New concept of transparent electrodes: the multilayer structure of TCO/Ag/TCO for PV applications

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Transparent electrodes (TE) are critical materials for many devices in strategic technological areas such as photovoltaics (PV) and flexible electronics. In the case of thin film PV, the thickness of the TE must be reduced with respect to standard bulk solar cells, this being a big issue in terms of electrical and optical properties. In the field of flexible electronics, the robustness and reliability under bending conditions is another hot topic to be considered. The need of simultaneously good electrical, optical and structural properties for TE pushes to study new materials with respect to the standard TCOs (transparent conductive oxides) largely employed today, often containing expensive and toxic elements such as In. Among these new materials, AZO/Ag/AZO multilayer structure (AZO = Al-doped ZnO) has shown very promising capacity of facing all the requirements for being one of the next generation TE. We grew AZO/Ag/AZO films on Si, quartz and plastic substrates in order to measure, electrical optical and bending properties. Samples contain 10nm of Ag intralayer in between 2 AZO films, each of different thickness in the range 25-85 nm. The ultrathin metal layer accounts for a very low electrical resistance (lower than a single TCO layer 10 times thicker) but high optical transmittance in the visible range. Also the flexibility benefits of the ductility of the metallic intralayer and of the very low thickness of the whole structure (about 100 nm) with respect to standard TCO. By properly choosing the thickness of the AZO top and bottom layers, we show as the optical reflectance of the film can strongly be lowered to match the requirements for a specific application (e.g. thin film photovoltaics). A step ahead is a similar multilayer but with a Ag mesh instead of a film, with benefits in terms of optical transparency and mechanical flexibility. To this end, we studied innovative IZO/Ag_mesh/IZO (IZO= In-doped ZnO) structures fabricated via colloidal lithography. Well-defined Ag grids were realized by covering an IZO film with a single layer of polystyrene spheres (1.6 μm in diameter) through the Langmuir-Blodgett process: we fabricated IZO/Ag/IZO multilayers having different Ag grids in terms of thickness and mesh openings. We found excellent electrical properties and a significant enhancement of the infrared transmittance (R_s=16.4 Ω/□ and $\overline{T}_{300-1300} = 66\%$) with respect to state-of-art transparent electrodes. In summary, we show how very thin TCO/Ag/TCO multilayers, with selected thickness of the two AZO layers and only 10 nm of Ag, or with Ag mesh, produces one of the most electrical reliable, structural flexible and optically tunable material to be employed as TE.