Novel optical MEMS / Micromechanical Devices as Field Selectors for Imaging Spectrometry

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ABSTRACT

Multi-object spectrometry is a special version of imaging spectrometry, where only a relatively small number of objects or interesting image points of a scene is spectrally resolved. This allows to measure nearly all interesting points of a typical astronomical scene within one or only a few measurement steps. The essential component of a multi-object spectrometer is the field selector device, which selects multiple image points for a simultaneous measurement. Reconfigurable field selectors or reconfigurable slit masks can be MEMS, such as micro mirror or micro shutter arrays.

Alternative field selectors will be based on micro-mechanical devices and can mostly be referred to as slit positioning systems, since the elements which form the slits are mechanically positioned. Novel examples for such field selectors are an individual micro-mirror element positioner and bar arrays with slit structures. Two layer devices are presented, which form transmissive and reflective slits.

The concepts are focused on the near infrared multi-object-spectrometer for the Next Generation Space Telescope.

Keywords: MEMS, MOEMS, Slit Masks, Slit Positioning System, Spatial Light Modulator, NGST, Imaging Spectrometry

1. INTRODUCTION

Figure 1a shows an imager with a real intermediate image plane. If a grating is added as shown in figure 1 (b), the slit scan mode of a field selector generates a spectral image of the whole field.

In typical astronomical applications only a small fraction of all spatial points, for instance the fraction which is occupied by stars, is of interest. All the other points of the examined scene need not to be observed. So in principle the remaining data points of the usual 3D spectral image data cube could be mapped onto the 2D detector array simultaneously. The observation strategy is called multi-object spectrometry and the instrument which performs it is called a multi-object spectrometer (MOS). The principle is shown in figure 1c. Here a field selector will be necessary. The most variable realization of a reconfigurable field selector is a two-dimensional MEMS such as a micro mirror or a micro shutter array.

Another possibility for the realization of a two-dimensional spatial light modulator is given by slit or fibre positioning systems, figure 1d.

An important example of a MOS for space will be found at the Next Generation Space Telescope (NGST). This telescope is planned to be equipped with a near infrared MOS, working in the wavelength range from 1μm to 5μm. The NGST-MOS will have a spatial resolution in the order of 2000 x 2000 pixels. Typical numbers of objects inside the field of view will be in the range from less than 100 to a few hundred.

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Figure 1: Principles of arrangement of an imager (a), an integral field spectrometer with an added grating and a field selector which performs a slit scan (b), a multi-object-spectrometer with random access two-dimensional field selector (MEMS) (c) and a multi-object spectrometer with slit masks (mechanical slit positioning system) as a field selector (d). The slit masks can be formed by two opposite bars for the multi-object mode (e) and the bars are removed from the field of view for imaging mode (f). The slit masks can also be formed by single bars which carry a fixed slit for multi-object mode (g). A reduced imaging mode is then only possible step by step.
2. MEMS AND MICROMECHANICAL DEVICES FOR OPTICAL FIELD SELECTION

2.1 Slit Mask Generation for Field Selection

As shown in the figures 1d, 1e, 1g and 2 the multi-object mode can be realized by a bar array or by groups of an array.

2.2 Selected Examples of Micromechanical Devices, One Layer and Two Layer Versions

The micro mirror and micro shutter arrays are prepared by micromachining technology. They are called MEMS. Slit masks can also be prepared by this technology 9 – 12, 16. They could be MEMS, too. But typically for the following selected examples a mixed technology and especially precision engineering are used. They are called micro mechanical devices. Versions are given in Table 1. Mechanical field selectors for NGST MOS are also under development at the NRC, Victoria 15, and by a group of CSEM, Neuchâtel.

In this section some selected examples of mirrors and slit masks are presented. One and two layer versions are considered. The slits are formed by bars with one plane or with two planes. The transmissive version has fundamental optical advantages 8. The stray light generation is reduced.

2.2.1 Individual two-dimensional Positioning System, Mirror Elements Positioner

This concept is shown in figures 3.1 … 3.3. It differs crucially from most other concepts in the point that not the stops, defining the edges of the slits, but the slits themselves are positioned. These slits are realized by small mirrors, which simply rest on a smooth underground, adhered by a static magnetic field. A robotic actuator is necessary to reconfigure the mask, i.e. to move the slits, figure 3.3.

The concept offers a large flexibility, since a single slit does not block a whole “row” in the field of view and in principle a very large number of slits can be placed independently in the image plane. Of course this is especially advantageous if the number of objects to be measured is very large, but also if the spectra are rather short. In the latter case it will be possible to measure more objects simultaneously than with only one slit per row, because often multiple objects will be located in one row and with one slit per row only one of them could be measured at a time, even if their spectra did not overlap.

The concept provides adjustable slit width in discrete steps and the so called peak up mode by using differently sized mirrors. The peak up mode is a strategy to determine the positions of interesting object before spectral detection for example by imaging with an increased slit width. Because the slit sizes are known very precisely, there will be a high photometric accuracy.
### Table 1: Overview and features of slit masks versions, individual two-dimensional positioning system (figures 3) with mirror elements, one layer architecture for masks, bars with mirror facets (figure 4), two layer mask architecture with transmissive Z-shaped bars and double slit shaped bars (figures 5, 6, 7). Three and more layer masks are not considered.

* The peak up mode is only possible step by step.
2.2.2 One Layer System, Bars with Mirror Facets

Every slit is formed by a small mirror which is located on a movable bar. The mirror is tilted with respect to the image plane to achieve a high slit contrast. Every bar always crosses the whole image field and is suspended on both ends of this field. This has some advantages. No light can travel behind the bars, except a small fraction which may leak through the gaps between neighbour bars and the structures behind the bars are not visible to the spectrograph. Hence it is possible to place the whole actuation mechanism behind the bars. Since the bars are guided over the length of the whole image field, angular errors will be small compared to guiding over a significantly shorter distance. This reduces the guiding forces which will have to be applied to achieve a certain angular stability and consequently it may reduce the power dissipation due to friction. Additionally the requirements on the bar’s minimal curvature radius are drastically relaxed.

Since the gaps between the bars can be made relatively small and the slits have the same widths as the bars, the fill factor will be very close to 100%.

Figure 4: Bars with integrated mirrors- or slits-elements, the slit patterns is generated by an array of bars and 3D view of a field selector system with a robotic actuator principle
2.2.3 Transmissive two-layer Systems

These systems are adaptations of the previous transmissive IPHT two-layer mask concepts of one-dimensional optical switching to the specific requirements of the NGST MOS. From different possible design goals adjustable slit width and the availability of an imaging or peak-up mode have been selected as the main design drivers. Every slit is formed by the edges of two masks which are located in two different layers. Every mask is suspended on both ends of the image field. To avoid cut out holes and the related trade-off between fill factor and mechanical stability, a design approach which can be called “slit row division” is used in these concepts. The basic approach is to manufacture at least two slits in every row which have a size below the row width but together can address the whole row. By using two layers one single slit can be selected at a time and the slit width can be adjusted by partial coverage of the selected slit.

Z-shaped bars

In order to have an imaging mode, each slit has a width as large as the image field, resulting in a Z-shaped mask layout as shown in figures 5 and 6. The two cooperating Z-shaped masks allow opening a slit of variable width in their upper or lower part depending on their relative position (figure 6). Imaging has to be carried out in two sequential steps, for instance first opening all upper parts (odd rows) and then all lower parts (even rows). This is shown in figure 6.

The Z-shape offers the possibility to achieve nearly 100% fill factor of a mask crossing the whole image field without having any structural weak points as they occur at the junctions between right and left part of a usual cut out hole slit mask.

Figure 5: Z-shaped bars, overview, slit layout of the two layers
If the requirement for imaging capability is dropped and only a variable slit width with a certain maximal possible size is wanted, a Z-shaped bar will turn into a simple bar with cut in slots on the right and the left side (figure 7). Now it is possible to place several groups of two cut in slots (slit groups) on each bar and reduce the necessary stroke of the bar by employing the Vernier principle (figure 7). Besides the reduced stroke this concept also provides an improved light tightness.

Figure 6: Z-shaped bars, multi-object mode with adjustable slit width and imaging mode by two steps

Double slit shaped bars

If the requirement for imaging capability is dropped and only a variable slit width with a certain maximal possible size is wanted, a Z-shaped bar will turn into a simple bar with cut in slots on the right and the left side (figure 7). Now it is possible to place several groups of two cut in slots (slit groups) on each bar and reduce the necessary stroke of the bar by employing the Vernier principle (figure 7). Besides the reduced stroke this concept also provides an improved light tightness.

Figure 7: Double slit bars by two layer version, the principle of an adjustable slit width mode (top) and the realization of reduced strokes by employing the Vernier principle is shown (bottom).
SUMMARY

The multi-object spectroscopy needs an optical field selector for selecting the object points to be spectrally detected. Reconfigurable field selectors are individually programmable MEMS, the well known micro-mirrors, the micro shutters, and - if a micromachining technology is used - the slit positioning system.

Novel selected examples for field selectors are micro-mechanical devices, based partly on precision engineering technologies. These are the individual micro-mirror element positioner and micro-bar arrays. We distinguish one layer versions and two layer versions. More than two layers increase the switching variability, but technologically the realization is difficult. Latter versions are not considered here. The concepts can realize arrays with a limited number of bars. Most of the concepts can perform the multi-object mode with an adjustable slit width. For finding the objects an imaging mode or a reduced imaging mode, a so called peak up mode, is possible.

The presented double slit bars concept belongs to the advantageous transmissive versions, needs a simple two sided guiding with a reduced stroke and the slit width is adjustable.

The concepts are focused on the near infrared multi-object-spectrometer for Next Generation Space Telescope (NGST) for space with about 2000 x 2000 image pixels. Typically around 100 objects have to be detected. In the case of NGST for MOS only nearly one measurement step is necessary. This means the efficiency of the multi-object spectrometer can be increased up to the factor of 1000.

Based on an optical micro-mechanical field selector device, there is also a future potential for high detectivity sensors with a low stray light level and high contrast. By selecting the interesting object points only, the masks can suppress effectively the parasitic stray light. We think that a future application is given for more inexpensive spectral screening architectures with a reduced number of bars made by a conventional or a mixed technology.

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