Nano Focus

Graded index nanoporous Teflon coatings make transparent polymers invisible

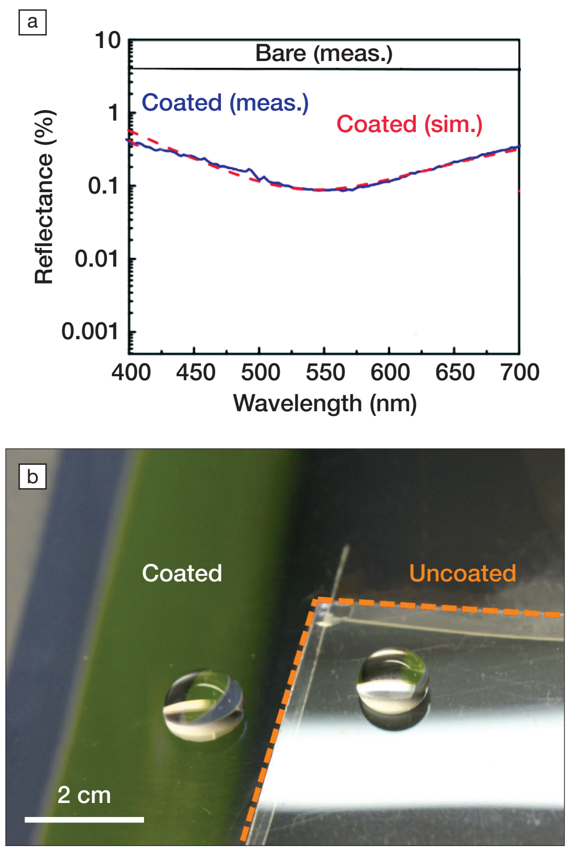
Plastics used for lenses and windows are optically transparent but reflect light at their surface due to the refractive-index mismatch between the plastic (typically 1.5) and air (1). Such reflection is undesirable and requires an antireflective (AR) coating for mitigation. Unfortunately, currently used inorganic methods leading to brittle layers are not suitable on flexible plastics. Similarly, the microstructuring of polymeric surfaces, another approach explored, is not easily scalable or robust.

To address this issue, the research group of Chris Giebink from The Pennsylvania State University uses coevaporation of Teflon with smaller molecules to build organic multilayers with a refractive-index gradient, as reported in a recent issue of *Nano Letters* (doi:10.1021/acs.nanolett.8b03886). Coevaporation is a thermal method where the polymeric chains are volatilized into smaller fragments and deposited on a substrate where they are repolymerized. It is not conventionally used for most polymeric materials, but it works well for Teflon. Coevaporating Teflon with a smaller molecule called *N*,*N*′-bis(3-methylphenyl)-*N*,*N*′-diphenylbenzidine (NDP) produces a Teflon layer with small inclusions of NDPs. After removal of the NDP with a solvent, nanopores are left behind, and the nanoporous Teflon shows a graded refractive index that decreases from the surface down to 1.07 as the concentration of NPD increases.

Coating plexiglass with three layers of nanoporous Teflon with thickness from 35 nm to 112 nm and decreasing refractive indices of 1.41, 1.31, and 1.15, respectively, from the surface down to the plexiglass, the researchers showed that the reflectance in the visible spectrum could be reduced by roughly a factor of 40 in comparison with bare plexiglass (Figure a). Looking straight or with an angle below 60°, the coated plexiglas almost disappears (Figure b).

The experimental data agree well with simulation models, such that the design can be employed for a wide range of antireflection applications (Figure a). However, according to Giebink, "one of the challenges is to accurately control the layer thickness when the layers get very porous (i.e., very low index). This seems mainly to be related to the pore collapse from the extraction solvent and can be improved by using a solvent with a lower surface tension."

These multilayered Teflon coatings are embodied with many advantages: hydrophobicity; resistance to chemical, mechanical, and environmental harsh conditions; and the process itself is scalable and can coat surfaces that are not flat. Adhesion tests using tape confirmed that the coatings adhered well and were not that easily damaged.



(a) Comparison between the reflectivity spectra over the visible spectrum, between uncoated plexiglass (black), and coated plexiglass as simulated (red) and as measured (blue). (b) Photograph showing a coated substrate next to an uncoated plexiglass substrate. With the three-layers Teflon-graded coating, the substrate is barely discernible as compared to without substrate. Credit: *Nano Letters*.

Alessandro Lauria, group leader at the Laboratory for Multifunctional Materials at ETH Zürich, Switzerland, says that despite the fact that the principle of exploiting nano-porosity to lower the refractive index was considered already for some inorganic materials—silica aerogels are common examples—"implementing inorganic coatings for plastic optics is still challenging due to the very different processing conditions. Therefore, the idea of this 'polymer on polymer' versatile deposition method to realize optical grade AR coatings, based on the same principle, is quite appealing."

Lauria continues, "The process reported is robust, and gives very good results thanks to the possibility to tune in a controlled manner the index profiling. The coatings realized in this work combine outstanding antireflective performance with quite good mechanical stability, which is of particular importance for optical elements subject to harsh conditions, such as sunglasses or smartphones that are handled 100 times a day. Considering that porous structures typically suffer quite poor mechanical resistance, it is remarkable that they seem already suitable for at least 'protected' optics, like telescope or camera lenses."

Indeed, Giebink's team has many plans for future work. "We are looking to better understand and further improve the adhesion to polymer substrates, identify primers that will enable adhesion to glass and inorganic hard coats, as well as to carry out more extensive mechanical testing," Giebink says.

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