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Spinodal Decomposition in $Pb_{1-x}Eu_xTe$ Alloy

Sahn Nahm, Mun Cheol Paek, Oh Joon Kwon

Materials &Characterization Section, Semiconductor Div. ETRI

Semiconductor alloys are important for the fabrication of devices such as lasers, transistors and detectors. $Pb_{1-x}Eu_xTe$ alloys are particulary important for the fabrication of devices involving PbTe/EuTesuperlattices and PbTe/$Pb_{1-x}Eu_xSe_yTe_{1-y}$ heterostructures. In order for the devices to be stable at thetemperature of operation, the alloy used to fabricate them should be stable. The stability of the alloys depends on the miscibility between the compound semiconductors. Alloys that show range of compositions where there is no miscibility are unstable or metastable in that range of compositions. In this work, we present electron microscopy observations of spinodal decomposition of $Pb_{1-x}Eu_xTe$ alloy ($x \sim 0.5$) grown on BaF_2 substrate using MBE at 573 K.

TEM samples were prepared by mechanical grinding and subsequent ion milling using argon gas at liquid nitrogen temperature. JEOL 2000FX-II transmission electron microscope was used to observe the samples.

$Pb_{1-x}Eu_xTe$ alloys with $0.4 < x < 0.52$ showed modulation which is associated with spinodal decomposition. Examples of this decomposition are presented in Figs. 1 and 2. Figure 1 shows the (-1-12) high resolution lattice image of $Pb_{0.59}Eu_{0.41}Te$ sample. This figure shows the (111) (growth direction) lattice fringes with spacing of ~ 0.37 nm and a long wavelength modulation with periodicity of ~2.1 nm along the <110> direction. This long wavelength periodicity can also be observed in the diffraction pattern (see inset to Fig. 1) by the appearance of diffuse satellites around the crystalline reflections and along the <110> direction.

In our system, the scattering modulation corresponds to a modulation in the composition of thePb and Eu atoms. There is also a modulation in the lattice spacing as a result of the composition modulation since Eu is bigger than Pb and the interplanar spacing of EuTe are larger than the corresponding ones of PbTe. The evidence of lattice modulation in our system is shown in the diffraction pattern (see inset to Fig. 1) where the intensity of satellite peaks n and -n (n is the order of the satellite) is not the same, in agreement with a modulated structure where there is a sinusoidal modulation of both scattering and inter-planar spacing.[1]

More of example of spinodal decomposition of $Pb_{1-x}Eu_xTe$ alloys are presented Fig. 2. The (1-10) electron diffraction patterns (Fig. 2) of $Pb_{0.57}Eu_{0.42}Te$alloy show periodicity of 1.46 nm along <111> direction.

Cahn calculated the elastic strain energy associated with the composition modulation in cubic system and suggested that the minimum valve of elastic energy depends on the sign of the anisotropy term, $2C_{44} - C_{11} + C_{12}$ where C_{ij} is an elastic constant.[2] If $C_{44} - C_{11} + C_{12} > 0$ the elatic energy is minimum along <100> and maximum along <111>. This implies that the system becomes unstable first along <100>. The opposite is true for both PbTe and EuTe where $2C_{44} - C_{11} - C_{12} < 0$. Therefore, a solid solution of $Pb_{1-x}Eu_xTe$ becomes unstable along <111> first, then along <110> last to <100> which agree with our experimental results.

In this study, spinodal decomposition was observed in $Pb_{1-x}Eu_xTe$ films grown on (111) BaF_2 substarte. The direction of decomposition are <111> and <1-10>, where the elastic energy is relative minimum.

[1] D. de Fontaine, in "Local Atomic Arrangements Studied by X-Ray Diffraction", (edited by J.B. Cohen and J.E. Hilliard, Gordon and Breach, New York, 1966), p.51.

[2] J.W. Cahn, Acta Metall. 10, 179 (1962).

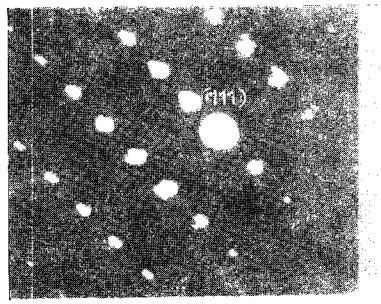

Figure 1 (-1 -1 2) lattice image of $Pb_{0.41}Eu_{0.59}Te$ alloy showing spinodal decomposition along the <1-10> direction with a modulation wavelength of ~2.1 nm.

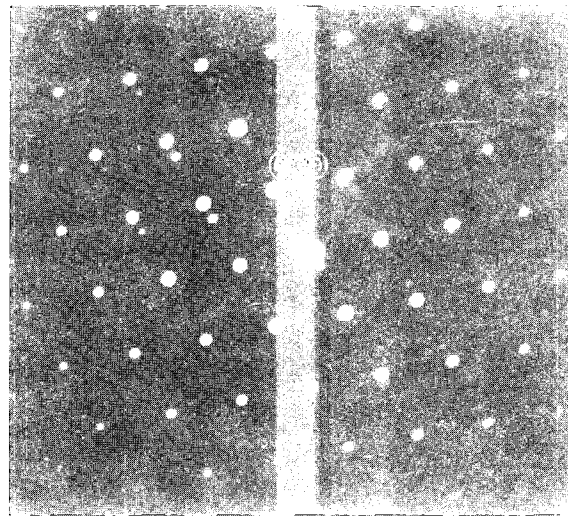

Figure 2 (1-10) electron diffraction pattern of a $Pb_{0.57}Eu_{.43}Te$ alloy showing periodicity of 1.46 nm along the <111> direction.