Abstract

This doctoral thesis investigates the electrical and thermal transport properties of conductive poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) thin films. Due to their high electrical conductivity, optical transparency, mechanical flexibility, and solution processability, PEDOT:PSS materials have attracted considerable attention for applications in flexible electronics, transparent electrodes, sensors, photovoltaic devices, and thermoelectric materials. However, the thermal transport behavior of conductive polymers and its relationship with electrical transport remain incompletely understood. To address this, PEDOT:PSS (F HC Solar) thin films with varying morphology, thickness, conductivity, and anisotropic structure were fabricated. The effects of film thickness, substrate type, and temperature on charge and heat transport were investigated using glass, silicon-doped gallium arsenide (GaAs:Si), and indium tin oxide (ITO)-coated glass substrates. Electrical transport properties were investigated using Hall-effect measurements in the Van der Pauw configuration and conductive atomic force microscopy (C-AFM), while thermal transport properties were studied using photothermal infrared radiometry (PTR) and thermoreflectance (TR) techniques, enabling determination of both cross-plane and in-plane thermal conductivity. The obtained results showed that charge transport in this particular PEDOT:PSS (F HC Solar) thin films occurs via tunneling mechanisms rather than conventional hopping transport, independent of film thickness and substrate type. PEDOT:PSS thin films deposited on ITO-coated glass substrates exhibited very high electrical conductivity values, which is highly important for transparent electrode applications in photovoltaic and solar-cell technologies. A major contribution of this work is the development of a custom-built electric-field-assisted spin-coating system, which enabled simultaneous application of a lateral electric field during thin-film deposition together with real-time current monitoring during film formation and solidification. The applied electric field induced directional reorientation of PEDOT:PSS dipolar structures, resulting in anisotropic electrical conductivity and directional charge transport within the thin films.

Another important contribution of this thesis is the comprehensive investigation of thermal transport properties in PEDOT:PSS thin films, which remains a relatively unexplored topic in the literature. Both theoretical and experimental analyses of in-plane and cross-plane thermal and electrical conductivities were performed, and the correlation between thermal and electrical transport was systematically investigated using the Wiedemann-Franz law. The results demonstrated that enhanced electrical conductivity was accompanied by enhanced thermal conductivity, indicating an electronic contribution to heat propagation and highlighting the importance of coupled transport behavior for thermoelectric applications. Furthermore, using C-AFM local charge concentrations and conductive regions on the PEDOT:PSS thin-film surface were studied. In agreement with the tunneling transport model, the observed local current variations indicate charge transport between conductive polymer segments associated with polaronic and bipolaronic structures within the polymer network. This thesis provides a comprehensive investigation of coupled electrical and thermal transport phenomena in PEDOT:PSS (F HC Solar) thin films and contributes to the understanding and optimization of conductive polymer materials for flexible electronic, thermoelectric, and energy-conversion applications.