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Optical testing of polycrystalline silicon flexure-type optical actuators

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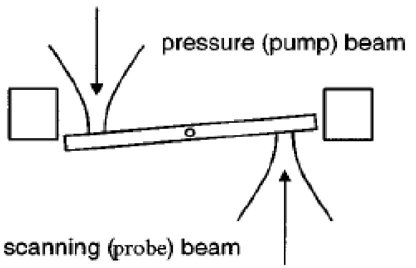
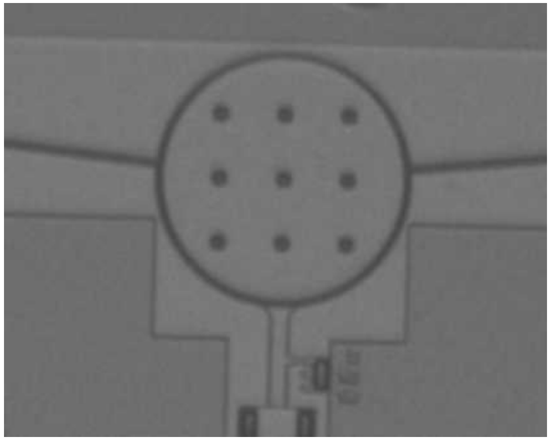
Optical actuation in MEMS

- **Requires no electrical connections → intrinsic isolation**
- **Compatible with harsh environments (radiation, high temperature, etc.)**
- **Enabling technology for all-optical MEMS devices**
- **Different actuation schemes include radiation pressure, use of photostrictive materials and photothermal processes**



Graebner, Pau, and Gammel, *Appl. Phys. Lett,* **81**, 3531 (2002)



Serrano, Phinney, and Brooks, *Proc. InterPACK'05*, IPACK2005-73322 (2005)

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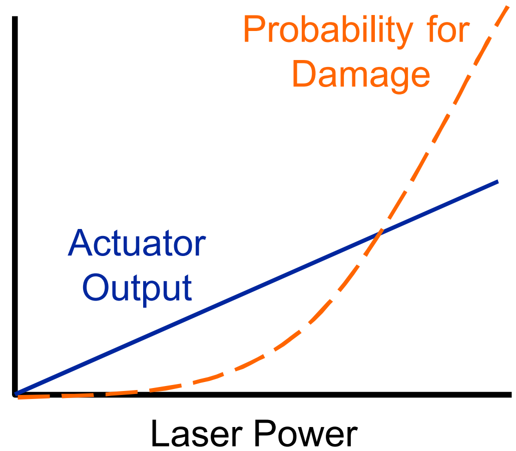
Photothermal Actuation

- **Can take advantage of electro-thermal actuation techniques and designs**
- **Uses laser-induced heating of device to generate motion/force**
- **Performance limited by damage to device**
- **Improved performance obtained by:**
  - **maximizing actuator output**
  - **minimizing damage risk**



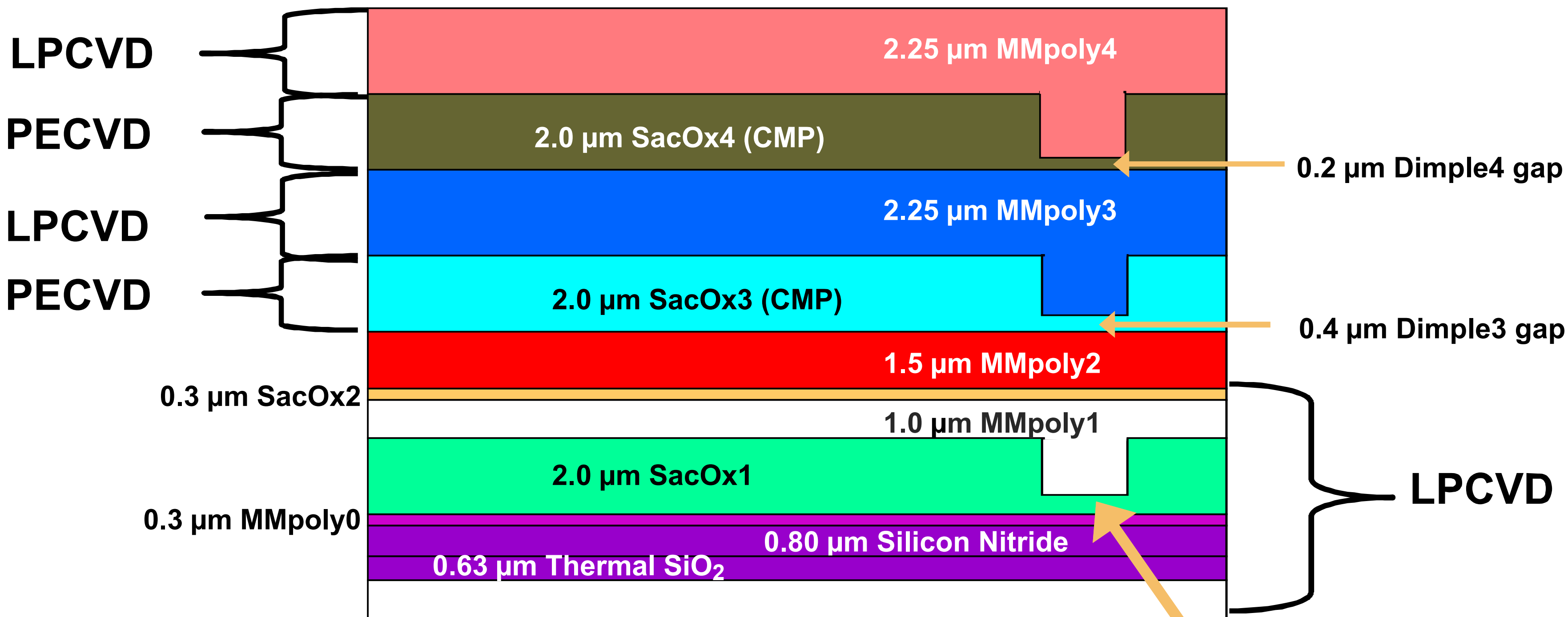
Caveats:

Damage risk and output are linked through applied power

SUMMiT™ V

Sandia's Ultra-planar Multi-level MEMS Technology

SUMMiT™ Layer Descriptions



** All PolySi is doped with Phosphorus **

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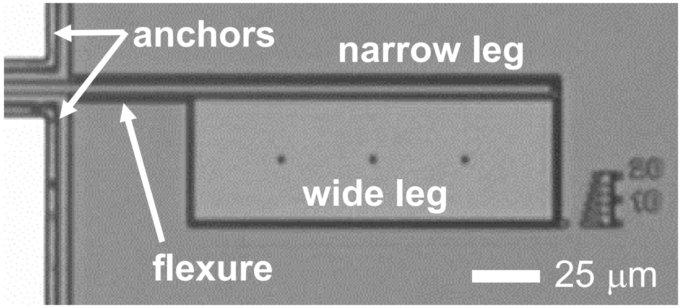
Flexure-type Optical Actuators



- **Actuator designs**
  - Composition: P4-only or P3-P4 laminate
  - Narrow leg: 2.5 x 200 μm
  - Wide leg: 2.5 x (50/100) μm
  - 50 μm flexure element
  - 2.5/5.0 μm leg-leg distance

- **Dissimilar thermal expansion between hot and cold sides used to generate motion**
- **Compared to ET flexure actuators**
  - **Larger wide leg which serves as target for laser**
  - **Wide leg is "hot" side of actuator**
  - **Motion is in the opposite direction**
  - **Different failure mechanism**

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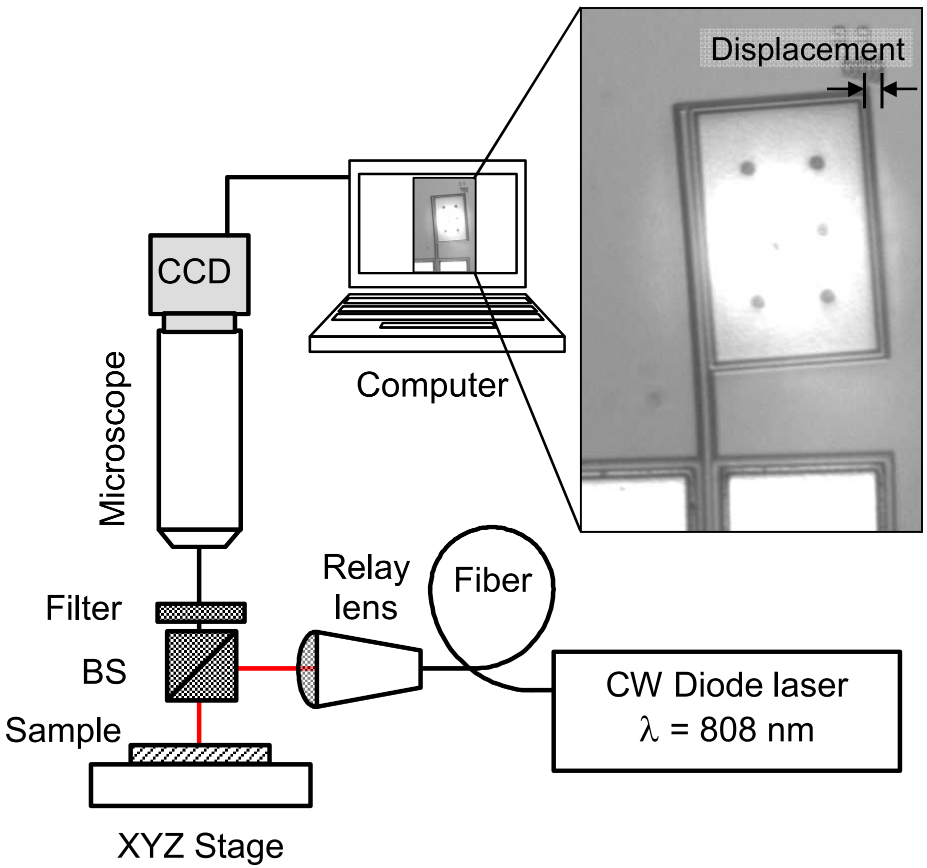
Experimental Details



- **Actuators irradiated with 808 nm, fiber-coupled, CW diode laser; 100 μm diameter spot**
- **Laser power varied from 100-650 mW**
- **Images of actuators captured before, during and after irradiation**

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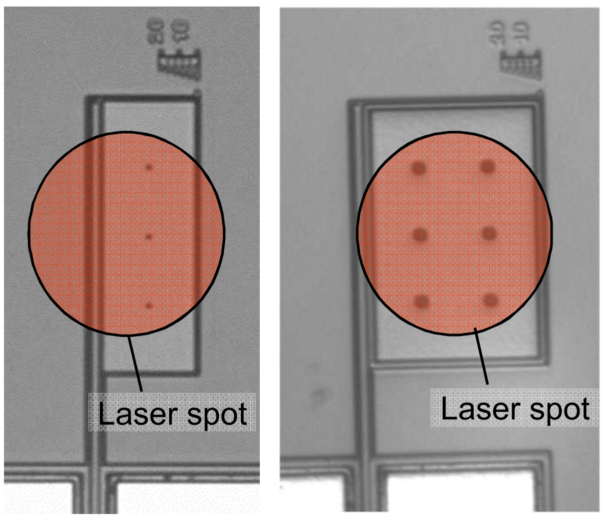
Experimental Details

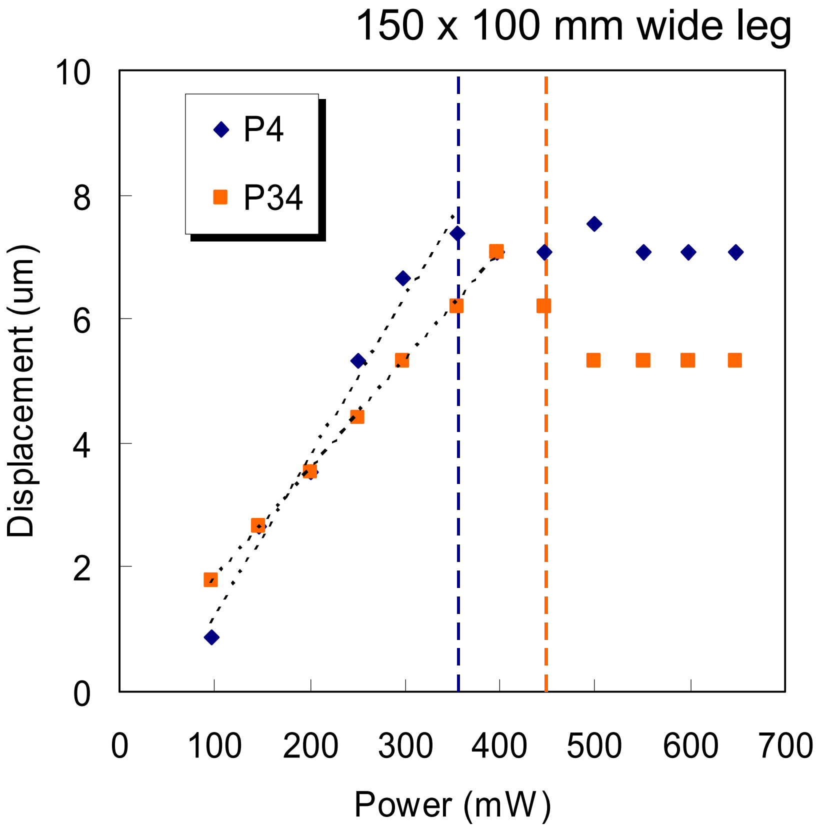


Laser spot centered on 100 μm wide leg; offset on 50 μm wide leg

- **Displacement measured at the top-right corner of device; determined with image analysis**
- **Displacement determined to ± 1 pixel (0.65 μm)**
- **Irradiation schemes:**
  - **Power ramp:** laser power always incident on actuator, increased slowly; images captured at regular power intervals
  - **On/off irradiation:** images captured, laser power increased with each on/off cycle
  - **Prolonged exposure:** laser incident on actuator for extended period; images captured at regular time intervals

Target Composition

- **Displacement is linear with power up to initiation of surface damage**
- **Maximum displacement similar for both compositions**
- **After damage, displacement recedes slightly (P34) or remains constant**
- **P4-only actuators significantly more robust than previous studies; possibly due to interference**



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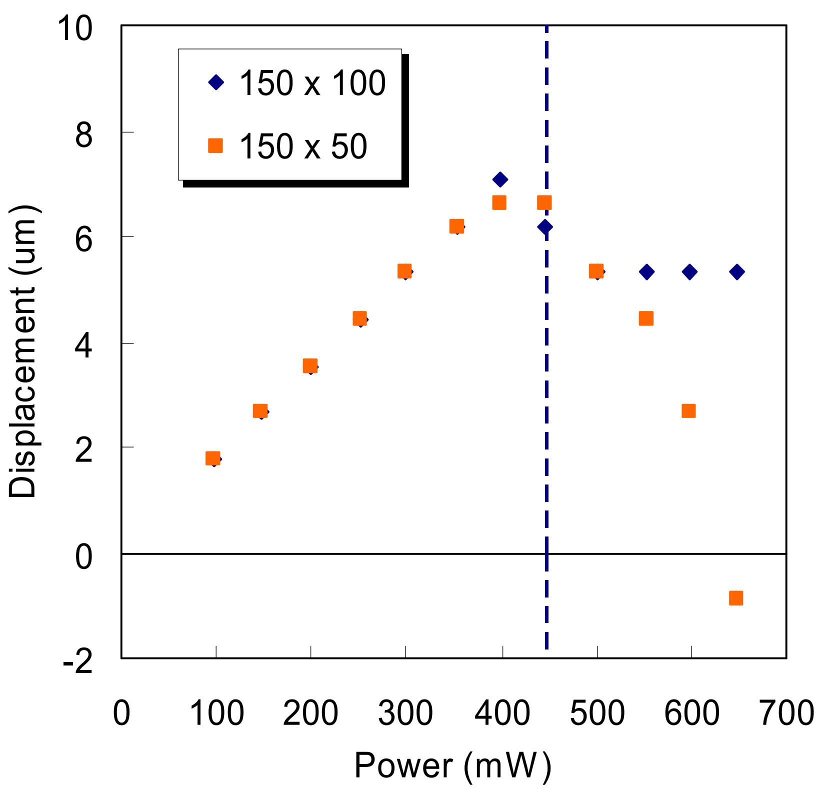
Displacement Recession



- **Narrower actuator shows significant recession in displacement after damage regardless of composition**
- **Displacement loss due to softening of the poly at elevated temperatures responsible for damage**
  - "Softening" compromises more of the actuator structure in the narrower device

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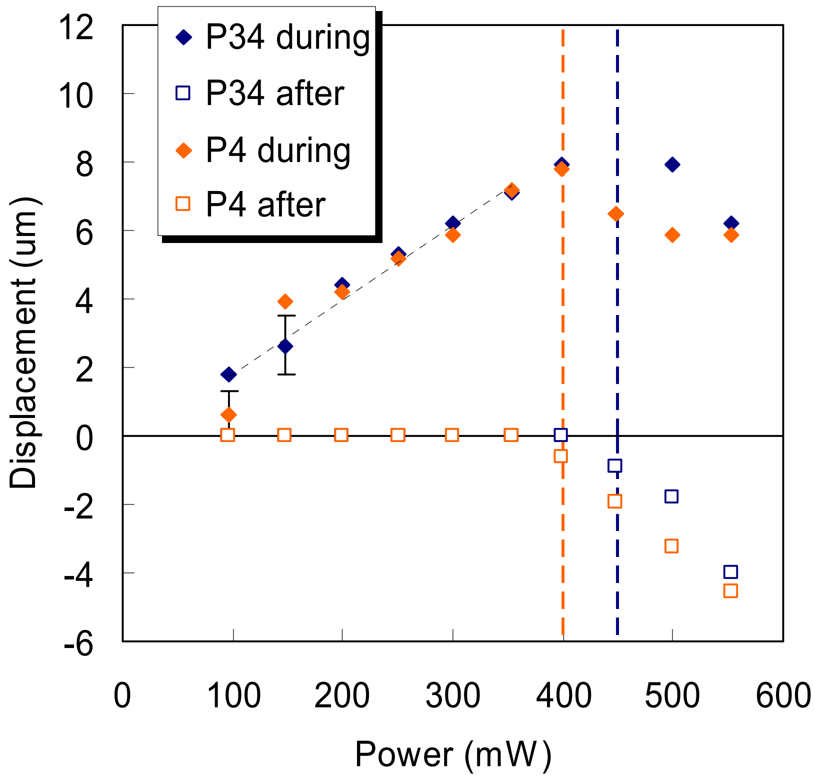
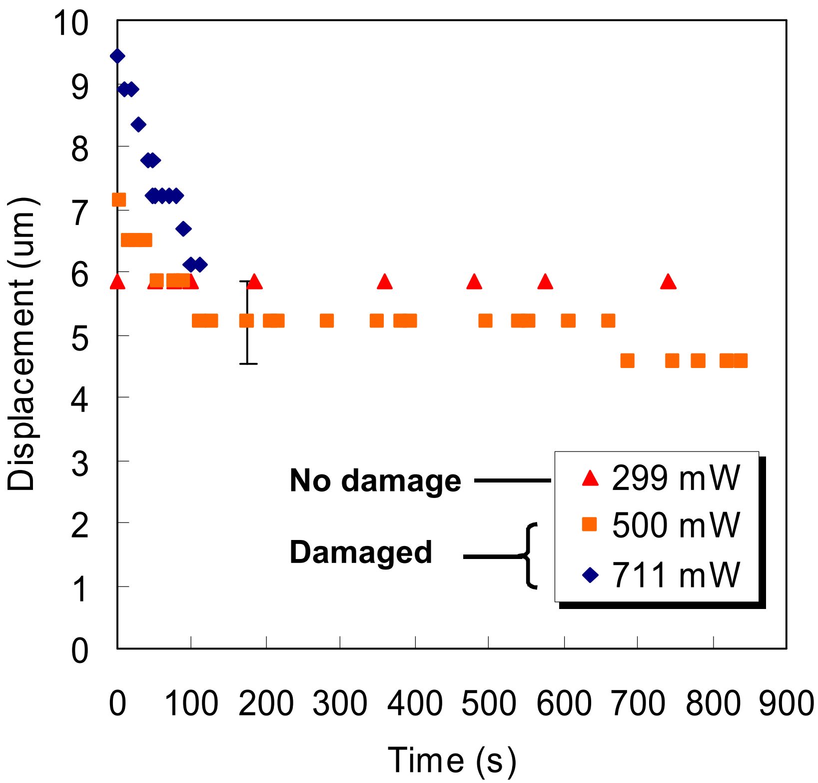
On/Off Cycling

- **Cycling laser power on/off results in repeatable displacement in undamaged surface**
- **After damage, displacement recession is clearly evident after irradiation**
  - initial position recedes with increasing laser power
  - relaxation during the damage event results in thermal contraction upon cooling



Prolonged Exposure: More Recession



- At powers below damage, displacement holds constant
- If the surface is undamaged prior to irradiation, powers that produce damage:
  - Result in large displacement recession within first 200 s of irradiation;
  - Slight increase in surface damage size during first 60 s; minimal afterwards

Summary and Conclusions

- Polysilicon flexure type optical actuators were evaluated for performance and robustness to damage
- Because heating power is applied directly to members responsible for motion, displacement is linear with power for laser powers that do not produce damage ($P < 400$ mW)
- Maximum displacement is 8-9 μm
- Increased incident power results in surface damage and recession in actuator displacement due to structural relaxation of the polysilicon layer
- Prolonged exposure to elevated laser powers further increases the recession in the displacement

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