



Fabrication Method for LOBSTER-Eye Optics in <110> Silicon

The major advantages are the potential for higher x-ray throughput and lower cost over the slumped micropore glass plates.

Goddard Space Flight Center, Greenbelt, Maryland

Soft x-ray optics can use narrow slots to direct x-rays into a desirable pattern on a focal plane. While square-pack, square-pore, slumped optics exist for this purpose, they are costly. Silicon (Si) is being examined as a possible low-cost replacement. A fabrication method was developed for narrow slots in <110> Si demonstrating the feasibility of stacked slot optics to replace micropores.

Current micropore optics exist that have 20-micron-square pores on 26-micron pitch in glass with a depth of 1 mm and an extent of several square centimeters. Among several proposals to emulate the square pore optics are stacked slot chips with etched vertical slots. When the slots in the stack are positioned orthogonally to each other, the component will approach the soft x-ray focusing observed in the micropore optics. A specific improvement Si provides is that it can have narrower sidewalls between slots to permit greater throughput of x-rays through the optics. In general,

Si can have more variation in slot geometry (width, length). Further, the sidewalls can be coated with high-Z materials to enhance reflection and potentially reduce the surface roughness of the reflecting surface.

Narrow, close-packed deep slots in <110> Si have been produced using potassium hydroxide (KOH) etching and a patterned silicon nitride (SiN) mask. The achieved slot geometries have sufficient wall smoothness, as observed through scanning electron microscope (SEM) imaging, to enable evaluation of these slot plates as an optical element for soft x-rays. Etches of different angles to the crystal plane of Si were evaluated to identify a specific range of etch angles that will enable low undercut slots in the Si <110> material. These slots with the narrow sidewalls are demonstrated to several hundred microns in depth, and a technical path to 500-micron deep slots in a precision geometry of narrow, close-packed slots is feasible. Although intrinsic

stress in ultrathin wall Si is observed, slots with walls approaching 1.5 microns can be achieved (a significant improvement over the 6-micron walls in micropore optics).

The major advantages of this technique are the potential for higher x-ray throughput (due to narrow slot walls) and lower cost over the existing slumped micropore glass plates. KOH etching of smooth sidewalls has been demonstrated for many applications, suggesting its feasibility for implementation in x-ray optics. Si cannot be slumped like the micropore optics, so the focusing will be achieved with millimeter-scale slot plates that populate a spherical dome. The possibility for large-scale production exists for Si parts that is more difficult to achieve in micropore parts.

This work was done by James Chervenak and Michael Collier of Goddard Space Flight Center, and Jennette Mateo of SB Microsystems. Further information is contained in a TSP (see page 1). GSC-16717-1

Compact Focal Plane Assembly for Planetary Science

New fabrication methods were incorporated to produce an ultra-lightweight and compact radiometer.

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A compact radiometric focal plane assembly (FPA) has been designed in which the filters are individually co-registered over compact thermopile pixels. This allows for construction of an ultra-lightweight and compact radiometric instrument. The FPA also incorporates micromachined baffles in order to mitigate crosstalk and low-pass filter windows in order to eliminate high-frequency radiation.

Compact metal mesh bandpass filters were fabricated for the far infrared (FIR) spectral range (17 to 100 microns), a game-changing technology for future planetary FIR instruments. This fabrication approach allows the di-

mensions of individual metal mesh filters to be tailored with better than 10-micron precision. In contrast, conventional compact filters employed in recent missions and in near-term instruments consist of large filter sheets manually cut into much smaller pieces, which is a much less precise and much more labor-intensive, expensive, and difficult process.

Filter performance was validated by integrating them with thermopile arrays. Demonstration of the FPA will require the integration of two technologies. The first technology is compact, lightweight, robust against cryogenic thermal cycling, and radiation-hard mi-

cromachined bandpass filters. They consist of a copper mesh supported on a deep reactive ion-etched silicon frame. This design architecture is advantageous when constructing a lightweight and compact instrument because (1) the frame acts like a jig and facilitates filter integration with the FPA, (2) the frame can be designed so as to maximize the FPA field of view, (3) the frame can be simultaneously used as a baffle for mitigating crosstalk, and (4) micron-scale alignment features can be patterned so as to permit high-precision filter stacking and, consequently, increase the filter bandwidth and sharpen the out-of-band rolloff.

The second technology consists of leveraging, from another project, compact and lightweight $\text{Bi}_{0.87}\text{Sb}_{0.13}/\text{Sb}$ arrayed thermopiles. These detectors consist of 30-layer thermopiles deposited in series upon a silicon nitride membrane. At 300 K, the thermopile arrays are

highly linear over many orders of magnitude of incident IR power, and have a reported specific detectivity that exceeds the requirements imposed on future mission concepts.

The bandpass filter array board is integrated with a thermopile array board by

mounting both boards on a machined aluminum jig.

This work was done by Ari Brown, Shahid Aslam, Wei-Chung Huang, and Rosalind Steptoe-Jackson of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16704-1

Fabrication Methods for Adaptive Deformable Mirrors

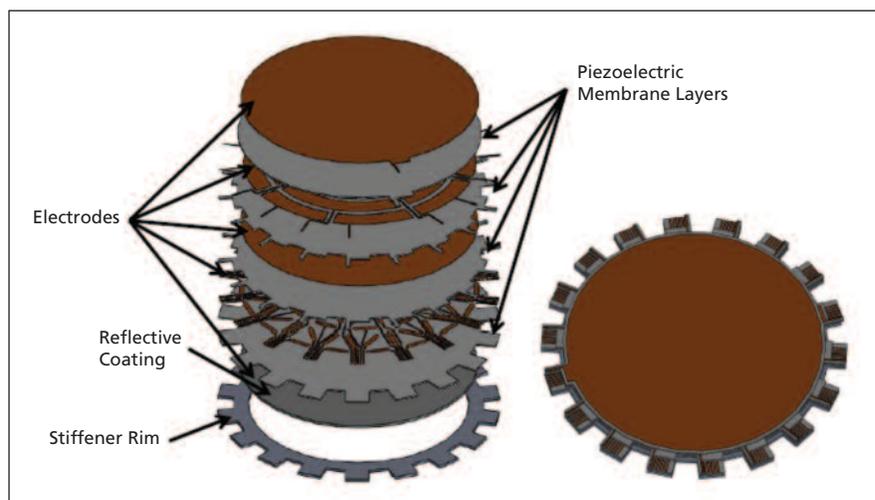
Two methods are presented.

NASA's Jet Propulsion Laboratory, Pasadena, California

Previously, it was difficult to fabricate deformable mirrors made by piezoelectric actuators. This is because numerous actuators need to be precisely assembled to control the surface shape of the mirror. Two approaches have been developed. Both approaches begin by depositing a stack of piezoelectric films and electrodes over a silicon wafer substrate. In the first approach, the silicon wafer is removed initially by plasma-based reactive ion etching (RIE), and non-plasma dry etching with xenon difluoride (XeF_2). In the second approach, the actuator film stack is immersed in a liquid such as deionized water. The adhesion between the actuator film stack and the substrate is relatively weak. Simply by seeping liquid between the film and the substrate, the actuator film stack is gently released from the substrate.

The deformable mirror contains multiple piezoelectric membrane layers as well as multiple electrode layers (some are patterned and some are unpatterned). At the piezoelectric layer, polyvinylidene fluoride (PVDF), or its co-polymer, poly(vinylidene fluoride trifluoroethylene) P(VDF-TrFE) is used. The surface of the mirror is coated with a reflective coating. The actuator film stack is fabricated on silicon, or silicon on insulator (SOI) substrate, by repeatedly spin-coating the PVDF or P(VDF-TrFE) solution and patterned metal (electrode) deposition.

In the first approach, the actuator film stack is prepared on SOI substrate. Then, the thick silicon (typically 500-micron thick and called handle silicon) of the SOI wafer is etched by a deep reactive ion etching process tool (SF₆-based plasma etching). This deep RIE stops at the middle SiO₂ layer. The middle SiO₂ layer is etched by either HF-based wet etching or dry plasma etch. The thin silicon layer (generally called a device



The **Deformable Mirror** concept includes electrodes, a reflective coating, stiffener rim, and piezoelectric membrane layers.

layer) of SOI is removed by XeF_2 dry etch. This XeF_2 etch is very gentle and extremely selective, so the released mirror membrane is not damaged. It is possible to replace SOI with silicon substrate, but this will require tighter DRIE process control as well as generally longer and less efficient XeF_2 etch.

In the second approach, the actuator film stack is first constructed on a silicon wafer. It helps to use a polyimide intermediate layer such as Kapton because the adhesion between the polyimide and silicon is generally weak. A mirror mount ring is attached by using adhesive. Then, the assembly is partially submerged in liquid water. The water tends to seep between the actuator film stack and silicon substrate. As a result, the actuator membrane can be gently released from the silicon substrate. The actuator membrane is very flat because it is fixed to the mirror mount prior to the release.

Deformable mirrors require extremely good surface optical quality. In the technology described here, the deformable mirror is fabricated on pris-

tine substrates such as prime-grade silicon wafers. The deformable mirror is released by selectively removing the substrate. Therefore, the released deformable mirror surface replicates the optical quality of the underlying pristine substrate.

This work was done by Risaku Toda, Victor E. White, Harish Manohara, Keith D. Patterson, Namiko Yamamoto, Eleftherios Gdoutos, John B. Steeves, Chiara Daraio, and Sergio Pellegrino of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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