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MEMS TUNABLE GRATING MICRO-SPECTROMETER

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ABSTRACT

The interest in MEMS based Micro-Spectrometers is increasing due to their potential in terms of flexibility as well as cost, low mass, small volume and power savings.
This interest, especially in the Near-Infrared and Mid-Infrared, ranges from planetary exploration missions to astronomy, e.g. the search for extra solar planets, as well as to many other terrestrial fields of application such as, industrial quality and surface control, chemical analysis of soil and water, detection of chemical pollutants, exhausted gas analysis, food quality control, process control in pharmaceuticals, to name a few.
A compact MEMS-based Spectrometer for Near-Infrared and Mid-InfraRed operation have been conceived, designed and demonstrated. The design based on tunable MEMS blazed grating, developed in the past at CSEM [**1**], achieves state of the art results in terms of spectral resolution, operational wavelength range, light throughput, overall dimensions, and power consumption.

1. INTRODUCTION

Various integrated MEMS-based micro-spectrometers have been demonstrated so far [2-6].
The proposed concept is based on a monochromator realized using tunable MEMS blazed gratings. The MEMS grating is stretched like an accordion, so that the change in the size of the grating changes directly the period of the grating and hence the filtered wavelength. Moreover, the input light always impinges normally to the blazed grating facets, that is satisfying the Littrow condition.
A unique property of this condition is that the efficiency of the gratings is high at all wavelengths, in contrast to what happens in standard scanning monochromators. This implies that the same device can be used for a wide range of spectral regions from the UV to the mid-IR. Moreover, no complex six-axis control is required as in normal spectrometers.
The benefits deriving from the use of such a technology are therefore the following ones:

- the micro-spectrometer can operate in different regions comprising visible, Near-Infrared and Mid-Infrared up to 10 µm wavelength;
- the complex mechanics for controlling the rotation of the grating in the standard configuration is replaced by simple electrostatic comb drives which stretch the MEMS grating.
- by operating at high orders, the achieved spectral resolution can be as high as 0.6 nm at 600 nm, 1 nm at 1500 nm or 40 nm at 10 µm;
- high throughput at each wavelength can be obtained (ideally 100% of the impinging light at a specific wavelength can be recollected at the output).
- the optical head dimensions of the spectrometer are dominated by fiber connector dimensions, without compromising in optical resolution;
- due to the electrostatic actuation, power consumption for the MEMS device is reduced to a negligible value, the electronic controller being the main source of power consumption.

The paper presents the micro-spectrometer concept and realization in Section 2, the tunable MEMS blazed grating, core of such instrument, in Section 3, and preliminary optical performances in Section 4.

2. MICRO-SPECTROMETER CONCEPT

Fig. 1 presents the concept of the tunable MEMS blazed grating based monochromator. The light is coupled into and out of the MEMS grating using a pair of fibres and collimating lenses. The MEMS chip size is 5mm x 5 mm. When the MEMS grating is actuated in its plane the filtered wavelength is modified, but the angle at which it is recollected remains the same at all wavelengths. Thus fiber connectors, collimators and beam-splitters are fixed elements.

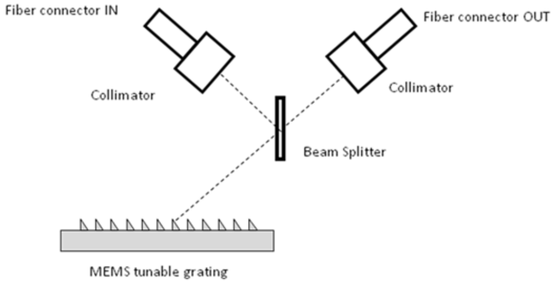

Fig. 1. Basic concept of the tunable MEMS blazed grating based monochromator.

Fig. 2 shows the block diagram of the micro-spectrometer for preliminary tests.

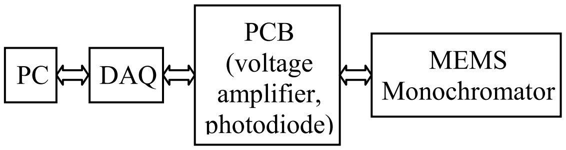

Fig. 2. Concept for the micro-spectrometer.

The miniaturized MEMS monochromator (Fig. 3) is 32mm x 53mm x 72mm, including fiber connectors.

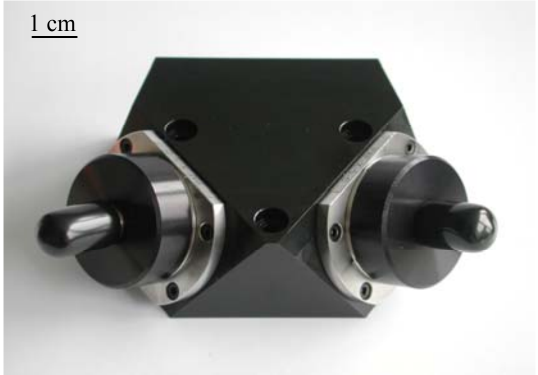

Fig. 3. The minaturized monochromator. The electrical connection are positioned on the bottom side.

3. TUNABLE MEMS BLAZED GRATINGS

The core technology of the MEMS monochromator is a tunable MEMS blazed gratings.

This section provides a description of the MEMS gratings as far as layout, process and mechanical properties are concerned.

3.1. Geometry

Fig. 4 shows a processed MEMS device which comprises of the tunable optical grating and the electrostatic comb drives which stretch the grating.

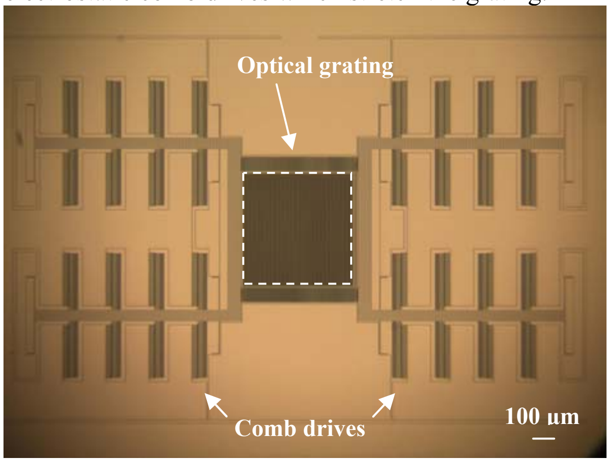

Fig. 4. Overview of a tunable MEMS grating. The white dotted region denotes the optical grating which is actuated by four sets of electrostatic comb drives.

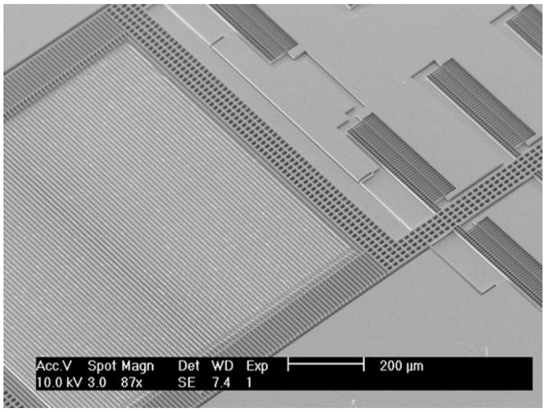

Fig. 5. SEM image of a tunable MEMS blazed grating.

The device has been fabricated using standard MEMS manufacturing techniques. The complete die measures 6 x 3 mm, with a 1 mm x 1 mm grating (Fig. 5). The grating itself is formed from free-standing beams with a 12 µm period and a 50% duty-cycle. A series of identical, compliant leaf springs interconnecting the individual elements of the grating array allow the membrane to stretch uniformly preventing distortions in the optical filtering response. Changes in the grating period are actively controlled through the application voltage to the stationary and movable arms of the opposing comb drives.

3.2. Process

In an earlier version of this device, we focused on an easy-to-fabricate, planar design; however, the reflected output of the device was found to be limited [3]. Current devices are fabricated on silicon-on-insulator (SOI) wafers using a combination of deep reactive ion etching (DRIE) and anisotropic KOH etching. They consist of a free-standing, 1x1mm optical grating with an initial period of 12µm and two sets of opposing electrostatic comb drives. The grating elements are blazed by exploiting anisotropic KOH etching (Fig. 6). In silicon this produces smooth, angled (54.74°), optical surfaces which greatly increase the diffraction efficiency of the device. The full process is reported in Fig. 4 and described in [**1**].

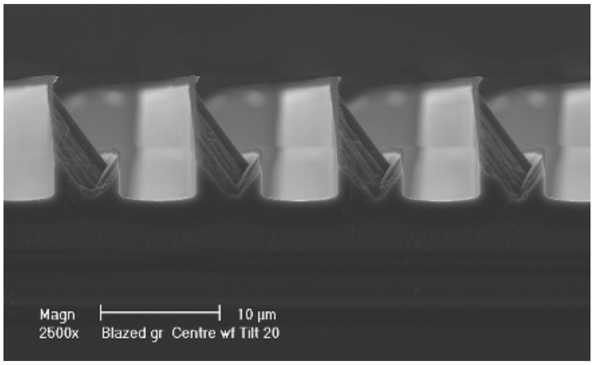

Fig. 6. SEM cross sectional view of blazed grating elements.

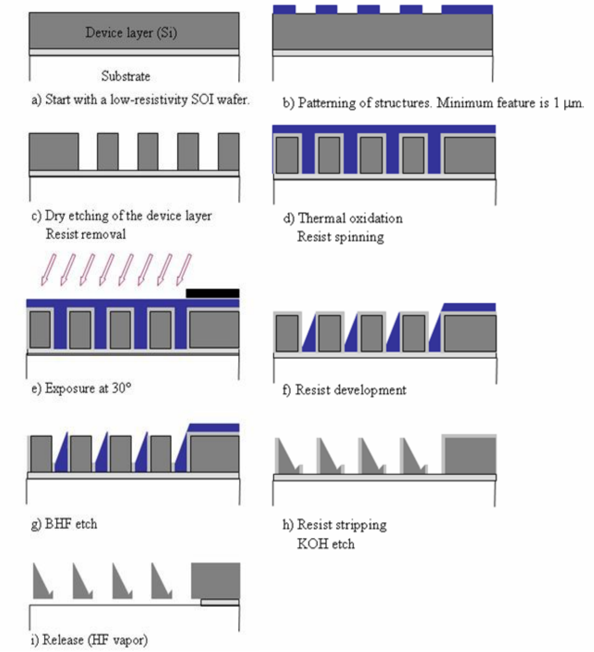

Fig. 7. Process flow for the blazed deformable MEMS gratings. Using KOH etch, an optically smooth surfaces can be obtained, corresponding to {1 1 1} Silicon planes. The entire process requires two masks.

3.3. Mechanics

Fig. 8 reports the experimental tuning of the grating on over a range of 1.5% (δλ/λ). It has been verified that the grating shows repeatable positioning exhibiting no hysterisis. Moreover expected theoretical relationships are closely followed: the change in reflected wavelength is proportional to the change in the grating period which is proportional to the square of the applied voltage.

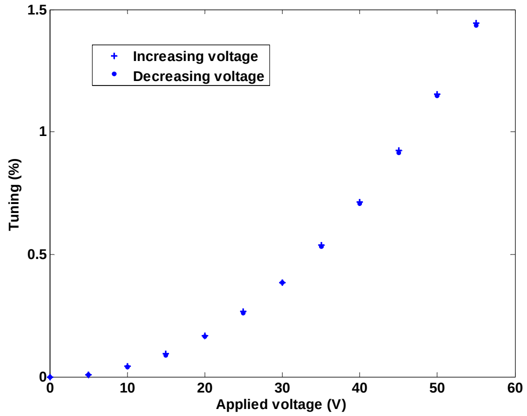

Fig. 8. Typical mechanical behaviour of a tunable MEMS blazed grating.

4. OPTICAL CHARACTERIZATION

The tunable MEMS blazed gratings have been characterized in the configurations they will be used in the micro-spectrometer, that is at normal incidence to blaze (Littrow condition).

4.1. Static Characterization

The MEMS gratings were first characterized statically. The optical setup, shown in Fig. 9, can characterize the gratings over a wide wavelength region, by using a fibre based super-continuum white light source. The light from the fibre is collimated onto the grating under test and the light reflected back from the grating is analyzed using a beam splitter and an aperture. The spectra are measured using an optical spectrum analyser.

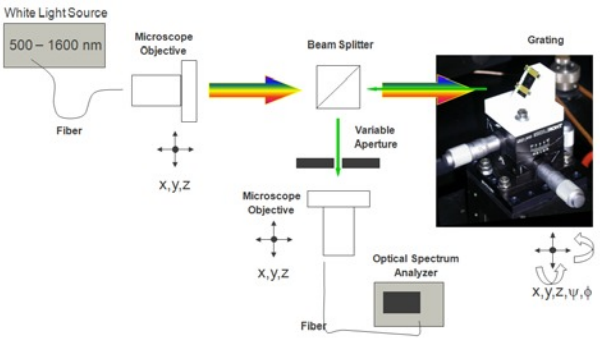

Fig. 9. Optical setup for the static characterization of the MEMS gratings.

Fig. 10 shows the relative efficiency of the gratings at 800 nm and 1500 nm. The MEMS gratings demonstrate the expected high optical performance: a linewidth of 0.4 nm at 800 nm has been demonstrated for a 1.4 mm long blazed grating. The linewidth measurements closely resemble theoretical values. Optical efficiencies of gold coated gratings were also measured and found to range between 90-94%.

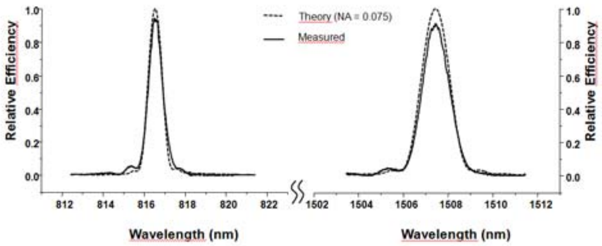

Fig. 10. Relative efficiency of MEMS gratings, showing measurement (solid line) and simulation (dotted line) at 800 nm and 1500 nm. A planar gold mirror was used as a the reference.

4.2. Dynamic measurements

A similar setup to the one shown in Fig. 9 was used to address the dynamic spectral response of the tunable MEMS grating. In this case the MEMS gratings were electrically connected in order to be actuated.
The resulting spectra are shown for different drive voltages in Fig. 11.

A tuning range of 3% and a 25 db rejection is reported. A maximum of 8% of tuning has been demonstrated experimentally.

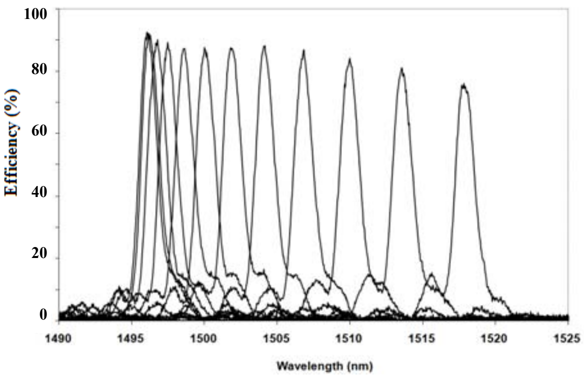

Fig. 11. The spectral response of the MEMS grating at different drive voltages ranging from 0 to 55V, step 5V.

5. SPECTROSCOPIC MEASUREMENTS

Preliminary demonstration of reconstruction of a spectrum generated at the output of an optical biosensor has been obtained. A diode is used as source. Fig. 12 reports the reconstruction of such a spectrum using the MEMS based monochromator. This preliminary result shows an optical resolution of the MEMS monochromator on the order of 1 nm.

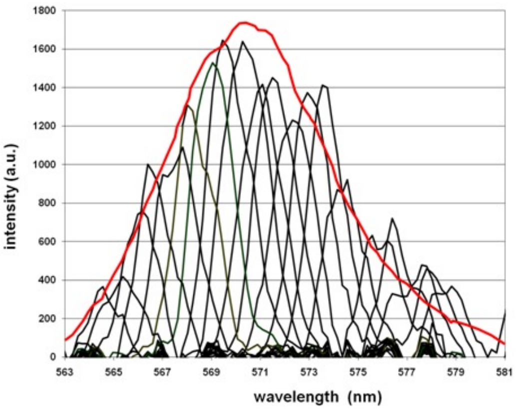

Fig. 12. A biosensor optical output (broad spectrum) is reconstructed through the envelope of multiple spectra (narrow spectra) acquired with the MEMS monochromator.

6. CONCLUSIONS AND OUTLOOK

In this paper a new concept of micro-spectrometer has been proposed and experimentally demonstrated.

The main advantages are the possibility to operate from the visible range to the Near-Infrared and Mid-Infrared range, up to 10 µm wavelength; no complex mechanics implicated; high spectral resolution; high throughput at each wavelength; really compact dimensions; negligible power consumption for the MEMS device.

Next steps of our future work are to demonstrate a fully assembled micro-spectrometer and to validate its potentialities for space applications, assessing its properties in space representative environment (radiation, temperature, vacuum, vibrations, limited lifetesting being the most important).

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