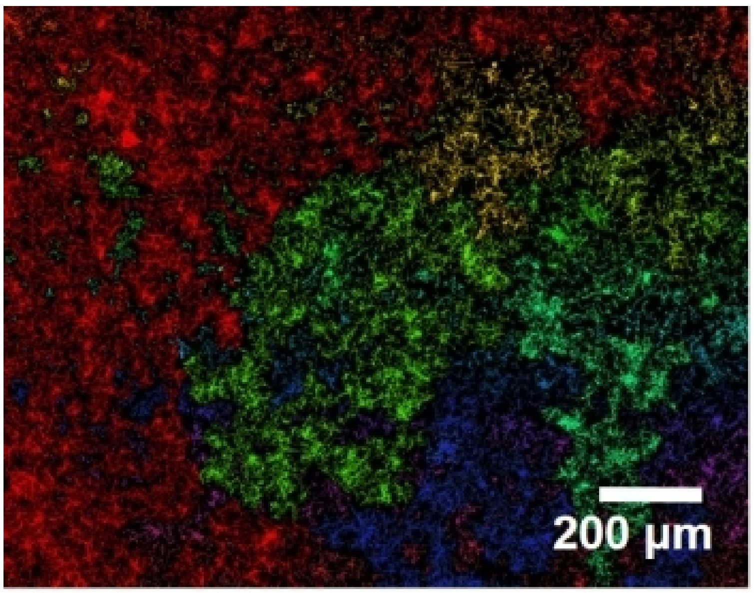
Transparent, electrically conductive network of encapsulated silver nanowires

July 31 2015



Quality map of the electrode: red regions are well connected. Credit: Elsevier in doi:10.1016/j.nanoen.2015.06.027

The electrodes for connections on the "sunny side" of a solar cell need to be not just electrically conductive, but transparent as well. As a result, electrodes are currently made either by using thin strips of silver in the form of a coarse-meshed grid squeegeed onto a surface, or by applying a transparent layer of electrically conductive indium tin oxide (ITO) compound. Neither of these are ideal solutions, however. This is because silver is a precious metal and relatively expensive, and silver particles with nanoscale dimensions oxidise particularly rapidly; meanwhile, indium is one of the rarest elements on earth crust and probably will only continue to be available for a few more years.

Mesh of silver nanowires

Manuela Göbelt on the team of Prof. Silke Christiansen has now developed an elegant new solution using only a fraction of the silver and entirely devoid of indium to produce a technologically intriguing electrode. The doctoral student initially made a suspension of silver nanowires in ethanol using wet-chemistry techniques. She then transferred this suspension with a pipette onto a substrate, in this case a silicon solar cell. As the solvent is evaporated, the silver nanowires organise themselves into a loose mesh that remains transparent, yet dense enough to form uninterrupted current paths.

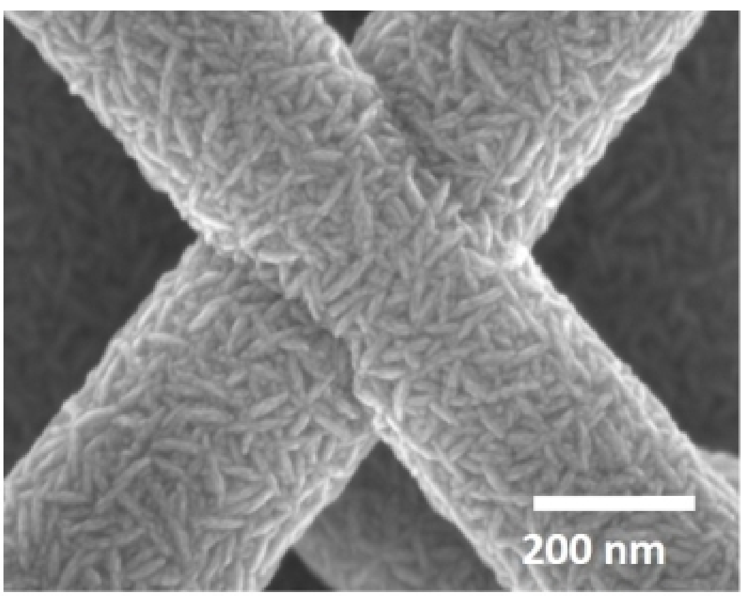
Encapsulation by AZO crystals

Subsequently, Göbelt used an atomic layer deposition technique to gradually apply a coating of a highly doped wide bandgap semiconductor known as AZO. AZO consists of zinc oxide that is doped with aluminium. It is much less expensive than ITO and just as transparent, but not quite as electrically conductive. This process caused tiny AZO crystals to form on the silver nanowires, enveloped them completely, and finally filled in the interstices. The silver nanowires, measuring about 120 nanometres in diameter, were covered with a layer of about 100 nanometres of AZO and encapsulated by this process.

Quality map calculated

Measurements of the electrical conductivity showed that the newly developed composite electrode is comparable to a conventional silver grid electrode. However, its performance depends on how well the nanowires are interconnected, which is a function of the wire lengths and the concentration of silver nanowires in the suspension. The scientists were able to specify the degree of networking in advance with computers. Using specially developed image analysis algorithms, they could evaluate images taken with a scanning electron microscope and predict the electrical conductivity of the electrodes from them.

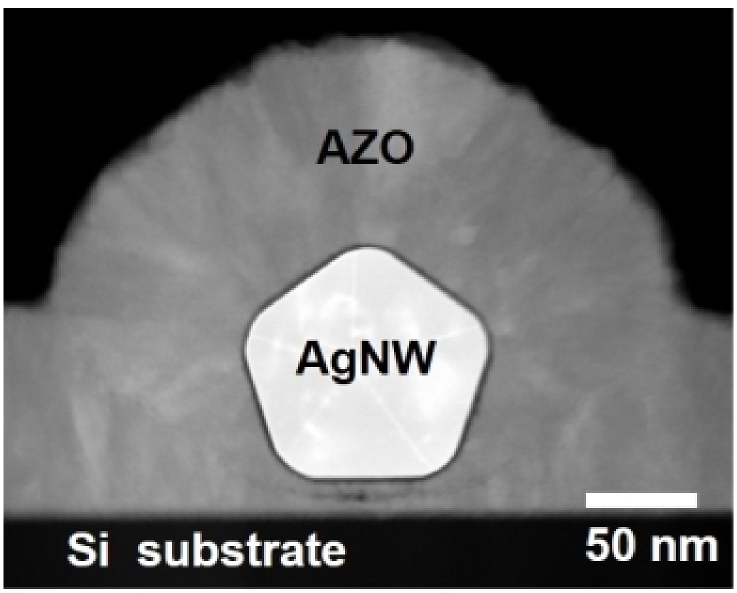
"We are investigating where a given continuous conductive path of nanowires is interrupted to see where the network is not yet optimum", explains Ralf Keding. Even with high-performance computers, it still initially took nearly five days to calculate a good "quality map" of the electrode. The software is now being optimised to reduce the computation time. "The image analysis has given us valuable clues about where we need to concentrate our efforts to increase the performance of the electrode, such as increased networking to improve areas of poor coverage by changing the wire lengths or the wire concentration in solution", says Göbelt.



A scanning electron microscopy of two crossing nanowires,covered with tiny AZO-crystals. Credit: Elsevier in doi:10.1016/j.nanoen.2015.06.027

Practical aternative to conventional electrodes

"We have developed a practical, cost-effective alternative to conventional screen-printed grid electrodes and to the common ITO type that is threatened however by material bottlenecks", says Christiansen, who heads the Institute of Nanoarchitectures for Energy Conversion at HZB and additionally directs a project team at the Max Planck Institute for the Science of Light (MPL).



A STEM-cross sectional image of an Silver-nanowire encapsulated by AZO. Credit: Elsevier in doi:10.1016/j.nanoen.2015.06.027

Only a fraction of silver, nearly no shadow effects

The new electrodes can actually be made using only 0.3 grams of silver per square metre, while conventional silver grid electrodes require closer to between 15 and 20 grams of silver. In addition, the new electrode casts a considerably smaller shadow on the solar cell. "The network of silver nanowires is so fine that almost no light for solar energy conversion is lost in the cell due to the shadow", explains Göbelt. On the contrary, she hopes "it might even be possible for the silver nanowires to scatter light into the solar cell absorbers in a controlled fashion through what are known as plasmonic effects."

More information: *Nano Energy* Volume 16, September 2015, Pages 196–206. DOI: 10.1016/j.nanoen.2015.06.027

Provided by Helmholtz Association of German Research Centres