Transparent and flexible electrodes based on metallic nanowire networks for optoelectronic devices

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Abstract

Transparent conductive thin films are widely used in technologies like solar cells, light-emitting diodes, and display technologies. The fabrication of transparent conductive films is currently realized with thin films of transparent conductive oxides (TCOs), and in particular indium tin oxide (ITO). The as-made ITO transparent conductors suffer from limitations like costly fabrication process and brittleness. The use of solution-processable nanomaterials appears as a promising alternative since it affords a large area, low-cost deposition method with high performances. In the past few years, extensive efforts have been performed to develop flexible transparent electrodes based on metallic nanowires and in particular silver nanowires (Ag-NWs) [1]. Among metals, silver has the highest thermal conductivity and the lowest electrical resistivity, thus it is a good candidate for fabrication of transparent conductive electrode.

Thanks to the polyol method, silver nanowires are rather easy to make in large amount from semi-batch solution reactions [2]. A simple decantation process has been developed to remove remaining nanoparticles and organics instead of tedious and time-consuming centrifugation steps. The mean length of nanowires is ~10 µm and diameters are in the 50-100 nm range (see figure 1). Very high aspect ratios are necessary to allow fabrication of percolating random networks with very good transparency and electrical conductivity.

Ag-NWs dispersed in methanol have been spin-coated or spray-coated on flexible substrates (see figure 1). The sheet resistances of the electrodes are measured by a four probe resistivity meter and the transmittance by a UV-Vis-NIR spectrophotometer. In the standard process, sheet resistance of only few tens of Ohm.sq^{-1} are achieved above 90% of transmittance, which is comparable to the ITO performances.
As shown in figure 2, flexible electrodes present good mechanical properties, allowing small radius of curvature and stable sheet resistance after hundreds of flexions.

Thanks to their performances, silver nanowires are good candidates to be integrated into flexible optoelectronic devices [3]. A key point of these devices is the control of energetic level alignment to allow charge injection and collection between electrode and active materials. For that, the work function of silver nanowire networks should be tuned. This modulation can be made by covering the nanowires with a thin layer of metal oxide (ZnO, TiOx, WO_3,…), polymer layer or self-assembled monolayers (SAMs). Work function values measured by Kelvin probe force microscopy (KPFM) will be presented.

We will present our work dealing with the solution processed fabrication of random networks of Ag-NWs, made by printing process. The very low sheet resistance and high transparency of the flexible electrodes, that are comparable to those of ITO, allowed us to integrate them in various functional devices such as thermochromic displays [2], organic solar cells or touch screens [4] (see figure 3).

References

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Figures

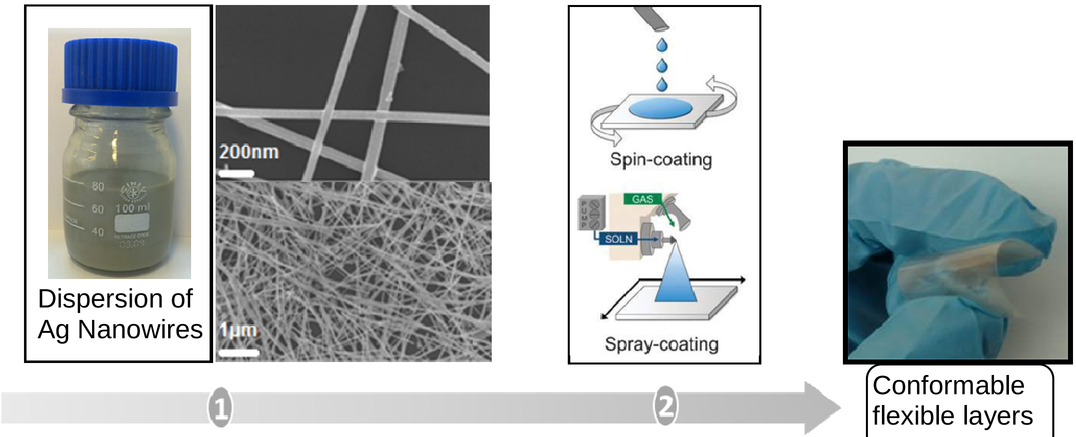

Figure 1: Fabrication process of transparent Ag NW Electrodes

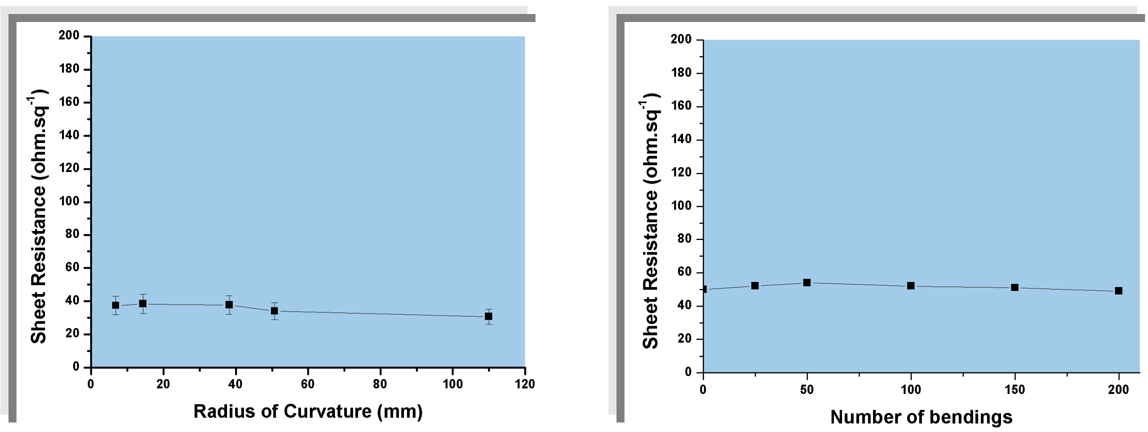

Figure 2: Mechanical properties of flexible silver nanowire based electrodes

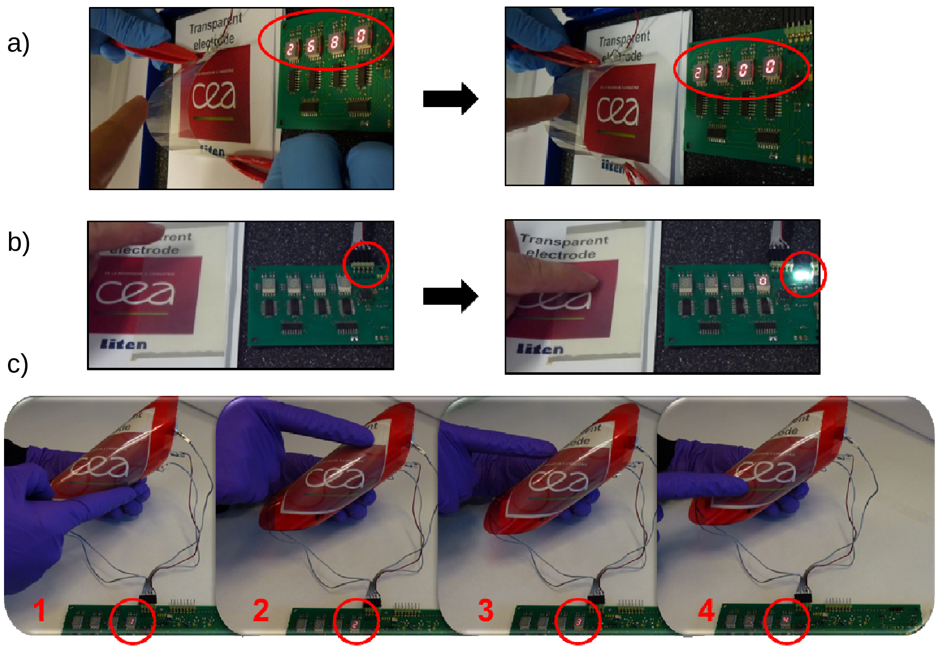

Figure 3: : Silver nanowire based transparent and flexible capacitive sensor a) Change of oscillation value by touching b) LED switching on c) Recognition of each electrode (1,2,3,4).