Applications of SLMs for advanced optical instrumentation in space

Frederic Zamkotsian

Laboratoire d’Astrophysique de Marseille, France
The Universe

- Dark Energy
  - Accelerated Expansion
- Afterglow Light Pattern
  - 400,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Inflation
- Quantum Fluctuations
- 1st Stars
  - about 400 million yrs.
- Big Bang Expansion
  - 13.7 billion years

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Future needs

- MOEMS devices designed/operating at cryo temperature + vacuum
  - Space instruments
  - Ground-based IR instruments
Instrumental needs using micro-opto-electro-mechanical systems (MOEMS)

- **Wavefront control**
  - Deformable mirrors

- **Object selection**
  - Programmable slits

- **Spectral domain application**
  - Programmable gratings

<table>
<thead>
<tr>
<th>Phase</th>
<th>Intensity</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavefront control</td>
<td>Object selection</td>
<td>Spectral domain application</td>
</tr>
<tr>
<td>Deformable mirrors</td>
<td>Programmable slits</td>
<td>Programmable gratings</td>
</tr>
</tbody>
</table>

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Most popular MOEMS devices available

Micro-mirrors
- 2048x1080 individually tiltable
- 13.68µm pixel pitch,
- Tilt angle of 12°

Numerous applications
- Prime use displaying images
- No customization possible

Space qualification tests (ESA contract)
- -40°C in 10⁻⁵ mbar vacuum
- Micro-mirrors in position for > 1500s
- DMD fully operational
- 1038 hours life test, radiations, vibrations
- No show-stopper for space application

Zamkotsian et al., SPIE 6884, 2008
PTT 111 DM

- 111 actuators, 37 piston-tip-tilt segments
- Segment pitch 606µm (segment size 700µm)
- Stroke 5 to 7 µm; Tilt angle ±4 or ±5.6 mrad
- Optical coating: protected silver, gold, protected alu, dielectric
PTT111 integration
• **Best flat**
  
  **10nm RMS**
  
  **79nm PtV**

Zamkotsian et al.,
Micromachines, 8, 233; 2017
doi:10.3390/mi8080233
• Best flat
86nm RMS
501nm PtV

Zamkotsian et al.,
Micromachines, 8, 233; 2017
doi:10.3390/mi8080233
PTT111 down to 160K

Tilt

Piston

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
• Best flat
  12nm RMS
  113nm PtV

Zamkotsian et al.,
Micromachines, 8, 233; 2017
doi:10.3390/mi8080233

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
MOEMS developments for cryo

♦ NASA-GSFC Micro-shutters
  (USA)
Selected for JWST NIRSpec

♦ LAM-IMT Micro-mirrors
  (Europe)
LAM – EPFL micromirror array development: MIRA project

Requirements

- Mirror size of 100 x 200 µm²
- Individual addressing of the micromirrors
- High contrast of at least 1000:1
- 20° mechanical tilt angle
- Uniform tilt angle over the whole array
- Fill factor of more than 90% (if possible >95% in one direction)
- Wavelength range from visible to infrared
- Optically flat mirrors in operation < λ/20 with λ = 1 µm
- Cryogenic operating temperature (<100K, 30K goal)
MIRA: concept

Frame
Stopper beam
Spacer
Suspended beam
Electrode
Mirror
Landing beam
Landing pad

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
MIRA: the realization

- Three SOI wafer process
- Two wafer-level bonding steps

Waldis et al., SPIE 6887, 2008
Canonica et al., JMM, 2013
MIRA: the realization
MIRA: the realization

2048 mirrors
(64 x 32)
MIRA: cryogenic test

- Specific cryo chamber developed, compatible with our interferometric bench
- Vacuum $10^{-6}$ mbar
- Cryogenic temperatures
MIRA: cryogenic test

300K
0 V

300K
130V

162K
130V

162K
148V

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Surface quality measurement in the ON position

- 293 K, 135 V, 9.8 nm PtV
- 162 K, 148 V, 27.2 nm PtV
- 293 K, 135 V, 9.9 nm PtV

Cryogenic test: mirror surface
- Device with lines tilting only
- 200µm object projected on the 100 x 200 µm²
Object tailoring

PSF slicing
Object tailoring

PSF slicing
PSF slicing
Object tailoring

PSF slicing
PSF slicing
Contrast measurement integrated over the micromirror surface

Contrast value: **1000:1**
MIRA 4 project
[ MIRA + hardened electronics ] : buttable arrays in FOV

Applications: Universe and Earth Observation, Physics, Biology

Funding

Frederic Zamkotsian
SLM technologies and applications, EPFL, Lausanne, 27 October 2017
MOEMS characterization platform

◆ Operational bench (completed 2002)
  - MOEMS components operational performances measurement (tilting micromirrors, programmable diffraction gratings, …)
  - Modular bench: multi-sources, multi-detectors and adjustable pupil

◆ Interferometric bench (completed 2004)
  - Surface quality, deformation static and dynamical measurement
  - Small and large FOV with sub-nanometer resolution (z-direction)

◆ Cryogenic bench (completed 2013)
  - Performances measurement under vacuum and at cryo. temp. (30K - ambient)
Tests on multiple devices: TI, EPFL, NASA, LAAS, MEMSCAP, OKO, ALPAO, BMC, CSEM ...

in cryo: MIRA project (with EPFL), TI-DMD for EUCLID, PTT111 from Iris-AO
Instrument developments using MOEMS: the BATMAN family

- Multi-Object Spectrograph
  - BATMAN
  - ROBIN
  - BATMAN flies

- Programmable wide field spectrograph
  - Flight model design
  - Full scale breadboard

Frederic Zamkotsian
SLM technologies and applications, EPFL, Lausanne, 27 October 2017
The Universe
EUCLID-NIS: the DMD option

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Multi-Object Spectroscopy (MOS)

Telescope’s field of view → Thousands of galaxies

Overlapping Spectra

Telescope (ground or space)

Reflective surface

Spectrometer

CCD Camera

Measured spectra

Hubble ultra deep field (HUDF), NASA, 3/9/2004
Multi-Object Spectroscopy (MOS)

Telescope (ground or space) -> Telescope's field of view -> Thousands of galaxies

Hubble ultra deep field (HUDF), NASA, 3/9/2004

Measured spectra

2D Micromirror array in the telescope focal plane

CCD Camera

Frederic Zamkotsian
SLM technologies and applications, EPFL, Lausanne, 27 October 2017
MOEMS-based Spectro-Imager

Universe Observation: Multi-Object Spectrograph + Imager

Field of view

TNG

Measured spectra

Spectrograph arm

CCD camera

Micro-mirror array in the telescope focal plane

Imaging arm

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
**BATMAN**

Spectro-Imager on Galileo telescope (3,6m)

Zamkotsian et al., SPIE 9908, 2016

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Imagery

z00 pattern2

z09 pattern2

z20 pattern1

z25 pattern1

z40 pattern1

z49 pattern2

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
Slits
Spectra

**Slit: 1 µM (13.68 µm)**

**Spectrum on 1.5 detector pixel (8,3µm) in 450-650nm wavelength range**

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017

Zamkotsian et al., SPIE 9147, 2014
Optical and opto-mechanical design
Images at DMD surface, spatial / spectral behaviour

- OLED: white slit at 45°
- DMD: order 1, order 0, order -1

Frederic Zamkotsian

SLM technologies and applications, EPFL, Lausanne, 27 October 2017
End-to-end measurement

- Input: OLED scanning slit, width 1 pixel
- DMD: 0-order removed
- Output: recombined slit
End-to-end measurement

- Input: OLED scanning slit, width 1 pixel
- DMD: 0-order removed
- Output: recombined slit
End-to-end measurement

- Input: OLED scanning slit, width 1 pixel
- DMD: 0-order + object removed
- Output: recombined slit
End-to-end measurement

- Input: OLED scanning slit, width 1 pixel
- DMD: 0-order + object + blue removed
- Output: recombined slit

Output

![Graph showing output data](image-url)
Large micro-mirror array with large tilt angle, excellent surface quality, high contrast and operation at cryo temperature are requested for spectro-imagery applications in space.

MIRA project is under way for the realization of large arrays dedicated to spectroscopy (next step: integration with hardened electronics).

- Spectro-imager for Universe Observation
- Programmable spectrograph for Earth Observation

frederic.zamkotsian@lam.fr