Micro-Mechanical Slit Positioning System as a Transmissive Spatial Light Modulator

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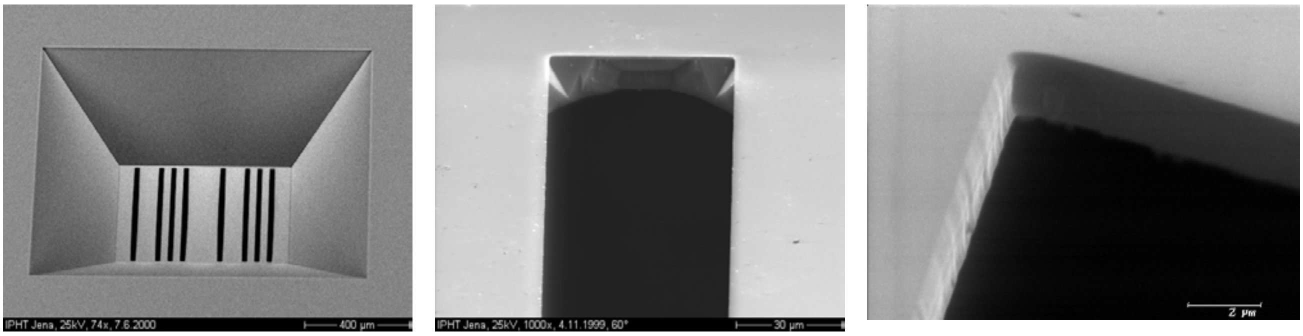
ABSTRACT

Micro-slits have been prepared with a slit-width and a slit-length of 2 … 1000 µm. Linear and two-dimensional arrays up to 10 x 110 slits have been developed and completed with a piezo-actuator for shifting. This system is a so-called mechanical slit positioning system. The light is switched by simple one- or two-dimensional displacement of coded slit masks in a one- or two-layer architecture.
The slit positioning system belongs to the transmissive class of MEMS based spatial light modulators (SLM). It has fundamental advantages for optical contrast and also can be used in the full spectral region. Therefore transmissive versions of SLM should be a future solution.
Instrument architectures based on the slit positioning system can increase the resolution by subpixel generation, the throughput by HADAMARD transform mode, or select objects for multi-object-spectroscopy. The linear slit positioning system was space qualified within an advanced micro-spectrometer.
A NIR multi-object-spectrometer for the Next Generation Space Telescope (NGST) is based on a field selector for selec-ting objects. The field selector is a SLM, which could be implemented by a slit positioning system.

Keywords: MEMS, Spatial Light Modulator (SLM), Spectrophotometer

1. INTRODUCTION

Simple micro slits are shown in figure 1, a Si-chip of an optical micro-slit array, a single optical slit with an excellent aspect ratio, its slit-edge, and a coded linear optical slit array [1, 2]. These are the elements for a mechanical slit positioning system, which are combined with an actuator for shifting the slit mask.



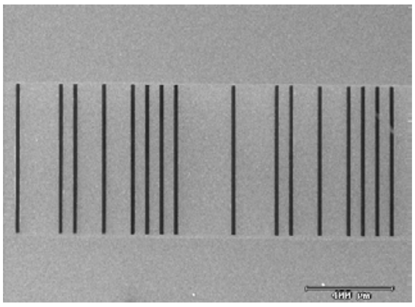


Figure 1: Optical slits, elements of the slit positioning system: Si-Chip with an optical micro-slit array (top left), single optical slit with an excellent aspect ratio and an excellent optical aperture (top), slit-edge (top right), and coded linear optical slit array with the view on top of the 2µm thick membrane, all are REM pictures

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Figure 2: Two-dimensional micro-slit array (Si-chip) with 10 x 110 single slits (two-dimensional slit positioning system), top view of the 2 µm thick membrane (REM picture). The chip is used as an entrance slit array, illuminated is a part of 10 x 10 slits for an imaging architecture to generate 10 x 10 subpixels by a simple multiplexing mode.

The light is switched by covering the slits (shutter mode) or by shifting the slit position. In this way a transmissive version of spatial light modulators is realized.

2. EXPERIMENTS AND DISCUSSION

2.1 Architectures based on Slit Positioning Systems

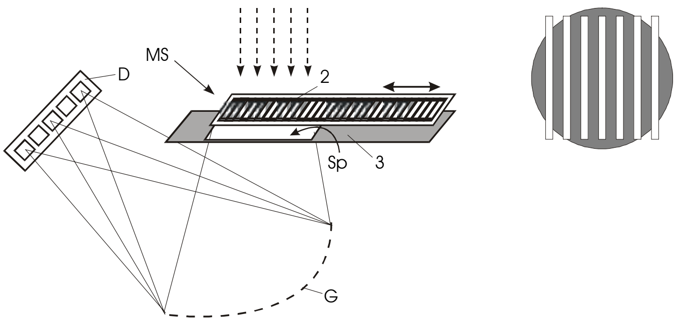


Figure 3: Example of a slit positioning system in a simple detector array grating spectrometer. It is shown a linear slit positioning system in one layer architecture as an entrance spatial light modulator. The architecture is a so called double array spectrometer architecture [3] (MS entrance slit array with 7 single slits (see top right), G imaging grating, D detector array, the slit-chip is shifted by an actuator).

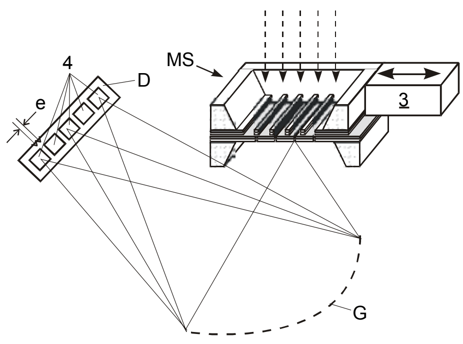


Figure 4: Example of a slit positioning system in a simple detector array grating spectrometer. It is shown a linear slit positioning system in *two* layer architecture (two Si-chips) as an entrance spatial light modulator (MS entrance slit array with 4 single slits in the example, G imaging grating, D detector array, the upper shadowing chip is shifted by an actuator, the lower slit-chip is fixed).

Figure 5: Switching mode of the linear slit positioning system as a spatial light modulator, two layer (two chip) architecture. The switching mode is a multiplexing mode, the HADAMARD transform mode [4] with 7 switching positions for 7 slits (switching modes are from above left to right 1010011, 0100111, 1001110, 0011101, 0111010, 1110100, 1101001, 1 is open and 0 switched off) and an additional special step for a commercial like single slit mode. The modes are generated by simple step by step shifting in the order of the slit width only.

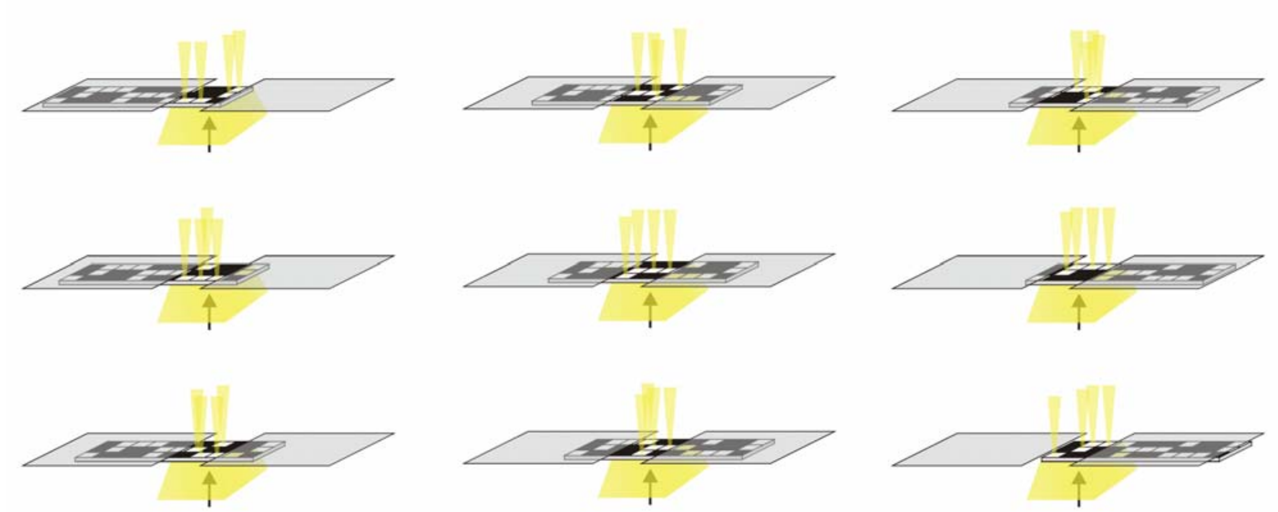


Figure 6: Switching principle of the transmissive spatial light modulator, shifting of a two dimensional slit positioning system, one layer (one chip) architecture, example of a HADAMARD transform mode for an imaging arrangement (for instance imaging spectrometer), example of 9 imaging pixels with 9 shifting steps

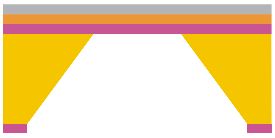
2.2 Preparation by Micromachining Technology

A typical version of the technology is given below. The technological steps are the standard micro-electronics/micromachining technology.

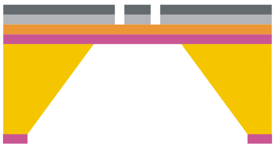
Si-Substrate with a special mechanical stress optimised multilayer membrane of a thickness of 1 … 2 µm, membrane on both sides of the Si-substrate

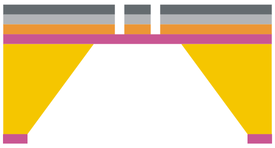
steps of technology to prepare the free standing membrane (bulk micromachining)

deposition of an additional adhesive film (NiCr) and an Al film

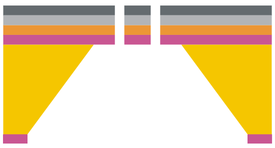


Preparation of the slit layout in the additional films by photolithography





dry etching of the membrane and removal of the Al-film



2.3 Characterization of Slit Positioning System for SLMs

The slit positioning systems belong to the micromechanical devices. They are MEMS based spatial light modulators. The well known LCD arrays are limited in spectral range and the transmission is reduced. Known MEMS based SLMs are micro-mirrors [5] (also digital mirror devices DMD and deformable mirror arrays DMA), micro-shutters [6], and the mechanical slit and fibre positioning system. A short overview about optical properties, the state-of-the-art-technology and addressing for switching of the SLMs is given in table 1. Usually the reflective and the transmissive version are distinguished. The principles for the optical properties are given in figure 6. The transmissive versions such as shutters, slits and fibres generate no additional stray light by diffraction, the micro-mirrors do so. Therefore the transmissive versions have fundamental contrast advantages (and signal-to-noise-ratio (SNR) advantages) over the reflective versions.

	micromirror	shutter	mechanical slit positioning system	fibre positioning system
Optical Properties	*decreased SNR* caused by stray light: By *diffraction of switched off positions*, on MEMS itself and by surface roughness	middle SNR, essential reduced stray light (the gaps generate a minimum stray light)	*good SNR* nearly no stray light (coded mask technology) (see 2.4.1)	*good SNR* nearly no stray light
Technology	state of the art: about 500 x 1000 problem: full space qualification MTTF ~ (number of pixels)$^{-1}$ integrated switching actuator	3 x 3 and more tested problem: array technology and space qualification MTTF ~ (number of pixels)$^{-1}$ additional switching actuator	10 x 10 basic technology space qualified, good stability MTTF const. or ~ to numbers of rows additional switching actuator	should be able to space qualification MTTF const. or ~ to numbers of rows additional switching actuator
Switching/ Multiplexing	*free addressing*, multiplexinging and scanning multiplexing limited by SNR	*free addressing*, multiplexinging and scanning	*design and software defined addressing*, some more switching steps, integrated superresolution	*design and software defined addressing,* some more switching steps
Evaluation	*reflective* version	*transmissive* version	*transmissive* version	*transmissive* version, limited spectral region by fibres

Table 1: Overview of spatial light modulators based on MEMS and micro-mechanical devices: mico-mirrors, micro-shutters, mechanical slit positioning system and fibre positioning system (MTTF- mean time to failure).

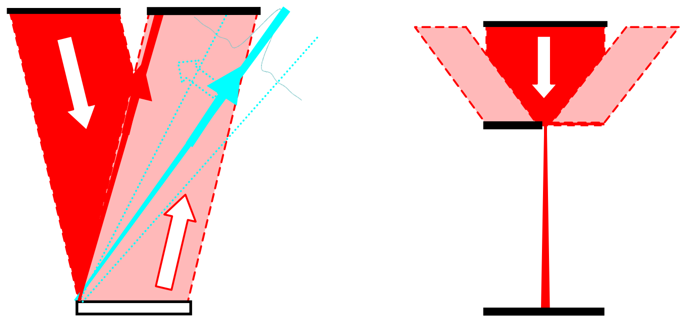
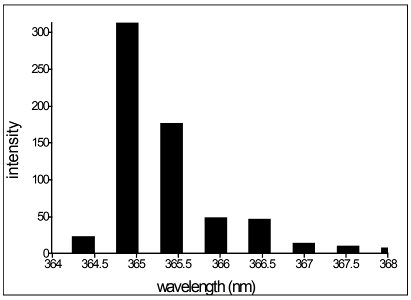


Figure 7: Reflective and transmissive spatial light modulators with entrance aperture, micro-mirror array (left) and slit mask or shutter (right) and imaging optics, principle of generation of stray light, the reflective version generates additional stray light especially by diffraction profiles and by the surface roughness of the switched off mirrors and by the reflection on the set-up.

2.4 Applications

2.4.1 Micro-spectrometer using a mechanical slit positioning system as a SLM

A micro-spectrometer using a mechanical slit positioning system was developed for space. For the set-up the limits of the spectral resolution in combination with the spectral range are given by the grating. Typically that means that an entrance slit is needed, which has a width in the order of 10 µm, and also that the (virtual) size of the detector pixel is smaller than 10 µm. A slit array and a simple double array architecture as given in figures 3 and 4 are a suitable solution [7].
The spectral resolution is increased up to the factor of 5 by subpixel imaging of the individual slits, figure 3, and the throughput is increased by multiplexing by the factor 1.5.
The spectrometer set-up including the slit positioning system has been qualified for space operation via tests carried out at vibrations, shocks, and temperatures cycles [8].
The measured monochromatic stray light was 2 x E –5 and was limited by the grating itself. No additional stray light generated by the slit positioning system could be detected. The programmable micro slit chips or the mechanical slit positioning system is the state-of-the-art.



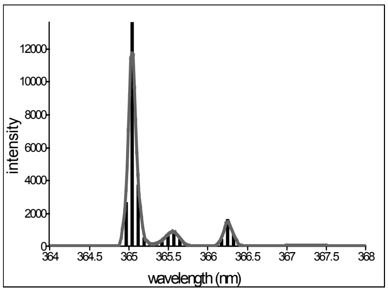


Figure 8: Image of the spectral triple line at 365 nm of a Hg-lamp, result of the commercial array-spectrometer set-up with a single slit (left), and results by sub-pixel imaging with a linear slit positioning system with 7 micro slits of a width of 14 µm and super-resolution analysis (right) [9], the spectral resolution is increased by the factor of 5 given on the basis of FWHM of the line

2.4.2 Spectral imaging

Two-dimensional versions of slit masks for new imaging instrument architectures are based on the full two-dimensional slit positioning system, figure 2. The architectures are important for instruments, whose detector arrays have a limited number of pixels (infrared focal plane arrays).
For a multi-object-spectrometer, e.g. for the Next Generation Space Telescope (NGST), a field selector is needed for selection of the objects to be spectrally resolved. A composed two-dimensional slit positioning system made of a set of independent linear systems (one dimension for individual switching and the second for scanning) can select objects (multi-object mode) [10]. One possibility is a version with slit masks. In this way 3D spectral imaging is reduced to nearly 2D detection. So the NGST multi-object-spectrometer will be 1000 times more effective than a commercial integral-field spectrometer.

3. SUMMARY

Micro-slits have been prepared for a slit positioning system by a micromachining technology on a 1…2 µm thick membrane with a slit-width and a slit-length of 2 … 1000 µm. Arrays of up to 10 x 110 slits are developed with a fill factor of up to 90 %. Light is switched by simple one- or two-dimensional shifting of the coded slit masks.
The slit positioning system belongs to the transmissive class of MEMS based spatial light modulators (SLM) as shutters. The transmissive class has fundamental advantages. No additional stray light is generated by diffraction. Also there are advantages for application in the full spectral region from UV to infrared. The transmissive class of SLM should be therefore the future solution.

Instrument architectures based on SLMs, especially on the slit positioning system, can increase the resolution by subpixel generation, the throughput by HADAMARD transform mode and are used for multi-channel detection or selecting objects for multi-object-spectroscopy.

A linear slit positioning system has been tested in an advanced space qualified HADAMARD-transform micro-spectrometer. The spectral resolution could be increased up of the factor 7. In figure 8 it is shown the increase of resolution by the factor 5.

The NIR multi-object-spectrometer for the Next Generation Space Telescope (NGST) is based on a field selector for selecting objects to be spectrally resolved. The field selector is a SLM, too. In this way 3D spectral imaging is reduced to nearly 2D detection. The SLM based NGST-MOS will be thus "1000 times more effective" than a known integral-field spectrometer. A contrast better than 1 x E 4 is required. Therefore transmissive SLMs are preferred.

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