Array of hope for silicon solar cells

A study of how light is absorbed by silicon nanowires of different shapes and composition - both singly and in arrays - has provided insights for designing more efficient solar cells. Contrary to current thinking, the results suggest that it may be possible to exploit the enhanced absorption of single nanowires when scaled up into arrays.

How well a solar cell converts light into electrical energy hinges on how well it absorbs light in the first place. And while the manufacture of photovoltaic devices based on silicon can benefit from decades of research and development in CMOS electronics, silicon's absorption properties are far from ideal.

"To date, the absorption efficiency of a crystalline Si-based solar cell is limited by the low absorption coefficient of Si, which is an intrinsic issue," explains Hong-Gyu Park of Korea University. However, as Park explains, silicon in the form of a nanowire offers much better absorption because the nanowire acts as an optical cavity that confines light – 'the antenna effect'. Harnessing this enhanced absorption could lead to low-cost, ultrathin solar-cell devices. "We wanted to understand the underlying principles and maximize light absorption in these nanowires," he adds.

In collaboration with Charles Lieber at Harvard University in the US and researchers at Kyung Hee University and Korea University in Korea, Park and his team embarked on a series of simulations to study how silicon nanowires absorb light and how the absorption is affected by the nanowire shape and composition, and when nanowires are packed into an array arranged either vertically or horizontally.

The work helped the researchers understand how the light was trapped in the nanowires, allowing them to determine which shapes and compositions would optimize the antenna effect. They were also intrigued to discover that the absorption continues to be enhanced when the system is scaled up from a single nanowire to an array.

Many researchers had thought the absorption efficiency of the array should be lower, since the antenna effect of a single nanowire vanishes on scaling up into an array. "This has been a lingering issue," Park explains. "However, in this work, we demonstrated that the absorption efficiency between a single
nanowire and a nanowire array is nearly the same because of an additional diffraction effect of a nanowire array."

The surprising result opens up the possibility of developing nanowire array solar cells in next-generation devices. To this end the authors plan to develop a nanowire alignment technique to scale up fabrication of a single nanowire to nanowire assembly over a wide area.

**Design strategies for shape and composition**

The researchers began with nanowires with hexagonal-shaped cross sections and three different silicon compositions: wholly crystalline; amorphous with a crystalline centre; or crystalline with an amorphous shell a certain distance between the centre and rim. They chose these types of nanowires because they are most readily fabricated experimentally.

Park explains why he and his colleagues considered the multishell nanowires and structures with a crystalline silicon core and a very thin amorphous Si layer. "Amorphous silicon generally has worse material quality than crystalline silicon, which hampers the diffusion of electrons and thus the carrier collection efficiency would be degraded." They also looked at nanowires with rectangular faces for comparison.

The team calculated the response of the nanowires to light using a numerical algorithm that calculates electromagnetic field values for discrete steps in space and time from Maxwell’s equations (the finite difference time domain algorithm). By mapping the calculated absorption across the nanowires for different shapes and compositions they were able to identify the light localization and antenna effects responsible for enhancing the absorption efficiency.

The researchers had noted from previous experimental work that precise control of nanowire composition and shape could dramatically affect the absorption properties. The results from these simulations will now allow the team to identify design rules for strategically tailoring nanowire absorption properties, and the next stage will be to demonstrate this approach experimentally. This should give insights into the feasibility of nano ‘tandem’ solar cells that use several photovoltaic material systems together, with each optimised to operate most efficiently over different bandwidths.

Details of the work are reported in *ACS Nano* (http://pubs.acs.org/doi/abs/10.1021/nn5003776)

**About the author**

Anna Demming is online editor of *nanotechweb.org*

**Further reading**

- Silicon nanowire based large-scale solar cells receive upgrade (July 2013) (http://nanotechweb.org/cws/article/lab/53942)
- Plasmonics and quantum dots team up for solar harvesting (Sep 2013) (http://nanotechweb.org/cws/article/lab/54813)
- Modified deposition structure delivers super-high density Si quantum dot thin film (July 2013) (http://iopscience.iop.org/0957-4484/labtalk-article/54066)