IR-Dielectric Functions of ZnBeTe Alloys Determined by Spectroscopic Ellipsometry

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ABSTRACT

We have used spectroscopic ellipsometry to determine the complex dielectric function of a series of ternary Zn$_{1-x}$Be$_x$Te thin films for the far-infrared spectral range. A rotating analyzer based, variable-angle spectroscopic ellipsometer was used to obtain spectra between 2,000nm and 40,000nm. The data obtained from ellipsometry was modeled in terms of oscillators, representing longitudinal (LO) and transverse (TO) optical phonons associated with the Zn$_{1-x}$Be$_x$Te lattice. The phonon spectra obtained from ellipsometry are consistent with Raman results. In addition, we were able to juxtapose these far-infrared dielectric functions with our earlier UV-VIS results. This gives us the dielectric function between 200nm to 40,000nm, covering both electronic as well as phononic transition in Zn$_{1-x}$Be$_x$Te alloys.

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 lifetime issues in devices based on them. It is believed that beryllium incorporated 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, Zn$_{1-x}$Be$_x$Te can be $p$-doped to a level of $10^{18}$ cm$^{-3}$ and also can be lattice matched to InP substrates. Due to these properties, researchers have successfully fabricated laser diodes and photodetectors using beryllium incorporated II-VI alloys.

Spectroscopic ellipsometry is a powerful, non-destructive technique for determining the complex dielectric function, $\varepsilon = \varepsilon_1 + i\varepsilon_2$, of thin films. Using $\varepsilon$ 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 $\varepsilon$ provides insights on the underlying transitions associated with the crystal.

Depending on the spectral range, $\varepsilon$ will convey information related to transition associated with electrons or phonons. In our previous study we mapped out the electronic transitions in Zn$_{1-x}$Be$_x$Te ternary films by examining $\varepsilon$ in the UV-VIS spectral range. In this study, we extend the ellipsometric measurements into the far-infrared. By examining the structure of $\varepsilon$ 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.

RESULTS AND ANALYSIS

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

$$R = \frac{\varepsilon - 1}{\varepsilon + 1} = \tan(\psi)e^{i\Delta}$$

Where $R_1$ is the complex reflection coefficient for light polarized parallel to the plane of incidence, and $R_2$ is the coefficient for reflection for light polarized perpendicular to the plane of incidence. Since $\psi$ and $\Delta$ depend on the optical properties for the entire semiconductor, a four layer model (i.e., InP substrate, InGaAs buffer, Zn$_{1-x}$Be$_x$Te layer, and surface-rough layer) was constructed for each sample to determine the optical properties of the Zn$_{1-x}$Be$_x$Te layer. In order to obtain the comprehensive characteristics of the phonons from $\varepsilon$, we model the far-IR in the following product-representation, allowing Lorentzian-type oscillators to signify the multiple phonon branches typical of semiconductor alloys:

$$\varepsilon = \sum_{\alpha} \frac{\alpha_{\alpha 0}}{\omega_{\alpha 0}^2 - \omega^2 - i\gamma_{\alpha 0} \omega}$$

Where $\alpha$ corresponds to the high frequency dielectric function, and $\alpha_{\alpha 0}$, $\omega_{\alpha 0}$, $\gamma_{\alpha 0}$, and $\omega_{\alpha 0}$ represent the LO, TO phonon-mode frequency and broadening parameters.

The experimental and the modeled $\psi$ and $\Delta$ for a representative sample of Zn$_{1-x}$Be$_x$Te is shown in Fig. 1 and the corresponding dielectric function for the sample is shown in Fig. 2. 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-modes frequencies found using the above model are consistent with ref. [6].

CONCLUSION

We have determined the complex dielectric function of a series of Zn$_{1-x}$Be$_x$Te ternary films using spectroscopic ellipsometry. The dielectric functions obtained from ellipsometry were further analyzed to obtain the phonon characteristics of Zn$_{1-x}$Be$_x$Te. We found that both LO and TO phonon frequencies blue shifted as a function of Be concentration.

REFERENCES


Fig. 1: $\psi$ and $\Delta$ spectra of Zn$_{0.48}$Be$_{0.52}$Te measured by spectroscopic ellipsometry at an angle of incidence of 75 degrees.

Fig. 2: Comparison of real ($\varepsilon_1$) and imaginary ($\varepsilon_2$) components of the dielectric function for different concentration in Zn$_{1-x}$Be$_x$Te.

Fig. 3: The real ($\varepsilon_1$) and imaginary ($\varepsilon_2$) components of the dielectric function of a representative sample of Zn$_{0.48}$Be$_{0.52}$Te. For completeness, we also show our previous results (i.e., the data below $\lambda = 1500$nm).[6]

Fig. 4: LO and TO phonon-mode frequencies for different concentration in Zn$_{1-x}$Be$_x$Te.