A Current-Controlled PCB Integrated MEMS Tilt Mirror

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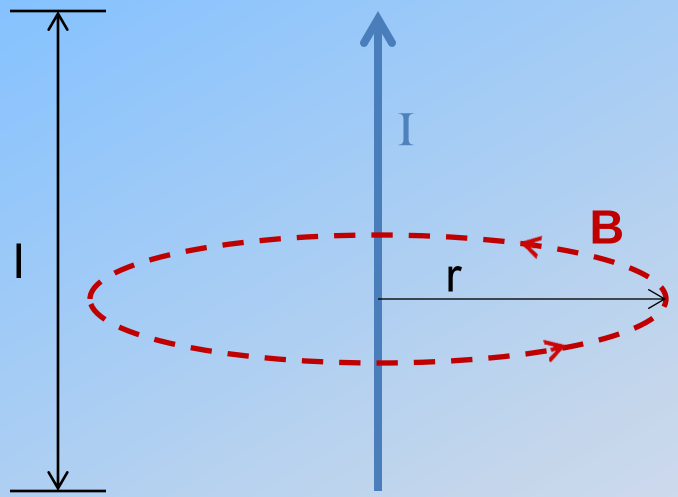
Introduction

- MEMS Tilt Mirror
  - a miniature planar micro-mirror that can experience a 1-D or 2-D tilt in response to a control signal
- Commonly used technologies
  - electrostatic
  - piezoelectric
  - electrothermal bimorph
- Applications
  - laser beam steering
  - interferometers
  - dynamic signal analyzers
  - optical cross-connect switches

Far-Field Magnetic Field About a Conductor

- A DC current in a conductor produces a DC magnetic field with a magnetic flux density, **B**
- B is obtained by the Biot-Savart law



$$B = \frac{\mu I}{4\pi} \int \frac{\sin(\theta)}{r^2} dl$$

Magnetic Field Close to a Current Carrying Trace

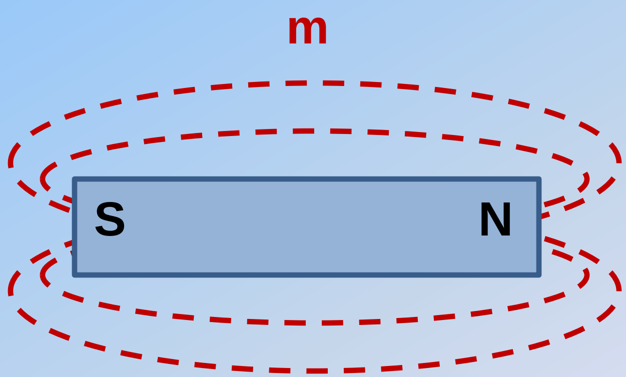
- Assumptions
  - Wide Cu trace of width w_t
  - Device is close enough to the trace so that the approximation for an infinite current sheet applies
  - The sheet current is the current in the PCB trace
- Therefore an approximation for B is

$$B = \frac{\mu_o I}{2 w_t}$$

Magnetic Dipole

- A permanent magnet has a magnetic moment, **m**
- For a magnet of volume, V, and magnetic flux density, B_m:

$$m = \frac{B_m V}{\mu_o}$$



Rare Earth Magnets

- Permanent magnets
- Strong magnetic field
- Samarium-cobalt (Sm-Co)
  - Useful up to 250°C+
- Neodymium-iron-boron (Nd-Fe-B)
  - Useful below 200°C
  - Lower cost than Sm-Co
  - Available in smaller sizes

3 miniature Nd-Fe-B magnets on a U.S. penny

Each magnet: 1.6mm on a side

Torque Produced

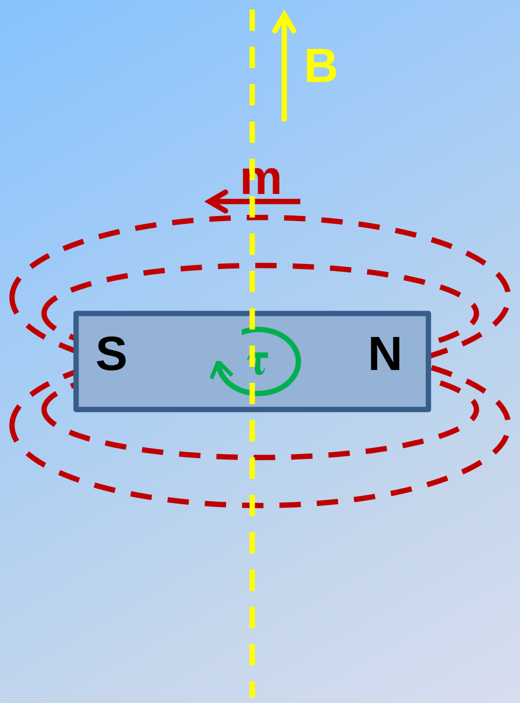
The vectors **B** and **m** interact and produce a torque, τ, that attempts to align **B** and **m**:

$$\vec{\tau} = \vec{m} \times \vec{B}$$

$$\tau = mB\sin(\theta)$$

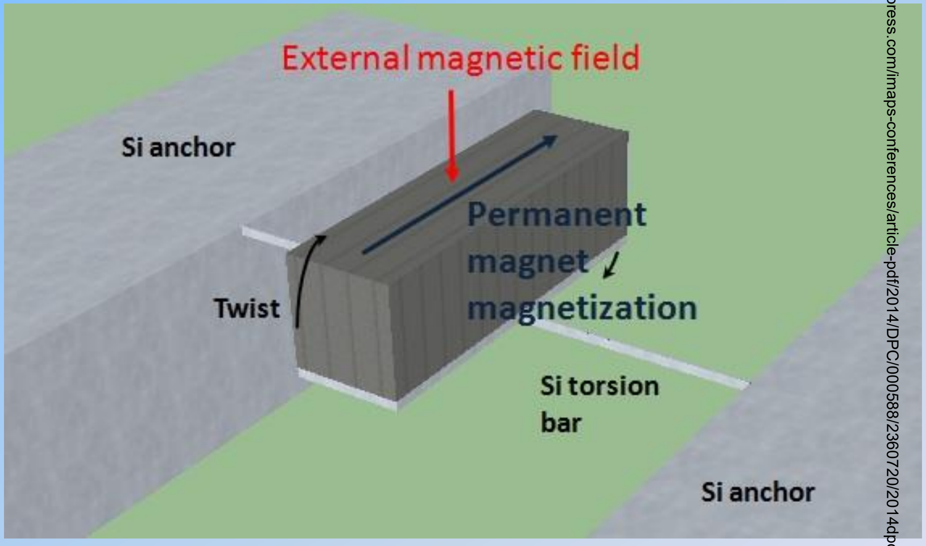
For close to a long, wide current trace and θ≈90°:

$$\tau \approx \frac{m\mu_o I}{2w_t}$$



MEMS Tilt Mirror Architecture

- Integrate the miniature Nd-Fe-B magnet onto a micromachined torsional platform
- Mount the MEMS device near a current carrying trace on a PCB



MEMS device concept

MEMS Torsional Platform

- Uses 2 rectangular cross-sectional torsional springs to attach the torsional platform to a surrounding frame
  - Dimensions w, t, L where w ≥ t
- Φ is the total angular displacement:

$$\Phi = \frac{\tau L}{JG} \quad \text{where}$$

$$J = wt^3\left[\frac{1}{3} - 0.21\frac{t}{w}\left(1 - \frac{t^4}{12w^4}\right)\right] \quad \text{and} \quad G = \frac{E}{2(1+\nu)}$$

Device Geometry

- Rare earth magnets
  - 1.6mm on a side
- Torsional Platform
  - 3.8mm long and 1.6mm wide
  - Can support 1, 2 or 3 magnets
- Torsional springs
  - 200µm thick, 50µm wide and 3.2mm long
- Gap between platform/springs and the frame
  - 225µm gap

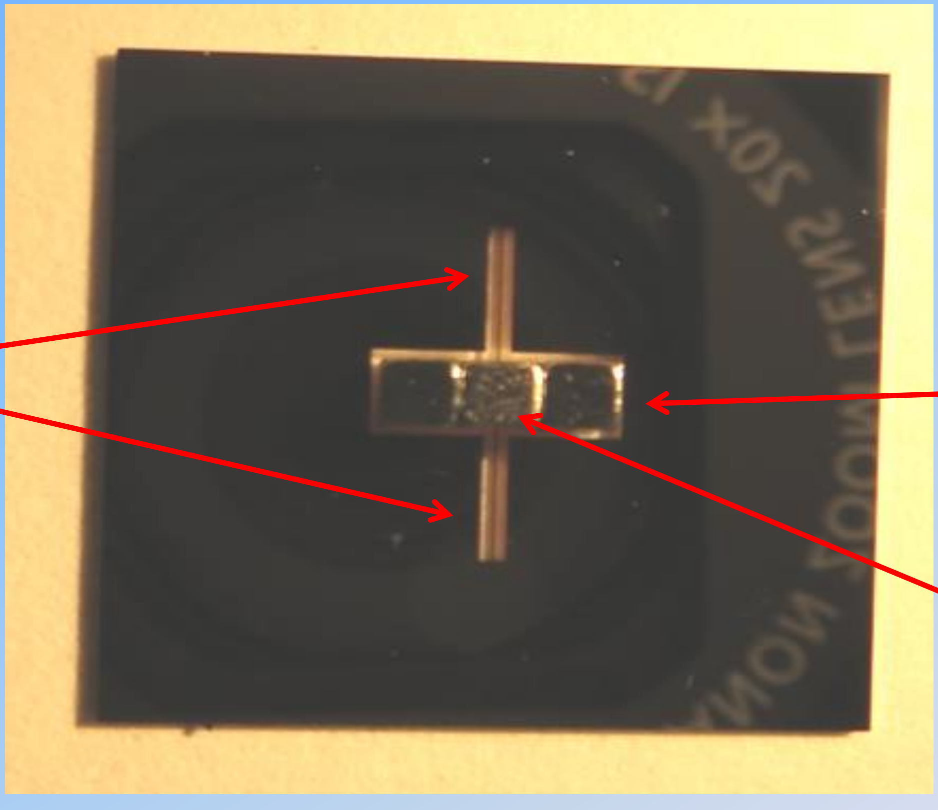
Microfabrication Procedure

- Begin with a (100) 375µm thick, DSP Si wafer
- Backside photolithography: Mask 1
- Backside DRIE etch to define torsional springs
- Frontside photolithography: Mask 2
- Frontside DRIE etch to release torsional platform and springs, and the die
- Device cleaning step
- Attachment of magnet to platform with epoxy
- Planar micromirror can be attached to magnet

Discussion on Attaching the Rare Earth Magnet(s)

- The only nonstandard fabrication step
- Care taken to avoid close proximity to any magnetic or ferromagnetic object
- A drop of a slow curing epoxy is placed onto the Si platform
- Plastic tweezers used to place magnet on the Si platform
- Epoxy allowed to air dry

Photograph of a Fabricated Device

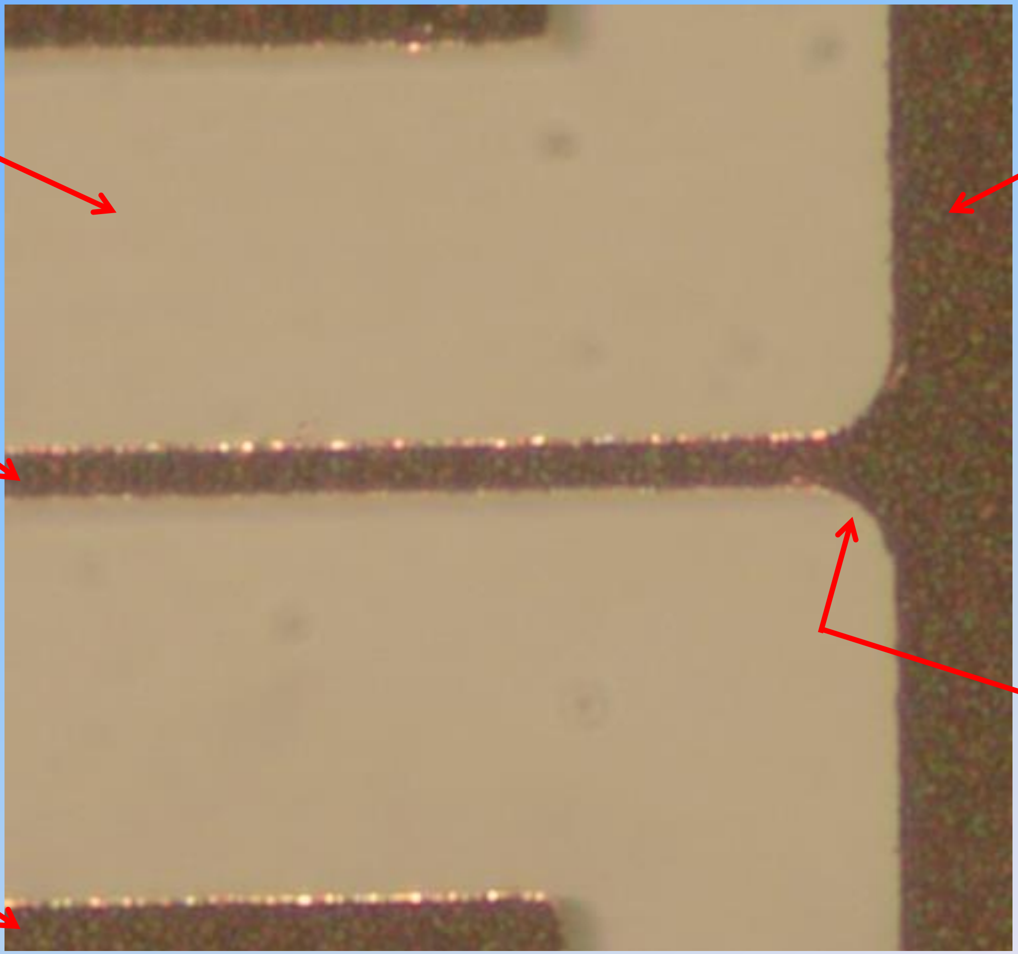


Micromachined Device Close-Up Photograph

Etched gap between spring and frame

Torsional Spring

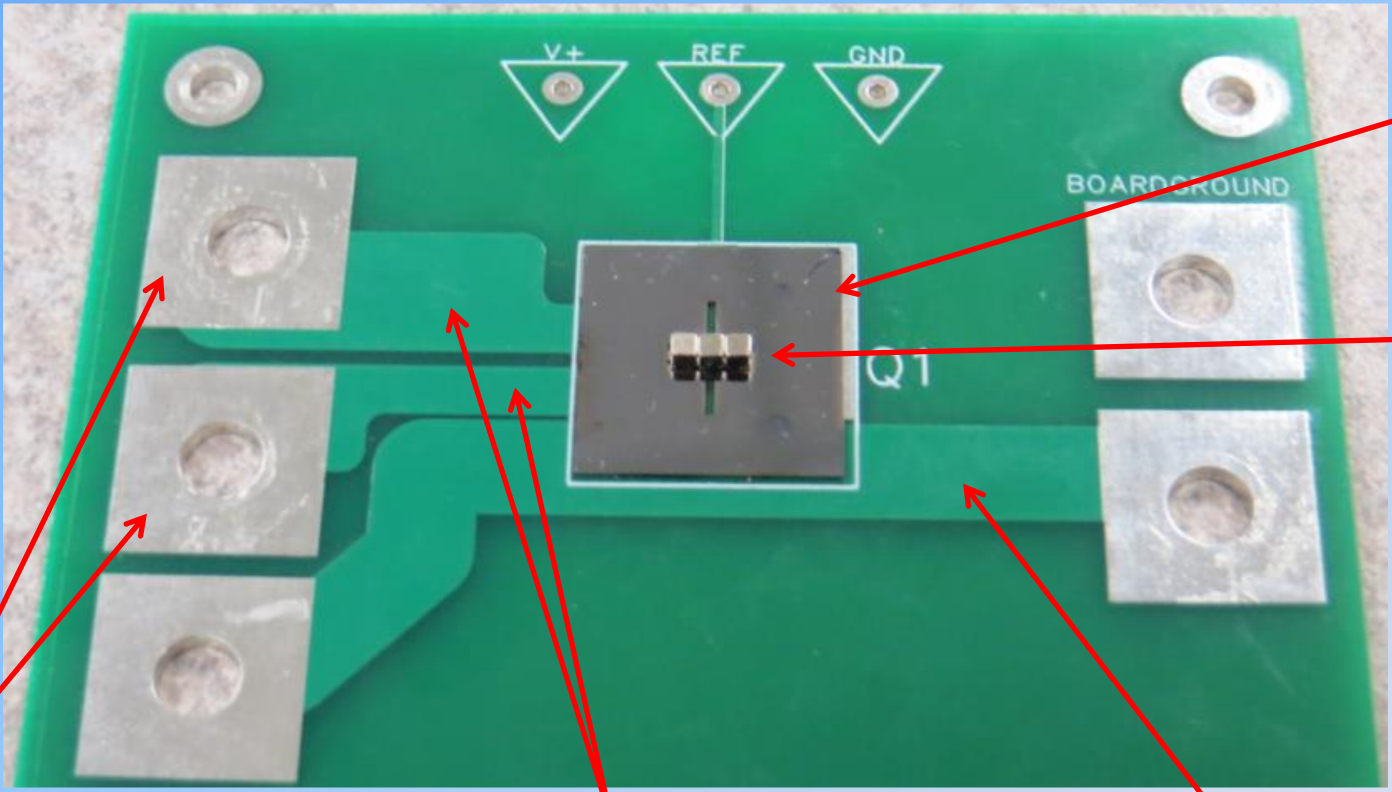
Frame



Torsional Platform

Fillet to improve structural integrity

Photograph of Packaged Device



Device

3 magnets on this device

DC current trace connectors

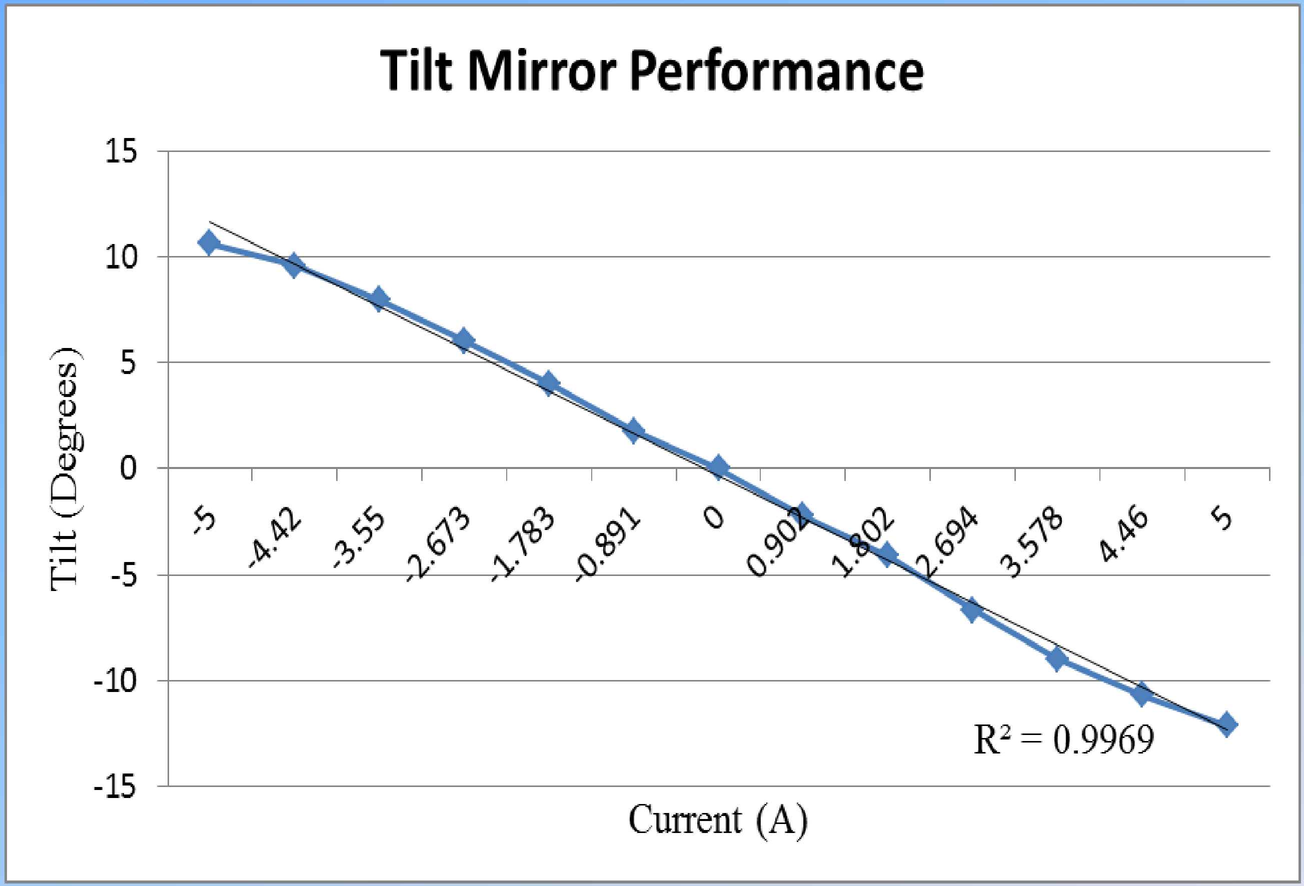
The Cu PCB current carrying trace (under soldermask layer) made a ¾ turn around the device.

Alternative DC current trace

Evaluation Procedure

- Class II HeNe laser with a sub-mm spot size used
  - 633nm wavelength
- Laser mounted w.r.t. the device so that the laser spot is reflected off of the torsional platform and onto a fixed vertical surface.
- A DC current is applied to the device and the distance that the laser spot moves on the vertical surface is recorded
- This process is repeated over a range of DC currents
- The tilt angle for each DC current value is then calculated

Evaluation Results



$$\theta \approx -(2.5\deg/\ A)I$$

Comparison with Other Technologies

- Magnetic actuator based
  - Tilt angle approx. linearly proportional to DC current
  - Requires a high current (high power usage)
- Electrostatic actuator based
  - Force is proportional to drive voltage squared
  - May require a voltage on the order of 100V
- Piezoelectric actuator based
  - May also require a high voltage
- Electrothermal bimorph actuator based
  - Requires a high current (high power usage)
  - Slow response time

Advantages of This Technology

- Tilt angle is linearly proportional to drive current
- Far more low-voltage, high-current electronic devices exist than high-voltage, low current devices
  - Si power MOSFETs
    - Very inexpensive
    - PWM can be used to adjust the applied DC current value

Future Work

- Add more turns onto the PCB to decease drive current
  - Goal: full tilt range for < 500mA
- Integrate capacitive electrodes to measure tilt angle
  - Goal: implement closed loop operation
- Develop 2-D tilt mirror device with this technology

Conclusions

- MEMS tilt mirrors are useful in many applications
- A DC current-controlled, magnetic actuator tilt mirror produces a response linearly proportional to the applied DC current
- A prototype device was successfully designed, fabricated and evaluated