Solar power from plastics?

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Colorful plastic panels collect and focus sunlight onto small solar cells, offering architects great design freedom in integrating solar-energy systems into the built environment.

Seamless integration of photovoltaics (PVs) into the built environment has proved a challenge. Limited adaptability in color, shape, and size, as well as costs associated with the standard silicon-based solar panel, have often failed to satisfy architects’ requirements for flexibility in design and esthetics. Recent research has rediscovered the potential of luminescent solar concentrators (LSCs) to bring solar-energy generation to homes and offices.

The LSC was originally suggested over 30 years ago and is very simple in concept. It consists of a plastic plate filled or topped by luminescent molecules that can absorb incident sunlight and re-emit it at longer wavelengths. A fraction of this light becomes trapped in the plastic plate through total internal reflection. The emitted light concentrates at the plate edges (see Figure 1), where small, efficient PVs for light conversion are placed. Traditional concentrators relying on focusing mirrors are often too unwieldy for easy integration into buildings and must track solar motions to be effective. LSCs do not need to track the sun and work equally well in both direct sunlight and diffuse environments. They can be made thin, thus reducing weight and allowing flexibility. The panels can be ‘cut to shape’ and made in a variety of colors.

So what has slowed the widespread use of LSCs? It all boils down to one simple aspect: the losses have simply been too high, thus limiting efficiency. Ten major loss mechanisms affect LSCs (see Figure 1). Over the past five years, there has been renewed interest in these devices and a number of laboratories have taken on the challenge of enhancing LSC efficiency.

Borrowing from research into liquid-crystal (LC) displays, my colleagues and I have applied LCs to LSC design to manage light ingress/egress and manipulate the direction of light emission. More than 50% of absorbed photons are lost through the top and bottom surfaces. To recover these photons, we have applied solution-processed wavelength-selective mirrors to LSC surfaces, specifically a polymeric chiral nematic (cholesteric) LC that is transparent to wavelengths absorbed by the dyes but reflective to wavelengths emitted by the dyes (see Figure 2). To date, we have recycled 35% of the photons that had been lost into useful output and are pursuing ways of fabricating broader-band cholesterics that should significantly enhance the harvesting of these stray photons. Similar results are reported by employing inorganic-based mirrors, but we believe that cholesterics hold advantages, primarily in their ease of application.

To enhance edge emission, we employed LCs for alignment of the fluorescing molecules. The dyes are dipolar in nature and, therefore, tend to emit in restricted directions, primarily perpendicularly to their absorption axis. By aligning the dyes in a plane, we enhance edge emission from two edges of a waveguide, thus obtaining 25% more energy than from any single LSC edge using isotropic dyes. This way, we can reduce the number of edges requiring PVs from four to two or one.

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As an extension of the LSC setup, we have exploited the potential for transparency by incorporating a ‘dye guest/LC host’ concept in a switchable system that is to be used as a ‘smart’ window. The windows are two glass panels filled with the dye/LC mix. By applying electric fields, the mixture may be switched between absorbing and nonabsorbing states, thus modulating light transmission while simultaneously generating electrical current by employing waveguides to channel emitted light to the integrated PV cells at the panel edges.

Current measured LSC efficiencies are moderate (~4.6% using PVs on one edge of a 5×5cm² waveguide), but the potential for the modified devices is great, at only minimal additional cost or processing. Given their adaptability, one can envision an enormous range of uses, including wall tiling, sound barriers, light poles, and bus-stop roofing. LSCs could bring solar-energy generation to the built environment and become a ubiquitous part of our everyday lives. Continuing work involves patterning the dye layers to reduce re-absorption losses, improving the cholesteric layers, and extending the LSC absorption range in an effort to make the device cost-competitive with both silicon-based PV panels and the grid itself.

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References