Self-assembling solar arrays as easy as mixing oil and water

Researchers modify tiny solar "chiplets" to get them to self-assemble, driven by the free energy of their interactions with an oil-water interface.

By John Timmer | Last updated January 11, 2010 7:19 PM

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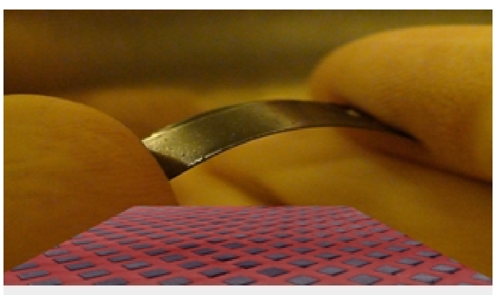
Heiko O. Jacobs

Modern manufacturing techniques generally require high degrees of control and intervention to get materials linked together in precise configurations. But researchers have become interested in the prospect of self-assembling systems, which can simplify existing manufacturing and allow us to produce devices on the nanoscale. Above a certain size it's possible to use gravity to drive self-organization; on the nanoscale it's possible to use chemical processes, like the base pairing of DNA, to drive the assembly process. That leaves an awkward range of devices on the micrometer scale in between that aren't heavy enough for gravity to drive assembly, but too big to be pushed around by substances like DNA. A paper that will appear in *PNAS* describes how it's possible to use an oil-water interface to drive the self-assembly of 20 micron silicon solar chips into a functional array.

To give some context, this is a problem that goes well beyond academic interest. The authors, Robert Knuesel and Heiko O. Jacobs, note that a lot of the silicon in a typical photovoltaic cell isn't active—it's there to provide structural support. And, although silicon isn't expensive compared to many metals, there are certainly cheaper materials out there that could replace it, lowering the cost of devices. It should also be possible to incorporate small photovoltaic chips into flexible and transparent materials, much as was done with LEDs, which could greatly increase the places where solar devices could be deployed.

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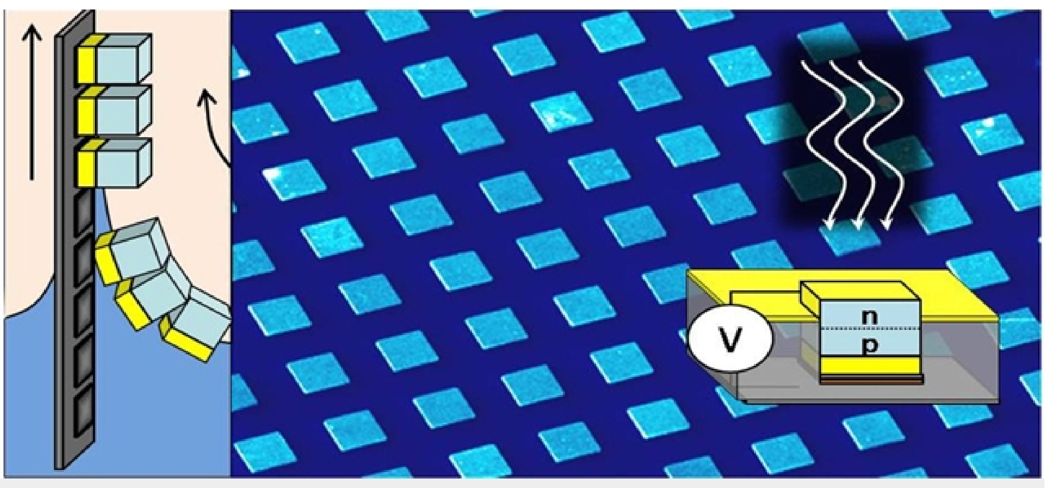
The photovoltaic devices used in this case are small silicon cubes, 20-60μm on a side, and have a gold contact on one face. The authors referred to these as "chiplets." These are light enough that the force imparted by gravity is quite small, but heavy enough that brownian motion shouldn't be a major problem. The authors then set about creating a set of conditions where the free energy of the two interfaces (silicon and gold) should dominate the behavior. So they coated the gold surface with an organic acid to make it hydrophilic, and used an organic methoxy-silane reaction to enhance the hydrophobic properties of the silicon.

When placed in an oil-water mixture, these modified chiplets will self-organize into tightly packed arrays at the interface between them, driven by the free energy. Put in terms of milliJoules per square meter, the gold surface-water interactions are favored by roughly $-55mJ/m^2$. The silicon surface prefers interacting with oil by another $7mJ/m^2$, making the spontaneous organization quite favorable, and far stronger than the forces of gravity or Brownian motion.

Of course, it's not simply feasible to leave the chiplets floating in a solution—they need to be hooked up to a conducting surface if the electricity they produce is to be harvested. Here, things were quite easy; provided the mixture was kept at 95°C, it's possible to find solders that will remain molten. Interactions between the gold and the solder is a whopping $400mJ/m^2$ more favorable than the water-gold interactions, meaning the chiplets should spontaneously link up with the solder and displace any water between them.

The actual process the authors developed involved creating a propylene-terepthalate (PET) polymer surface covered in a thin copper sheet. Squares the size of the chiplets were etched into the PET, and the exposed copper was coated with solder simply by dipping the sheet in a bath of it. With the solder in place, the sheet was simply drawn slowly through the oil/water/chiplet mixture, and the chiplets spontaneously occupied the solder-filled holes. The authors were able to fill about 98 percent of the surface with chiplets by making several passes through the oil-water mix at 30mm/second. That may not sound like it was that fast, but they were able to assemble about 62,000 chiplets in three minutes.



The self assembly process (left) and the results (right).
Image courtesy of study author Heiko O. Jacobs.

Once assembled, the researchers simply layered some epoxy on top of the chiplets, locking them into place, and added a second conducting electrode layer. The resulting device operated nearly as efficiently as single, isolated chiplets. The devices could also handle bending without a significant drop in performance—the authors attribute the differences to the fact that bending the device took some of the chiplets out of direct illumination, dropping their power output.

All told, their device reduces the silicon needed in the final product by a factor of 10, largely replacing it with cheap polymers. The authors also demonstrated devices with different spacing, irregular substrates, and triangular chiplets, showing the technique's flexibility. Greater automation of the process, they suggest, could probably improve the yields and speed of manufacture.

It's difficult to tell how this will play out, because the cost-performance ratio in photovoltaics seems to be changing on a weekly basis, with silicon competing with various forms of thin-film metallic materials. Still, it's likely that different technologies will find homes in specialized applications, and a flexible polymer is likely to have advantages in some use cases.

But the approach itself may be as important as this specific result. Some people working in the area have suggested that the problem with photovoltaics won't be manufacturing enough capacity; it will be hooking what we can manufacture into the grid fast enough, a problem that has led to the suggestion that a form of self-assembling solar paint will ultimately be required. This sort of simplified self-assembly may be a step in that direction.

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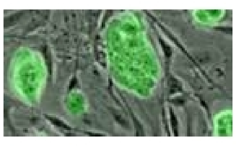
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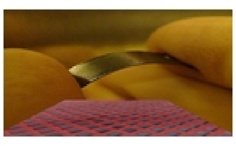
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