Energy Focus

Peel-and-stick method transfers thin-film solar cells

Thin-film solar cells are currently prepared on temperature-resistant substrates due to the relatively high temperatures required for their fabrication. For this reason, they have been traditionally formed on thick silicon wafers or glass. The weight and rigidity of both these types of substrates greatly limits the range of applications of these solar cells in terms of portability, and also impedes their price for the end user. While thinner, flexible substrates are being explored to replace silicon during the fabrication process, they still need to be temperature-resistant. To dissociate the problem of the high-temperature deposition of the photovoltaic layers from the versatility required for commercialization, C.H. Lee from Stanford University, D.R. Kim from Hanyang University, N. William from the US National Renewable Energy Laboratory, and their colleagues recently introduced a way to efficiently transfer amorphous silicon thin-film solar cells from the fabrication substrate onto a variety of different substrates, including glass, paper, and plastic.

This technology is akin to transfer stickers favored by children. The thin-film solar cell is initially fabricated on a silicon substrate, and is then transferred onto a flexible intermediate transfer holder made of thermal release tape before being attached on the end substrate. Finally, the intermediate is removed by gentle heating (90°). As described in the December 2012 issue of *Nature's Scientific Reports* (DOI: 10.1038/srep01000), the key element of the transfer process is a 300 nm layer of nickel deposited between the silicon substrate and the actual solar cell. Once the solar cell is ready and tested, the transfer holder is attached on top and the covered solar cell is placed in a water bath at room temperature. The nickel layer unbinds from the silicon surface, thus separating the solar cell from its heavy fabrication substrate, as is shown in the figure. The solar cell can then be stuck onto a variety of end substrates.

Very importantly, the researchers show that the solar cells do not lose efficiency subsequent to the transfer process and that bending of the transferred thin-film solar cells does not degrade the photovoltaic performances.

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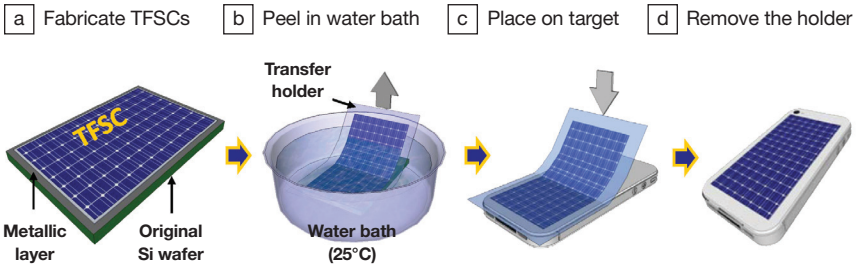
The "peel-and-stick" process to transfer thin-film solar cells to the end substrate. TFSC is thin-film solar cell. Reproduced with permission from *Sci. Rep.* DOI:10.1038/srep01000. © 2012 Macmillan Publishers Ltd.



Nano Focus

Two-dimensional dielectric monolayer grown on metal-supported graphene

The formation of continuous interfaces between graphene and dielectric materials, as is required for fabrication of various integrated devices, is problematic due to dewetting and thermal instability; most materials do not wet graphene because it has a low-energy surface. Recently, however, M. Batzill and co-researchers from the University of South Florida grew a complete monolayer of yttria (Y_2O_3), which displays a high dielectric constant, on Pt-supported graphene. The researchers showed that even though the Y_2O_3 monolayer interacts weakly with graphene, it is stable at high temperatures. Furthermore, their procedure is consistent with the growth of graphene on metal surfaces, so it holds the potential for large-scale heterostructure fabrication.

Batzill and co-researchers report in the December 23, 2012 issue of *Nature Nanotechnology* (DOI: 10.1038/NNANO.2012.217) that a uniform, two-dimensional, yttria monolayer was grown on graphene supported on a clean Pt(111) single crystal, using reactive vapor deposition at room temperature. Ordered structures appeared only after annealing above 550°C but characterization by LEED, STM, x-ray photoemission spectroscopy (XPS) and Auger electron spectroscopy (AES) was presented for samples annealed up to 700°C. The researchers showed that the graphene layer remains intact with no formation of covalent bonds between graphene and yttria. However, the yttria layer maintains rotational registry with the graphene, indicating a preferential alignment with respect to each rotational domain.

In order to test their expectation that yttria growth on other metal-supported graphene substrates is similar to that on Pt(111)-graphene, the researchers grew yttria films on graphene supported on Ni(111) and Ir(111) substrates. Measurement of the oxygen to carbon ratios as functions of deposition time gave values identical to those observed for yttria/graphene/Pt(111), demonstrating monolayer growth. Commenting on their results, the researchers said that "yttria functionalization of graphene may be incorporated into the formation of large-scale graphene wafers on various metal supports. Such yttria monolayers may act as an atomic buffer or nucleation layers between graphene and other materials in subsequent processing steps. "

Steven Trohalaki

Nano Focus

Theoretical thermocrystals control heat like sound

Martin Maldovan of the Massachusetts Institute of Technology has produced a theoretical framework that could lead to improved control of heat flow in materials. Thermocrystals, comprising alloys containing nanoparticles, are materials that can manipulate thermal energy flow by exploiting the coherent reflections of phonons from internal surfaces. Potential applications including heat waveguides, heat lensing, thermal diodes, and thermal cloaking may become possible.

"The theory outlines a completely new way of manipulating heat," Maldovan says. "When they created photonic crystals, it was a completely new way of manipulating light. Then, they created phononic crystals as a completely new way to manipulate sound. This is equivalent to that, but for heat."

The key to the theory, as reported in the January 11 issue of *Physical Review Letters* (025902; DOI: 10.1103/PhysRevLett.110.025902), is to transfer thermal energy flow from standard short wavelength particle transport to long wavelength wave transport—to make "heat behave like light," according to Maldovan. Particle transport occurs when a phonon hits an interface and scatters diffusely in all directions. Wave transport happens when a phonon hits an interface and reflects and transmits coherently, like light in a mirror. Most of the time, heat phonons are scattered diffusely when they encounter an interface because their wavelengths are so small. For coherent scattering to occur, the interface has to be almost perfect (defect –free), rendering it almost impossible to make.

Instead of trying to make the perfect interface, Maldovan decided to try to make the phonon wavelength larger by reducing its frequency. Such phonons should transmit and reflect like light from even an imperfect interface.

From previous experience, Maldovan knew that in thermoelectrics, researchers use alloys and nanoparticles in order to block *all* frequencies of phonons. In this work, he used $Si_{1-x}Ge_x$ alloys with Ge nanoparticles to block only select frequencies. The mass-difference scattering in the alloy blocks some high-frequency phonons, and the nanoparticles block another portion. "I use the nanoparticles in such a way to kill only the really high-frequency phonons," he says, "so the nanoparticles in my case must be very, very small." In this work, he considered Ge nanoparticles with 1 nm diameter.

After killing the high-frequency phonons, Maldovan's theory was still left with a large number of wavelengths of heat that it could not handle, so he decided to narrow the frequency range by requiring the material to be a thin film, which kills the very low phonon frequencies. Having chopped off the highest and lowest frequencies, the heat that was left was concentrated into a narrow, intermediate band of wavelengths. Specifically, for $Si_{90}Ge_{10}$ thermocrystal thin films containing Ge nanoparticles, the heat spectrum was concentrated into a relatively narrow, low frequency window between 0.1 THz and 2.0 THz. Up to 40% of this heat was restricted to a narrow hypersonic range of 100–300 GHz.

Next, Maldovan investigated the design of periodic structures in the thin films to better manage the flow of this narrow range of heat frequencies, effectively engineering the thermal bandgap of these materials to match the heat frequency range. He found that by patterning the film periodically with lattice constants of 10 nm and 20 nm, the material could be tuned so that up to 23% (for two-dimensional patterning) of the thermal transport could be carried by phonons with frequencies in the engineered thermal bandgaps.

"The idea was that once I had the heat concentrated in a window, I wanted to match those frequencies for heat to the bandgap of a phononic crystal,"Maldovan says. "Then I can control heat as if it is sound."

Future work will include collaborating with experimental materials scientists to try to produce thin films that might verify this theory. Maldovan says that although he focused on Si in this article, the theory is applicable to a wide range of materials, which he hopes experimentalists will be interested in exploring.

Tim Palucka