Status and Accomplishments of Microshutters for use on JWST/NIRSpec

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Abstract

Microshutters are a new piece of technology being used on the Near Infrared Spectrograph (NIRSpec) instrument on the James Webb Space Telescope (JWST). NIRSpec is an instrument that will allow scientists to capture the spectra of more than 100 objects simultaneously. Because the objects NIRSpec will be looking at are so far away and so faint, the instrument needs a way to block out the light of nearer bright objects. The microshutters were developed to help solve this problem. Micro shutters are tiny doors that measure 100 by 200 microns or about the width of three to six human hairs. The microshutters are arranged in a waffle-like grid that contains approximately 250,000 shutters in flight configuration. The microshutter cells have lids that open and close when a magnetic field is applied. Each door can be controlled individually, allowing it to be opened or closed to view or block a portion of the sky. It is this adjustability that allows the instrument to do spectroscopy on up to 100 objects simultaneously! NASA's Goddard Space Flight Center has worked on the microshutter technology for over six years. This paper will describe the overall status and accomplishments that have been achieved on the microshutters during this time period.

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

1. Introduction

Microshutters is a subsystem on the Near Infrared Spectrometer (NIRSpec) that will be flown on the James Webb Space Telescope (JWST). Microshutters is the programmable mask for this spectrometer that will allow NIRSpec to map the sky up to 100 times faster than previously flown instruments.

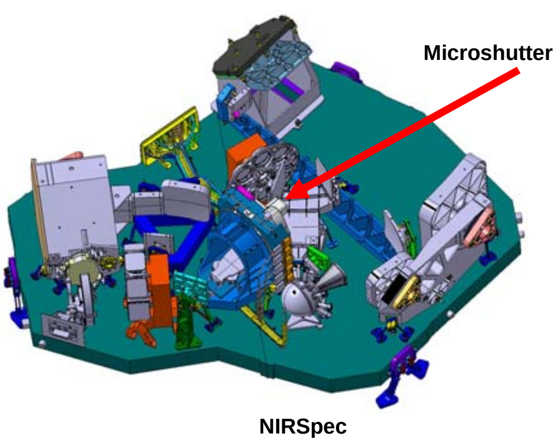

Figure 1. The NIRSpec Instrument

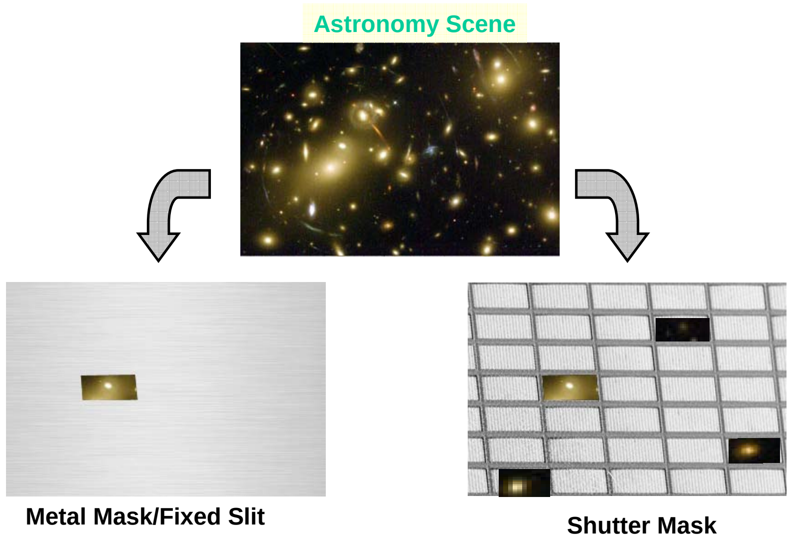

Figure 2. Metal Mask/Fixed Slit View Versus Microshutters

Microshutters became the NIRSpec enabling technology out of a competition that took place in 2001. This competition pitted Microshutters against two other MEMS Micromirror technologies. Microshutters won this competition because it was the only one of the three MEMs technologies that showed the capability to meet and exceed the NIRSpec contrast requirement of greater than 2000. Since that time microshutters has gone from a developmental research project to a flight ready technology.

2. The Microshutter System Development 2002-2005

Since the time of the competition the Microshutter team continued development of the array. The first array was a 3 x 3 array that demonstrated the concept. The first electrically and mechanically functional array was a 128 x 128 array[1]. This array demonstrated the ability to electrostatically latch and release the shutters. Figure 3 shows a single cell array concept.

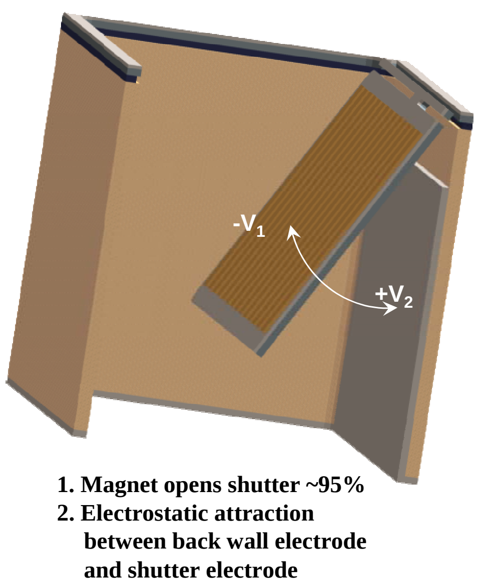

Figure 3. Conceptual Microshutter Array Cell

Since that first array many different versions of the shutters were produced to develop and improve production techniques. The final array configuration for the NIRSpec application is a 171x365 microshutter array. In order to accommodate the full field of view of the NIRSpec Instrument four 171x365 arrays are used. This configurations provides nearly 250,000 programmable viewing windows for the NIRSpec Instrument (post editorial note, I see you addressed this below, so you can delete this if you wish.

The packaging of the array for use on NIRSpec evolved over these years to the following configuration. The 171 x 365 microshutter array is mounted on a single crystal silicon substrate. This silcicon substrate provides the electrical circuitry for driving the arrays as well as a mounting interface for the array with no CTE mismatch to the array. This substrate is then bonded to invar buttons on a titanium flexure. This flexure design maintains the optical alignment of the array over temperature.

Also mounted to the flexure is the daughter board. The daughter board is a standard printed circuit board which provides the electrical interface to the control electronics mounted in the warm section of JWST. This daughter board is wire bonded to the silicon substrate so that it does not impart any stress on the silicon substrate that would interfere with the alignment. The array, silicon substrate, daughter board, and flexure comprise one quadrant of the microshutter system for NIRSpec.

This quadrant assembly is then mounted on a titanium mosaic baseplate. A total of four quadrants are mounted on the baseplate which provide a programmable mask for NIRSpec made up of 249660 shutters.

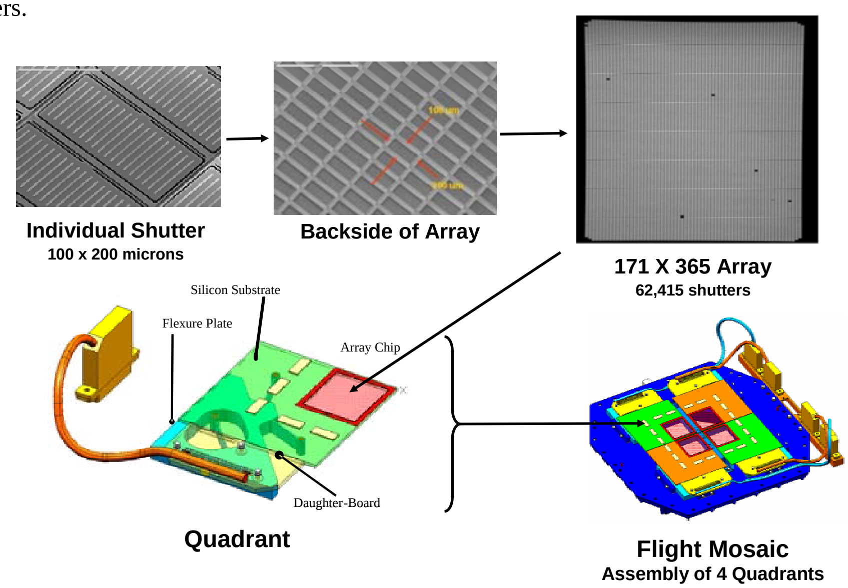

Figure 4. Array to Mosaic Baseplate Assembly

On top of the mosaic baseplate a mechanism layer is mounted that contains the magnet to actuate the array and the motor to drive the magnet mechanism. On top of this assembly sits the MSA cover.

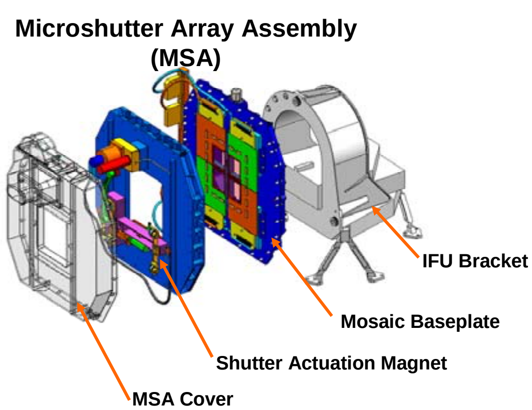

Figure 5. Microshutter Assembly

3. Microshutter Accomplishments 2006-Present

In 2006 the push was on to qualify all the JWST technology developments for flight use by December 2006. Microshutters as part of the JWST technology development entered into a year long rigorous test program. The purpose of this testing was to prove that microshutters could survive the rigors of a flight mission. Three test programs were identified for microshutters. These were life testing, radiation testing, and environmental testing. One other purpose of the overall test program was to insure that the production techniques used for microshutters were stable and repeatable, therefore 3 different arrays would be used in the testing.

The first test effort entered into was the life test. For this test the microshutter array was installed in a cryogenic test dewar, cooled to the operational temperature of 35°K for NIRSPec, and operated for approximately 3 times the expected number of cycles for the NIRSpec mission. The goal for this lifestest was to operate the array for 100,000 cycles, after 50,000 cycles have less than a 3% change in the number of failed shutters and at the end of the 100,000 cycles have greater than 90% of the shutters properly operating.

The life testing took place in the spring of 2006. Microshutter array Serial Number (S/N) 069 was incrementally cycled to 100,000 cycles. At intervals along the way the unit underwent performance testing in order to evaluate the change in the number of failed shutters. At the end of the life test the number of failed shutters had actually decreased by 1% indicating that some of the failed shutters noted at the beginning of the test had not permanently failed but merely stuck during the initial evaluation. The microshutter team had successfully passed the first of the three tests!

The next test effort started was the environmental testing. For this testing the microshutter would be subjected to qualification level vibration and acoustic environments that would be seen on the NIRSpec instrument during launch on an Arian 5 vehicle. This testing started in mid summer of 2006 and proved to be the most challenging for the team.

The first array to enter into this test program successfully passed vibration but showed a weakness in the manufacturing screening of the arrays when it was subjected to the acoustic test. After the test it was found that a large number of shutters had been jammed into the lightshields on the front side of the array. The detailed failure analysis of the part showed that the alignment selection criteria of the lightshield to the array was not stringent enough. The array production team manufactured a new array with slightly larger lightshields and more stringent lightshield alignment specifications. Array 098 went into the test program in late October 2006 and successfully passed all environmental testing.

The final test program entered into was the radiation test. In this test the array would be subjected to radiation that would provide a total dose several times higher than what would be seen on the NIRSpec mission. Pretest analysis of the array showed that this test would not be a problem. In the fall of 2006 array S/N 059 was subjected to a total dose of 200Krads and successfully passed all tests before, during, and after being radiated.

At the end of January 2007 the results of this testing were presented to a NASA Headquarters review panel. The panel’s conclusions were that microshutters had achieved a flight technology readiness level and could be used on JWST/NIRSpec.

This Microshutter team demonstrated through this test program that the shutter technology was robust and would survive the rigors of space flight. However this test program did not demonstrate that the arrays fully met the NIRSpec criteria for beginning of life (BOL) and end of life (EOL) failed shutter requirements. One more array went into testing in January 2007. This was a high quality array that was subjected to environmental testing prior to lifetesting in order to demonstrate that the BOL and EOL failed shutter requirements could be met. Array S/N073 went into testing in January 2007. In March 2007 this testing on this array accumulated almost 90,000 cycles and successfully demonstrated that the NIRSpec requirements could be met.

Currently the microshutter team is working on the flight qualification build of the microshutter arrays and the mechanical and electrical systems that will be used for flight. The flight system will go into qualification testing late November of this year. Flight hardware production will start in December (CDR is in December and you have already started flight hardware production, i.e. shutters, flexures, etc so I would claim December) 2007 with delivery of the flight Microshutter Assembly to ESA in Fall 2008.

REFERENCES

[1] 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, "Complex MEMS Device: Microshutter Array System for Space Applications"