Optical MEMS Devices and Their Applications in Optical Biomedical Imaging

Optical biomedical imaging

- Much higher resolutions than ultrasound imaging, so early cancer detection possible
- Much safer and much lower cost than CT and MRI, leading to affordable cancer screening to save millions of lives
- Noninvasive or minimally invasive imaging, enabling real-time surgery monitoring to significantly reduce mortality
- But still bulky and slow, limiting their applications in internal organ where most of cancers occur
- **Our solution: The small size and high speed of MEMS devices ➔ Miniature Catheters for *in vivo* Endoscopic Imaging**

Optical MEMS Devices

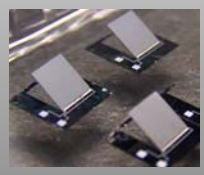
Numerous MEMS mirrors have been developed for displays and optical communications. However, there exist a few limitations for bioimaging:

1. ***High driving voltage (~100V), which raises safety concern***
2. ***Small rotation angle (<30°), resulting in low imaging efficiency***
3. ***Relatively small aperture size (~0.5mm), resulting in low image resolution***
4. ***Small linear displacement (<45μm) ➔ small imaging depth for confocal imaging***
5. ***Limited degree-of-freedom (DOF) ➔ Multiple DOF desired***

Our Solutions

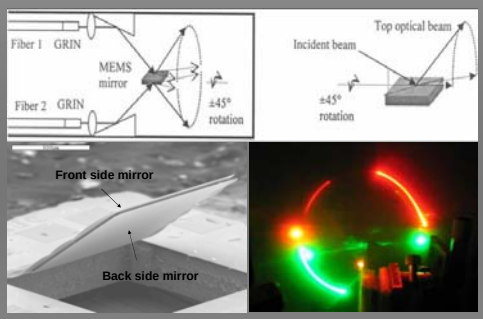
For transverse line-mode scanning and beam steering: 1-D Micro mirror

Scanning Range: >120°, among the largest ever reported
Driving Voltage: < 20V, lowest among devices with similar scanning range
Aperture Size: 1 mm



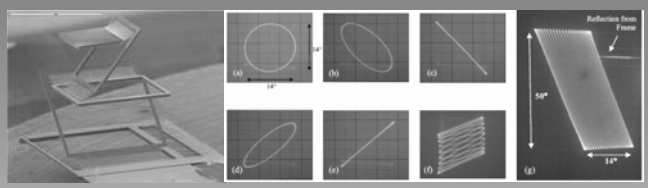
Similar devices designed and fabricated for even larger aperture size: 3mm by 3mm
Collaborator: Kodak

For full-circumferential-scanning: Dual reflective 1-D micro mirror



- With this dual reflective design, 360°full circumferential scanning can be achieved with driving voltage less than 20V
- Aperture Size: 1mm

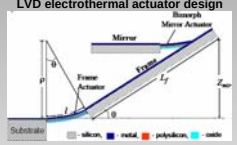
For transverse 2-D scanning: 2-D micro mirror



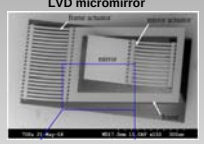
2-D micro mirror and the Lissajous and Raster scan pattern generated with driving voltage less than 12V

For longitudinal 2-D scanning: 2-D micro mirror / micro lens

LVD electrothermal actuator design

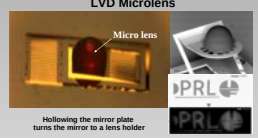


LVD micromirror



Angular rotation is compensated by two bimorphs with the same length but extending to opposite direction, resulting in pure vertical motion on the mirror plate

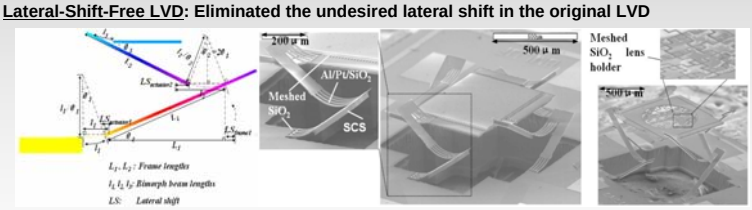
LVD Microlens



Hollowing the mirror plate turns the mirror to a lens holder

LVD lens holder can be used in refractive imaging where internal adjustment of the focal point is desired

Lateral-Shift-Free LVD: Eliminated the undesired lateral shift in the original LVD



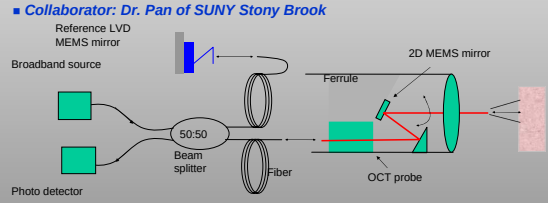
Angular rotation is jointly compensated by three series connected bimorphs with calculated lengths, lateral shift is also diminished with the directional reciprocity
State-of-the-art result: Millimeter operating range with micrometer later shift.

Optical Bioimaging Applications

- Optical biopsy provides high-resolution, cross-sectional imaging of tissue non-invasively. There are several optical biopsy techniques including optical coherence tomography (OCT), nonlinear optical (NLO) imaging and confocal imaging.
- Conventional optical imaging systems are too bulky and have slow imaging speed
- Our solution: Use MEMS mirrors and lenses for miniaturization

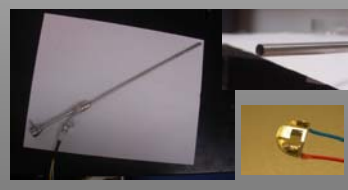
1. MEMS Endoscopic OCT Imaging --- *Application of 1-D scanning micro mirror*

- *Collaborator: Dr. Pan of SUNY Stony Brook*

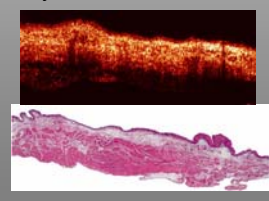


- **Large scanning angle**
- **Fast scanning speed**
- **Low operating voltage**
- **High resolution**
- **Small size**

Schematic of endoscopic OCT system



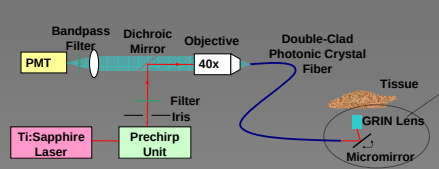
MEMS-based Endoscope fits into a standard Cystoscope



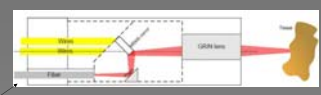
Compararison of an OCT image with histological image of rat bladder

2. Nonlinear Optical Imaging --- *Application of 2-D scanning micro mirror*

- *Collaborator: Dr. Gu of Swinburne University of Technology*

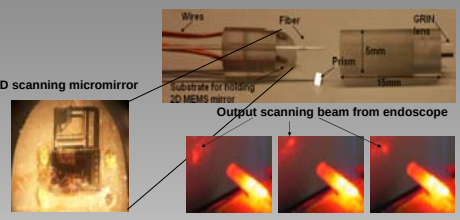


Endoscopic two-photon imaging system block diagram

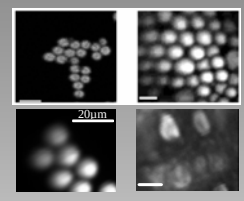


Endoscope with 2D scanning mirror integrated

- **Two-Photon Excitation Fluorescence Imaging**
- **Second Harmonic Generation Microscopy**
- **Imaging Resolution: ~1 μm**

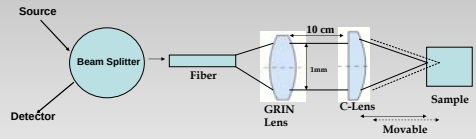


Catheter design with device integration



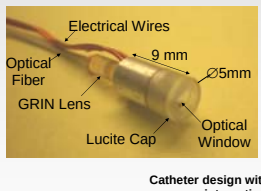
TPEF imaging of 10μm diameter fluorescent micro beads

3. Confocal Microscopic Imaging --- *Application of LVD / LSF-LVD mirror*

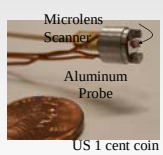


- **Single mode fiber point detection**
- **Axial scanning lens**
- **Non invasive**
- **Axial Resolution: ~1 μm**

Confocal Microscopy Concept

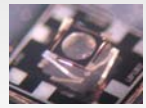


Catheter design with device integration



LVD Microlens Scanner

LSF-LVD Microlens Scanner



LVD Lens Holder and LSF-LVD Lens Holder

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