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Discovery could dramatically boost efficiency of perovskite solar cells

可以显著提高钙钛矿太阳能电池效率的发现

Nanoscale images yield surprise that could push efficiency to 31 percent

纳米级图像展示惊喜可以推动钙钛矿电池效率到 31%

Date: July 4, 2016
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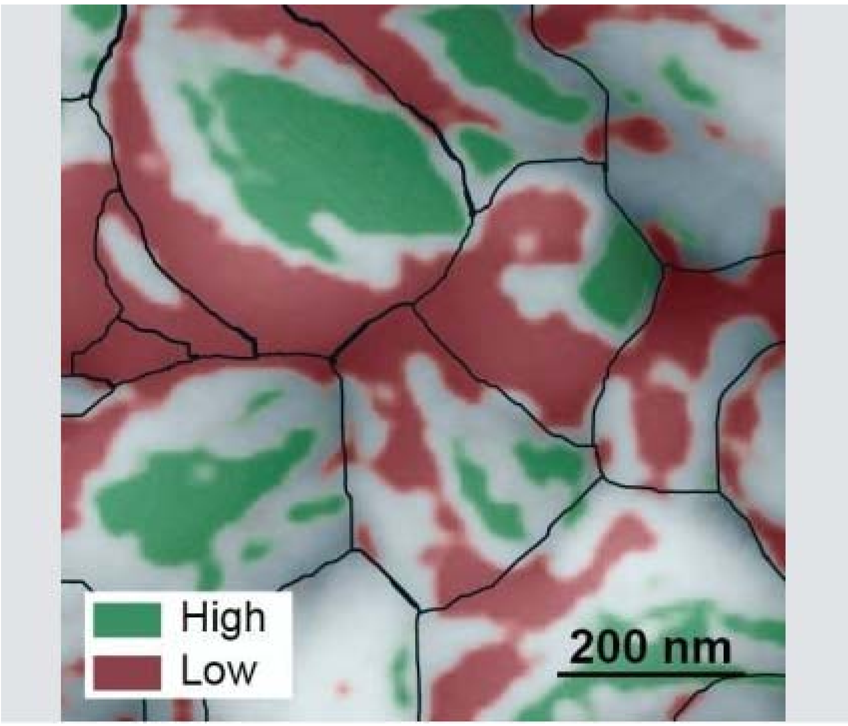
Summary: Scientists have discovered a possible secret to dramatically boosting the efficiency of perovskite solar cells hidden in the nanoscale peaks and valleys of the crystalline material.

科学家发现了一种可能显著提高钙钛矿太阳能电池效率的秘密，这种秘密隐藏在晶体材料的纳米级峰谷之中。



This atomic force microscopy image of the grainy surface of a perovskite solar cell reveals a new path to much greater efficiency. Individual grains are outlined in black, low-performing facets are red, and high-performing facets are green. A big jump in efficiency could possibly be obtained if the material can be grown so that more high-performing facets develop.
Credit: Berkeley Lab

钙钛矿太阳能电池晶粒表面的原子力显微镜图像揭示了提高钙钛矿电池效率的新路径。图中单个晶体之间以黑色轮廓线区分，表现不佳的晶面呈红色状，高性能的晶面则是绿色。如果这种材料能长成更多高效晶面的话，效率上的大飞跃很有可能实现。

Scientists from the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) have discovered a possible secret to dramatically boosting the efficiency of perovskite solar cells hidden in the nanoscale peaks and valleys of the crystalline material.

来自能源部洛伦兹伯克利国家实验室的科学家们发现了一种可能显著提高钙钛矿太阳能电池效率的秘密，这种秘密隐藏在晶体材料的纳米级峰谷之中。

Solar cells made from compounds that have the crystal structure of the mineral perovskite have captured scientists' imaginations. They're inexpensive and easy to fabricate, like organic solar cells. Even more intriguing, the efficiency at which perovskite solar cells convert photons to electricity has increased more rapidly than any other material to date, starting at three percent in 2009 -- when researchers first began exploring the material's photovoltaic capabilities -- to 22 percent today. This is in the ballpark of the efficiency of silicon solar cells.

由矿物质钙钛矿晶体结构的化合物制备而成的太阳能电池激发了科学家的想象力。它们价格低廉又易于制造，就像有机太阳能电池。更有趣的是，在钙钛矿太阳能电池转换光子为电能时，这种效率的提升比其它任何材料更加迅速. 从 2009 年研究者第一次开始探索钙钛矿材料的光伏电池性能时的 3%上升到今天的 22%. 这已经和硅太阳能电池的效率相当。

Now, as reported online July 4, 2016 in the journal *Nature Energy*, a team of scientists from the Molecular Foundry and the Joint Center for Artificial Photosynthesis, both at Berkeley Lab, found a surprising characteristic of a perovskite solar cell that could be exploited for even higher efficiencies, possibly up to 31 percent.

目前，据 2016 年 7 月 4 日《自然能源》期刊在网上的报道，来自劳伦斯伯克利国家实验室和人工光合作用联合中心的科学团队，两个团队都是伯克利实验的，他们发现了一个钙钛矿太阳能电池的惊奇特性，该特性可以被利用开发更高效率的电池，很有可能让效率上升至 31%。

Using photoconductive atomic force microscopy, the scientists mapped two properties on the active layer of the solar cell that relate to its photovoltaic efficiency. The maps revealed a bumpy surface composed of grains about 200 nanometers in length, and each grain has multi-angled facets like the faces of a gemstone.

通过使用光导原子力显微镜，科学家们绘制了与太阳能电池活性层上光伏性能相关的两种参数。 图片显示由颗粒状组成的一个凹凸不平的表面， 长度大约在 200 纳米，并且每一个晶粒具有多个晶面，就像一个宝石的表面。

Unexpectedly, the scientists discovered a huge difference in energy conversion efficiency between facets on individual grains. They found poorly performing facets adjacent to highly efficient facets, with some facets approaching the material's theoretical energy conversion limit of 31 percent.

科学家们出乎意料的发现了能量转换效率在各个晶粒晶面之间存在巨大的差异。他们发现性能不佳的晶面与高性能晶面相邻，同时一些晶面达到材料的理论能量转换极限 31%。

The scientists say these top-performing facets could hold the secret to highly efficient solar cells, although more research is needed.

尽管还是需要更多的研究，科学家们判断这些高性能晶面隐藏着使太阳能电池效率提高的秘密。

"If the material can be synthesized so that only very efficient facets develop, then we could see a big jump in the efficiency of perovskite solar cells, possibly approaching 31 percent," says Sibel Leblebici, a postdoctoral researcher at the Molecular Foundry.

来自劳伦斯伯克利国家实验室的博士后研究人员指出：如果这种材质能被合成，从而只制备高效性能的晶面，我们将会在钙钛矿太阳能电池效率上看到一个大的飞跃，有可能接近 31%。

Leblebici works in the lab of Alexander Weber-Bargioni, who is a corresponding author of the paper that describes this research. Ian Sharp, also a corresponding author, is a Berkeley Lab scientist at the Joint Center for Artificial Photosynthesis. Other Berkeley Lab scientists who contributed include Linn Leppert, Francesca Toma, and Jeff Neaton, the director of the Molecular Foundry.

在 Alexander Weber-Bargioni 实验室工作的 Leblebici，是报道此次研究的通讯作者。Ian Sharp 也是一名通讯作者，他还是 Berkeley Lab 联合中心的科学家。Berkeley Lab 中其他有贡献的科学家还包括 Linn Leppert, Francesca Toma，以及 Molecular Foundry 的董事 Jeff Neaton。

A team effort 团队的努力

The research started when Leblebici was searching for a new project. "I thought perovskites are the most exciting thing in solar right now, and I really wanted to see how they work at the nanoscale, which has not been widely studied," she says.

当 Leblebici 在为一个新项目做研究的时候，这个研究就开始了。她说道："我认为钙钛矿是目前太阳研究中最令人激动的发现，我真的想要看一下它是怎样在纳米量级工作，即使这还没有被广泛研究。"

She didn't have to go far to find the material. For the past two years, scientists at the nearby Joint Center for Artificial Photosynthesis have been making thin films of perovskite-based compounds, and studying their ability to convert sunlight and CO2 into useful chemicals such as fuel. Switching gears, they created pervoskite solar cells composed of methyl ammonium lead iodide. They also analyzed the cells' performance at the macroscale.

她不需要从其它地方去寻找材料。在过去的两年中，附近的人工光合作用联合中心的科学家制成了钙钛矿结构化合物的薄膜，并且研究这种材料将日光和二氧化碳转化为有用化学物质的可能，如燃料。通过切换，他们制备了由甲基氨碘化铅合成的钙钛矿太阳能电池。同时，他们也分析了电池的宏观性能。

The scientists also made a second set of half cells that didn't have an electrode layer. They packed eight of these cells on a thin film measuring one square centimeter. These films were analyzed at the Molecular Foundry, where researchers mapped the cells' surface topography at a resolution of ten nanometers. They also mapped two properties that relate to the cells' photovoltaic efficiency: photocurrent generation and open circuit voltage.

科学家同时也制成了第二组没有电极层的半成品电池，他们将八块电池制作在一平方厘米的膜层上。通过在 Molecular Foundry 中心分析这些薄膜，研究膜层表面形态的分辨率为 10 纳米。他们同时也绘制了与电池光伏效率相关的两种参数：光电流和开路电压。

This was performed using a state-of-the-art atomic force microscopy technique, developed in collaboration with Park Systems, which utilizes a conductive tip to scan the material's surface. The method also eliminates friction between the tip and the sample. This is important because the material is so rough and soft that friction can damage the tip and sample, and cause artifacts in the photocurrent.

通过与 Park Systems 合作，科学家使用最先进的原子力显微镜技术，利用导电探针扫描钙钛矿材料表面。这种方法可以消除了探针和样品之间的摩擦，这点非常重要，因为这种材料表面粗糙而且很软，摩擦会损害探针与样品，这会产生错误的光电流响应。

Surprise discovery could lead to better solar cells

惊奇的发现会让太阳能电池越来越好

The resulting maps revealed an order of magnitude difference in photocurrent generation, and a 0.6-volt difference in open circuit voltage, between facets on the same grain. In addition, facets with high photocurrent generation had high open circuit voltage, and facets with low photocurrent generation had low open circuit voltage.

实验结果显示在相同晶粒的不同晶面上，光电流响应会有一个数量级差异，开路电压会有 0.6 伏的差异。另外，有高光电流响应的晶面也有一个高的开路电压输出，低光电流响应的晶面开路电压也不高。

"This was a big surprise. It shows, for the first time, that perovskite solar cells exhibit facet-dependent photovoltaic efficiency," says Weber-Bargioni.

Weber-Bargioni 说“这是一个大的惊喜。这表明，钙钛矿太阳能电池第一次展示了晶粒不同晶面会产生不同光电转换效率。”

Adds Toma, "These results open the door to exploring new ways to control the development of the material's facets to dramatically increase efficiency."

Adds Toma“这些结果打开了一栓门：寻找新的方法来控制钙钛矿材料晶面的生长，这可以显著提高转换效率。”

In practice, the facets behave like billions of tiny solar cells, all connected in parallel. As the scientists discovered, some cells operate extremely well and others very poorly. In this scenario, the current flows towards the bad cells, lowering the overall performance of the material. But if the material can be optimized so that only highly efficient facets interface with the electrode, the losses incurred by the poor facets would be eliminated.

实际上，这些晶粒的晶面就像数以亿计的微小太阳能电池，并联在一起。科学家的发现，一些电池非常好，而另一些电池则不佳。在这种情下，电流流向不好的电池，这会降低钙钛矿材料的整体光电转换性能。但是如果这种材料能被优化，仅使高效率晶粒晶面与电极相接，那么不好晶粒晶面导致的损失将会被消除。

"This means, at the macroscale, the material could possibly approach its theoretical energy conversion limit of 31 percent," says Sharp.

“这也意味着，在宏观上，这种材料有可能接近其理论能量转换极限 31%。”Sharp. 说。

A theoretical model that describes the experimental results predicts these facets should also impact the emission of light when used as an LED. Linn Leppert, Sebastian Reyes-Lillo, and Jeff Neaton performed this particular work.

一个描述实验结果的理论模型预测这些晶粒晶面也将影响发光，如果用这类材料制备 LED 器件。Linn Leppert, Sebastian Reyes-Lillo, 和 Jeff Neaton 完成了此次特定工作。