SUCCESSFUL DEMONSTRATION OF AN ELECTROSTATIC ACTUATED MICROSHUTTER SYSTEM FOR SPACE TELESCOPE FLIGHT MISSIONS

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Abstract— After developing magnetically actuated microshutter array sub-systems as a field object selector for the James Webb Space Telescope (JWST), a team at the NASA Goddard Space Flight Center (GSFC) focused on the development of electrostatically actuated microshutter arrays – Next Generation Microshutter Arrays (NGMSA). The demonstration described in this late news is for the first NGMSA array that performed shutter operations for telescope imaging and spectroscopy in space. The carrier telescope, the Next-Generation Far-UV Off Roland-circle Telescope for Imaging and Spectroscopy (NG-FORTIS), has been designed and produced by Prof. Stephan McCandliss and his team at Johns Hopkins University. NG-FORTIS was launched into space successfully.

Index Terms— **Electrostatic Actuation, MEMS, Microshutter Array, Object Field Selector, Sounding Rocket, Space Telescope, UV and Visible Applications.**

I. Introduction

On Oct. 27, 2019, a NASA/JHU sounding rocket carrying NG-FORTIS was launched successfully at White Sands Missile Range in New Mexico[1]. Applied as a multi-object selector, our newly developed electrostatically actuated 128x64 microshutter array that was assembled to the focal plan of NG-FORTIS functioned perfectly in the NG-FORTIS space operation mission. With the prototype NGMSA operating in space, we reached a major milestone towards producing large format electrostatically actuated microshutter array for future major space telescopes with large field of views.

NG-FORTIS is not the first sounding rocket instrument launched that carried microshutter arrays. The collaboration between NASA GSFC and JHU in microshutter array development for far-UV telescope applications, using the arrays as field object selectors, started in 2010. There were two FORTIS sounding rockets launched in 2013, and 2015 respectively[2,3]. Each carried a 128x64 microshutter array that was actuated magnetically. The microshutter array on NG-FORTIS, called the Next Generation Microshutter Array (NGMSA), is actuated electrostatically, defining a revolutionary modification from the previous one for JWST. By getting rid of the magnet and its accessories, the modification promises simplified fabrication processes, reduced weight for final assembly, fast operation, and overall reliable performance.

II. NGMSA Development

At NASA GSFC, our team developed the magnetically actuated microshutter arrays in previous years for the James Webb Space Telescope (JWST - a flagship space flight mission) [4,5] prior to the development of electrostatically actuated microshutter arrays. The former, JWST MSA, designates our first generation of microshutter technology, while the latter, named NGMSA, represents our next generation microshutter array technology[5,6,7]. The modifications on NGMSA include not only

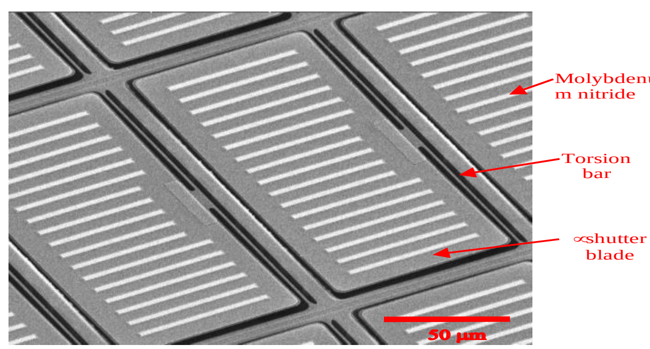

Fig. 1. A SEM image of the front side image of NGMSA. On the microshutters the patterned microshutter blade, torsion bar and strips of metal nitride are shown.

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the actuation mechanism but also several major design and fabrication reforms as described below.

A. NGMSA Fabrication, Packaging, and Assembly

In the NGMSA fabrication for NG-FORTIS, the thickness of shutter blades and the torsion hinges were reduced to minimize actuation voltages, and the conductive materials on shutter blades were changed from metal nitride to aluminum to control the flatness of the shutters (Fig. 1). The light shields that cover the gaps between shutter blades and the frame were widened to

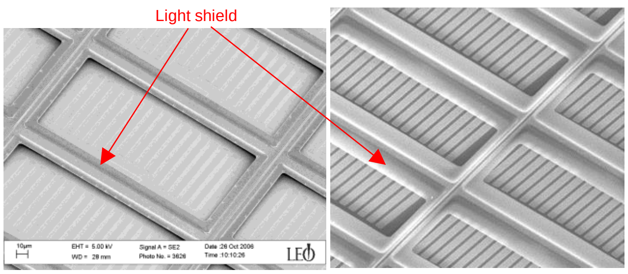

Fig. 2. A SEM images of the MSA with the light shields that prevent light passing through the gaps between shutter blades and the frame. Left: JWST MSA, right: FORTIS NGMSA with much wider light shields (right)

increase the optical contrast (Fig. 2). The silicon oxide insulation layer for array backside electrodes was replaced by the atomic-layer-deposited aluminum oxide to minimize electrical shorts to the silicon substrate[6]. Many other modification steps were made to produce the NGMSA arrays towards simplification of fabrication and optimization of shutter performance: modifications of anti-stiction features, sacrificial oxide deposition and etch, and array releasing processes. The modifications led the NGMSA to meet the scientific requirements from NG-FORTIS mission.

In the packaging, the NGMSA arrays were attached to their silicon substrates through indium flip-chip bump bonding for fan out of electrodes. The resulting hybrid was then assembled

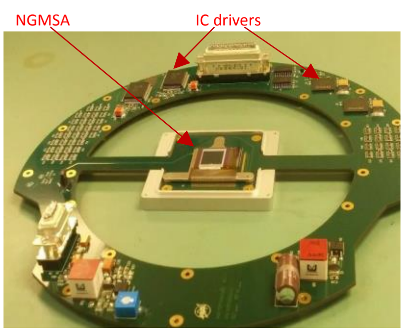

Fig. 3. Final Big θ assembly for NG-FORTIS. Center: 128x64 NGMSA. Surrounding circle: IC drivers and other electronics.

to a specially designed printed circuitry board for NG-FORTIS telescope, based on the NG-FORTIS mission instruments requirements. The board was fabricated with multilayer PCB, and populated with four IC drivers and all other needed passive electronic components. The ICs are used to execute operation commands from a computer through LabView software for 2-D addressing of the shutters in the NGMSA array. The NGMSA assemblies turned into the final products that we have a special name for, Big θ, from an unique shape of the PCB (Fig. 3).

B. NGMSA Characterization and Testing

NGMSA on Big θ assemblies was characterized and tested for functional operations in a test chamber system that were designed and built by our collaborators in JHU. Shutters are individually actuated and addressed by applying a pulsed voltage to the front electrodes and a DC voltage to back

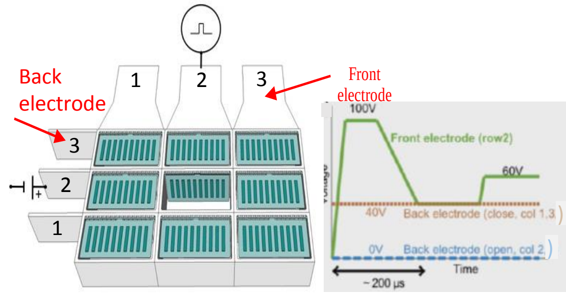

Fig. **4**. An illustration of how a microshutter is individually actuated: a pulsed DC voltage is applied to the front electrodes for actuation (top), and a DC voltage is applied to the back electrodes for latching (left).

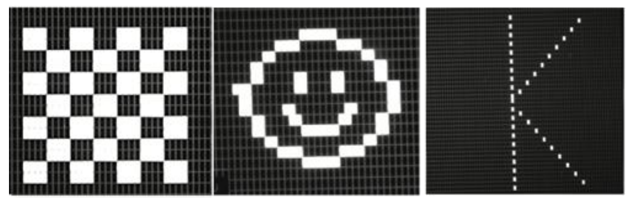

Fig.**5**. NGMSA 2-D addressing images with open shutter patterns.

electrodes. Only the shutters with voltage difference between the front and back electrodes latched open by rotating 90^0 against their torsion bars (Figs. 4 & 5). After a comprehensive acceptance tests in the fully functional testing chamber (Fig. 6),

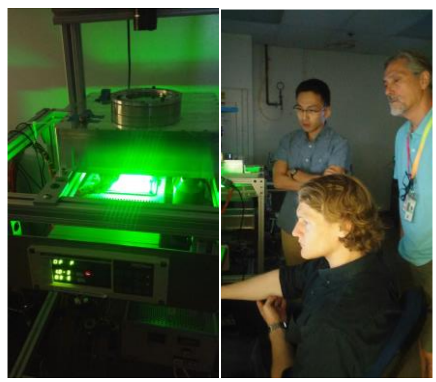

Fig. 6. Photos of NGMSA-Big θ functional tests conducted at the product acceptance test. Left: the functional test chamber in 2D addressing tests; Right: NASA test engineer K. Kim, PI Prof. McCandliss, and his student B. Welch from JHU.

two NGMSA-Big θ assemblies were delivered to JHU for optical and functional tests with the NG-FORTIS detector that consists of borosilicate micro-channel plates (MCP) provided by Sensor Sciences. On an UV test bed, optical testing was conducted for the shutter system together with the detector. NGMSA that was located on the focal plane of the detector, performed computer-selected shutters open, latch, and close. Various 2-D addressing patterns were tested, enabling the MCP

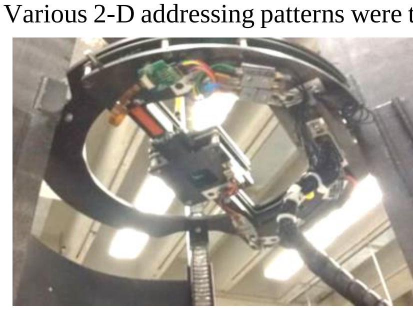

Fig. 7. A photo of the NGMSA-Big θ assembly mounted in the NG-FORTIS telescope before the sounding rocket launch.

detector to collect image and spectroscopy from multiple light sources simultaneously. NG-FORTIS also utilized the new technologies of an autonomous targeting system developed at JHU, beside NGMSA and borosilicate MCP[1]. Mechanical vibration tests were conducted in NASA Wallops Facility in Virginia when the telescope assembly was completed (Figs. 7). The NGMSA assembly was tested in functionality again at the White Sand Missile Range before the sounding rocket launch.

III. Current Work Belonged NG-FORTIS

Upon the successful launch of NG-FORTIS in Oct. last year, our first 128x64 NGMSA assembly passed the launch and operation tests for space flight, reaching the high NASA Technology Readiness Level (TRL) 9 for a sounding rocket. This is a major milestone because NG-FORTIS carried the pilot NGMSA to space and fully functionality was demonstrated in space. Our team is currently working on the development of large format NGMSA for future major space telescope flight missions. Working closely with scientists in several study groups for future major space telescopes, we have designed the 736x384 NGMSA and fabricated the mechanical structure arrays that involved all the mechanical components in a shutter array including individual shutters with torsion bars, but no metal traces. The goal of the efforts is to verify the mechanical strength of the designed large arrays against various vibrations in a space launch environment. Based on the results of finite element modeling, four mechanical beams were introduced in the mechanical structure arrays and ceramic substrates as shown in Fig. 8 (right). The modification of using ceramic substrates instead of silicon substrates that were used in previous programs like JWST, two FORTIS, and NG-FORTIS, is for enhancing electrical insulation of the substrates and mechanical strength so to improve shutter array performances. Hybrids were produced through epoxy bonding between the array and the substrate. One hybrid went through various vibration tests required for space flight missions and passed all of the tests (see Fig. 9).The team is currently producing fully-functional 736x384 NGMSA arrays. We plan to demonstrate the large NGMSA 2D-addressing functions in 2021, strategically aligning to the requirements from flagship mission telescopes including Large UV/Optical/Infrared Surveyor (LUVOIR), the Habitable Exoplanet Image Mission (HabEx), and Large Format Space Telescopes such as Cosmic Evolution Through UV Spectroscopy (CETUS), and other future NASA missions.

Fig. 8. Two generations of microshutter arrays: the first generation - JWST MSA - 365 x 171 (middle); NGMSA for NG-FORTIS 128 x 64 (left),the pilot of NGMSA for future space telescopes; NGMSA mechanical array 736 x 384 (right) developed recently.

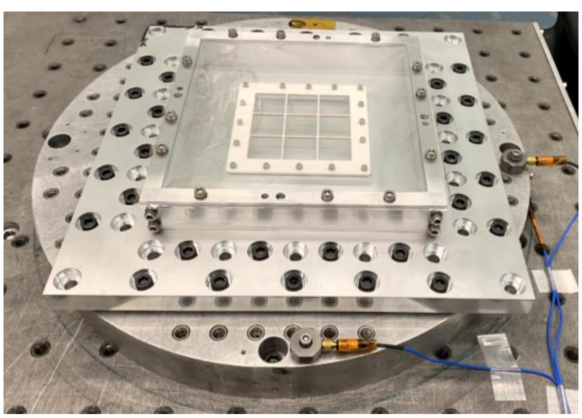
Fig. 9. An image of a 736x384 NGMSA mechanical structure hybrid mounted on a vibration table for random vibe and acoustic vibe tests.

IV. Summary

Through nine years of collaboration between NASA and JHU, the second generation of microshutter arrays, NGMSA, has been developed and demonstrated, featuring electrostatic actuation and 2-D addressing operation. A 128x64 NGMSA assembly was assembled to the telescope NG-FORTIS, and the NG-FORTIS sounding rocket was launched to space in October, 2019 as multi-object selector for the telescope. The new technology development continues towards large-format NGMSAs that will be employed as multi-object selectors for future large-format telescopes with large field of view. The NGMSA technology has been chosen by several future flagship class space missions. The new technology will increase the instrument efficiency two orders of magnitudes for those flagship-class telescopes.

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