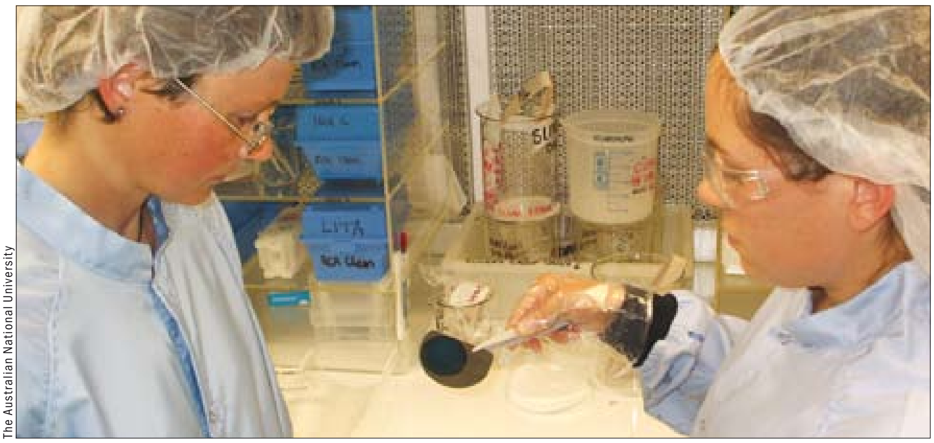
# Nanoparticles inspire plasmonic solar cells

Combining the properties of plasmonics with thin-film solar cell technology could disrupt the future of grid electricity. **Caryl Richards** talks to Kylie Catchpole at the Australian National University to find out more about advancements in plasmonic solar cells.

As demand grows for greener power generation and energy conservation, how can renewable technologies take on the might of goliaths of the fossil fuel industry? In the case of thin-film solar cells, the weapon of choice comes in the diminutive form of metallic nanoparticles. Thanks to a combination of the resonant plasmonic properties of metallic nanoparticles with thin-film photovoltaic technology, a new generation of plasmonic solar cell has evolved with similar performance to silicon cells but at potentially a fraction of the cost.

Today, plasmonic solar cells are emerging as promising candidates amongst many solar energy technologies spurring continuing research to improve device performance. One leading research group in this area is based at the Centre for Sustainable Energy Systems at the Australian National University (ANU) who are working alongside other principal groups led by Harry Atwater and Albert Polman at Caltech, California, US and the FOM-Institute, AMOLF, the Netherlands, respectively.

The group at ANU measured an enhanced photocurrent attributed to the increased trapping of light scattered into a thin-film silicon cell by silver metal nanoparticles excited at their surface plasmon resonance. Now, leading scientists in the field are looking to drive plasmonic solar cells out of the science of the small into the next big thing in the photovoltaics industry (*Optics Express* **16** 21793).



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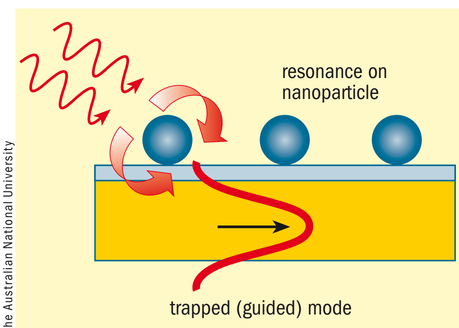


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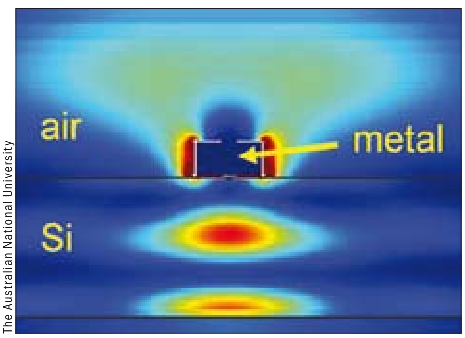


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**Top: Kylie Catchpole and Fiona Beck inspect a silicon wafer coated with silver nanoparticles. Bottom left: Light excites a surface plasmon resonance on a metal nanoparticle and is coupled into silicon. Bottom right: Simulation of increased light intensity beneath a metal nanoparticle on a silicon cell.**

### A thin slice of the solar industry

The global photovoltaic market as a whole looks set to ride out the economic downturn with a predicted growth hitting $2.4 bn in 2011 and $7.5 bn by 2015, according to a recent report by NanoMarkets. In spite of this fact, photovoltaics will only outshine existing methods of generating electricity if they can genuinely compete with current fossil fuel technologies in terms of cost and performance. This requires at the least halving the price of current solar cells.

Thin-film cells are made from a thin semiconducting layer – usually of amorphous or polycrystalline silicon, cadmium telluride or copper indium diselenide – deposited on a cheap glass, plastic or stainless steel substrate. Now, researchers believe that thin films will succeed as alternative energy sources by eliminating the need for thick and expensive silicon wafers.

"The thickness of the thin-film silicon solar cell is only 1 or 2 µm compared with the 200 µm for the wafer cells," Kylie Catchpole, research fellow at the ANU, told *OLE*. "That can dramatically reduce your materials cost as it reduces the amount of high purity semiconductor that you need."

However, while thin-film silicon solar cells are a cheaper alternative to silicon wafers the poor absorption of near-band-gap light remains a severe limitation on their performance.

"When you decrease the thickness that much, you also decrease the absorption," said Catchpole. "So for thin-film solar cells you really need to increase the absorption. For wafer-based solar cells there are already quite good ways for increasing the absorption but not for thin-film solar cells".

In line with this, the solar cells need to be structured so that light remains trapped inside to increase the absorption. For thin-film cells, the thickness range of a few microns is too small to support surface texturing commonly used in the wafer-based silicon cells where pyramids in the range of 2–10 µm are etched into the surface. This has prompted several research groups to look to alternative methods, one of which was to use the scattered light from the surface plasmon resonance of metallic nanoparticles on the surface of the thin-film cell.

According to Catchpole a texture on the surface of the thin-film solar cell can also reduce the maximum voltage produced by the cell through increased electron-hole recombination at the surface. Metal nanoparticles remain independent of the structure of the solar cell itself and so increase the absorption while leaving the electrical performance intact.

### Silver takes first place

The optical properties of metal particles have been a subject of great interest in the last few decades, especially with the potential applications of plasmonic resonances in integrated optics and biosensing.

At wavelengths near the plasmon resonance, metal nanoparticles are strong scatterers of light. A plasmon arises from the collective oscillation of the free electrons in the metal particle. For particles with diameters well below the wavelength of light, the absorption and scattering cross-sections can be described by those of a point dipole. At the surface plasmon resonance, the scattering cross-section is found to exceed the geometrical cross-section of the particle, thereby increasing the amount of light scattered into the cell.

Noble metals are ideal for this purpose as they do not have many interband transitions and do not absorb much light as a result. Significant enhancements in photocurrent measurements have been found using noble metals such as silver or gold. While the dielectric functions of silver and gold are reported to be very similar, the group at ANU believes silver to be the better choice due to its lower absorption and lower cost.

"What you want is for the light to come in, scatter from the nanoparticle and go into the solar cell. You really don't want the light to be absorbed in the metal particle itself," described Catchpole. "Silver is by far the best for that. Other metal particles tend to absorb the light just because of their atomic structure."

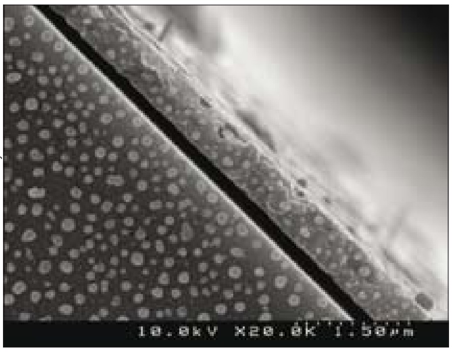
### Between the lines

While there are many techniques and materials for plasmonic solar cell fabrication, the group at the ANU uses boron-doped silicon solar cells and evaporates a layer of hemispherical silver nanoparticles close to 100 nm in size on the surface.

Starting with the silicon cell, an oxide is grown on the surface in an oxygen furnace at high temperature. The metal nanoparticles are then deposited on the thin-film silicon cells by vacuum evaporation. This process initially involves evaporating a thin silver film onto the cell surface and then heating the sample to 200 °C. Even though this is below the melting point of the metal, the layer is thin enough so that little blobs form under surface tension. This creates roughly evenly sized, evenly distributed particles on the solar cell surface.

In this way it is possible to cover any desired area with these very tiny particles. This would otherwise be a very difficult and expensive process were each individual particle to be made via techniques such as electron beam lithography.

This process also has the advantage of having no effect on the electrical perform-



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**A SEM image of silver nanoparticles on a solar cell, each averaging only 100 nm in diameter.**

ance of the solar cell and has no influence on the fabrication process of the solar cell itself (as metal evaporation is performed after the thin-film solar cell is made).

One of the main challenges that the group found, however, was getting the nanoparticles close enough to the surface of the cell. "Putting the nanoparticles extremely close to the silicon surface turned out to be very important for getting a good enhancement in the absoption," described Catchpole. "A difference of 20 nm makes a big difference in this situation. You need to have the metal nanoparticles really close to the surface and so we have had to understand how the absorption enhancement works to figure out what we really need to do with the particles."

Evaporating the metal particles to within the desired 20 nm of the silicon surface requires control over the thickness of the oxide layer grown on the cell surface. This can be achieved through controlling the temperature or duration of the oxidation process or by etching the oxide layer after it has been grown

## The future's bright?

According to Catchpole, progress in plasmonic solar cells has recently been dramatic thanks to a fuller understanding of plasmonics. "Plasmonics has become a big field. It is now possible to make nanoscale particles and nanoscale type structures, and so a lot of people have become interested in it. There has been work done to figure out what happens at that scale," she said.

Research into plasmonic solar cells is rapidly expanding, exploiting the benefits offered by plasmonics with those of thin-film technology.

Fabricating thin-film solar cells uses a lot less material and can take place on a very large scale – a big advantage for reducing the installation costs that form a significant part of the whole cost of a solar system.

One of the added advantages of using metal nanoparticles is that they are generally applicable to any thin-film solar cell irrespective of the underlying semiconductor be it a silicon or organic solar cell.

"It's essentially all about cost in the solar industry. Whatever you can do to lower the cost, that is what is going to win out in the end," added Catchpole. "There are a number of things that affect cost. It can be the efficiency of the cell or it can be the cost of the process, or how fast you can do the process. But all of these things are headed towards the reduced overall cost of the solar cells."

Research is ongoing into improving the performance, which includes looking into how differences in particle size and shape influence the photocurrent measurements. The group expects a commercial form of their solar cell to emerge in the next three years. □

*Kylie Catchpole is the group leader in nanophotonics at the Australian National University.*