PHOTOVOLTAICS

More solar cells for less

A solar-cell design based on silicon microwires achieves efficient absorption of sunlight while using only 1% of the active material used in conventional designs.

Jia Zhu and Yi Cui

Supplying the world with energy in a sustainable manner is one of the most pressing issues in modern society. Converting the energy of sunlight into an easily usable form is one of the most attractive solutions because daily sunshine delivers energy to the Earth that is 10,000 times larger than present world energy consumption. Photovoltaic devices, which convert light into electricity, are therefore widely studied as a means to harvest solar energy. Although the photovoltaic industry has indeed seen a large growth rate in the past couple of decades, the energy produced by solar cells contributes to less than 0.1% of the world total energy consumption[1]. One of the main reasons for this is that solar electricity is still significantly more expensive than electricity generated traditionally by the burning of fossil fuels.

Writing in *Nature Materials*, Michael Kelzenberg and co-workers now report on an improved design for solar cells that requires 100 times less material than conventional wafer-based devices[2]. Moreover, despite using less material the conversion efficiency of these solar cells is close to that of conventional designs and may even be further improved. Eventually, designs like these could lead to significantly reduced costs of solar electricity generation.

To improve solar-cell operation a number of physical processes must be optimized[3]. A representative traditional planar solar-cell device is shown in Fig. 1a. When sunlight reaches the solar cell, some of the light is reflected back and lost, so that a special antireflection layer is needed to minimize the loss. This requires the use of a material with either a low refractive index or a textured morphology. Furthermore, the active semiconductor layer needs to be thick enough to harvest as many photons as possible. For crystalline silicon, an indirect bandgap semiconductor, the typical film thicknesses is 300 μm. And last but not least, the electrons and holes created by the absorbed photons must be separated and collected to generate electricity with minimum loss. How to maximize the efficiency of all these steps is a key area of research.

In the reported work[2], Kelzenberg and colleagues design a silicon microwire-array structure (Fig. 1b) that improves the efficiency of all three of the above processes. They used vertical microwire arrays grown by means of a process that was previously developed for growing silicon nanowires[4]. However, in the present case the microwires have a diameter of a few micrometres and a length of tens of micrometres. A key benefit of the microwire design is that the arrays can be embedded into a transparent polymer matrix, which allows the entire device to be peeled off from the crystalline silicon substrate to produce a flexible and free-standing film. The substrate can then be re-used for the growth of further devices.

The flexibility of the microwire films as well as their comparatively inexpensive fabrication method and reduced weight promises a number of applications, ranging from portable solar cells to large-area installations on roof tops. The potential for applications is further enhanced because a clever device design leads to very efficient light absorption. Specifically, the arrays were coated with silicon nitride as an antireflection coating, followed by the deposition of optically transparent Al_2O_3 nanoparticles. These nanoparticles scatter the incoming light towards the microwires so that light absorption is maximized. The entire microwire array functions as a highly efficient light trap in which sunlight makes several turns and travels horizontally for distances much longer than the array thickness.

The light-trapping mechanism enables near-complete absorption of sunlight above the silicon bandgap. This is a very exciting achievement, as the microwire array occupies only a small percentage of the device area, and despite this absorbs most of the incident sunlight with energies above the bandgap from a wide range of angles. In the present study the same absorption efficiency of planar devices is achieved with an equivalent of only 1% of the silicon material used in conventional designs. Moreover, the authors demonstrate that nearly all the charge carriers generated by the absorbed photons can be collected in a photoelectrochemical cell.

Nanowire and nanocone structures for solar-cell applications have of course been studied previously by several research groups[5–9], and there has also been a strong interest to explore these nanostructures for antireflection and light-trapping applications[8–9]. However, in comparison with such nanowire structures the microwire rods used by Kelzenberg and co-workers are much larger. The reason is that simulations predict that the optimal diameter for wires in such solar cells is on the order of the minority-carrier diffusion length, which in the case of low-purity silicon is several micrometres. Therefore, microwire arrays

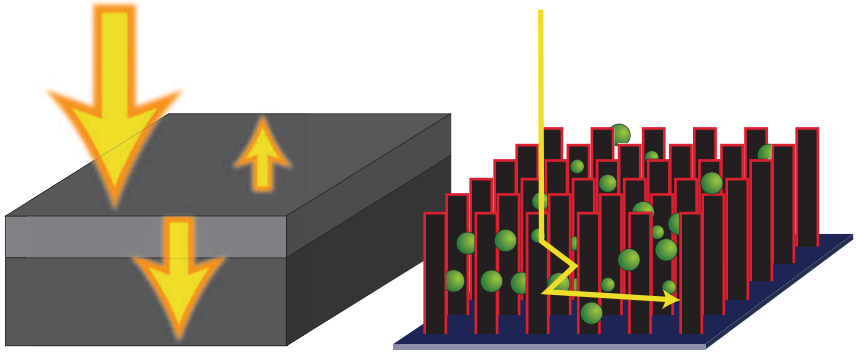

Figure 1 | Solar-cell light management. **a**, Conventional thin-film solar cells where incident light gets partially reflected. **b**, In the microwire arrays, Al_2O_3 nanoparticles (shown in green) reflect incident light and redirect it towards the micropillars.

turn out to be very efficient not only in the absorption of sunlight but also in the collection of charge carriers.

The concepts on light management demonstrated in this study can be applied to other solar-cell materials such as CdTe and $CuIn_{1-x}Ga_xSe_2$. These results therefore point towards a much cheaper way of generating solar electricity, while at the same time promising potentially higher absorption efficiencies. ❐

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MAGNETIZATION DYNAMICS

Ferromagnets stirred up

Conflicting observations of the speed at which various ferromagnetic materials respond to an external femtosecond laser excitation have generated considerable controversy. It is now shown that ferromagnets can be divided in two categories, according to the values of specific magnetic parameters.

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The speed at which magnetic data-storage elements can be manipulated is ultimately dependent on the elementary spin-scattering processes and how they influence the demagnetization of the material used in new femtosecond laser-writing schemes[1]. High-power femtosecond lasers have allowed this speed to be reduced to below the 100 fs range. In 1996, Beaurepaire *et al.*[2] showed that ferromagnetic Ni could demagnetize within a few hundred femtoseconds following an external excitation. The result was in strong contrast to the expectations at that time. It was believed that the maximum speed of demagnetization was determined by the interaction of the spins with the lattice, which is a rather weak interaction. On the other hand, materials with a much slower demagnetization were observed. These are materials with a weaker magnetic ordering and therefore lower Curie temperature (T_C), such as Gd, FeTb (refs 3,4 and M. Wietstruk *et al.*, submitted), as well as some magnetic oxides and half-metals[5].

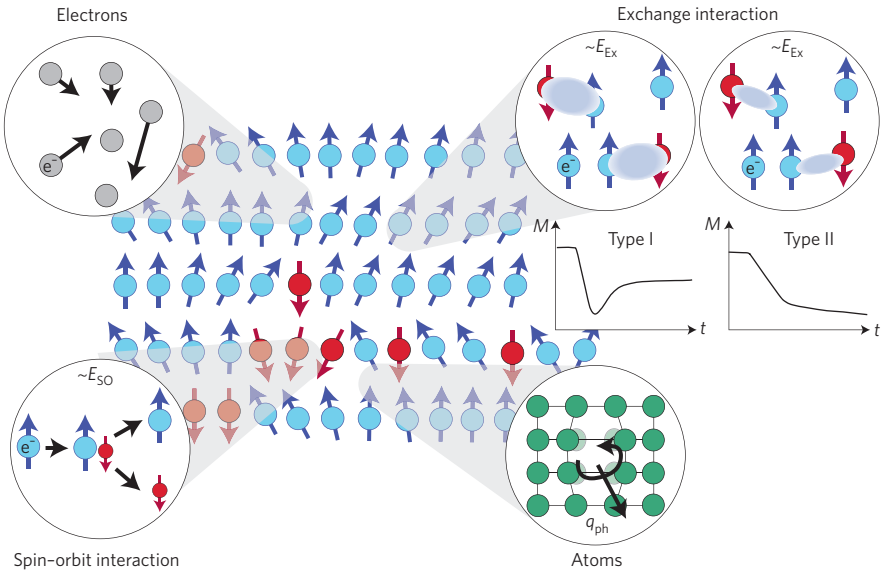

Figure 1 | Frozen image of a heated-up ferromagnet. The magnified schematic shows the situation after excitation by a femtosecond laser pulse. Type I and II materials are classified by a stronger or weaker magnetic interaction in the electron system, respectively. In the inset graphs, for each case the corresponding behaviour of the magnetization *M*, fast demagnetization and two-step demagnetization is depicted. The magnetic exchange interaction is denoted by E_{Ex}; the spin–orbit interaction is denoted by E_{SO}. The dynamics of the atoms is determined by the phonon's momentum (q_{ph})

Unfortunately, no successful quantitative approach to describe femtosecond dynamics has been presented over the years. It should be emphasized that any such model has to take into account a rather complex system of interdependent interactions among photons, electrons, phonons and magnetic fluctuations on different length scales as schematically depicted in Fig. 1. Reporting in *Nature Materials*, Bert Koopmans and coauthors[6] have now used a description of the electron, phonon and spin dynamics that, despite being relatively simple, allowed them to pinpoint the main spin-scatter mechanisms and to explain why different materials have different ultrafast demagnetization times. The model is based on a thermodynamic treatment of the fluctuations in the spin system, known as mean-field Weiss model, and an oscillator model to describe the dynamics of the atoms. They derived a simple expression connecting the demagnetization time τ_M to the spin-flip scattering parameter a_{sf}, and the ratio between T_C and the magnetic momentum per atom μ_{at}. The spin-flip scattering parameter a_{sf} is related to the elementary femtosecond spin-scattering mechanism of the electron system, determining the thermal coupling between electrons and the spin of the electron. The second key indicator, T_C/μ_{at}, describes the magnetic interaction strength within the spin system itself. It is connected to the magnetic fluctuations that arise when a material is approaching its ferromagnetic transition. Such fluctuations occur on