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ABSTRACT

We have used spectroscopic ellipsometry to determine the complex dielectric function of a series of ternary ZnBeTe thin films grown by molecular beam epitaxy (MBE). After preparing the semi-insulating (001) InP substrates, an ~100nm thick lattice matched InGaAs buffer layer was grown prior to the ZnBeTe layer. The growth was performed at 270°C and the rate was approximately 0.5 µm/h. The thickness of the ZnBeTe layers were around 0.5-1.5 µm while the Be concentrations (x) ranged from x = 0.1 to x = 0.516. The alloy concentrations of ZnBeTe were determined using single crystal x-ray diffraction, which is a linear dependence between the lattice parameter and the alloy composition (i.e., Vegard’s law). Spectroscopic ellipsometry was performed using a J.A. Woollam IR-ellipsometer, covering a spectral range from 2000 nm to 40,000 nm, and with a spectral resolution of 2 cm⁻¹. Our results were also compared with ellipsometric measurements from two published papers (i.e., the data below x = 1500nm).

INTRODUCTION

The incorporation of beryllium into traditional II-VI semiconductors such as ZnSe and ZnTe has allowed one to address some of the problems associated with these materials that culminate in reducing life times in devices based on them. It is believed that beryllium incorporation into II-VI films rectify some of these conventional problems because they form high degree covalent bonds, resulting in greater lattice-hardening and lower degradation rates. In addition, ZnBeTe can be p-doped to a level of 10²⁸ cm⁻³ and also can be lattice matched to InP substrates. Due to these properties, researchers have successfully fabricated laser diodes and photocathodes using beryllium incorporated II-VI alloys.

Spectroscopy ellipsometry is a powerful, non-destructive technique for determining the complex dielectric function, εᵢ(ω, x), of thin films. Using ε from ellipsometry, one could easily obtain the index of refraction and the absorption of thin film, two parameters that are essential in designing optical devices using these materials. The information derived from structure of ε provides insights on the underlying transitions associated with the crystal.

Depending on the spectral range, ε will convey information related to transition associated with electrons or phonons. In our previous study we mapped out the electronic transitions in Zn₁₋ₓBeₓTe ternary films by examining ε in the near-infrared range. In this study, we extend the ellipsometric measurements into the far-infrared. By examining the structure of ε determined in the IR region, we are able to uncover phonon transitions related to these alloys. Since the phononic structure reveals the mechanical and the thermodynamics properties of the underlying alloy system, there are several advantages in studying this behavior.

EXPERIMENTAL DETAILS

All the Zn₁₋ₓBeₓTe thin films were grown by molecular beam epitaxy (MBE). After preparing the semi-insulating (001) InP substrates, an ~100nm thick lattice matched InGaAs buffer layer was grown prior to the Zn₁₋ₓBeₓTe layer. The growth of Zn₁₋ₓBeₓTe layers was performed at 270°C and the growth rate was approximately 0.5 µm/h. The thicknesses of Zn₁₋ₓBeₓTe layers were around 0.5-1.5 µm while the Be concentrations (x) ranged from x = 0.1 to x = 0.516. The alloy concentrations of Zn₁₋ₓBeₓTe were determined using single crystal x-ray diffraction, which is a linear dependence between the lattice parameter and the alloy composition (i.e., Vegard’s law). Spectroscopic ellipsometry was performed using a J.A. Woollam IR-ellipsometer, covering a spectral range from 2000 nm to 40,000 nm, and with a spectral resolution of 2 cm⁻¹. Our results were also compared with ellipsometric measurements from two published papers (i.e., the data below x = 1500nm).

RESULTS AND ANALYSIS

For a particular sample, at each wavelength, ellipsometry measures two parameters, ψ and δ, which are related to the ratio of reflection coefficients by:

\[ \rho = \frac{R_L}{R_T} = \tan(\psi)e^{i\delta} \]

Where RL is the complex reflection coefficient for light polarized parallel to the plane of incidence, and RT is the coefficient for reflection for light polarized perpendicular to the plane of incidence. Since ψ and δ depend on the optical properties for the entire semiconductor, a four-layer model (i.e., InP substrate, InGaAs buffer, Zn₁₋ₓBeₓTe layer, and surface-rough layer) was constructed for each sample to determine the optical properties of the Zn₁₋ₓBeₓTe layer. In order to obtain the comprehensive characteristics of the phonons from ε, we model the far-IR ε in the following product-representation, allowing Lorentzian-type oscillators to signify the multiple phonon branches typical of semiconductor alloys:

\[ \varepsilon = \varepsilon_{\infty} + \sum \frac{\omega_{LO}^2 - \omega^2 - i\gamma_{LO}}{\omega_{LO}^2 - \omega^2 - i\gamma_{LO}} \]

Where ε₁, ε₂, ... represent the high frequency dielectric function, and \( \omega_{LO}, \gamma_{LO} \), etc. represent the LO, TO phonon-mode frequency and broadening parameters.

The experimental and the modeled ψ and δ for a representative sample of Zn₁₋ₓBeₓTe is shown in Fig. 1 and the corresponding dielectric function for the sample is shown in Fig. 3. The comparison of the dielectric function for different alloy concentration is shown in Fig. 2. The features of the dielectric function change progressively as a function of alloy concentration. As shown in Fig. 4, the LO and TO phonon-mode frequencies found using the above model are consistent with ref. [6].

CONCLUSION

We have determined the complex dielectric function of a series of Zn₁₋ₓBeₓTe ternary films using spectroscopic ellipsometry. The dielectric functions obtained from ellipsometry were further analyzed to obtain the phonon characteristics of Zn₁₋ₓBeₓTe. We found that both LO and TO phonon frequencies blue shift as a function of Be concentration.

REFERENCES