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Beyond Silicon: Cutting the Costs of Solar Power

New method of fabricating semiconductors from gallium arsenide promises more affordable solar power, improved semiconductor devices.

The biggest single barrier to widespread adoption of solar power continues to be the cost of solar cells. University of Illinois materials scientists supported by the DOE Office of Science have scored a breakthrough in this area that could help transform the economics of solar power. They have devised a cost-effective means of fabricating solar photovoltaic cells from an alternative material nearly twice as efficient as today's silicon-based semiconductors in converting sunlight to electricity. Their technique could be especially helpful in easing the economics of large-scale solar deployments by utility companies. In time, it could have application to many of today's countless other semiconductor-based technologies.

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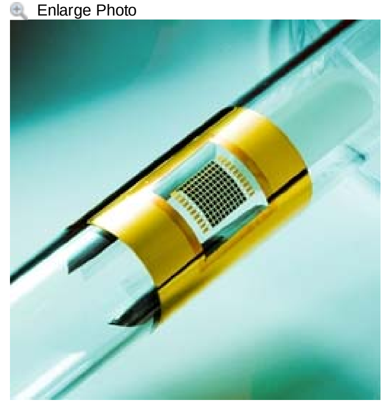

Courtesy of University of Illinois

Mechanically flexible, high efficiency solar module that uses an interconnected array of microscale GaAs photovoltaic cells, grown in a multilayer stack on a wafer and then printed onto a sheet of plastic.

Today silicon dominates the semiconductor industry, and it is also the industry standard semiconductor for photovoltaic cells. But it is hardly the most efficient material available for photovoltaics, converting the sun's energy to electricity at an average efficiency of only about 20 percent. Cells based on compound semiconductors, such as the compound gallium arsenide, convert sunlight to electricity nearly twice as efficiently as silicon. So far, however, these materials have made little headway in the marketplace because of the high-cost specialized growth techniques that are required to fabricate device-quality layers of them.

U. of I. professors John Rogers and Xiuling Li recently demonstrated more cost-effective ways to grow high-quality gallium arsenide semiconductors and to build unusual classes of solar panels that offer promise for use in utility-scale power generation.

"If you can reduce substantially the cost of gallium arsenide and other compound semiconductors, and the ways that these materials are used and incorporated into devices, then you could expand their range of applications," said Rogers, the Lee J. Flory Founder Chair in Engineering Innovation at the university, and a professor of materials science and engineering and of chemistry.

Typically, gallium arsenide is grown in a single thin layer on a small wafer. The desired devices are then made directly on the wafer, or the wafer is cut up into chips of the needed size and then manipulated with robotic pick-and-place tools. These methods are poorly suited for the sort of bulk manufacturing needed in large-scale applications such as photovoltaics because it is time-consuming and expensive to produce and use even a relatively small amount of material. Furthermore, the wafer substrate, which often does not play an active role in the device, is consumed in the process, adding further to the cost.

The U. of I. group developed a way to increase the manufacturing volume and speed, and to free the gallium arsenide from the wafer in manner that bypasses its size and mechanical property constraints. To accomplish these outcomes, they begin by depositing multi-layer stacks of material on a single wafer, creating a thick, layered, "pancake" stack of gallium arsenide thin films, each separated from one another by "sacrificial" layers that can be subsequently removed. In this manner, bulk quantities material can be formed in a single growth process, and the released materials can then be assembled onto a target substrate for device integration.

In a paper published recently in the journal *Nature*, the group described these methods and demonstrated their use in three types of devices: infrared cameras, high-speed electronics, and solar cells. The authors also provided a detailed cost comparison.

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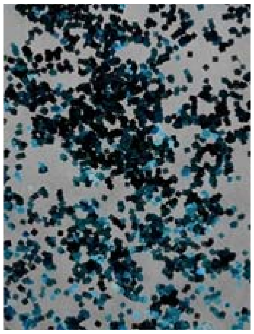
"If you grow 10 layers in one growth, you only have to load the wafer one time," said Li, a professor of electrical and computer engineering. "If you do this in 10 growths, loading and unloading with temperature ramp-up and ramp-down take a lot of time. If you consider what is required for each growth—the machine, the preparation, the time, the people—the overhead saving our approach offers is a significant cost reduction."

Once the stack is made, the researchers individually peel off the layers and transfer them. To make the separation possible, the researchers alternate layers of aluminum



Courtesy of University of Illinois

Large collection of microscale GaAs solar cells, released from a multilayer stack of material grown on a wafer.

arsenide with the gallium arsenide. Bathing the stacks in a solution of acid and an oxidizing agent dissolves the layers of aluminum arsenide, freeing the individual thin sheets of gallium arsenide, which is more resistant to the solution. A soft stamp-like device picks up the layers one at a time from the top down for transfer to another substrate, such as glass, plastic or silicon, depending on the application. Then the wafer can be reused for another growth—yet another cost-saving advantage.

"By doing this we can generate much more material more rapidly and more cost effectively," Rogers said. "We're creating bulk quantities of material, as opposed to just the single-layer manner in which it is typically grown."

Layers with varying functionalities can also be grown on the same stack. The researchers can grow layers of gallium arsenide specially designed for transistors, LEDs, sensors or solar cells in the same step. Rogers envisions a stack that contains all the components of a functional system, for example, an array of transistors that are acting as switches for an array of LEDs in a display. They could grow a stack with LEDs on top, transistors on bottom, peel them off, and lay out the LEDs and then the transistors.

As the layers are removed from the stack, they can be laid out in dense or sparse configurations, in small or large pieces, on another substrate to cover a much larger surface area, whereas the typical single-layer process limits area to the size of the wafer. The process can also be used with a wide-range of device substrate types, such as plates of glass or sheets of plastic, the latter enabling thin, lightweight, and mechanically flexible solar modules, for instance.

"For photovoltaics, you want large area coverage to catch as much sunlight as possible. In an extreme case, we might grow enough layers to have 10 times the area of the conventional single-layer route," Rogers said. "You really multiply the area coverage, and by a similar multiplier you reduce the cost, while at the same time eliminating the consumption of the wafer," he said. The advantages become even more significant if the layers themselves are sliced into small pieces that are then distributed in sparse arrays.

Semprius Inc., a North Carolina-based startup company, is using this type of approach under license to manufacture solar panels that contain collections of thousands of tiny photovoltaic cells, each the size of the head of a pin, made of compound semiconductors. Miniaturized focusing lenses direct sunlight onto these cells, to form integrated modules. The resulting technology appears to have potential as a cost-effective form of alternative energy. A first commercial system was delivered to Tucson Electric Power Company in summer 2010, and has cumulatively generating more than 1 MW of power, at remarkably high efficiencies. Semprius is currently scaling up their manufacturing infrastructure to increase its capacity.

Next, the U. of I. group plans to explore more device applications in solid-state lighting and other areas, by exploiting these same ideas with other semiconductor materials and film configurations.

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