Nanolaminate foils are being combined with micro-electro-mechanical electrostatic actuators to create deformable mirrors for optical correction at a wide range of sizes.

Deformable mirrors offer astronomers better focus control over mirrors in large telescopes. On Earth, their active control compensates for atmospheric blurring. For very-large telescopes in space, deformable mirrors may be lighter (less expensive to boost into orbit) and can be adjusted to the desired surface shape.

At Lawrence Livermore National Laboratory (LLNL), we are working with Boston Micromachines and MicroAssembly Technologies to develop nanolaminate-based deformable mirrors for both terrestrial and space-based optical systems. We are combining two complementary technologies: high-spatial-density electrostatic actuators and thin, flexible, lightweight nanolaminate mirrors. Electrostatic actuation of micro-electro-mechanical systems (MEMS) and similar structures provides densely-spaced, repeatable deflections on the order of 10 μm. The nanolaminate foils provide a mirror surface that is simultaneously flexible enough to deform under electrostatic forces and tough enough to survive handling and bonding.

We are working on two similar deformable mirrors that will demonstrate the feasibility of nanolaminate-based deformable mirrors over a wide range of sizes. The first is a high-actuator-density device that uses silicon MEMS actuators. The second is a large low-density device that uses electrostatic actuators formed from the nanolaminate foil itself together with electroplated posts and ridges.

Electrostatic actuators
Parallel-plate electrostatic actuators are among the simplest and most ubiquitous MEMS devices. They can be arrayed densely and they use little power. However, they are limited to small displacements of a few microns and produce very little force. These characteristics are useful for deformable mirrors and spatial light modulators in applications for which dense actuation of mirrors over small displacements is valuable.

Nanolaminates
Nanolaminate foils are a new class of materials under development at LLNL, and are produced by sputtering thin layers of alternating materials. Though each layer is only a few nanometers thick, by depositing thousands of layers we can create foils with thicknesses of 1–100 μm. The foils are deposited on a mandrel coated with a parting layer. When released from the mandrel, the foil duplicates its high-quality surface figure. The foils can have very-high ultimate tensile strengths and toughnesses due to their nanostructured nature. Grain growth in these materials is restricted by the thickness of the individual layers, resulting in a material with very small grains. This leads to a high dislocation density and excellent strength and toughness: these foils are strong enough to withstand handling and bonding while being thin and flexible enough to be deformed by electrostatic actuators.

High-actuator-density deformable mirror
The high-actuator-density mirrors are designed to meet the needs of large terrestrial telescopes (see Figure 1). These mirrors must have around 1000 pixels capable of low-spatial-frequency deformations of 5–10 μm, and high-spatial-frequency deformations of 1–3 μm, spaced by about 1 mm. To accomplish this we are combining nanolaminate mirrors with silicon MEMS actuators.
Figure 2. The large-scale deformable mirror uses MEMS-like components. The electrically-grounded spring layer is deformed by electrostatic attraction to electrodes on the base layer. Its motion is translated to the mirror through a set of posts.

Figure 3. This large-scale nanolaminate deformable mirror has four pixels.

Figure 2. The large-scale deformable mirror uses MEMS-like components. The electrically-grounded spring layer is deformed by electrostatic attraction to electrodes on the base layer. Its motion is translated to the mirror through a set of posts.

Large low-density deformable mirrors

The large-scale deformable mirrors are designed to work in conjunction with non-actuated nanolaminate mirrors to form extremely large space telescopes (see Figure 2). These mirrors will need diameters on the order of 1m, approximately 10,000 actuators, and an areal density (the mass per unit area) of about 1kg/m$^2$. Although we would like MEMS functionality, scaling conventional silicon MEMS technology to mirrors with diameters of a meter or more is nearly impossible. Instead, we are creating a MEMS-like structure with technologies that can be scaled to meter-diameter devices.$^6,7$

Here, the vertical vias that separate layers in a MEMS actuator are replaced with electroplated metal ridges and posts, and the horizontal silicon layers with nanolaminate. The resulting nanolaminate actuator layer is attached to metal ridges that suspend it above electrodes on the surface. A set of metal posts is electroplated on the back side of the mirror and is used to attach the mirror to the actuator. The structure is tolerant of line-width errors on the order of 50$\mu$m, allowing the parts to be defined by conventional printed-circuit-board lithography techniques that can be used on the meter scale. Since the active layers of this design are extremely-thin metal foils, the areal density can be kept low, on the order of 2kg/m$^2$.

Together, these two classes of mirrors will demonstrate the feasibility of creating deformable mirrors with high-quality continuous mirror surfaces over a wide range of size scales.

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References