THz Spectroscopic Studies of Transparent Conducting Nanomaterials

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Time-domain terahertz spectroscopy (THz-TDS) provides a non-contact method for characterizing the electrical and dielectric properties of technologically important materials, e.g., transparent and conducting Indium Tin Oxide (ITO) thin films, which are widely used in optoelectronic devices. Recently, ITO nanomaterials have attracted a lot of attention, because of its omidirectional and wideband anti-reflection characteristics. Indium-tin-oxide (ITO) nanorods (NRs) and nanowhiskers (NWhs) were fabricated by an electron-beam glancing-angle deposition (GLAD) system. Two terahertz (THz) time-domain spectrometers (TDS) with combined spectral coverage from 0.15 to 9.00 THz were used. These allow accurate determination of the optical and electrical properties of such ITO nanomaterials in the frequency range from 0.20 to 4.00 THz. Together with Fourier transform infrared spectroscopic (FTIR) measurements, we found that the THz and far-infrared transmittance of these nanomaterials can be as high as 70% up to 15 THz, as opposed to about 9% for sputtered ITO thin films. The complex conductivities of ITO NRs, NWhs as well films are well fitted by the Drude-Smith model. Taking into account that the volume filling factors of both type of nanomaterials are nearly same, mobilities, and DC conductivities of ITO NWhs are higher than those of NRs due to less severe carrier localization effects in the former. On the other hand, mobilities of sputtered ITO thin films are poorer than ITO nanomaterials because of larger concentration of dopant ions in films, which causes stronger carrier scattering. We note further that consideration of the extreme values of Re{σ} and Im{σ} as well the inflection points, which are functions of the carrier scattering time (τ) and the expectation value of cosine of the scattering angle (γ), provide additional criteria for accessing the accuracy of the extraction of electrical parameters of non-Drude-like materials using THz-TDS. Our studies so far indicate ITO NWhs with heights of ~1000 nm show outstanding transmittance and good electrical characteristics. Improved performance of a liquid-crystal-based THz phase shifter using ITO NWhs as electrodes will be shown as an example.