electron-beam-induced thermal waves that have many of the characteristics of conventional waves and interact with thermal features of a solid by scattering and reflection from regions with sufficiently different thermal characteristics from their surroundings, and the electron-acoustic signal will therefore produce an "image" of these regions. In Fig. 2 the information of the image is well-distributed, the bright speck is the surface defect, and the contrast of light and shade is due to Zn-doped concentration change. The SEAM image illustrates that the epilayer has a high crystalline quality.

IV. THE STRUCTURE AND CHARACTERISTIC OF INFRARED DETECTOR

The structure of the detector is shown in Fig. 3(a); Fig. 3(b) shows the complete band diagram of the epitaxial structure, which includes the p^+-GaInAsSb/p-GaInAsSb/n-GaSb heterojunction. The device is operated in the backside illuminated mode, in which the photons enter the GaSb transparent substrate and reach the p-n junction and the p-GaInAsSb layer, where they are absorbed. This GaSb substrate determines the short-wavelength cut-on value, which is 1.7 μm at room temperature, and the long-wavelength cut-off value is related with the p-GaInAsSb layer. A thin p^+-GaInAsSb layer was formed with Zn diffusion to form

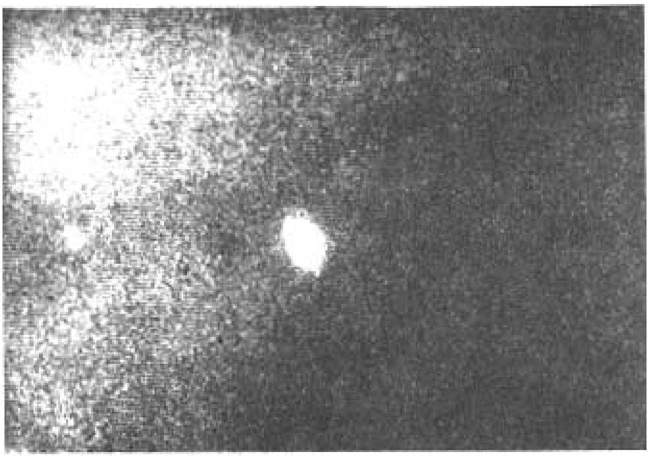
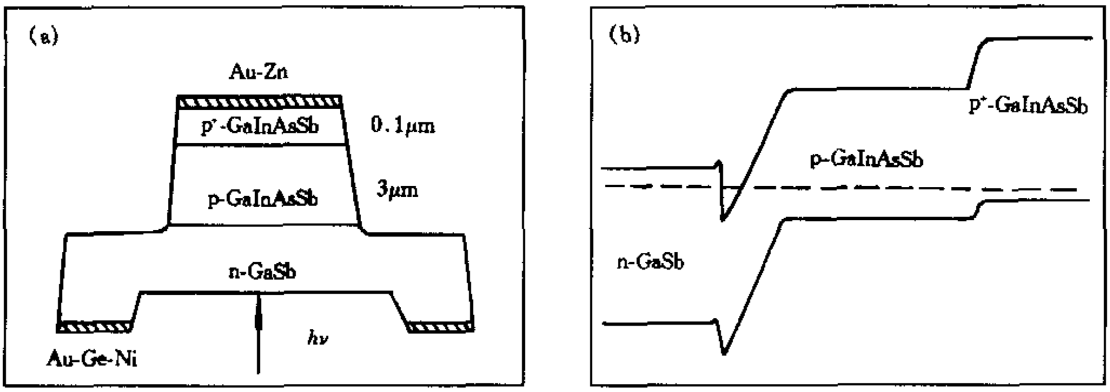


Fig. 2. SEAM image, $f = 225$ kHz, Mag. ×970.

a high conductive layer. Undoped GaInAsSb with the acceptor concentration around a value of 10^{16} cm^{-3} requires relatively thick layers for maximum light absorption. The contacts formed by evaporating and alloying Au-Zn on p^+-GaInAsSb and Au-Ge-Ni on the n-GaSb substrate respectively. The mesa and illumination hole were defined using photolithographic techniques. The area of mesa is about 3.14×10^{-4} cm^2. Figure 4 shows the current-voltage characteristic of p^+-GaInAsSb/p-GaInAsSb/n-GaSb detector at room temperature, with dark current about 50 - 100 μA at 1V reverse bias. Its spectral response at room temperature is shown in Fig. 5, the peak wavelength is at about 2.25 μm, and the wavelengths cut off at 1.7 μm and 2.4 μm are caused by GaSb substrate and $Ga_{0.78}In_{0.22}As_{0.20}Sb_{0.80}$ layer respectively. At room temperature the detectivity D^* is up to 1.2×10^9 cmHz$^{0.5}$/W, and the quantum efficiency at 2.25 μm is about 40%. This detectivity and quantum efficiency of the infrared detector may have military and civilian applications, its significant advantage is the room temperature operation with no need of expensive cryogenically cooled cost.



(a) The basic structure. (b) The energy-band diagram of structure.

Fig. 3. Backside-illuminated p^+-GaInAsSb/p-GaInAsSb/n-GaSb infrared detector.

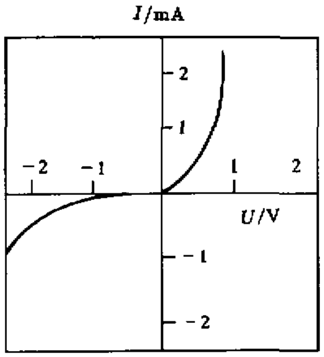


Fig. 4. I-U characteristic of p-$Ga_{0.81}In_{0.19}As_{0.18}Sb_{0.82}$ at room temperature.

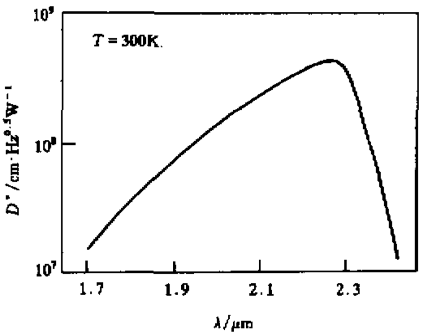


Fig. 5. Spectral response of p-$Ga_{0.81}In_{0.19}As_{0.18}Sb_{0.82}$/n-GaSb at room temperature.

V. CONCLUSIONS

Heterojunctions of p^+-GaInAsSb/p-GaInAsSb/n-GaSb have been grown by MOCVD technique. The results of X-ray single-crystal diffraction pattern, double-crystal rocking curve, PL spectra, infrared absorption spectrum and SEAM image indicated that p^+-GaInAsSb/p-GaInAsSb alloys are high-quality solid solutions. The infrared detector is obtained with wavelength cut off at 2.4 μm and detectivity $D^* = 1.2 \times 10^9$ $cmHz^{0.5}/W$ at room temperature, which omits the expensive cryogenically cooled cost.

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REFERENCES

[1] Antoni Rogalski, *Optical Engineering*, **33**(1994), 1395.
[2] Antoni Rogalski, *Optical Engineering*, **33**(1994), 1392.
[3] *E. Tournie, J. L. Lazzari, E. Villemain and A. Joullie, Electronics Letters*, **27**(1991), 1237.
[4] J. E. Bowers, A. K. Srivastava, C. A. Burrus, J. C. Dewinter, M. A. Pollack and J. L. Zyskind, *Electronics Letters*, **22**(1985), 137.
[5] Zhou Tianming, Zhang Baolin, Jin Yixin, Jiang Hong and Ning Yongqiang, *Rare Metals*, **11**(1992), 190(in Chinese).
[6] G. S. Cargill III, *Nature*, **286**(1980), 691.
[7] M. Urchulutegui, J. Piqueras and J. Llopis, *J. Appl. Phys.*, **65**(1989), 2677.