MBE Growth and Characterization of $Sn_{1-x}Eu_xTe$

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Epilayers of $Sn_{1-x}Eu_xTe$ $(0 < x < 0.03)$ were grown by molecular beam epitaxy on freshly cleaved BaF_2(111) substrates and their structural, electrical and optical properties were investigated. The thicknesses of epilayers were about 1.5 μm and deposition was carried out at growth temperatures of 300 ^{o}C. The structural properties were investigated by high resolution X-ray diffraction and a sharp film degradation could be observed with increasing europium content. Electrical measurements with temperature varying from 300 to 10K indicated that the epilayers present carrier concentration ranging between 3×10^{20} and 6×10^{20}cm^{-3} and a low resistivity from 6.3×10^{-5} to 1.2×10^{-4} Ω.cm. From optical measurements it could be seen that spectra present a low energy edge corresponding to the beginning of intra band excitations and the high energy edge due to inter band excitations.

1 Introduction

IV-VI semimagnetic semicondutor compounds have been investigated by several groups in the last decades. The incorporation of Eu, for instance in the lead salts has demonstrated to be useful for infrared optoelectronic applications, in particular for the fabrication of PbTe/PbEuTe heterojunction diode lasers including quantum well structures [1]. SnTe is a IV-VI narrow gap semiconductor whose optical and electrical properties have been extensively investigated since the beginning of 1960's [2-4]. In the case $Sn_{1-x}Eu_xTe$ alloys most of work has been focused in the magnetization studies in samples grown by Bridgman method [5-10]. A correlation between magnetic and electronic properties of $Sn_{1-x}Gd_xTe$ samples grown also by Bridgman method, has also been done [11-12]. In this work we present some results obtained in the investigation of structural, optical and electrical properties of $Sn_{1-x}Eu_xTe$ $(0 < x < 0.03)$ epitaxial films grown by molecular beam epitaxy on freshly cleaved BaF_2(111) substrates. Although SnTe and EuTe compounds have the same crystal structure (FCC) and lattice mismatch about 4.3%, a complete miscibility is not expected for the whole composition range of $Sn_{1x}Eu_xTe$ alloy, because it would violate the well known 15% Hume-Rothery rule [13]. Table 1 summarizes some properties of SnTe and EuTe compounds.

Table 1. General properties of SnTe and EuTe

	SnTe	EuTe
Crystalline structure	FCC	FCC
Lattice constant (Å)	6.327	6.598
B_{lin} (K^{-1})	21.0×10^{-6}	13.6×10^{-6}
Density (g/cm^3)	6.45	6.45
Melting point (^{o}C)	806	2183
Energy Gap (eV)	0.3 (0 K) 0.18 (300 K)	2 (300 K)

2 Experimental Procedures

In order to investigate the peculiarities of this interesting $Sn_{1x}Eu_xTe$ pseudo-binary alloy various series of samples were grown by molecular beam epitaxy in a Riber 32P system. The epilayers were fabricated by using three different effusion cells, which are able to evaporate SnTe, Eu and Te, separately. Prior the growth, freshly cleaved BaF_2(111) substrates were preheated at 200 ^{o}C during 30 min, in the preparation chamber, and at 500 ^{o}C during 15 min, in the main chamber. The substrate holder was kept rotating during the growth to insure a reasonable thickness homogeneity for all samples. Epilayers of about 1.5 μm thick were deposited with growth rate of approximately 2 Å/s and substrate temperature kept at 300 ^{o}C. The Volmer-Weber growth mode was observed by RHEED patterns for all samples.

Ex-situ characterization methods were performed mainly by using three different equipments. Firstly, high resolution X-ray diffraction measurements were carried out in a Philips X'Pert diffractometer in Ω direction, using the open detector mode for scans in [222] Bragg reflex. Then, an automated Keithley 180A Hall effect system was used to measure the electrical properties of the samples contacted in the Van der Pauw geometry. The resistivity and Hall effect measurements, with temperature varying from 300 to

10K were performed Finally, a Fourier transform infrared spectrophotometer (Perkin Elmer – FTIR 1600) and a NIR-UV-VIS spectrophotometer (Hitachi – U3501) were used for optical transmission measurements at room temperature.

3 Results and Discussions

Although $Sn_{1x}Eu_xTe$ samples with x as high as approximately 20% have been grown in this work, it could be observed by high resolution X-ray diffraction that a good crystal quality is achieved only for x values lower than 0.03, as can be seen in Fig. 1. This limitation is due to the fact that the difference between the atomic radius of Eu (2.04Å) and Sn (1.62Å) is more than 20%, which is much higher than the condition established by one of Hume-Rothery rules for solid solutions [13].

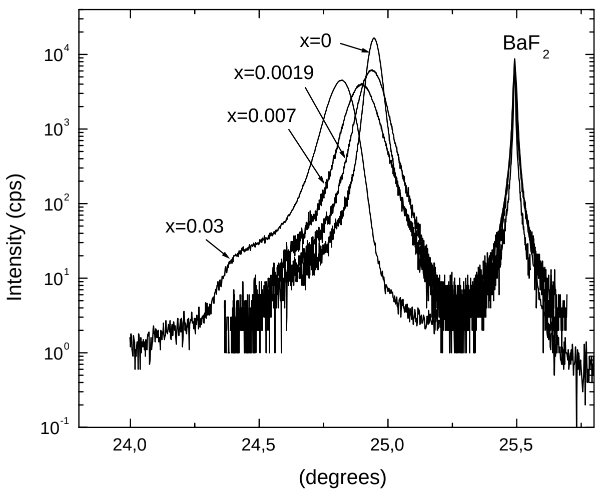

Figure 1. X-ray data of the (222) diffraction peak for different $Sn_{1x}Eu_xTe$ samples grown on BaF_2 (111).

Figure 2 shows that the lattice parameter increases from 6.327 to 6.368 Å as the Eu content varies from 0 to 0.022. It is important to notice that these alloys do not obey Vegard's law. Actually the lattice constant considered for 0.03 is not so accurate because a phase separation is occurring probably due to spinodal decomposition [14], which is a well known phenomenon taking place in fluids, glasses and solids.

The crystal quality degradation is much more pronounced in Fig. 3, where it can be seen that the full width at half maximum (FWHM) varies from 164 to 571 arcsec for Eu content varying from 0 to 0.022. Again because the phase separation occurring in the sample with x=0.03 the FWHM is not so accurate.

Figure 4 shows how the mobility varies as a function of temperature for samples with low Eu concentration, namely x=0.00017;0.0019;0.007; 0.022, respectively. It can be seen that the highest mobility (636 cm^2/V.s) is achieved at temperatures about 12K for the sample with x=0.00017. At room temperature the mobility of this sample decreases to 171 cm^2/V.s. Electrical measurements with temperature varying from 300 to 10K also indicated that the epilayers present carrier concentration ranging from 3×10^{20} and $6 \times 10^{20} cm^{-3}$ and a low resistivity from 6.3×10^{-5} to 1.2×10^{-4} Ω.cm.

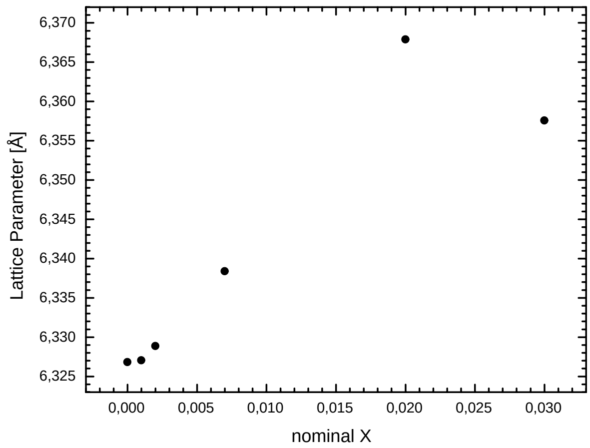

Figure 2. Lattice parameter of the $Sn_{1-x}Eu_xTe$ layers as a function of nominal Eu content.

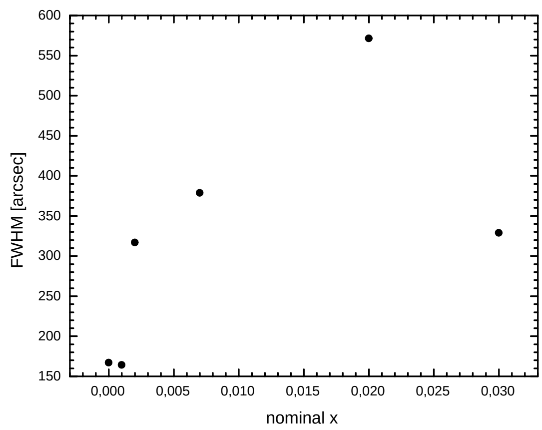

Figure 3. Full width at half maximum of the (222) x-ray rocking curves for the $Sn_{1-x}Eu_xTe$ layers.

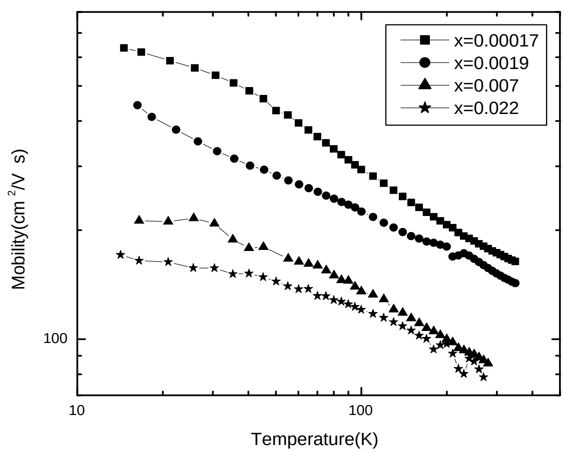

Figure 4. Temperature dependence of Hall mobility for $Sn_{1-x}Eu_xTe$ layers with different Eu compositions.

Due to high concentrations of holes in all samples the observed transmission spectra shown in the Fig. 5 present a low energy edge corresponding to the beginning of intra band excitations and the high energy edge due to inter band excitations.

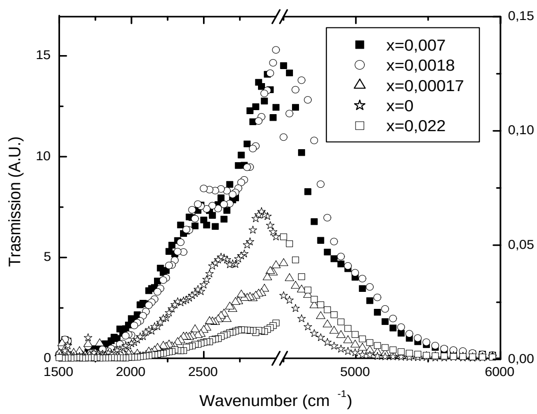

Figure 5. Transmission spectra at room temperature of the $Sn_{1-x}Eu_xTe$ layers.

4 Conclusion

In this work structural, electrical and optical properties of $Sn_{1-x}Eu_xTe$ $(0 < x < 0.03)$ samples grown by molecular beam epitaxy on freshly cleaved $BaF_2(111)$ substrates were investigated. X-ray diffraction measurements indicated that layers with good crystalline quality were possible to be grown only for nominal $x < 0.03$. Electrical measurements pointed out the increase of europium content in the lattice causes a drastic deterioration in the electrical properties of the samples. A low energy edge corresponding to the beginning of intra band excitations and the high energy edge due to inter band excitations were observed by optical measurements.

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