

Transparent, Conductive Coatings From Latex-Based Dispersions

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The emergence of flexible electronics, such as flat panel displays based on polymer substrates, requires compliant, transparent electrode coatings. Although indium tin oxide (ITO) and antimony-doped tin oxide (ATO) can be deposited onto polymeric substrates, these ceramic coatings are brittle and cannot withstand a large degree of deformation. However, the fabrication and application of flexible electronics often require a certain degree of mechanical deformation, and therefore flexible coatings are advantageous.

Flexible, transparent and conductive coatings were prepared using polymeric latex as the matrix starting material and transparent and conductive nanoparticles (ATO or ITO) as the conductive filler [1,2]. A stable aqueous dispersion of latex and conductive filler was prepared, and deposited onto polymer substrates. As water evaporates during drying, latex particles consolidate and compact, forcing the conductive nanoparticles into the boundary regions between latex and thereby resulting in a segregated microstructure. If drying temperature is above the glass transition temperature of the latex, latex particles eventually coalesce, likely improving the physical contact between conductive particles and therefore enhancing the conductivity. This segregated microstructure enables electrical conduction at relatively low filler concentration.

The conductivity of the composite coatings is described by the percolation theory. The conductivity of ATO/poly (vinyl acetate-*co*-acrylic) (PVAc-*co*-acrylic) coatings follows the percolation power law equation with a percolation threshold of ~0.06 volume fraction ATO. This percolation threshold is much lower than the universal value (~0.15 volume fraction) for a random 3-dimensional (3D) system due to the formation of a segregated microstructure. The highest conductivity of the ATO/PVAc-*co*-acrylic coatings is on the order of 10^{-2} S/cm at 0.20 volume fraction ATO loading. As one dimension of the ATO network in ATO/PVAc-*co*-acrylic coatings is much smaller than visible light wavelength,

these coatings are transparent or partially transparent depending on coating thickness and ATO content. As ATO content increases, coating transparency decreases due to the Rayleigh scattering at the interface between filler and polymer. For a given ATO loading, reducing coating thickness does not greatly affect conductivity but significantly improves transparency. As a result, a good combination of conductivity and transparency can be achieved by reducing coating thickness for a given ATO loading.

The electrical properties of the composite coatings are affected by the physical morphology and intrinsic resistivity of conductive fillers as well as the interaction between polymer and filler. In addition to ceramic nanoparticles, intrinsically conductive polymer gel particles were explored as the conductive filler [3,4]. Transparent, conductive polymer blend coatings were prepared from aqueous dispersions of poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS) gel particles and PVAc-co-acrylic latex. PEDOT/PSS-latex polymer blend coatings containing a small amount of dimethyl sulfoxide (DMSO) had the best combination of properties so far: percolation threshold of ~ 0.02 volume fraction, conductivity of ~ 3.0 S/cm, and transparency of 87 % in the visible range for a 0.20 volume fraction composite coating.

The mechanical properties of the thin ATO/PVAc-co-acrylic coatings were characterized using the depth-sensing indentation techniques [5]. Several methods were used to reduce difficulties with indenting viscoelastic polymeric materials. The moduli determined by these methods were different partly due to artifacts and partly to substantial differences in state of stress. In general, the moduli increase with ATO content, an effect most accurately measured with dynamic indentation. Results from this research show that the choice of measurement techniques is critical for evaluating the properties of thin polymer-ceramic composite coatings.

References

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