P-0166

MEMS Microshutter Array System for James Webb Space Telescope

Mary J. Li, Tomoko Adachi, Christine Allen, Sachi Babu, Sateesh Bajikar, Michael Beamesderfer, Ruth Bradley, Kevin Denis, Nick Costen, Audrey Ewin, Dave Franz, Larry Hess, Ron Hu,
Kamili Jackson, Murzy Jhabvala, Dan Kelly, Todd King, Gunther Kletetschka, Alexander Kutyrev, Barney Lynch, Timothy Miller, Harvey Moseley, Vilem Mikula, Brent Mott, Lance Oh,
James Pontius, Dave Rapchun, Chris Ray, Knute Ray, Eric Schulte, Scott Schwinger, Peter Shu,
Robert Silverberg, Wayne Smith, Steve Snodgrass, David Sohl, Leroy Sparr,
Rosalind Steptoe-Jackson, Valeriano Veronica, Liqin Wang, Yun (Tony) Zheng, Chris Zincke

NASA Goddard Space Flight Center, Greenbelt MD 20771

ABSTRACT

A complex MEMS microshutter array system has been developed at NASA Goddard Space Flight Center (GSFC) for use as a multi-object aperture array for a Near-Infrared Spectrometer (NIRSpec). The NIRSpec is one of the four major instruments carried by the James Webb Space Telescope (JWST), the next generation of space telescope after the Hubble Space Telescope retires. The microshutter arrays (MSAs) are designed for the selective transmission of light with high efficiency and high contrast[1]. It is demonstrated in Figure 1 how a MSA is used as a multiple object selector in deep space. The MSAs empower the NIRSpec instrument simultaneously collect spectra from more than 100 targets therefore increases the instrument efficiency 100 times or more. The MSA assembly is one of three major innovations on JWST and the first major MEMS devices serving observation missions in space.

The MSA system developed at NASA GSFC is assembled with four quadrant fully addressable 365x171 shutter arrays that are actuated magnetically, latched and addressed electrostatically[2]. As shown in Figure 2, each MSA is fabricated out of a 4" silicon-on-insulator (SOI) wafer using MEMS bulk-micromachining technology. Individual shutters are close-packed silicon nitride membranes with a pixel size close to 100x200 μm (Figure 3). Shutters are patterned with a torsion flexure permitting shutters to open 90 degrees with a minimized mechanical stress concentration. In order to prevent light leak, light shields are made on to the surrounding frame of each shutter to cover the gaps between the shutters and the frame (Figure 4). Micro-ribs and sub-micron bumps are tailored on back walls and light shields, respectively, to prevent sticktion, shown in Figures 4 and 5. JWST instruments are required to operate at cryogenic temperatures as low as 35K, though they are to be subjected to various levels of ground tests at room temperature. The shutters should therefore maintain nearly flat in the entire temperature range between 35K and 300K. Through intensive numerical simulations and experimental studies, an optically opaque and electrically conductive metal-nitride thin film was selected as a coating material deposited on the shutters with the best thermal-expansion match to silicon nitride -- the shutter blade thin film material. A shutter image shown in Figure 6 was taken at room temperature, presenting shutters slightly bowing down as expected. Shutters become flat when the temperature decreases to 35K. The MSAs are then bonded to silicon substrates that are fabricated out of 6" single-silicon wafers in the thickness of 2mm. The bonding is conducted using a novel single-sided indium flip-chip bonding technology[3]. Indium bumps fabricated on a substrate are shown in Figure 7. There are 180,000 indium bumps for bonding a flight-format MSA array to its substrate. Besides a MSA, each substrate houses five customer-designed ASIC (Application Specific Integrated Circuit) multiplexer/address chips for 2-dimensional addressing, twenty capacitors, two temperature sensors, numbers of resistors and all necessary interconnects, as shown in Figure 8.

Complete MSA quadrant assemblies have been successfully manufactured and fully functionally tested[4]. The assemblies have passed a series of critical reviews required by JWST in satisfying all the design specifications. The qualification tests cover programmable 2-D addressing, life tests, optical contrast tests, and environmental tests including radiation, vibration, and acoustic tests. A 2-D addressing pattern with "ESA" letters programmed in a MSA is shown in Figure 9. The MSAs passed 1 million cycle life tests and achieved high optical contrast over 10,000. MSA teams are now making progress in final fabrication, testing and assembly (Figure 10). The delivery of flight-format MSA system is scheduled at the end of 2008 for being integrated to the focal plane of the NIRSpec detectors.

KEYWORDS: microshutter, MEMS, RIE, DRIE, micro-optics, near infrared, space telescope, flip chip bonding

REFERENCES

[1] S. H. Moseley, et al, "Microshutter Arrays for the JWST Near-infrared Spectrometer", Proc. SPIE Vol. 5487, pp. 645-652, Optical, Infrared, and Millimeter Space Telescopes; John C. Mather; Ed., SPIE conference "Astronomical Telescopes and Instrumentation 2004: Space Telescopes and Astronomy", Glasgow, Scotland 2004.

[2] M. Li, et al., invited paper "Microshutter Array Development for the James Webb Space Telescope", Smart Structures, Devices, and Systems II, Proc. SPIE, **5650**, pp. 9-16 (2005)

[3] Christine A. Allen, et al, "Flip Chip Integration of a Large Format Array of MOEMS Devices for Space Infrared Astronomy", Proc. of the SMTA International Conference, Emerging Technologies Summit, 2006

[4] M. Li, et al, invited paper "Complex MEMS Device: Microshutter Array System for Space Applications", Micro (MEMS) and Nanotechnologies for Defense and Security, Proc. SPIE, **6556**, 2007.

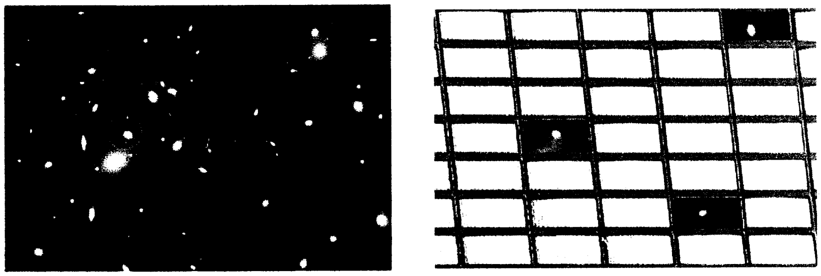


Figure 1. Demonstration of a microshutter array used as an aperture (right) to select multiple objects from sky (left)

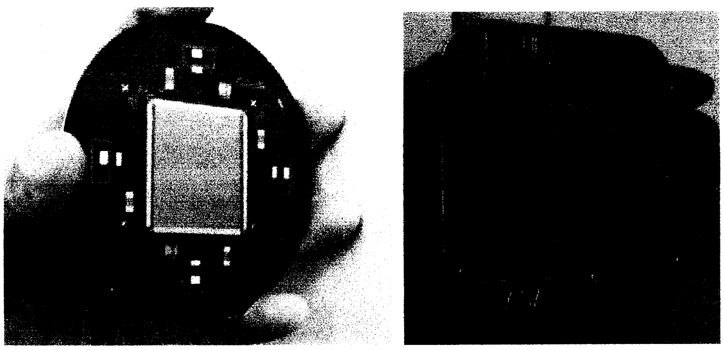


Figure 2. A flight-format 365x171 microshutter array (right) is fabricated out of a 4" SOI wafer (left)

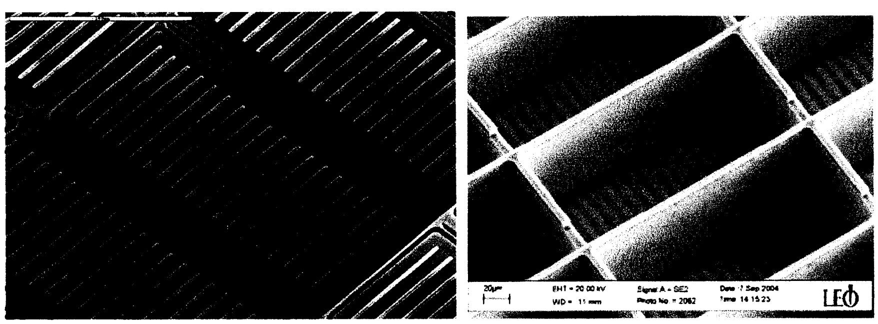
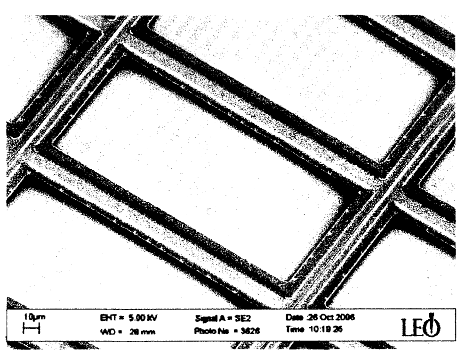


Figure 3. Shutters in 100x200um pixel size on front side of MSA (left), and silicon frame on backside of MSA (right)



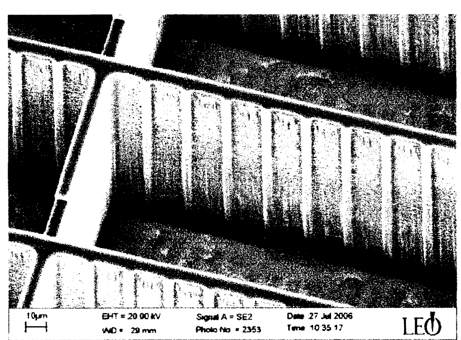


Figure 4. Light shields are patterned to cover the gaps between shutters and frame; and sub-micron-bumps on light shields (left);

Figure 5. micron-ribs are made on back walls to prevent sticktion (right).

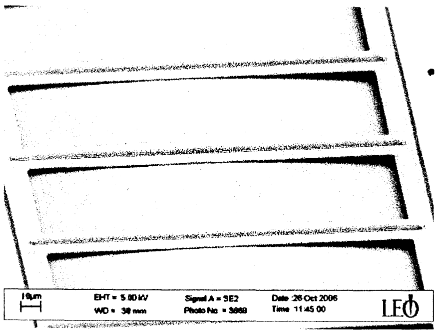


Figure 6. Shutters are slightly bowing down at room temperature and will become flat when the temperature reaches 35K

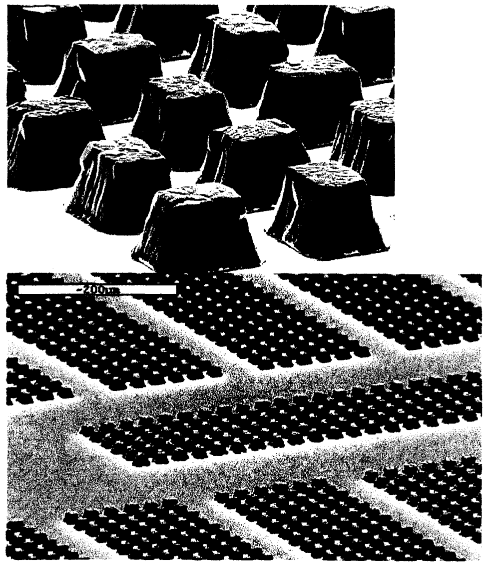


Figure 7. Indium bumps (top) are patterned on a MSA substrate (bottom) for flip-chip bonding between MSAs and their substrates

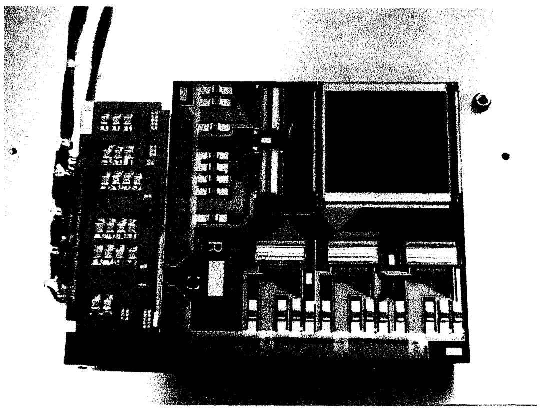


Figure 8. A MSA quadrant assembly consists of a MSA array (top right), a silicon substrate populated with ASIC 2-D addressing components, a daughter board (left), and a flexure (underneath the substrate)

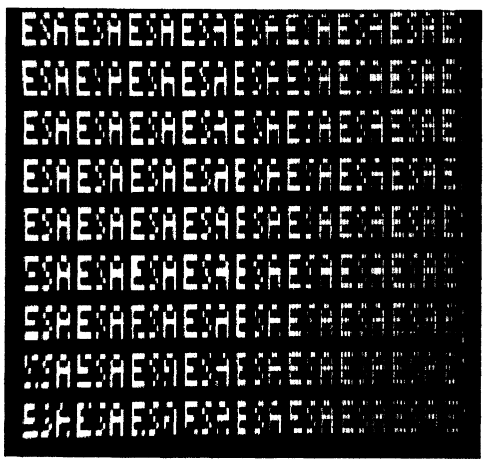


Figure 9. A 2-D addressing pattern from a flight-format 365x171 microshutter array showing "ESA" letters

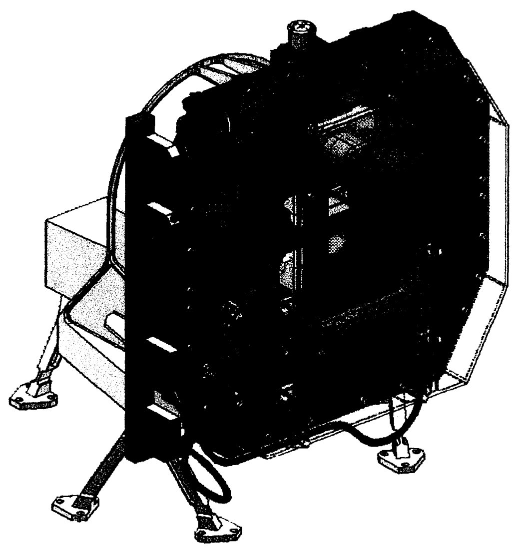


Figure 10. Final design of a microshutter array assembly with four MSA quadrants located in the center, a permanent magnet (pink) in up-down motion programmed to synchronize shutter open and close, step motors, and harnesses connected to the NIRSpec instrument

Word Count: 598

Contact Information: Mary Li, NASA Goddard Space Flight Center, Code 553, Greenbelt Rd, Greenbelt, MD 20771
Phone: (301) 286-9921 email: mary.j.li@nasa.gov