Space Instruments based on MOEMS Technology

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A summary of current activities of the European Space Agency (ESA) related to optical MEMS technologies with a strong emphasis on the instrument aspects is presented. Future space applications and planned activities where optical MEMS might be an interesting option conclude this paper.

I. INTRODUCTION

Space and particularly planetary exploration missions demand very small, light weight, low power, rugged, flexible and high performance instruments. Micromachined devices might be key components offering exactly these characteristics for a broad range of applications. Optical MEMS technologies, usually also called MOEMS technology, for space instruments are currently being developed or investigated within ESA R&D programmes.

II. SPACE INSTRUMENTS

Telecommunications

An important application of optical MEMS in space telecom payloads is to provide circuit switching and redundancy functionalities. ESA is presently investigating novel payload concepts for space telecom based on photonic technologies, whose core element for switching RF/microwave channels is an optical switch [1]. A promising technology for implementing such an optical switch is MEMS technology. These photonic payloads aim at broader bandwidth, signal transparency, and enhanced routing flexibility at lower mass and size than typical for telecom payloads in full microwave implementation.

Another application of optical MEMS for telecommunications is beam steering in an inter-satellite laser link. Such a link has been established for the first time between the GEO and LEO satellites Artemis and SPOT 4 in 2001 and between two LEO satellites TerraSAR-X and NFIRE in 2008. The steering mirrors use classical electromagnetic or piezoelectric actuation; they are therefore relatively heavy components. An ongoing ESA activity aims at miniaturisation of a high precision optical micro-scanner and tracker. The requirements on the achievable scan angle and tracking precision are very challenging. They depend mainly on the front optics aperture and output scan angle of the laser link instrument.

X-ray Telescope

For ESA's X-Ray Evolving Universe Spectroscopy Mission (XEUS) a new technique for manufacturing large scale x-ray optics is being developed, using commercially available silicon wafers [2]. These wafers already have a surface roughness which is sufficiently low for x-ray reflection (grazing incidence). The silicon wafers are processed to form wedged plates with a rib structure on their non-reflecting side. Each plate is then pre-bent to the required shape, stacked and bonded to the underlying plate to form a monolithic silicon structure with pores on a sub-millimetre scale. These silicon stacks (fig.1) are aligned to form an x-ray optic unit, which forms the elementary part of a large x-ray telescope aperture of diameter 4 m and focal length 35 m. One of the particularly challenging processes is the bonding of 45 structured silicon plates, having a surface area up to 15 cm x 10 cm.

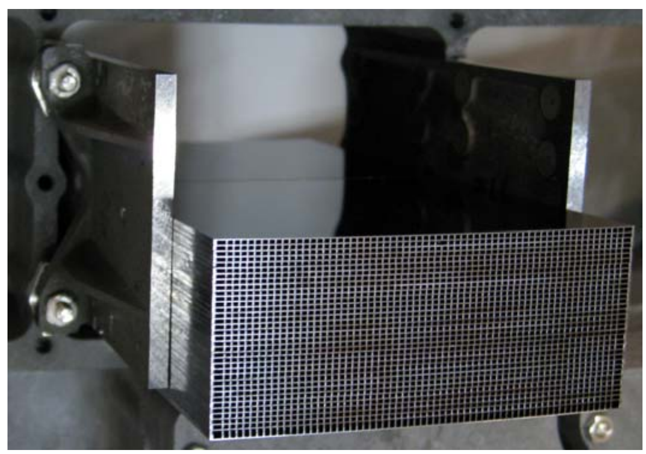

Figure 1: A silicon plate stacks aligned and mounted to form a mirror module. X-rays are focused after 2 reflections from the mirror like surfaces. Courtesy of cosine Research B.V.

Lidar optical circuits

Differential absorption atmospheric remote sensing, altimetry, range-finding and Doppler anemometry are some lidar applications in space. A novel hollow waveguide lidar optical circuit approach has been investigated for a wavelength of 1.5 μm in the frame of an ESA activity. Hollow waveguides, machined into the surface of a dielectric substrate, are used to guide optical beams through a circuit of components. The optical components are simply inserted into alignment slots which are precisely machined into the substrate. A silicon wafer substrate based hollow waveguide circuit, machined

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using Deep Reactive Ion Etching (DRIE) has also been investigated. Results show that the hollow waveguide circuit shows a significant improvement on the optical component misalignment tolerance compared to free space optical bench circuits and requires only a few fabrication steps.

Spectrometers

Most scientific and earth observation spacecraft, have one or several spectrometers on board. Their miniaturisation is therefore interesting, particularly for planetary probes.

The Programmable Micro Diffraction Grating (PMDG) is an optical MEMS device which could find multiple applications in space spectrometers. From the instrument designer point of view the PMDG can be implemented in the pupil plane or in the image plane of a spectrometer. First results of an ESA study investigating space instrument concepts based on existing PMDG technology show that it could have advantages in the infrared domain when implemented in the pupil plane of a spectrometer. In this case the first order diffraction efficiency of a PMDG could be over 80% using a blazed profile with at least 4 ribbons per period**.** When implemented in the image plane of a spectrometer, after a dispersive element, it can be used as a wavelength selective spatial modulator in order to select certain wavelengths and reject others. The potential PMDG applicability to ESA missions is under investigation for both discussed implementations. The length of the PMDG ribbons limits the field of view of a spectrometer. Existing PMDG technology seems therefore to be limited to single point source spectrometry, which somewhat narrows its application range for space instruments. Another ESA activity aims to develop a new, European based, PMDG technology.

A slightly different diffractive optical MEMS device for a gas sensing instrument is also currently under development. The primary objective is to build a fully functional demonstrator of a sensor for methane (CH_4) gas concentration measurement. This activity aims for a simple, robust, and potentially low-cost design. The key component of this sensor instrument is a micromechanically controllable two-state optical filter device. The filter device is realized using a Configurable Diffractive Optical Element (CDOE) technology [3].

In traditional spectrometer designs, there is an inherent trade-off between resolution and light throughput. While spectral resolution increases as slit width decreases, the narrowing of the input slit reduces photon throughput and consequently measurement sensitivity. An ESA activity has demonstrated that by using a micromachined multi slit mask SNR improvements of more than a factor of 2.5 have been achieved on absorption measurements of SO_2 for a detector-noise-limited measurement, in accordance with the theory.

III. PLANNED ACTIVITIES INVOLVING MOEMS

The Near Earth Object Micro Explorer (NEOMEx) is an ESA straw man mission to provide a focus application for a micro-system based spacecraft concept. In the frame of a technology development program it is planned to start an activity on a micro-system capable of demonstrating that space optics applications can benefit from microtechnology.

IV. FUTURE MOEMS BASED SPACE INSTRUMENTS

Spectrometer

Spatial Light Modulation (SLM) is a very useful function for both object selection in space as well as spectroscopy. The James Webb Telescope (JWST) has a spectrometer (NIRSpec) on board [4] with a micro-shutter array as key component for object selection. Applying a micromirror array (SLM) differently, namely as an adaptive and programmable aperture/slit mask, could improve the performances of future spaceborne spectrometers whilst maintaining reasonable size and mass.

Telescope primary mirror

Future space telescopes, in particular for science and Earth observation from the Geostationary Orbit (GEO), are foreseen to become larger for increase resolution. The primary mirror's area mass needs to be less than 10 kg/m^2 if diameters of over ten meters shall be attained. MEMS technology could contribute to fulfil this challenging requirement by providing light weight large area wave front correction mechanisms for instance.

Adaptive optics

Adaptive mirrors are key components for future large-aperture space telescopes and high power laser based systems such as Raman spectrometers (ExoMars), lidars (Aladin), altimeters and deep-space inter-satellite communications. For very large space telescopes the required precision for surface shape control and deployment stability cannot be reached without active control. In such cases the telescope will likely have to be corrected by an adaptive mirror using MEMS technology for instance. Optical MEMS based adaptive optics could also be used in high power laser based systems. Thermal stresses in the optical system create optical beam shape instabilities. In the worst case a beam focalises on an optical component and causes damages. An adaptive optical element is therefore very useful to stabilize and control the laser beam shape.

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