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MEMS-activated mirrors for arming and safing in optical firing sets

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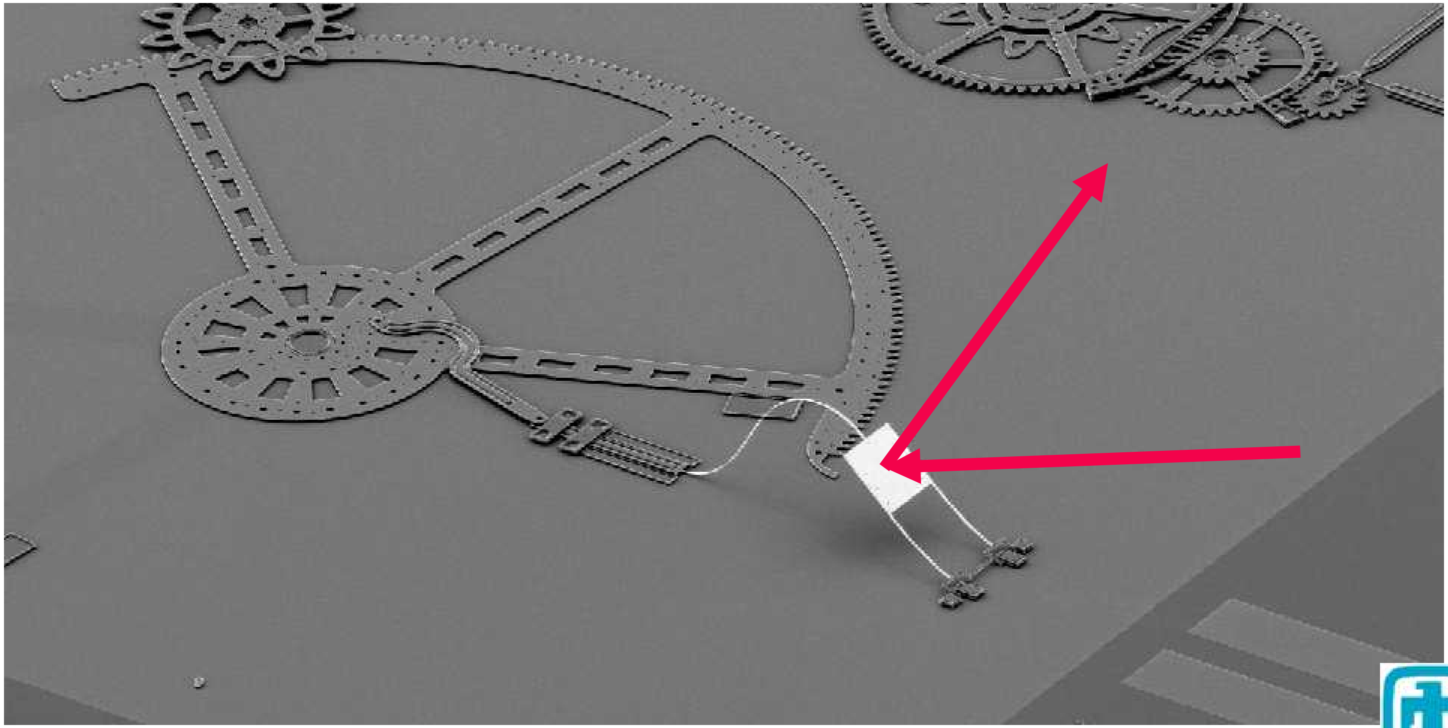
Concepts for using MEMS devices in optical firing sets

- MEMS devices are potentially very useful in optical firing sets:
  - miniature devices to allow/stop optical trigger signals or optical power flow
  - allow moving parts (mirrors, shutters, etc.)
  - allow compact integration of electronics and logic with actuators



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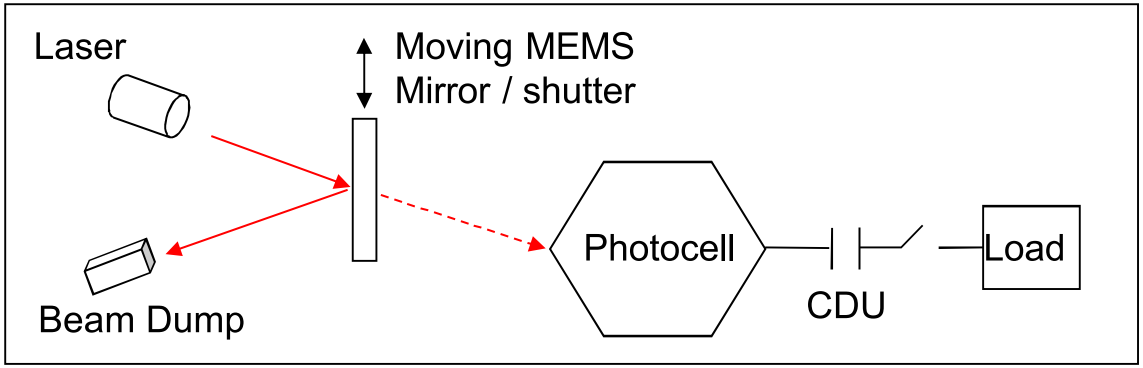
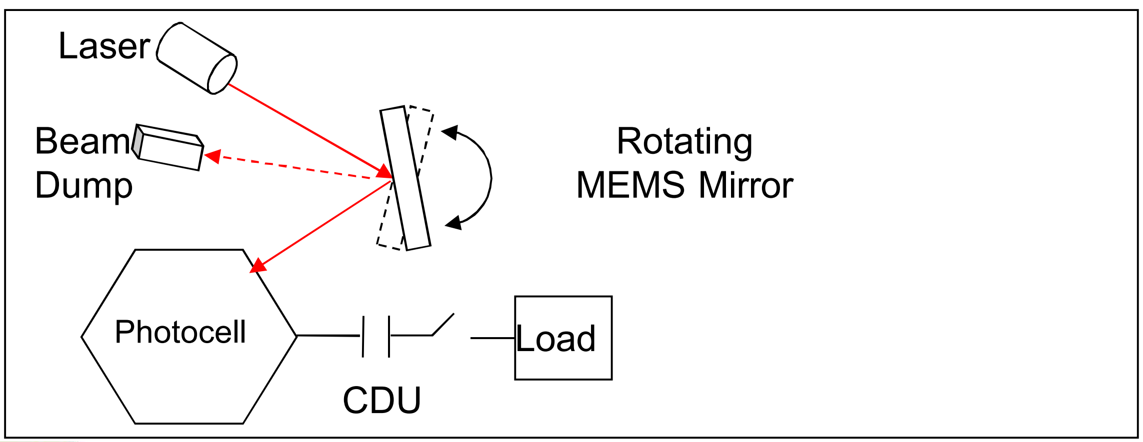
Two generic safing and arming architectures using MEMS mirrors



a.) Beam Shuttering



b.) Beam Redirection

- mirror used as shutter to safe fire set by blocking light from reaching transducer
- mirror used to reflect light to transducer
  - sliding mirror
  - rotating mirror
- in either architecture, the mirror must have very high reflectivity or the system will fail

High-damage-threshold mirror coatings on MEMS structures are critical for optical firing set applications

- Very high optical reflectivity is required:
  - shutters may be damaged or fail completely if they absorb too much optical energy
  - mirrors to redirect beams need high reflectivity for high efficiency
  - mirrors may be damaged if they absorb too much energy
- Silicon has high absorption at wavelengths of interest.
  - 800 nm to 1064 nm
- MEMS parts are thin, small in area, low in mass and poor heat sinks

In this study, we have coated thin polysilicon membranes with a high-reflectivity multilayer dielectric coating and performed optical damage tests to show feasibility of using these MEMS parts in optical firing sets

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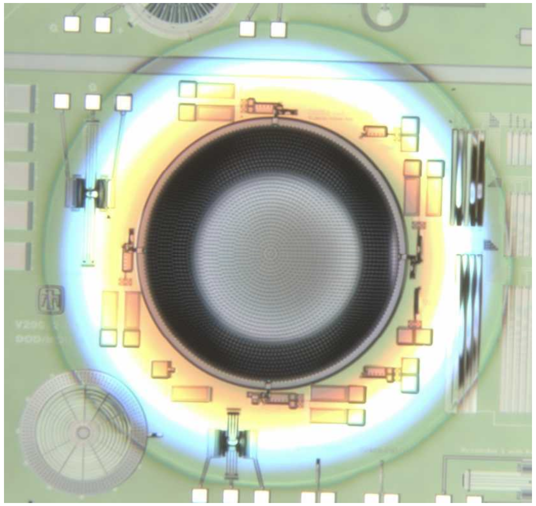
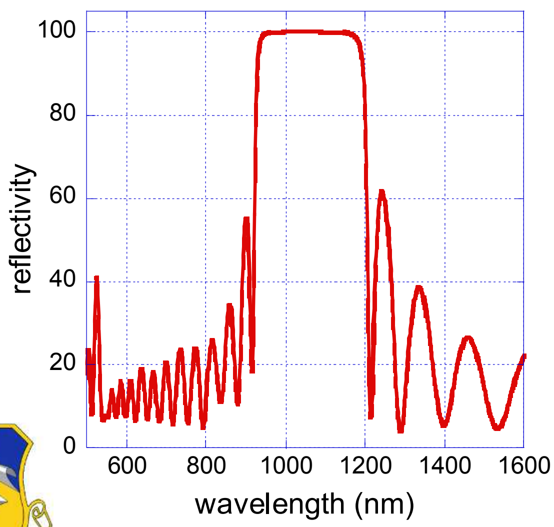
An existing MEMS device was used as a substrate for the mirror coating





- The MEMS device was fabricated at Sandia using the SUMMiT V process.
- coating applied to center gear
  - d ≈ 1.6 mm
  - substrate thickness = ~13 μm
- Coating deposited by reactive DC magnetron sputtering
  - 25 alternating λ/4-thick layers of ZrO_2/SiO_2
  - R > 99.9% at 1064 nm at 0°
- coating designed and applied at the Air Force Research Laboratory (AFRL/DESE) Optical Coating Engineering Lab (OCEL)
- Due to schedule and budget constraints, we used an existing MEMS device for the mirror substrate and piggybacked onto an already-scheduled coating run.
  - coating was not optimized for low stress
  - coated substrates bowed due to stress
  - laser damage testing not affected by bowed mirrors

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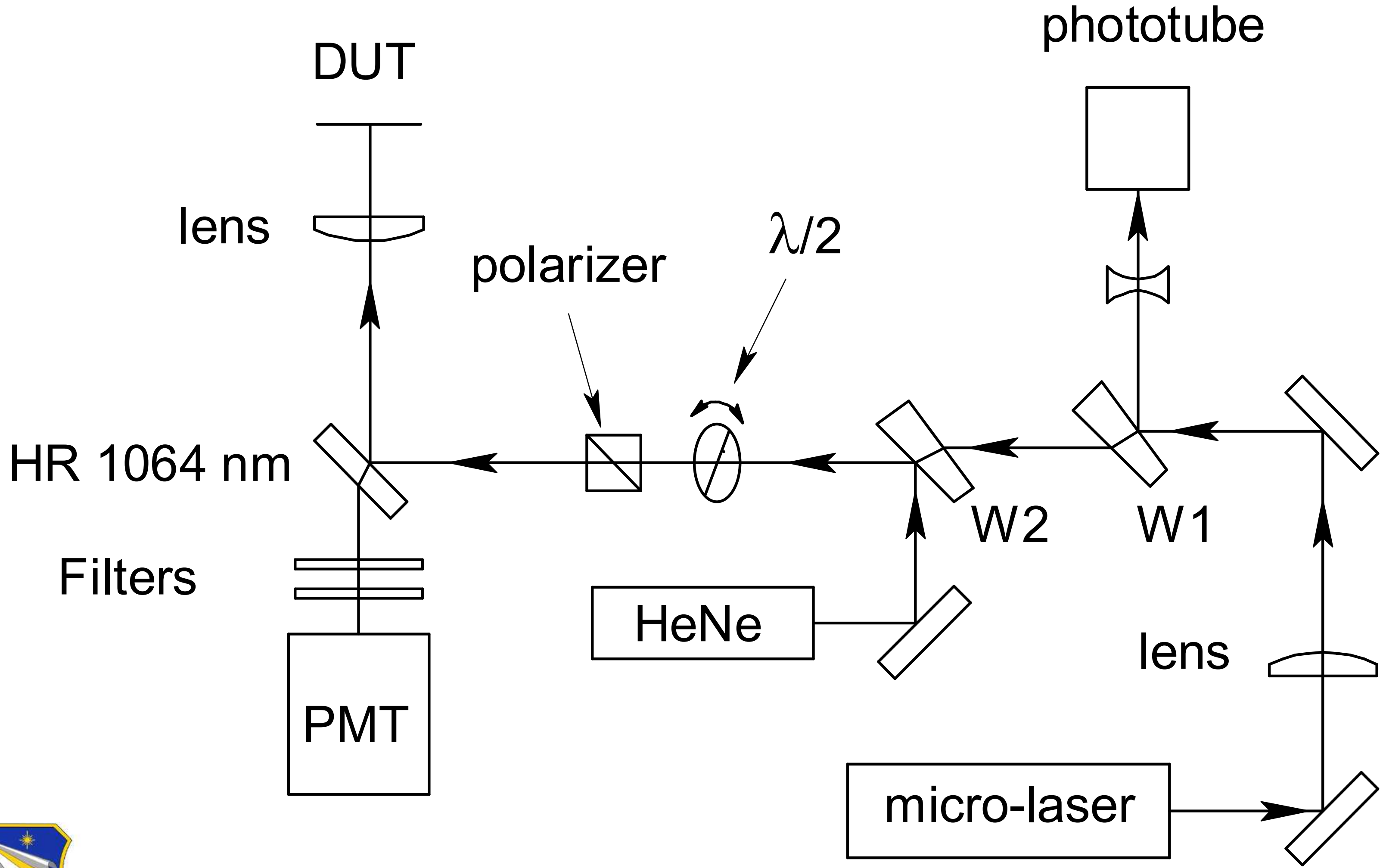
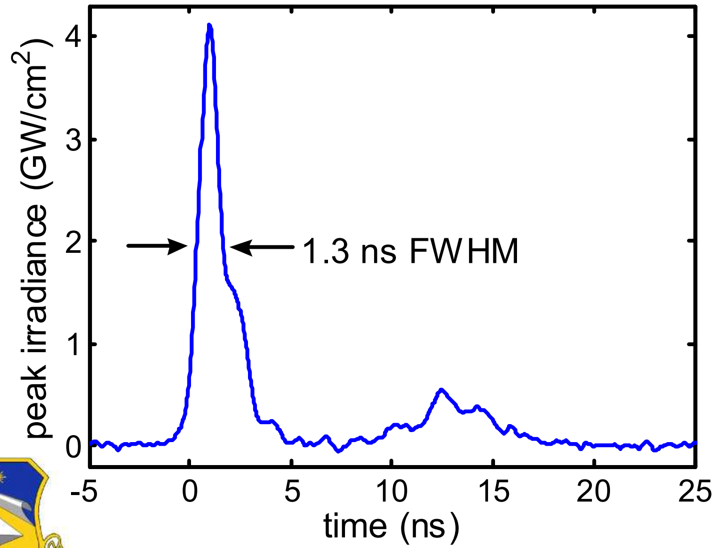
Laser Damage Test Setup



We used a Cr:Nd:GSGG microlaser as the damage test laser

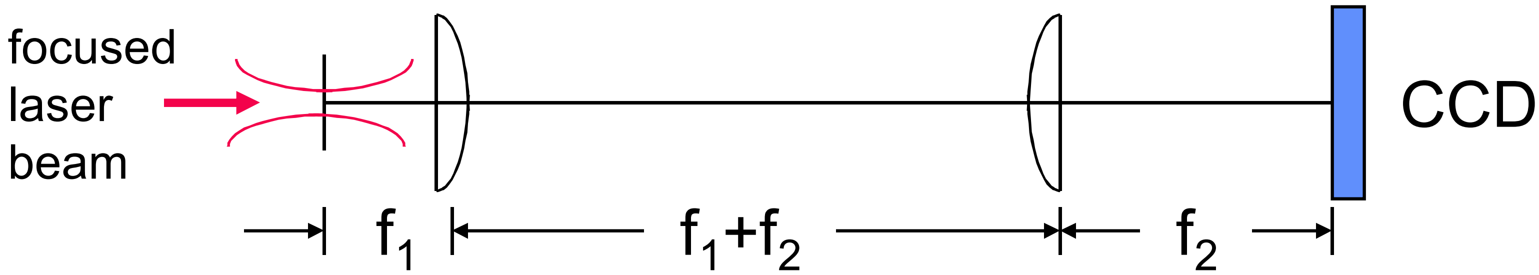


- Cr:Nd:GSGG microlaser designed for possible optical firing set applications
  - diode laser pumped
  - passively Q-switched
  - monolithic construction
  - good beam quality
  - smooth gaussian spatial profile
- short pulse length
  - ~1.3 ns FWHM
  - very reproducible pulse shape
  - after-pulse contains <23% total energy
  - each pulse is single mode
- pulse-to-pulse output energy stability ~1%

Experimental procedure to determine laser damage threshold

- alignment and focus:
  - find best focus using blank Si wafer and maximize white light from laser-induced breakdown on surface
  - depth of focus of 30-μm-dia laser spot ~ z_R= 600μm
    - ±60 μm focus error would only result in <1% error in beam area
- for each test spot on mirror:
  - start at low laser energy
  - fire single laser shots at test surface
  - monitor PMT for white light emission indicative of laser breakdown at the surface
  - slowly increase laser energy until breakdown in observed
  - measure laser energy for breakdown
- criterion for threshold:
  - highest energy to cause *no* damage after 20 consecutive shots
- use recorded pulse shape, measured energy, and measured beam spot size to compute irradiance vs. time and peak irradiance

Measurement of laser spot size is needed to compute damage test irradiance

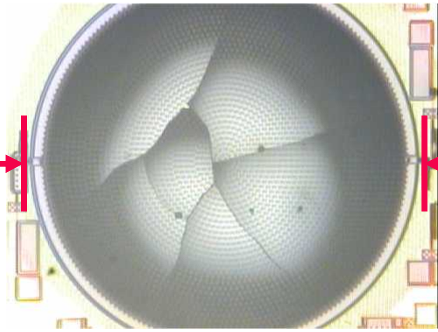


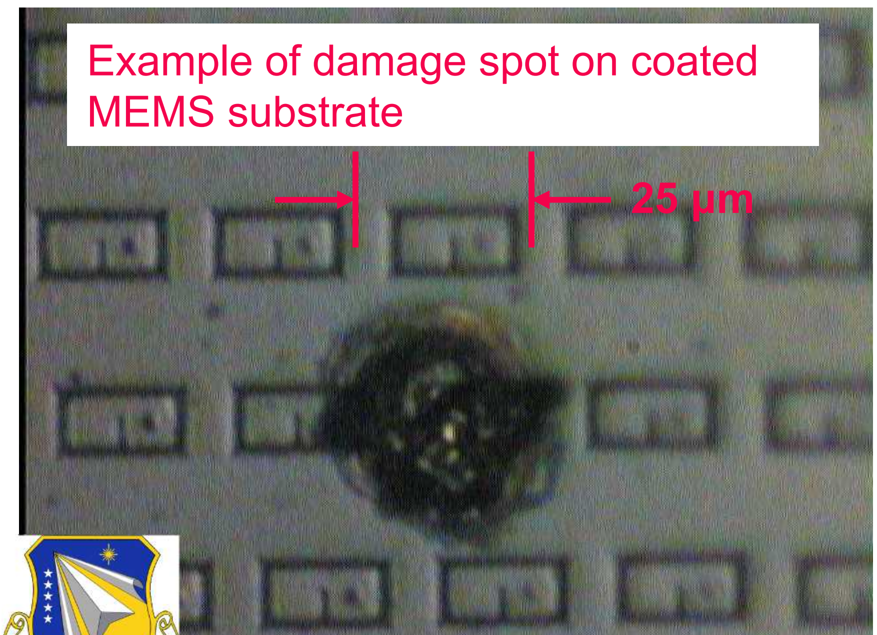
$M = f_2/f_1$

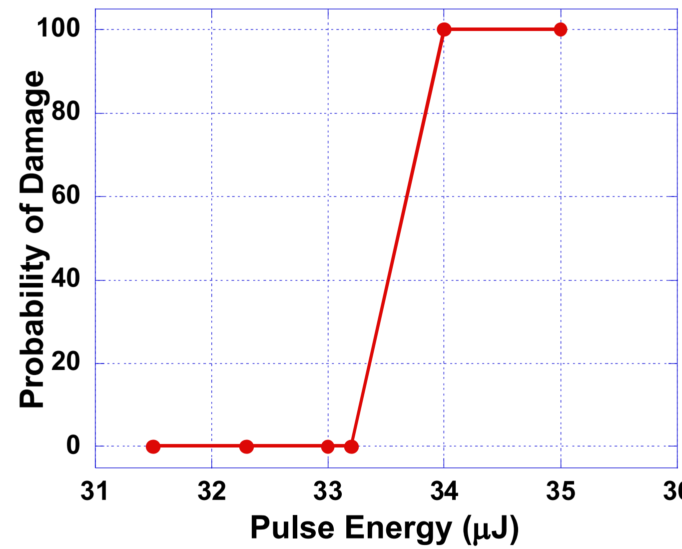
- use telescope configured for M = 5
- CCD with 4.65 μm square pixels
- digital system
  - (no RS-170 framegrabber to distort x,y scale factors)
- calibrated magnification of system using USAF resolution target
  - M = 5.01 measured

Using a 30-µm-dia laser spot we were able to perform multiple tests on each sample

Example of 1.6-mm-dia coated mirror







- the coated polysilicon damaged at 4.1 ± 0.1 GW/cm^2
- the uncertainty in laser energy is ± 0.4 µJ (~1%)
- 0.6 µJ spread for 0 to 100% damage probabilities

Summary of experimental results on coated and uncoated mirror substrates

- the HR coated polysilicon damaged at ~ 4 GW/cm^2
  - calculation assumes
    - Gaussian beam beam profile
    - measured spot size is 30 μm diameter ($1/e^2$)
  - this value is conservative

- the uncoated polysilicon membrane damaged at peak irradiance of ~1 GW/cm^2
  - surprisingly robust
    - may merit further investigation

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Summary

- We have laser damage tested high reflectivity coatings applied to thin polysilicon MEMS structures
- We found the damage irradiance ~4 GW/cm^2 at 1061 nm
- This damage fluence is adequate for many high-peak-irradiance laser applications in optical firing sets
- In future work, we will optimize both the MEMS mirror substrate and the multilayer dielectric coating design to produce flat micromirrors with potentially higher optical damage threshold

Overall, we have shown that highly reflective coatings applied to polysilicon can withstand high peak fluence laser pulses and may be suitable to application in MEMS devices.