A continuous membrane, microelectromechanical systems-based deformable mirror represents a promising solution to the problem of detecting extrasolar planets.

The purpose of the Gemini Planet Imager (GPI) is to directly detect Jupiter-like planets outside of our solar system. These planets are a billion times fainter than the sun and obscured by light from their parent stars, atmospheric aberrations, and optical imperfections in the imaging systems. These high-contrast ratios of $10^7$ to $10^8$ require the use of extreme adaptive optics to detect this type of object, but such detection had never been attainable because of limitations in deformable mirror (DM) technology.

Frequently used for microscopy, laser communication, and a variety of astronomical applications, microelectromechanical systems (MEMS) DMs are a desirable choice for many imaging systems. Their inherent small size, high speed, and low cost as compared with macroscale DMs offer reliable, robust performance capabilities to a variety of industries.

In an experimental extreme adaptive optics testbed, a 1024-element MEMS DM was characterized to determine whether the technology is suitable for extrasolar planet detection. The testbed showed that the MEMS DM could be flattened to less than 1nm RMS (root mean square) within controllable spatial frequencies over an aperture of 9.2mm with an average long-term stability of less than 0.18nm RMS phase, thereby demonstrating that the MEMS DM is a feasible wavefront compensator for high-contrast imaging.

A 4096-element MEMS DM, with a stroke of up to 4µm and a surface figure of 10nm RMS, is required for the GPI instrument. Although MEMS DMs with array sizes up to $32 \times 32$, a 4µm stroke, and 10nm RMS surface quality have been demonstrated, all three criteria have not been achieved on the same device. The development reported here aims to extend the design, fabrication, and packaging processes used to successfully produce Boston Micromachines Corporation’s kilopixel and long-stroke (12 × 12) MEMS DMs.

Boston Micromachines’ MEMS DMs are based on the surface-micromachined, polysilicon double-cantilever actuator architecture pioneered at Boston University, illustrated in Figure 1. The device’s structure consists of an array of electrostatic actuators that support the flexible mirror facesheet through a small attachment post at the center of each actuator, which translates the actuator motion to a mirror surface deformation. This MEMS DM architecture allows for local deformation of the mirror membrane because a single actuator influences only its near neighbors. It does not cause deformations over the entire aperture as with membrane mirrors. Consequently, high-order aberrations in the optical path can be corrected using these DMs. Figure 2 shows surface measurements of the DM with a single actuator, as well as with a pattern of actuators deflected.

A sample of devices, designed to determine the final manufacturing processes and device design that will be used for the 4096-element DM, were manufactured in the first phase of this development, and packaging processes used to successfully produce Boston Micromachines Corporation’s kilopixel and long-stroke (12 × 12) MEMS DMs.

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Figure 2. In this image of an optical surface measurement of a 144-element DM, a single pixel is actuated (left). The influence of the single element deflection extends only to its immediate neighbors, leaving the rest of the mirror surface unchanged. This local influence characteristic of the DM allows for high-order and otherwise arbitrary shapes on the DM (right).

Figure 3. In this prototype of a 4096-element MEMS DM, the central 64 × 64 array out of a 68 × 68 array is active.

development effort and have been evaluated for surface figure and electromechanical performance. A prototype of the DM is shown in Figure 3.

A measurement of this DM shows that a surface finish of less than 10nm RMS has been achieved using the modified device design. Most of the phase I devices were capable of 4µm of total stroke at a voltage below 250V, with an inter-actuator stroke of more than 1µm. The second phase of the development program, in which a 4096-element MEMS DM will be fabricated based on the phase I device designs, is currently under way.

MEMS DMs offer an attractive solution to extrasolar planet imaging, providing the high speed, compact size, low cost, and high-order wavefront correction necessary for this demanding application. The best performance characteristics and fabrication processes used for Boston Micromachines’ commercial MEMS DMs are being combined to produce the first 4096-element MEMS DM, which will enable high-contrast imaging instruments seeking to image extrasolar Jovian planets.

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References