on, but differs from, a standard configuration known in the art as that of the Littman-Metcalf design. Whereas heretofore, a flat feedback mirror would be used to select a single laser output wavelength, in the present case, a curved feedback mirror is used to select multiple wavelengths. Preferably, the feedback mirror is cylindrical or spherical and is positioned with its center of curvature at the point of diffraction (the intersection of the laser beam with the diffraction grating).

In this configuration, each wavelength component diffracted from the grating is reflected from the mirror back to the point of diffraction. Thus, many wavelength components are simultaneously oscillating in the external cavity. The wavelength range is determined by the range of angles intercepted by the mirror; hence, the wavelength range can be adjusted by moving the mirror to a different position on the diffraction circle. The zeroth-order output of the diffraction grating is used as the laser output.

The length of the external cavity (including the mirror radius) determines the longitudinal mode spacing. It is preferable to make this spacing smaller than the wavelength resolution of tunable filter, so that for the purpose of filtering, the ECDL spectrum can be regarded as continuous.

*This work was done by Jeffrey S. Pilgrim of Southwest Sciences, Inc. for* **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17486-1.*

# High-Efficiency Solar Cells Using Photonic-Bandgap Materials

## Energy-conversion efficiencies exceeding 50 percent may be possible.

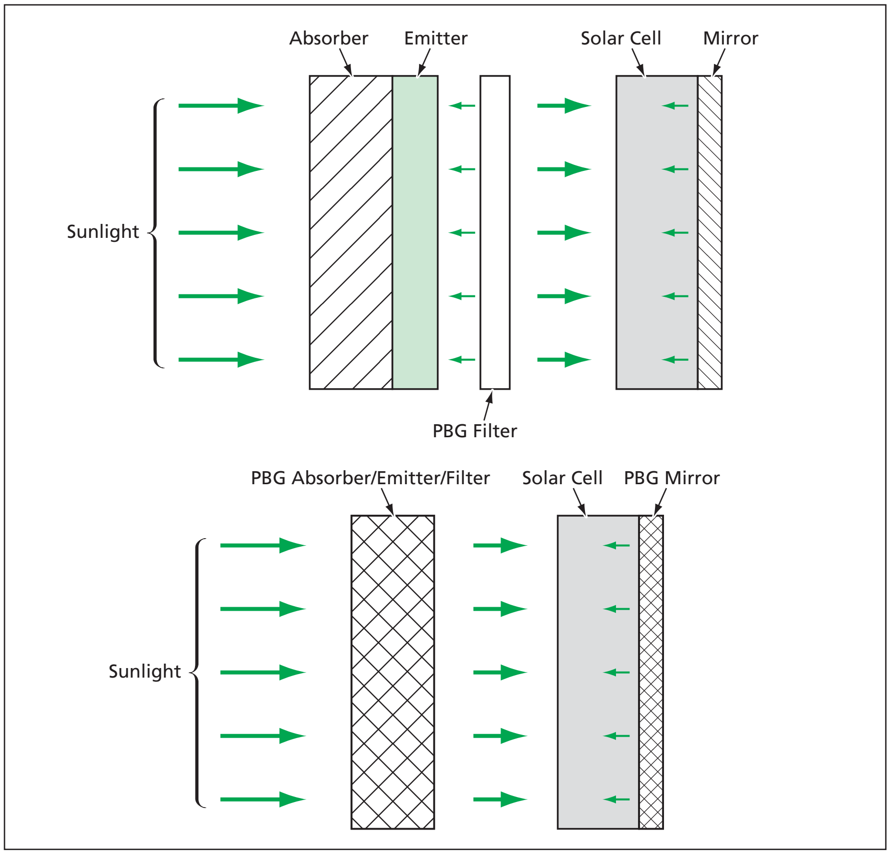
*NASA's Jet Propulsion Laboratory, Pasadena, California*

Solar photovoltaic cells would be designed to exploit photonic-bandgap (PBG) materials to enhance their energy-conversion efficiencies, according to a proposal. Whereas the energy-conversion efficiencies of currently available solar cells are typically less than 30 percent, it has been estimated that the energy-conversion efficiencies of the proposed cells could be about 50 percent or possibly even greater.

The primary source of inefficiency of a currently available solar cell is the mismatch between the narrow wavelength band associated with the semiconductor energy gap (the bandgap) and the broad wavelength band of solar radiation. This mismatch results in loss of power from both (1) long-wavelength photons, defined here as photons that do not have enough energy to excite electron-hole pairs across the bandgap, and (2) short-wavelength photons, defined here as photons that excite electron-hole pairs with energies much above the bandgap. It follows that a large increase in efficiency could be obtained if a large portion of the incident solar energy could be funneled into a narrow wavelength band corresponding to the bandgap. In the proposed approach, such funneling would be effected by use of PBG materials as intermediaries between the Sun and photovoltaic cells.

The approach involves a thermophotovoltaic principle in addition to the use of PBG materials. The basic idea is to tailor the wavelength- and direction-dependent emissivity of one or more PBG material(s) such that as much as possible of the wavelength-mismatched portion of the incident broad-band solar power would be absorbed — the absorbed power would cause heating, and the resulting thermal radiation would be funneled into a narrow band corresponding to the bandgap of the semiconductor material of a solar cell. Recent experiments unrelated to the development of solar cells have shown that as much as half of the thermal power could be thus re-routed into the bandgap.

The figure depicts two of many conceivable configurations for implementing the proposal. In one configuration,



**PBG Materials Could Be Utilized** in these and other configurations to increase the energy-conversion efficiencies of solar cells.

the incident solar radiation would be intercepted by an absorber and absorbed energy would be re-radiated by an emitter. A filter behind the emitter would allow primarily bandgap-energy photons to pass through and would reflect most other photons back into the absorber, helping to keep the absorber hot. A mirror at the rear surface of the solar cell would reflect any remaining non-bandgap-energy photons back to the absorber. The filter would be made of a PBG material: the advantage to be gained by using a PBG filter instead of a traditional optical filter is that a PBG structure could be designed to modify the wavelength distribution of thermal radiation from a conventional blackbody distribution to reduce or increase the spectral power densities at selected wavelengths.

In the other configuration, the functions of the absorber and filter would be combined in a single monolithic PBG absorber/emitter that could comprise, for example, thin absorbing layers alternating with thin non-absorbing, wavelength-selective layers. Optionally, the mirror behind the solar cell could also be made of a PBG material.

*This work was done by Jonathan Dowling and Hwang Lee of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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