Dissertation title:

Ressource-efficient fabrication of ultra-transparent electrodes based on percolating nano-sized conductors

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Considering shorter product life cycles of displays and the emerging market of flexible electronics, which demands bendable displays, the electronic industry is seeking for a cost-efficient substitution of the conventional but brittle material indium tin oxide. Although several alternative materials such as nano-carbons (graphene and carbon nanotubes), metallic nanowires or conductive polymers are frequently discussed candidates as an alternative material, indium tin oxide has not been replaced yet.

Within this work, networks of silver nanowires are evaluated with regard to their eligibility in transparent electrodes. The basic concept of electrical conductivity is electrical percolation which allows charge carriers to diffuse along the entire network. This requires structural percolation of the rod-like conductors, creating a jackstraw-like network.

The conventional quality requirement for transparent electrodes is optical transmission higher than 90 % and sheet resistance lower than 100 Ω/sq. However, silver nanowire networks exhibit significant haze which does not match today's quality standards. It is found that silver nanowire networks are only suitable for the use in displays if the optical transmission is higher than 97 % where the area density of the light-scattering rods is low enough and haze is in acceptable range. Hence, this work focuses especially on such ultra-transparent films. Extensive measurement series are carried out in order to describe electrical percolation in ultra-transparent silver nanowire films. Besides the optical and electrical analysis, scanning force microscopy is applied in order to gain information about the structure of the alignment. It is observed that close at the percolation threshold the system is significantly more sensitive towards changes than it is at higher area coverage.

The addition of carbon nanotubes increases the electrical conductivity of the silver nanowire network. This concept of co-percolation exhibits its strongest impact close at the percolation threshold. Moreover, anisotropic orientation of the silver nanowires is found to cause different conductivity in parallel and orthogonal direction. However, this effect is only relevant for the most transparent samples.

This thesis proves several theoretical predictions for electrical percolation in ultra- transparent networks based on rod-like conductors. However, the experimental data of this work also show that there are still several open

questions about percolation theory which have not been considered in previous theoretical works.

Besides the characterization of the films with regard to fundamental and technological interests, this thesis addresses the production process. Dip-coating offers the benefit of self-metered liquid film coating. As this process does not require a coating tool, possible congestions by nanoparticles do not have to be considered. The dip-coating process is analyzed with regard to the resulting film homogeneity on glass substrates and PET foils. As for the PET-foils, previous surface-activation with oxygen-plasma allows sufficient wettability. The coating is scaled on commercial smartphone glass, and ultimately the thesis presents a conceptual manufacturing plant for the production of silver nanowire films.