Influence of Thickness and Temperature on Electronic Transitions of Bi_2Se_3 Thin Films

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Abstract

We have determined the dielectric functions of a series of Bi_2Se_3 films grown on sapphire substrates. Temperature dependent in-situ ellipsometry spectra were obtained for several samples with varying thicknesses ranging from 5 nm to 60 nm. After the dielectric functions were modeled using the in-situ spectra, they were represented by Kramers-Kronig consistent oscillators. We observe that the dielectric function of Bi_2Se_3 has a slight thickness dependence and that it also varies with temperature. Specifically, the oscillators red-shift as temperature increases, which was modeled using a Bose-Einstein distribution.

Oscillator Model

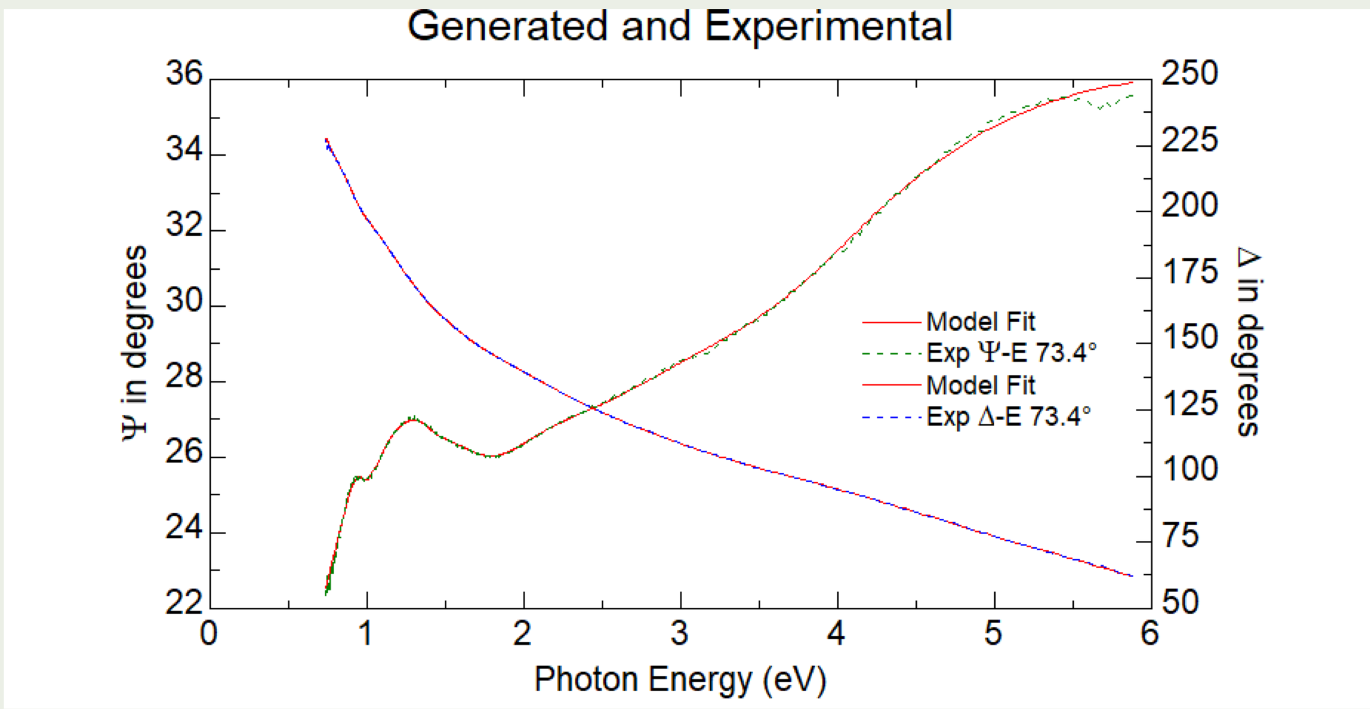


Figure 1: ψ and Δ spectra along with the model.

In Fig. 1, the ψ and Δ spectra are shown to verify that the models we used to obtain the fit are suitable. In Fig 2, we show ε obtained for a specific sample along with the contributions from the individual oscillators

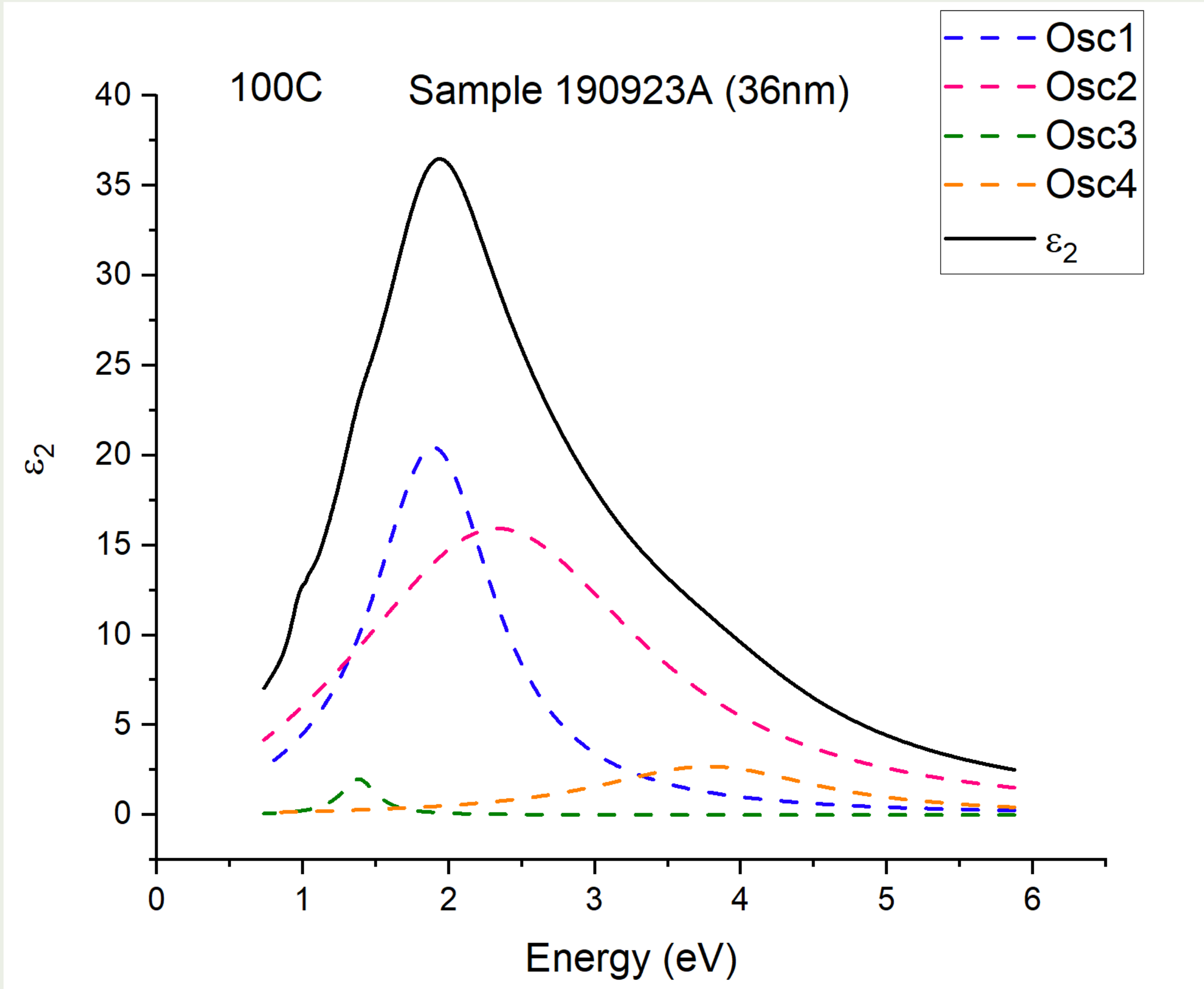
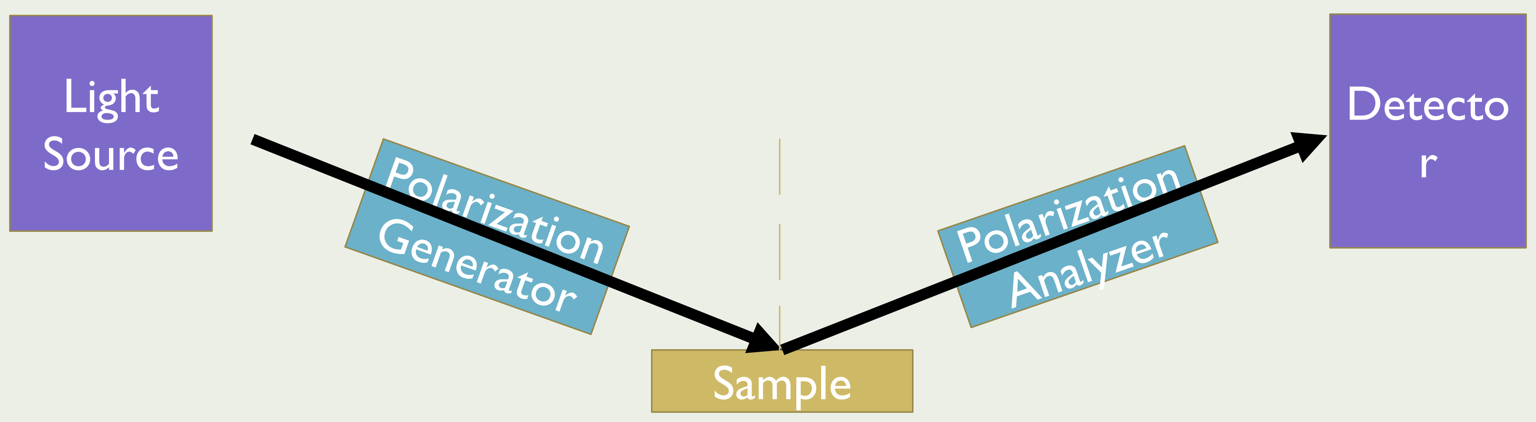


Figure 2: Oscillator model for the dielectric function of a representative sample. The figure also shows the contributions from each oscillator.

Ellipsometry



Ellipsometry measures the change in polarization of light reflected from surface via ψ and Δ:

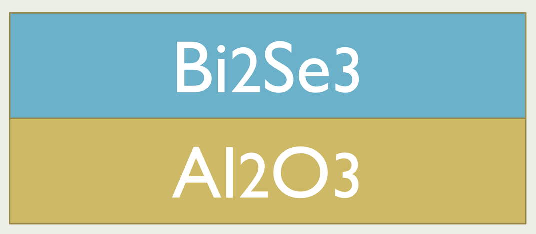
$$\rho = \tan(\psi)\, e^{i\Delta} = \frac{\widetilde{R_p}}{\widetilde{R_s}},$$

Where $\widetilde{R_p}$ and $\widetilde{R_s}$ are the two polarization states. Using ellipsometry spectra, one can determine the complex refractive index and the dielectric function:

$$\tilde{n}(\lambda) = n(\lambda) + ik(\lambda)\,; \qquad \varepsilon(\lambda) = \varepsilon_1(\lambda) + i\varepsilon_2(\lambda)$$

where $n + ik = \sqrt{\tilde{\varepsilon}} = \sqrt{\varepsilon_1 + i\varepsilon_2}$.

Samples



Sample	Thickness (QL)	Thickness (nm)
190920A	20	19nm
191022A	30	31nm
190923A	38	36nm
191021A	87	83nm

We have four samples, each with a different thickness but the same components: Al2O3 as the substrate and Bi2Se3 as film on the substrate. For each of the sample, the dielectric function is measured at 100C, 150C, 175C, 200C and 225C.

Thickness Dependence

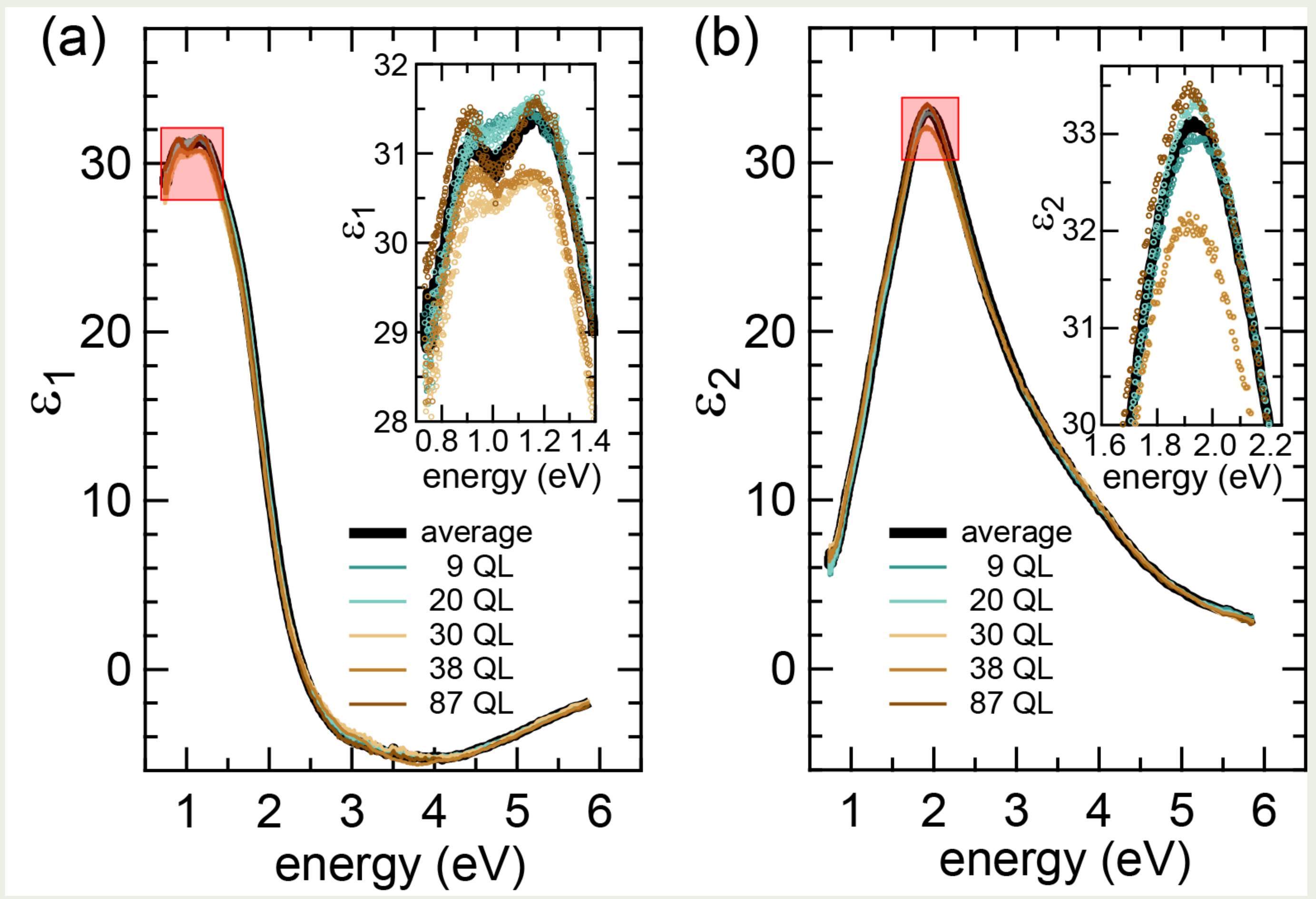


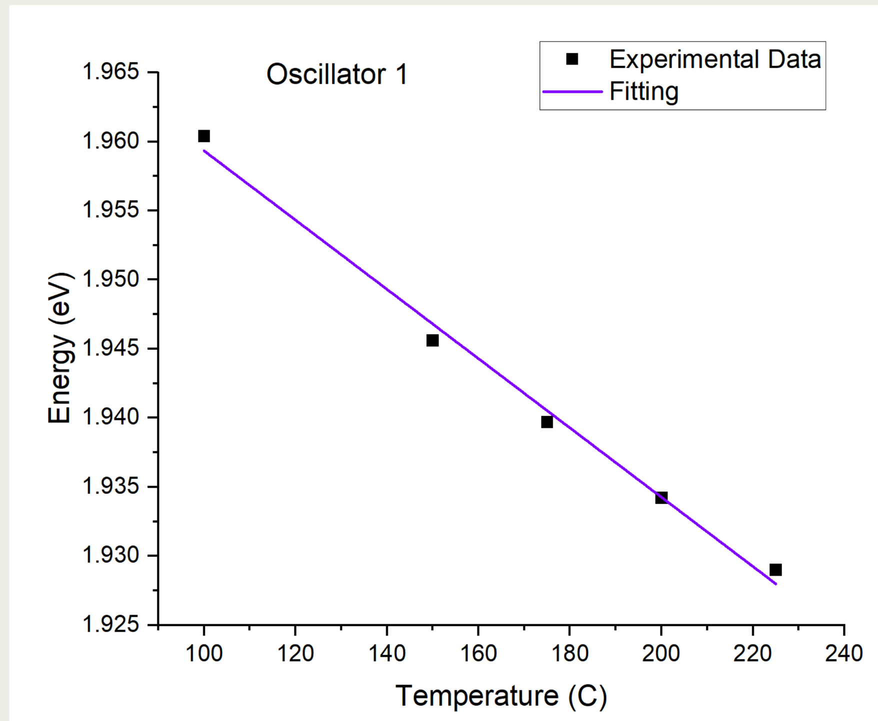
Figure 3: The dielectric function of several Bi_2Se_3 films with varying thickness values.

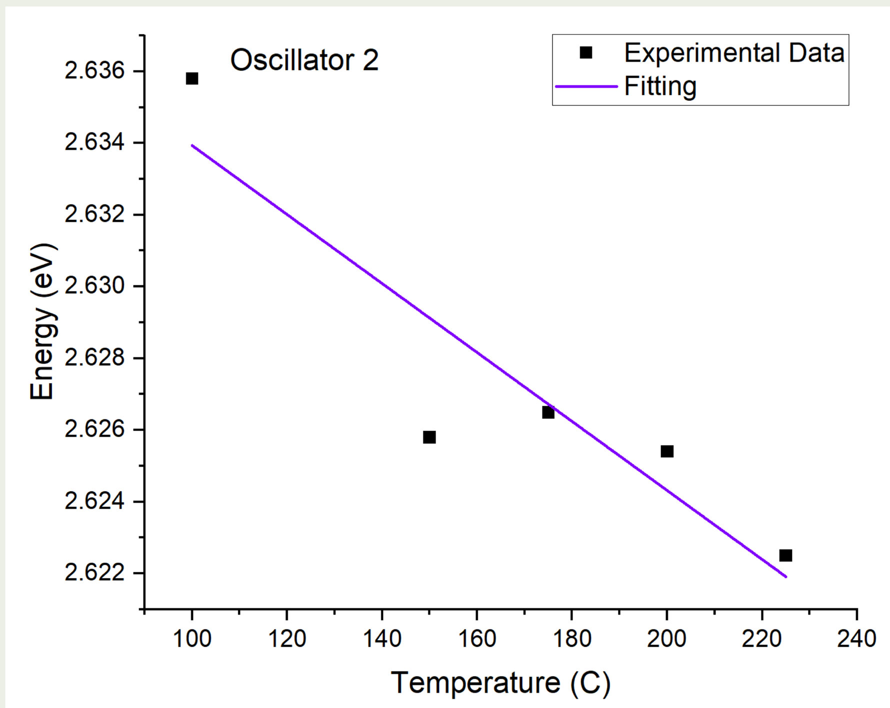
The results in Fig. 3 indicate that there is only a very small dependence with thickness.

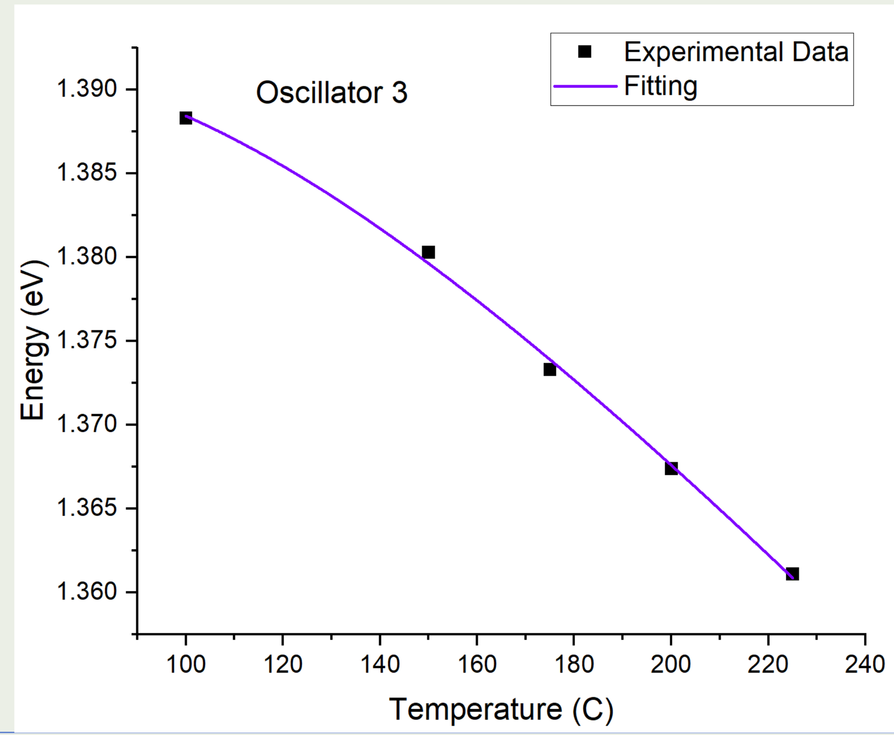
Temperature Dependence

For one of the samples (36nm), we plot the energy position of three Lorentz oscillator vs. temperature, which are shown in the figures on the right. We notice that with the increase in temperature, the energy positions of the oscillators red-shift, which can be modeled using Bose-Einstein distribution function;

$$E = E_B - a_B\left(1 + \frac{2}{e^{\Theta/T} - 1}\right)$$







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