Foam core enables stiff lightweight mirrors

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Low-mass mirrors made from silicon or silicon-carbide offer athermal performance for cryogenic, high-energy-laser, and fast beam-steering applications.

Current state-of-the-art large-scale lightweight mirrors are used in directed-energy, cryogenic, and precision-imaging environments, but suffer from performance-hindering issues. In cryogenic environments and high-energy-laser (HEL) applications, the thermal gradients change the surface figure of the mirror; the honeycomb or other support structures used to reduce the weight of the mirror also reduce the quality of the surface, a defect called print-through. A third problem affects beam steering applications: the mass and inertial properties of the mirror limit not only the rate at which the mirror can be driven, but also the power requirements and total system mass. Consequently, a fast steering mirror (FSM) system that uses traditional glass optics require a large actuator mass, a large reaction mass, and a bulky superstructure. These systems also generate excess heat and have relatively low peak frequencies. For airborne and spaceborne systems, which need low mass, high operational bandwidth, and thermal stability, large glass-mirror technologies fall short.1

Scientists and engineers have been investigating advancements in alternative mirror technologies to increase performance in all these areas. One possibility is switching from glass to beryllium, which possesses attractive thermal properties and is lightweight by definition. However, beryllium’s toxicity during manufacturing has led many government and commercial customers to reject the material completely.

Optical ceramics such as silicon and silicon carbide are also promising because these materials are very stiff and thermally stable. Their mass density, however, often results in optics that are heavier than their glass counterparts. In response to this concern, silicon and silicon carbide vendors employ traditional methods of reducing the weight of the mirrors by hollowing out portions of the backside. This geometric light-weighting, unfortunately, can yield errors in the surface quality, called optical print-through.

Figure 1. A skin of silicon carbide covers the light silicon carbide foam that forms the core of the 12.7cm-diameter mirror. In the next step, the SiC skin is covered with silicon. The reflective surface is made of polished silicon. In the fourth segment, this mirror is subjected to a high-energy-laser (HEL) test.

These materials are the basis of our Silicon Lightweight Mirror Systems (SLMS™) technology, which has proven to be a viable, lightweight, and thermally-stable solution for these applications. Because these mirrors use silicon or silicon carbide or both in their construction, they possess the ceramic’s beneficial stiffness and thermal-stability characteristics.2 The foam-core mirror does so, however, at a fraction of the mass, thus yielding the highest commercially-available stiffness-to-weight ratio for an optic. The ceramic closed-cell foam may possess as little as 5% of the density of its solid counterpart (see Figure 1), which gives it attractive thermal and inertial properties. We have built mirrors as large as 0.5m like this. The foam-cell structure of the mirror quickly distributes heat evenly across the surface, thus eliminating the optical distortions caused by hot-spotting. This reduces the problems caused by the large temperature varia-

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Figure 2. A foam-core mirror makes a lightweight fast steering mirror (FSM) with a 12.7cm-diameter clear aperture. The mirror weighs only 127.9g, and has a low areal density of 9.9kg/m².

The foam-core optic’s low mass can dramatically improve closed loop performance for active beam steering (see Figure 2). A SLMS FSM requires relatively little power to operate, uses far smaller actuators than traditional glass FSMs and, in some cases, can completely eliminate the need for a reaction mass.

One of our SiC SLMS mirrors was subjected to live-fire laser testing: in multiple tests the the 12.7cm mirror, which weighs less than 230g, was blasted with HEL-equivalent optical intensities for over 90s.4 Our mirror produced minimal thermally-induced distortion and greatly outperformed a gold-coated glass mirror tested under the same conditions. The tests also confirmed that the SiC-SLMS reaches achieves steady-state heating after only a few seconds, after which the distortion does not worsen.5

Schafer’s SLMS technology provides the highest stiffness-to-weight ratio of any available optic thus far, while providing zero-print-through, and offering the athermal performance of silicon and silicon carbide. We are now investigating designs for FSMs with larger-diameter SLMS optics.

References