Molecular Beam Epitaxy of HgCdTe for IR FPAs Detectors

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Abstract: The recent progress in MBE growth of HgCdTe at the Epitaxy Research Center for Advanced Materials, and the National Laboratory for Infrared Physics is reported. It is found that the excellent compositional uniformity and reproducibility of HgCdTe can be archived by MBE technique. The results of surface morphology, dislocation density, electrical properties and focal plane array detectors are described in the paper.

1. INTRODUCTION

Molecular beam epitaxy (MBE) of Hg1-xCdxTe has been demonstrated[1] to be a flexible technology for the manufacturing of IR detectors. MBE technology is developing rapidly, specially in the recent years. The performance of IR FPAs made from MBE grown materials has reached the stage that it becomes comparable to those made from LPE materials1,2. In view of future developments, because MBE technique has potential advantages of low temperature and UHV growth environment, flexibility in controlling compositions1, availability of in situ growth of pn junctions[2], multilayered heterostructures1,2 and CdTe passivation layers[3], it is more promising for developing future detectors with sophisticated structures.

2. EXPERIMENTAL

HgCdTe epilayers were grown in a Riber 32P MBE system without intentionally doping. The details of growth procedures can be found elsewhere[4]. The composition (x value) of Hg1-xCdxTe is an important parameter which determines the cutoff wavelength of the materials or the IR devices. In this study, the x value and the thickness of epilayers were evaluated by IR transmission measurements. To avoid the uncertainties in determining x and thickness resulted from the multilayer interference in transmission curves, a computer simulation based on a simple model of multilayer interference was performed in an attempt to unambiguously determine these parameters[5].

3. RESULTS AND DISCUSSION

Compositional reproducibility is a major issue of concern in developing HgCdTe MBE technology. The uncertainties in flux measurements as well as the long-term flux stability of source ovens can significantly cause run to run deviations in x values. Fig.1 compares the compositional reproducibility results obtained in two different runs, where 10~12 samples with thickness of 10~14 μm were grown in a run to run base. It is easily seen that by refining the processes of both flux measurement and the amount of charging material in crucibles, a significant improvement in compositional reproducibility was achieved.

Grown under the optimized conditions, the epilayers showed excellent lateral uniformity in both composition and thickness. The results showed a standard deviation (STDDEV) in x-value of only 0.0004 for a 2-inch sample with an averaged x-value of 0.222, and a STDDEV for thickness of 0.238 μm with an averaged thickness of 10.88 μm. The relative deviations for x and thickness are 0.18% and 2.19%, respectively. This is the best result among those reported. The uniformity in vertical direction was obtained by real-time ellipsometry measurements. A STDDEV in x value of less than 0.002 was obtained over a thickness of ~3 μm.

Dislocation density in HgCdTe is another major issue of concern. Dislocations in HgCdTe are known as device killer[6,7], which seriously shorten the lifetime of minority carriers, hence reduce the performance of PN junctions in IR detector devices. Because of a large lattice mismatch (14.6%) between CdTe buffer layer and GaAs substrate, a high density of misfit dislocations is generated at the GaAs/CdTe interface, which results in threading dislocations going through the CdTe buffer layer, and extending to the subsequently grown HgCdTe.

The dislocation density for as-grown HgCdTe is usually ~1x107 cm-2, which could be reduced by a post growth annealing process at high temperature[8,9]. In this work, the annealing was carried out at various temperatures and periods of time. A statistical result[10] on a large quantity of experiment data showed that a reduction in dislocation density by ~50% could be obtained even by 200~250 °C low temperature annealing. This is very interesting because the annealing at low temperature is well employed for archiving n-type HgCdTe. The dislocation density was further reduced by annealing at high temperatures, a typical value of 2~3x106 cm-2 was obtained at 490 °C. The understanding of dislocation density in growth direction is extremely important for detector applications. To evacuate the dislocation distribution in the vertical direction, a process of layer-by-layer etching was performed. It was found that because the large lattice mismatch (0.4%) between CdTe and HgCdTe, the EPD value in the as-grown samples was very high near the CdTe/ HgCdTe interfaces at 2x107 cm-2, and fallen down to a lower value of 1x107 cm-2 in the HgCdTe surfaces. For 490°C annealed samples, the reduction in EPD near the CdTe/ HgCdTe interfaces was more dramatic as compared to that in the surface region, an almost constant value of 2~3x106 cm-2 was observed across over the whole epilayer at various depths.

To confirm the device quality of the MBE grown materials, small scale 32x32 FPAs were fabricated with n+p junctions formed by using Boron implantation (with a dose of 0.5-1x1014 cm-2 at 130 KeV) into a p-type HgCdTe epilayer, which were interconnected to Si read-out chips by indium bumps. Examples of the thermal images at room temperature are shown in Fig.2. The x-value of HgCdTe for this device is 0.24. The preliminary results showed that the average detectivity D*λwas approximately 1~2x1010cm√Hz/W, with an average NEΔT value of less than 0.1 K. The average nonuniformity for responsivity is less than 12.5%. Obviously, the device performance still needs to be improved. One approach of doing this is to reduce the density of dislocations in HgCdTe layers arising from the lattice mismatch, which is known to shorten the lifetime of minority carriers.

4. CONCLUSIONS

We have studied MBE growth and annealing of HgCdTe epilayers. Small scale 32x32 FPAs were fabricated with n+p junctions using MBE grown p-type HgCdTe. It is found that the surface morphology is very sensitive to the growth temperature and/or Hg to Te flux ratio. The compositional reproducibility was studied in a limited number of samples, a STDDEV for x-values of 0.0017 deviated from an average value of 0.229 was obtained. The HgCdTe epilayers showed an excellent lateral uniformity in x-values as well as in thickness. Relative deviations for x-value and thickness over a 2-inch wafer were found to be 0.18% and 2.19%, respectively. Ellipsometer was used in monitoring the compositional variations during growth. The post growth annealing process was found to be effective in reducing the dislocation density, a reduction in dislocation density by ~50% could be obtained even by ~250 °C low temperature annealing.

MBE grown p-HgCdTe epilayers were successfully incorporated into 32x32 FPAs detectors. The average detectivity D*λ was approximately 1-2x1010cm√Hz/W. A NEΔT value of less than 0.1 K and an average nonuniformity for responsivity of less than 12.5% were obtained.

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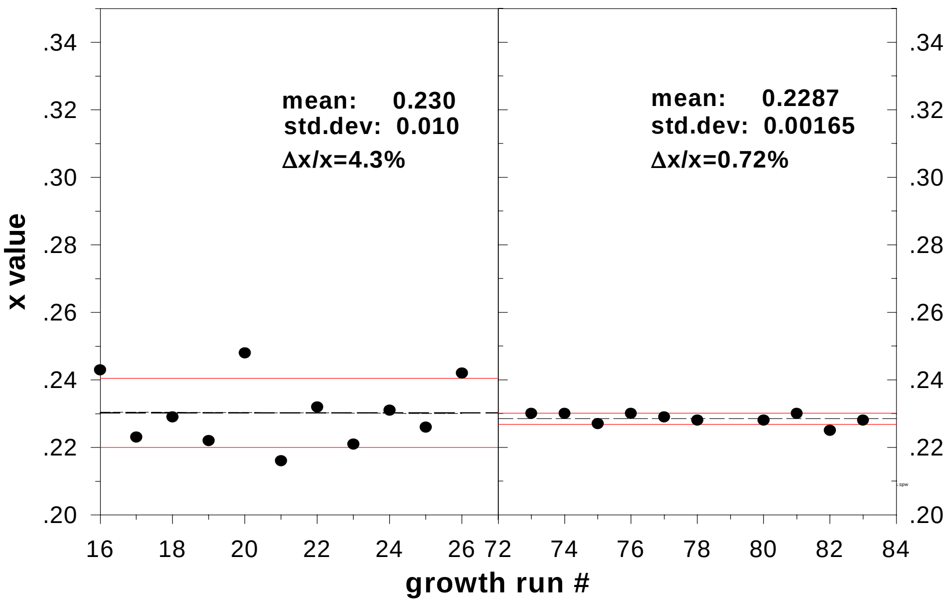

Fig.1 Improvement in compositional reproducibility

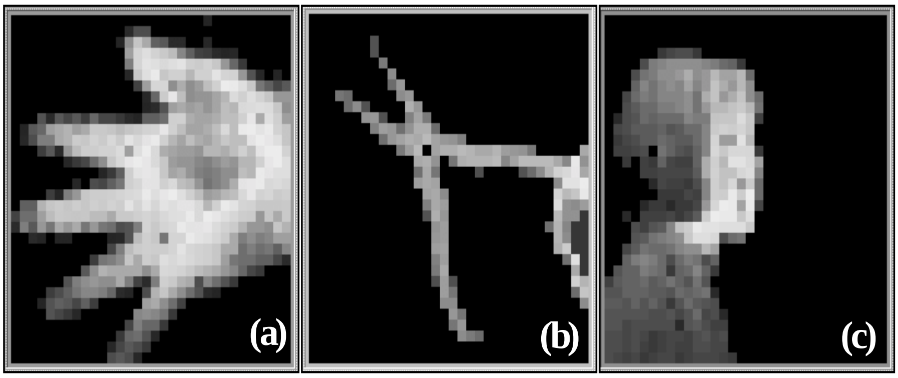

Fig.2 Thermal images obtained from a 32x32 FPAs detector.