

Nanolaminate Mirrors With “Piston” Figure-Control Actuators

Lightweight adaptive imaging mirrors can be built faster than can heavier glass mirrors.

NASA's Jet Propulsion Laboratory,
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Efforts are under way to develop a special class of thin-shell curved mirrors for high-resolution imaging in visible and infrared light in a variety of terrestrial or extraterrestrial applications. These mirrors can have diameters of the order of a meter and include metallic film reflectors on nanolaminate substrates supported by multiple distributed piezoceramic “piston”-type actuators for micron-level figure control. Whereas conventional glass mirrors of equivalent size and precision have areal mass densities between 50 and 150 kg/m², the nanolaminate mirrors, including not only the reflector/shell portions but also the actuators and the backing structures needed to react the actuation forces, would have areal mass densities that may approach ≈5 kg/m². Moreover, whereas fabrication of a conventional glass mirror of equivalent precision takes several years, the reflector/shell portion of a nanolaminate mirror can be fabricated in less than a week, and its actuation system can be fabricated in 1 to 2 months.

The engineering of these mirrors involves a fusion of the technological heritage of multisegmented adaptive optics and deformable mirrors with more recent advances in metallic nanolaminates and in mathematical modeling of the deflections of thin, curved shells in response to displacements by multiple, distributed actuators. Because a nanolaminate shell is of the order of 10 times as strong as an otherwise identical shell made of a single, high-strength, non-nanolaminate metal suitable for mirror use, a nanolaminate mirror can be made very thin (typically between 100 and 150 μm from the back of the nanolaminate substrate to the front reflecting surface). The thinness and strength of the nanolaminate



A Cu/Cu₂Zr, Nanolaminate was fabricated on a super-polished low-thermal-expansion glass form.

are what make it possible to use distributed “piston”-type actuators for surface figure control with minimal local concentrated distortion (called print-through in the art) at the actuation points.

Nanolaminate mirror substrates are fabricated in a direct replication process that consists of magnetron sputtering on precise, optical-quality master tools. As a result, the mirror substrates as manufactured (see figure) have nearly optical quality. Because nanolaminates are metals, their coefficients of thermal expansion are greater than those of the low-thermal-expansion glasses ordinarily used to make precise curved mirrors. Hence, backing structures should be made

of materials with coefficients of thermal expansion matching those of the nanolaminate mirror shells. The actuators could be used to compensate for any residual thermally induced surface-figure distortions up to a few microns.

This work was done by Andrew Lowman, David Redding, Gregory Hickey, Jennifer Knight, Philip Moynihan, and Shyh-Shiuh Lih of Caltech and Troy Barbee of Lawrence Livermore National Laboratory for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-30222

Mixed Conducting Electrodes for Better AMTEC Cells

These electrodes conduct both electrons and sodium cations.

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Electrode materials that exhibit mixed conductivity (that is, both electronic and ionic conductivity) have been investigated in a continuing effort to improve the performance of the alkali metal thermal-to-electric converter (AMTEC). These electrode materials are intended primarily for use on the cathode side of the sodium-ion-conducting solid electrolyte of a sodium-based AMTEC cell. They may also prove useful in

sodium-sulfur batteries, which are under study for use in electric vehicles.

An understanding of the roles played by the two types of conduction in the cathode of a sodium-based AMTEC cell is prerequisite to understanding the advantages afforded by these materials. In a sodium-based AMTEC cell, the anode face of an anode/solid-electrolyte/cathode sandwich is exposed to Na vapor at a suitable pres-

sure. Upon making contact with the solid electrolyte on the anode side, Na atoms oxidize to form Na⁺ ions and electrons. Na⁺ ions then travel through the electrolyte to the cathode. Na⁺ ions leave the electrolyte at the cathode/electrolyte interface and are reduced by electrons that have been conducted through an external electrical load from the anode to the cathode. Once the Na⁺ ions have been reduced to Na atoms,