Influence of Different Substrates on In-plane Electrical Conductivity of PEDOT:PSS Thin Films

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Abstract

The charge transport properties of conductive poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) layer-by-layer (LbL) thin films were investigated using different substrates, including glass, indium tin oxide (ITO), and GaAs:Si. The use of an ITO substrate significantly enhanced the electrical conductivity of the films, reaching up to 8004.52 S/cm. This improvement is attributed to enhanced charge transfer at the interface, which may promote better alignment of polymer chains near the surface, thereby increasing overall conductivity. Figure 2 presents the temperature-dependent electrical conductivity of films coated on ITO. Temperature-dependent electrical conductivity was measured using a low-temperature Hall system. The experimental data were fitted with two charge transport models: (a) tunneling and (b) variable range hopping (VRH). The results indicate that the tunneling model provides a better fit, suggesting that charge transport in PEDOT:PSS primarily occurs through carrier tunneling between polar and bipolar regions within the polymer chains. Figure 3 compares the experimental data with both models.

Sample preparation

Glass substrates (5×5 mm) were cleaned using acetone and isopropanol via spin coating (3500 rpm, 30 s each), then dried with air. Polymer solution was deposited and spin-coated (3500 rpm, 30 s). Samples were dried on a hot plate at 110 °C for 15 minutes. A second polymer layer was applied using the same procedure.

Fitting Theory

Two models were used to investigate the charge transport properties in the PEDOT:PSS thin films.

Hopping Model:

$$\sigma_{VRH}\,(T) = \sigma_0 \exp\left[-\left(\frac{T_0}{T}\right)^{\frac{1}{n+1}}\right]$$

which σ_0 characteristic of the overall conductivity, T_0 related to the activation energy n the dimension of the conduction.

Tunneling Model:

$$\sigma_{Sheng}\,(T) = \sigma_s \exp\left(-\frac{T_1}{T+T_2}\right)$$

Which σ_s is a constant parameter, T_1 and T_2 are the tunneling temperatures depend on the barrier geometry and energy.

Results

ITO has shown quasi-metal behaviour. The quasi-metal equation has been used for theoretical fittings.

$$\sigma_{disordered\ metal} = \sigma_0 + mT^{1/2} + BT^{p/2}$$

where σ_0 is the"zero temperature" pure metallic conductivity, the second term reflects electron-electron interactions and the third term is a correction due to localization effects.

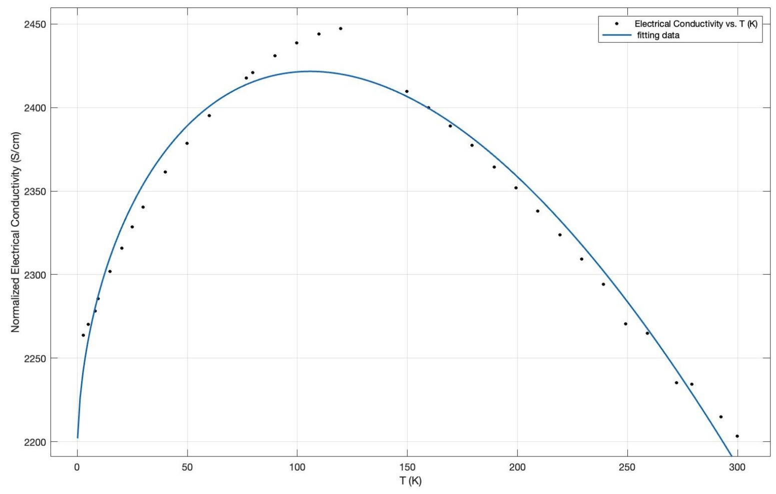

Figure 2. The temperature depennce electrical conductivity for PEDOT:PSS films coated on ITO fitted by semi-metal model equation.

Conclusion

- Electrical conductivity increases by increasing the temperature
- Tunneling model is a better fit for charge transport in PEDOT:PSS
- ITO substrates acts as a semi-metal material and increases electrical conductivity significantly
- In the case of using ITO, electrical conductivity decreases by increasing the temperature, which shows the semi-metal behaviour of the substrate.
- T1(K) and T2(K) did not show a linear behaviour regarding increasing the thickness.

Molecular structure of the Material

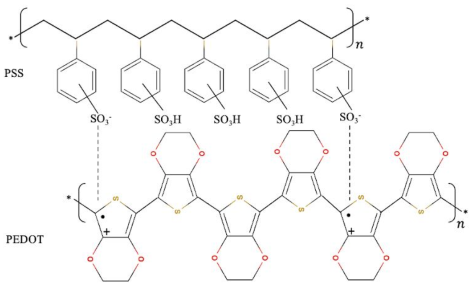

Figure 1. Molecular structure of PEDOT:PSS

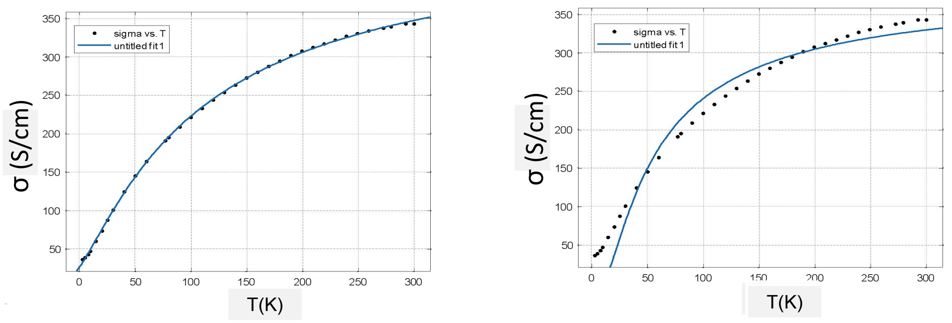

Figure 3. Electrical conductivity as a function of temperature for PEDOT:PSS (FHC Solar) and comparison of two models a) tunneling, b) hopping.

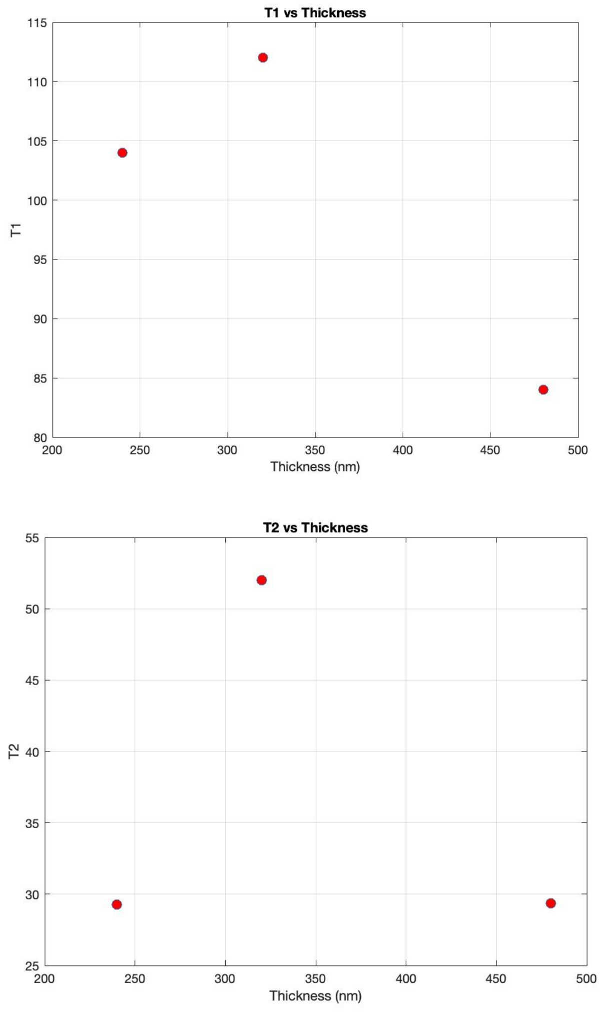

Figure 4. The thickness depence T1 and T2 for PEDOT:PSS Thin films coated on glass sunstrate.

References

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