PHOTOVOLTAICS

Solar cells on curtains

Crystalline silicon solar cell arrays on flexible, transparent substrates may lead to unconventional new applications.

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Photovoltaic devices directly convert solar energy into electricity, and thus are highly attractive for a wide range of applications. Although the energy harvested by solar cell technology accounts for only about 0.04% of today's global energy consumption[1], it is one of the fastest-growing energy sectors, in part because of the vast research and development efforts that have been undertaken in recent years for pursuing clean, renewable energy. On page 907 of this issue[2], John Rogers and colleagues report on a technique that may contribute to this expansion of solar energy, as they demonstrate the integration of silicon solar cell modules on highly flexible, lightweight polymer substrates (Fig. 1), by using a simple transfer printing technique, previously pioneered by the same researchers.

Solar energy is one of the most abundant natural sources of energy. For instance, the total solar energy that bombards the United States alone is about 20,000 times higher than the energy needed to power the entire country, and yet most of this energy is lost without ever being harvested. In recent years, considerable improvements have been made to the efficiency of inorganic and organic photovoltaics through materials innovation and device engineering. Silicon photovoltaic devices, however, remain the dominant technology in the market owing to the natural abundance of silicon (leading to relatively low costs), and its high reliability, ease of processing and high efficiency. For these reasons, there is great interest in exploring new Si-based structures in non-conventional approaches to broaden the application spectrum. In this area, Rogers and colleagues offer a versatile approach for achieving flexible, crystalline Si photovoltaics with user-defined, tunable properties.

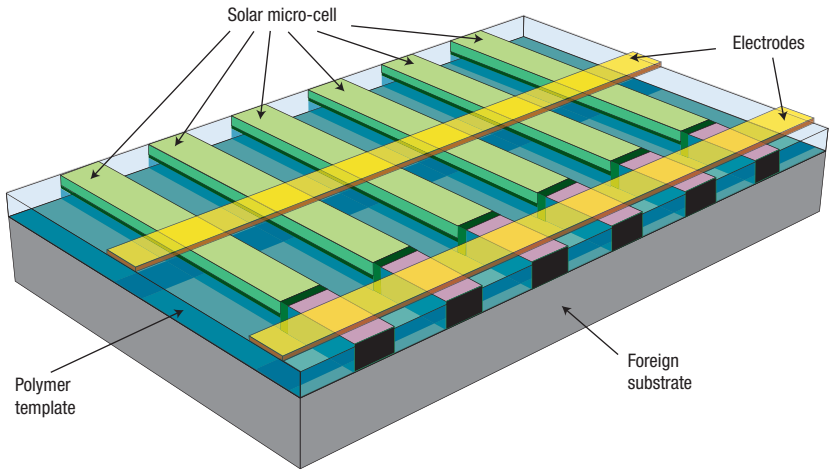

Figure 1 Schematic diagram of a flexible photovoltaic device based on crystalline silicon micro-cells. The solar micro-cells are first fabricated on a bulk silicon wafer and are transferred to a plastic substrate by a printing process.

In their work, solar micro-cells are first fabricated on bulk silicon wafers by using conventional lithography and doping techniques. The fabricated micro-cells have thicknesses down to about 100 nm and widths down to a few micrometres, and are suspended on the source wafer with minimal anchoring by means of a wet etch process. Following the fabrication processing, these micro-cells are transferred to a soft, elastic stamp, and then printed on a foreign substrate, such as a plastic or glass. Given the right thickness of silicon combined with the use of backside reflectors, individual micro-cells demonstrate a respectable conversion efficiency of 4–13%.

Uniquely, the surface coverage of the printed silicon micro-cells on a transparent substrate determines the total conversion efficiency, as well as the transparency of the final module. Specifically, the researchers demonstrate the modulation of transparency from 35% to 70% by varying the solar micro-cell spacing from 26 μm to 170 μm. This unique feature may have important implications for certain applications where some transparency is desirable, such as for windows of buildings.

The concept of flexible solar cells has been around for many years. In the past, however, most efforts for flexible applications have focused on solution-processed organic and nanocrystal films. Although tremendous progress has been made in this field, and it remains an exciting and active area of research[3], the relatively poor performance and stability of organics have limited their commercialization. But crystalline, inorganic semiconductors with high efficiency and robustness can also be made flexible if they are trimmed to small scales and transferred to flexible support substrates. In recent years, various approaches for printing crystalline thin films, micro-strips and nanowires on a wide range of foreign substrates, including plastics, have been successfully demonstrated[4–7]. As Rogers and colleagues have now shown, mechanically flexible and monocrystalline Si cells can indeed offer both high versatility and performance. An important feature is that most of the fabrication steps, including high-temperature doping and etching, are carried out on bulk silicon wafers using well-established Si processing. After the transfer of the micro-cells onto the

final substrate, electrode metallization is the only step needed to create fully operational devices. Therefore, the choice of the support substrate is not limited. Additionally, as this approach uses minimal crystalline Si material for light absorption and energy harvesting and uses well-established Si fabrication processing, in principle it offers a cost-effective route for large-scale manufacturing.

The work by Rogers and colleagues demonstrates a unique strategy for producing highly efficient, lightweight, low-cost and mechanically flexible solar cells based on ultra-thin, single-crystalline Si. The quest for lower cost, higher performance and more versatile photovoltaics continues, and this work offers us an interesting technique that could open up whole new areas of application.

References

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DRUG DELIVERY

The heart of the matter

A polymeric delivery vehicle, with neutral degradation products, keeps inflammation at bay during sustained drug release following myocardial infarction.

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Controlled drug delivery is a field dedicated to the spatial and temporal release of therapeutically active agents into the body. One approach for managing drug release rates is to embed the drug within a hydrolytically degradable material of micrometre dimensions, generally polymers that erode on injection, much like a bar of soap in water (Fig. 1). The rate of polymer erosion controls the rate of drug release. One challenge associated with this paradigm is that the by-products of polymer erosion, often acidic in nature, can lead to significant local inflammation. Although an intrinsic inflammatory response is not troublesome for some sites of injection (for example, intramuscular), such a response limits the use of these polymeric materials for some diseases, such as myocardial infarction. An undesired inflammatory response in the myocardium can lead to tissue fibrosis and diminished cardiac function. On page 863 of this issue, Davis and co-workers directly address the problem of inflammation in the treatment of myocardial infarction using a polymer-based delivery system[1].

The field of controlled drug delivery has matured over recent decades with the development of new matrix materials in a range of polymer classes including, but not limited to, polyesters[2,3], polyanhydrides[4], polyorthoesters[5] and polycarbonates[6,7]. Both acute and chronic biocompatibility is of

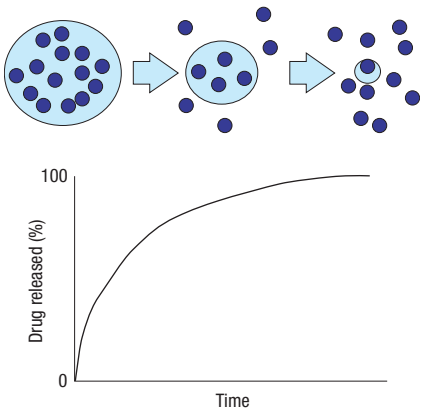

Figure 1 Drug release from a degradable matrix. The rate of drug (dark blue) release from erodible microspheres (light blue) is governed by the rate of matrix degradation. Faster erosion leads to faster release.

paramount importance for the development of matrix materials. One approach towards improving biocompatibility is to build polymers from materials that are readily metabolized by the body. Polyesters based on lactic acid and glycolic acid (PLGA) are primary examples of these, but although their degradation products can be metabolized, they are acidic and cause local inflammation (Fig. 2a).

For the controlled release of the drug, Davis and co-workers use a micrometre-sized delivery vehicle made of a polyketal[8]. The polyketal degrades into non-acidic by-products, and therefore the local inflammatory response to the polymer is minimal (Fig. 2b). By using this polymer, Davis and colleagues envisaged reducing the natural inflammation response in the myocardium that occurs after infarction. Inside the polyketal delivery vehicle is an inhibitor of the p38 mitogen-activated protein kinase (MAPK) pathway — a signalling pathway that has a central role in the inflammatory response by altering macrophage activation and death.

Davis and co-workers hypothesized that the effect of infarction on cardiac function could be attenuated if the inhibitor of the p38 MAPK pathway was released in a sustained local fashion within the myocardium at the site of infarct. This hypothesis was supported by their data that showed that the controlled release of the inflammatory inhibitor significantly inhibited the p38 pathway within the infarct zone, whereas injection of free inhibitor had no effect. As a result of their size (~20 micrometres), the polyketal microspheres were found to remain within the myocardium for several days, thereby allowing the p38 inhibitor to bathe the infarct area over time. Functionally, the fractional shortening (a ratio of the left ventricle's diameter when contracted and relaxed) of treated animals was significantly improved compared with untreated controls. More importantly, in a direct head-to-head comparison, p38 inhibitor released from polyketal microspheres was extraordinarily superior to the same compound released from PLGA microspheres. The superiority of the polyketal in this animal model of myocardial infarct can be attributed to a diminished formation of tissue fibrosis owing to the neutral degradation products of the polyketal compared with the acidic degradation products of PLGA.