Micromechanical Uncooled Photon Detectors

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Background

For detection of infrared (IR) photons there are two main classes: photon detectors and thermal detectors. Recent advances in micro-electro-mechanical systems (MEMS) allow MEMS to be used for IR detection.

- **photon detectors have fast response times and high detectivities, D^*.**

- **thermal detectors have slow response times but usually have a broadband response.**

Introduction

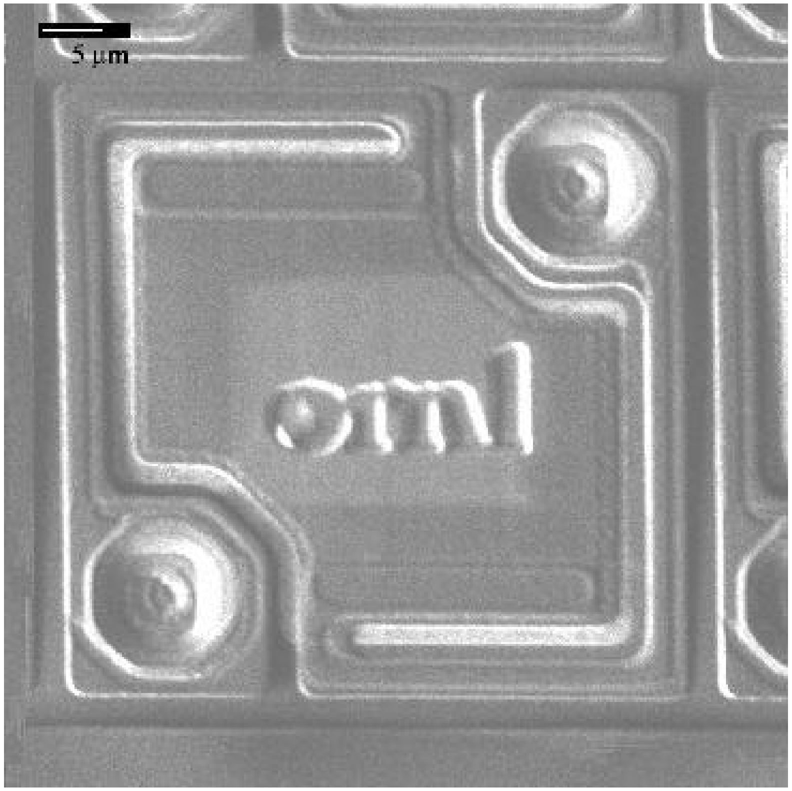
In this work we investigated micromechanical photon detectors:

- **Stress due to photo-generation of free charge carriers (electrons, holes) in semiconductor MEMS**
- **Stress due to internal photo-emission in MEMS**
- **Thermal stress in semiconductors**
- **Very sensitive deflection measurements**
- **Different geometries**

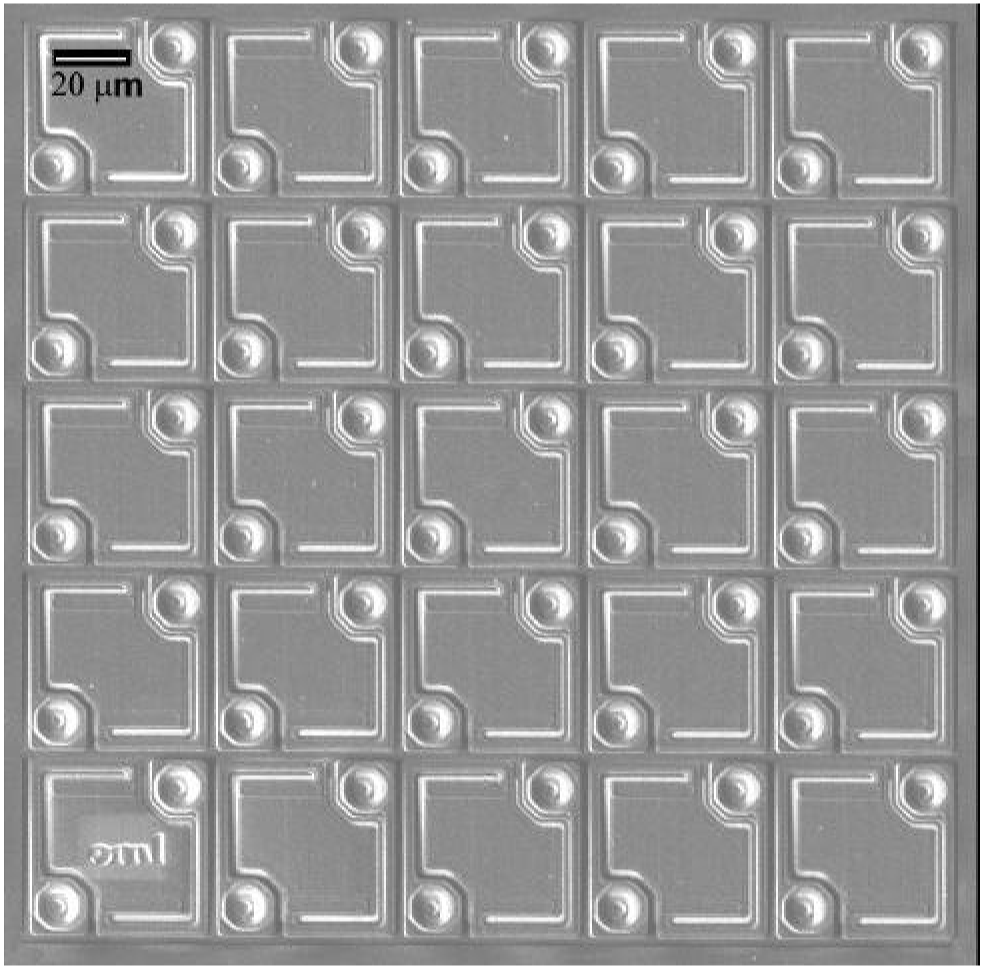
Microbolometer Thermal Detector

Lockheed Martin (640x480 array)

Single Pixel Geometry



5x5 ARRAY

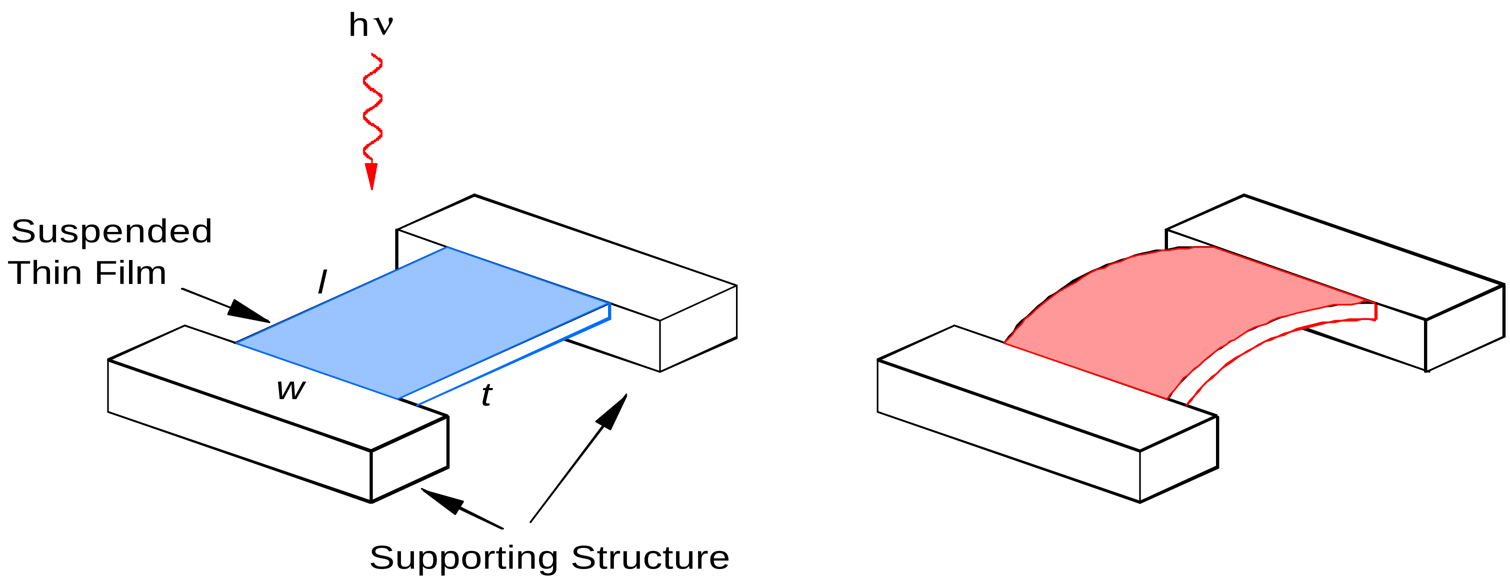


Microstructure Bending
(thermal)

$$z_{\max} = \frac{3l^2}{t_1 + t_2}\left[\frac{1+(t_1/t_2)^2}{3(1+t_1/t_2)^2 + (1+(t_1E_1/t_2E_2)(t_1^2/t_2^2 + t_2E_2/t_2E_2)}\right]$$

$$\times \frac{E_1a_1 - E_2a_2}{E^*}\Delta T$$

z_{max}	**deflection of microstructure tip**
l; t; w	**length; thickness; width**
E	**Young’s modulus**
a	**thermal expansion coefficient**
J_L	**charge carrier lifetime**
DT	**temperature change**

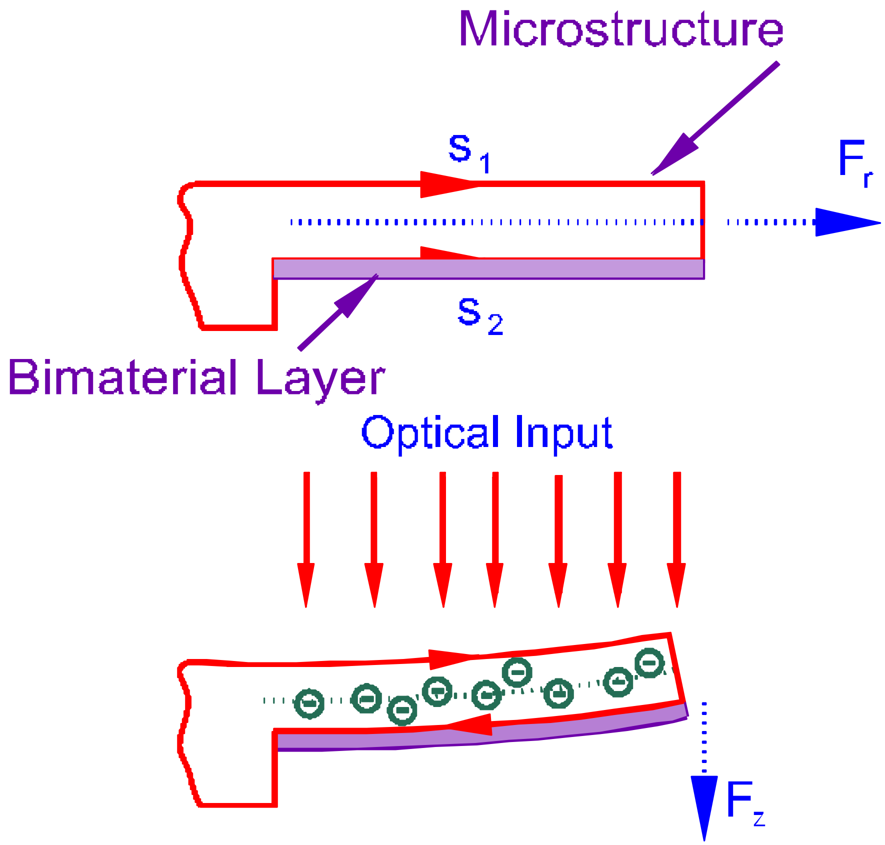


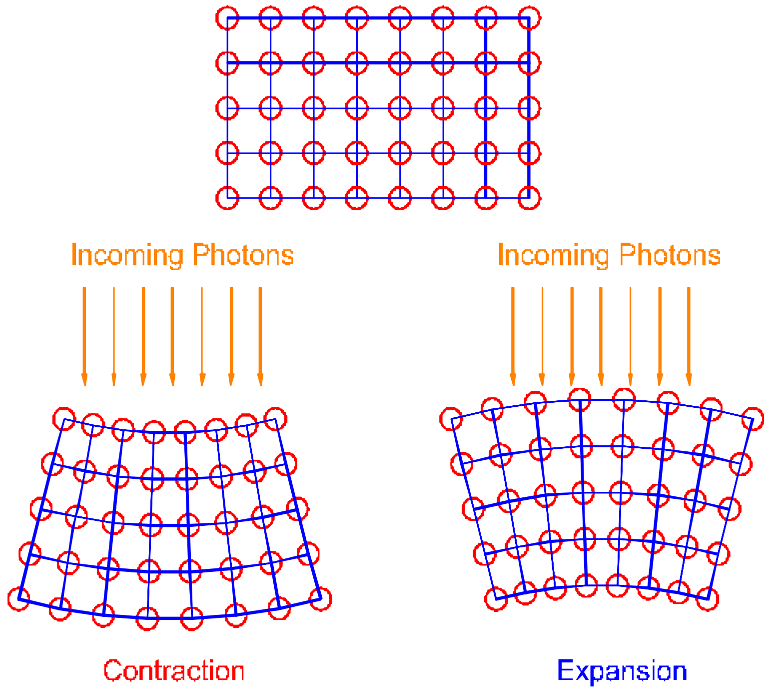
IR Photons → Charge Carriers

Detection

Stress

Detection Principle (cont.)





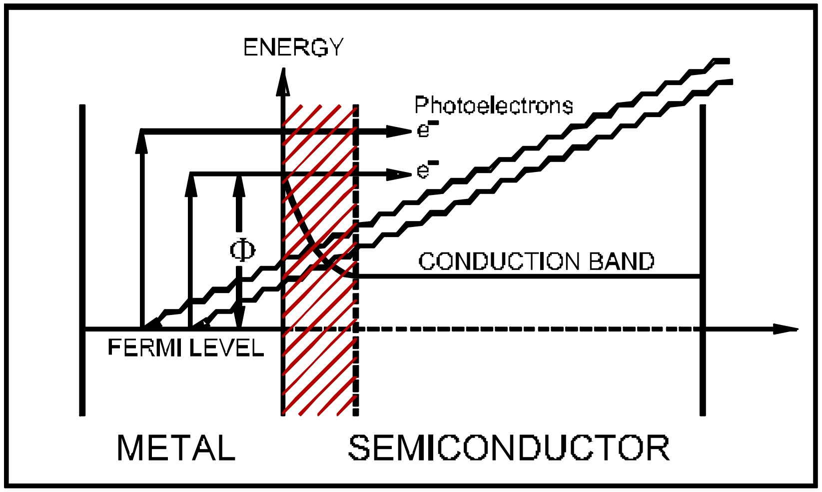
Microstructure Bending
(photo-induced)

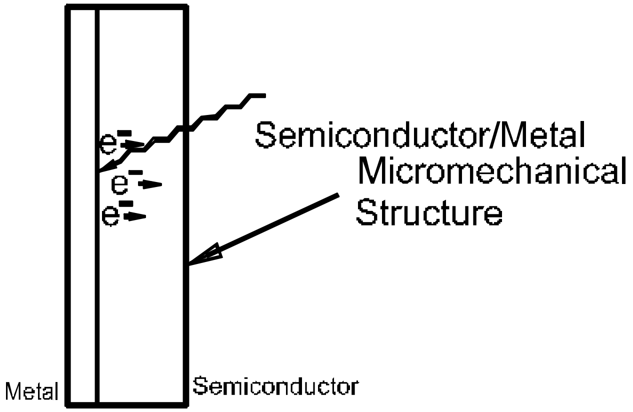
$$z_{\max} = \frac{l}{w(t_1 + t_2)^2} \left[\frac{1 + (t_1/t_2)^2}{3(1 + t_1/t_2)^2 + (1 + (t_1 E_1/t_2 E_2)(t_1^2/t_2^2 + t_2 E_2/t_2 E_2)} \right] \frac{E_1}{E^*}$$

$$\times h \frac{l}{hc} \frac{de_g}{dP} t_L \Phi_e^{abs}$$

z_{max}	**deflection of microstructure tip**
l; *t*; *w*	**length; thickness; width**
E	**Young's modulus**
M_e	**radiant power**
J_L	**charge carrier lifetime**
de_g/dP	**pressure dependence of bandgap**
l	**photon wavelength**

Other IR Detection Mechanisms





Schottky Barriers

Microstructure Bending

(interface absorption)

$$z_{\max} = C_0 \frac{l}{w(t_1+t_2)^2}\left[\frac{1+(t_1/t_2)^2}{3(1+t_1/t_2)^2+(1+(t_1E_1/t_2E_2)(t_1^2/t_2^2+t_2E_2/t_2E_2)}\right]$$

$$\times \frac{E_1}{E^*}\left(1-\frac{l}{l_c}\right)^2 \frac{de_g}{dP} t_L \Phi_e^{abs}$$

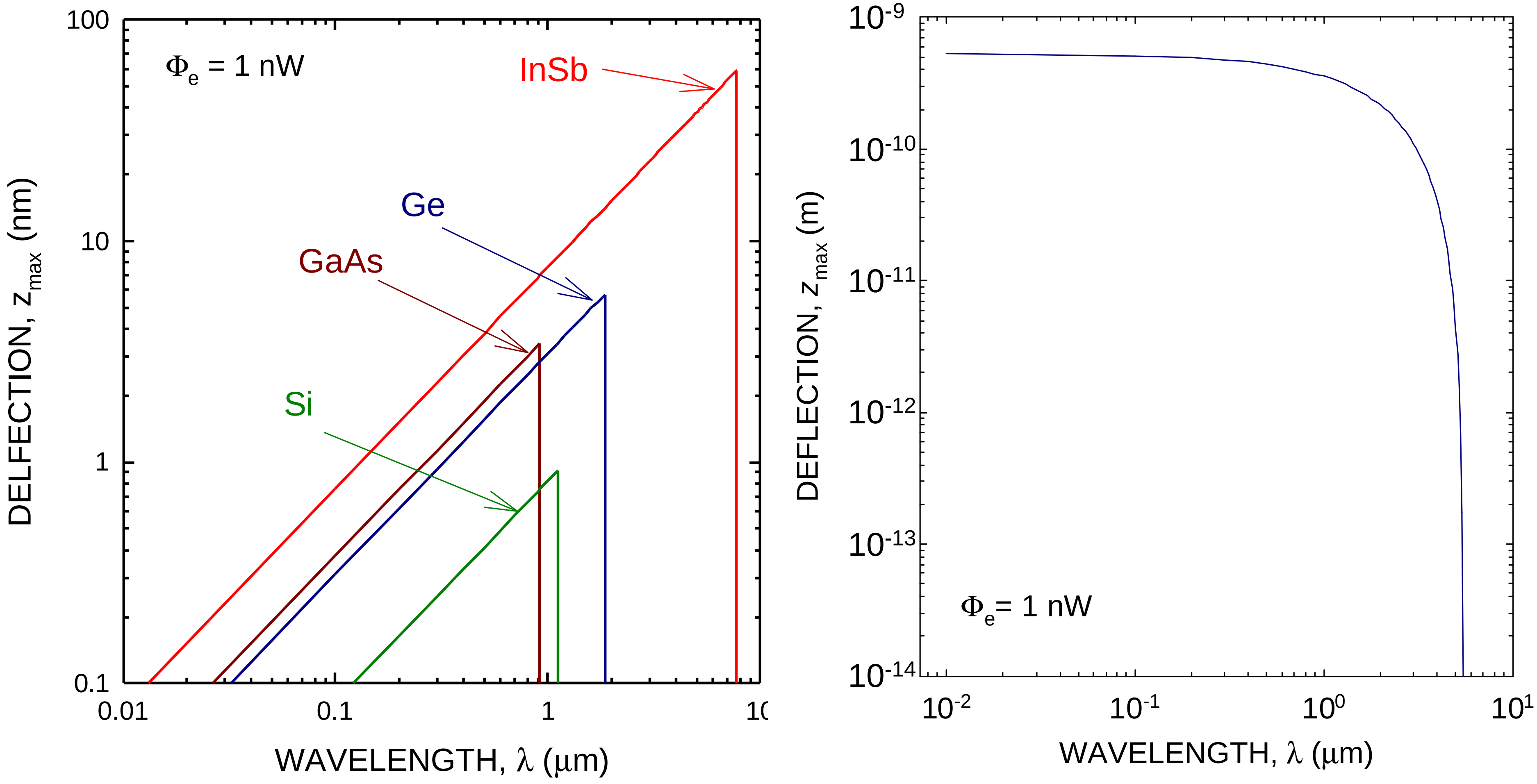
z_{max}	**deflection of microstructure tip**
l; *t*; *w*	**length; thickness; width**
E	**Young’s modulus**
M_e	**radiant power**
J_L	**charge carrier lifetime**
de_g/dP	**pressure dependence of bandgap**
l	**photon wavelength**
C_0	**quantum yield**

Table I. Properties of semiconductor materials that can be used as micromechanical photon detectors.

Semiconductor Material	g_g (eV)	$d\,,_g / dP$ (10^{-24} cm^3)	E (GPa)	G (W $m^{-1}K^{-1}$)
GaAs	1.35 [a]	-13.67 [b]	85.5	55
Si	1.12 [a]	-3.14 [c]	130.91	163
Ge	0.67 [a]	11.52 [c]	102.66	59
InSb	0.16 [a]	23.61 [c]	42.79	36

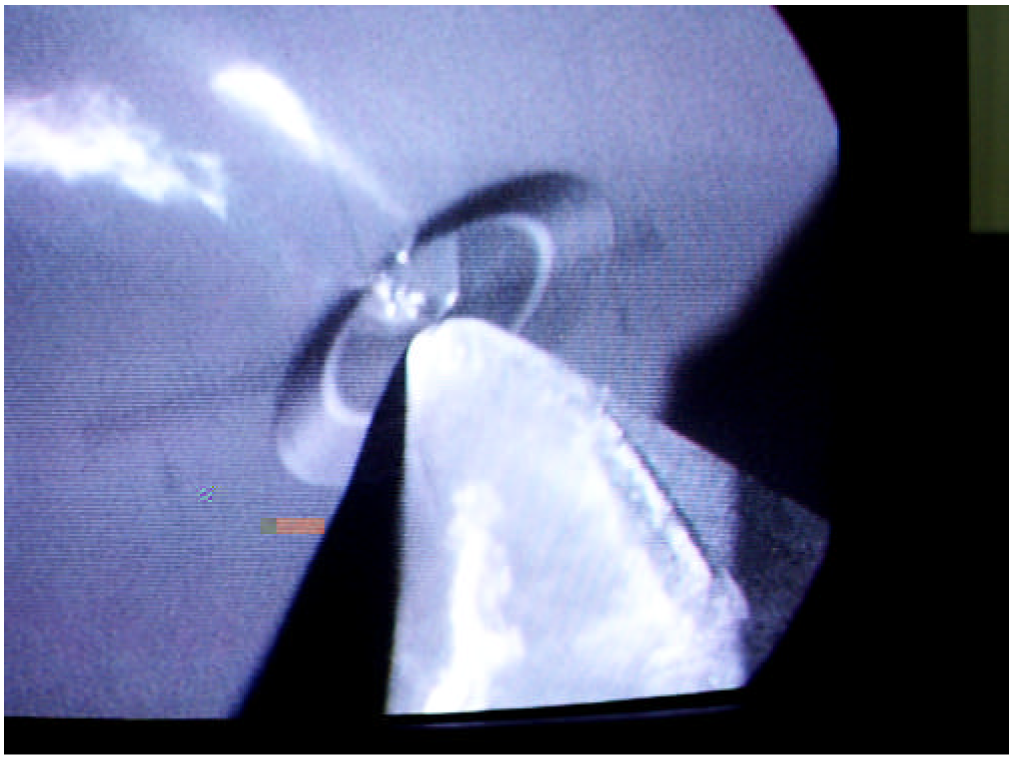
[a] From reference [Dereniak, 1996].
[b] From reference [Weast, 1972].
[c] From reference [Aigrain, 1961].

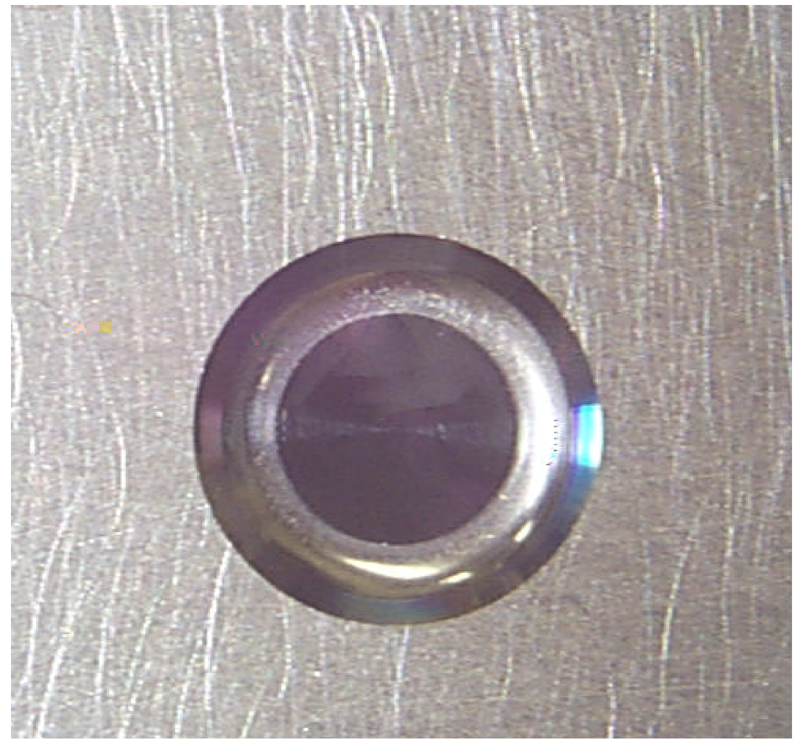
Calculated Deflection Responsivity



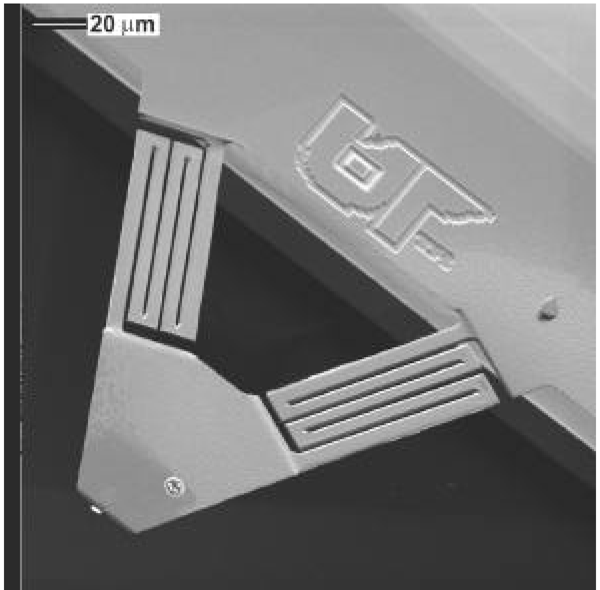
Diamond-Turned InSb Diaphragm

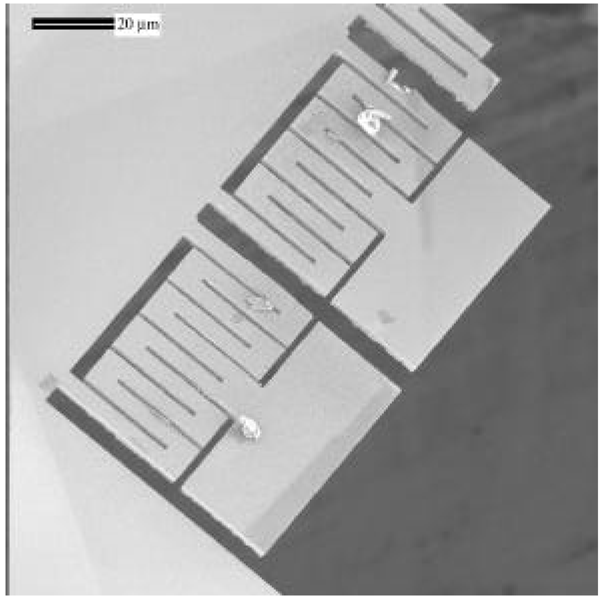
(4mm DIAMETER / 6mm THICKNESS)





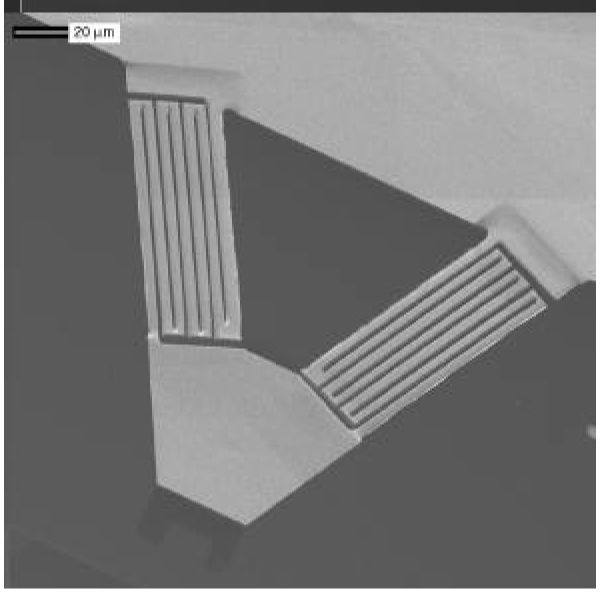
Micromechanical Quantum or Thermal Detectors

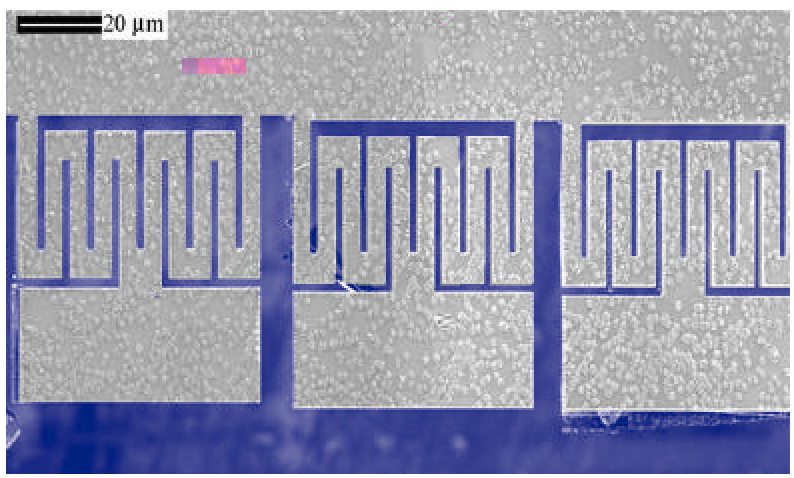




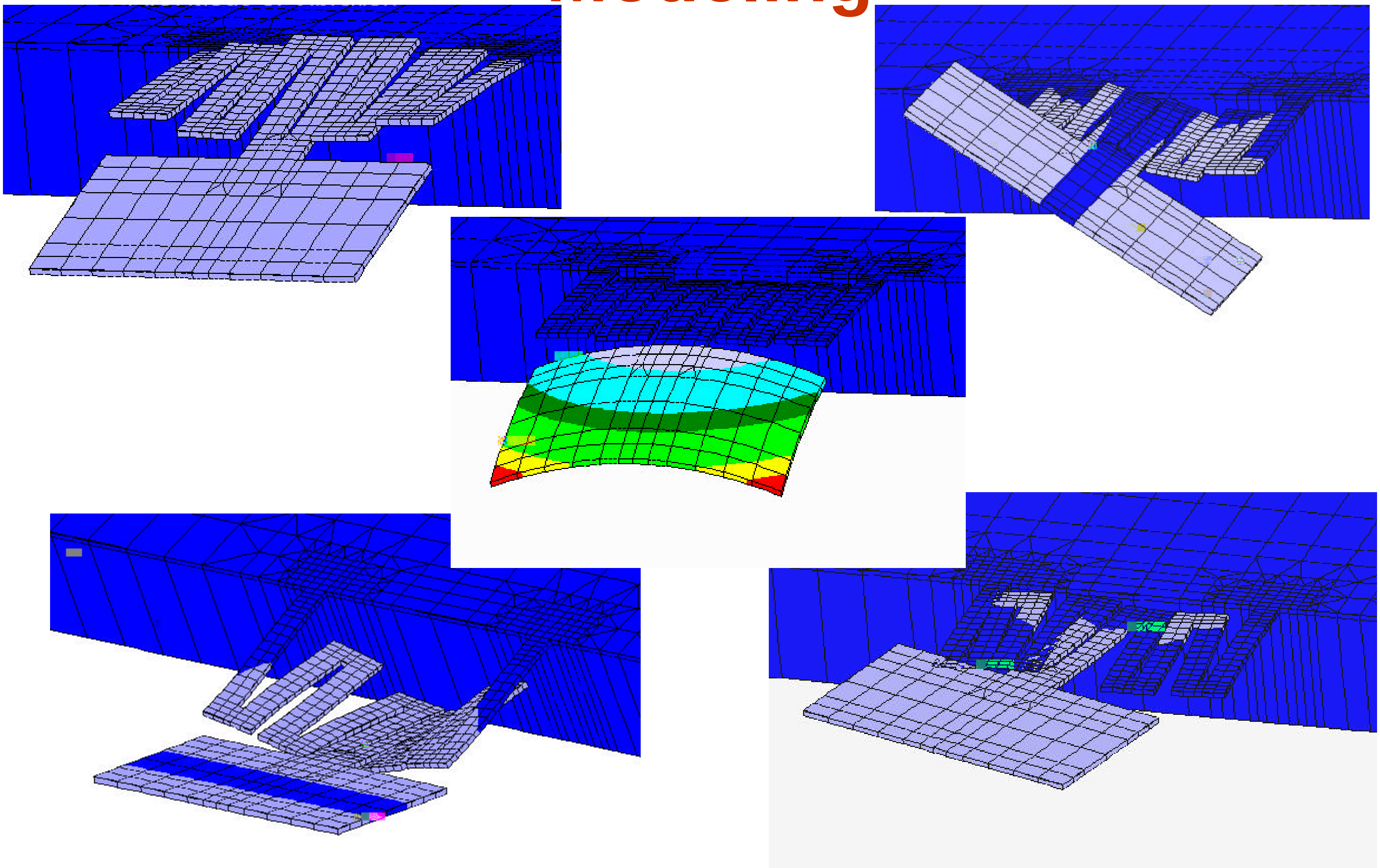
- ORNL fabricated small linear arrays of microstructures using rapid prototyping methods (made from InSb, GaAs, and Si/Pt).

- These devices have been produced using new microfabrication approaches.

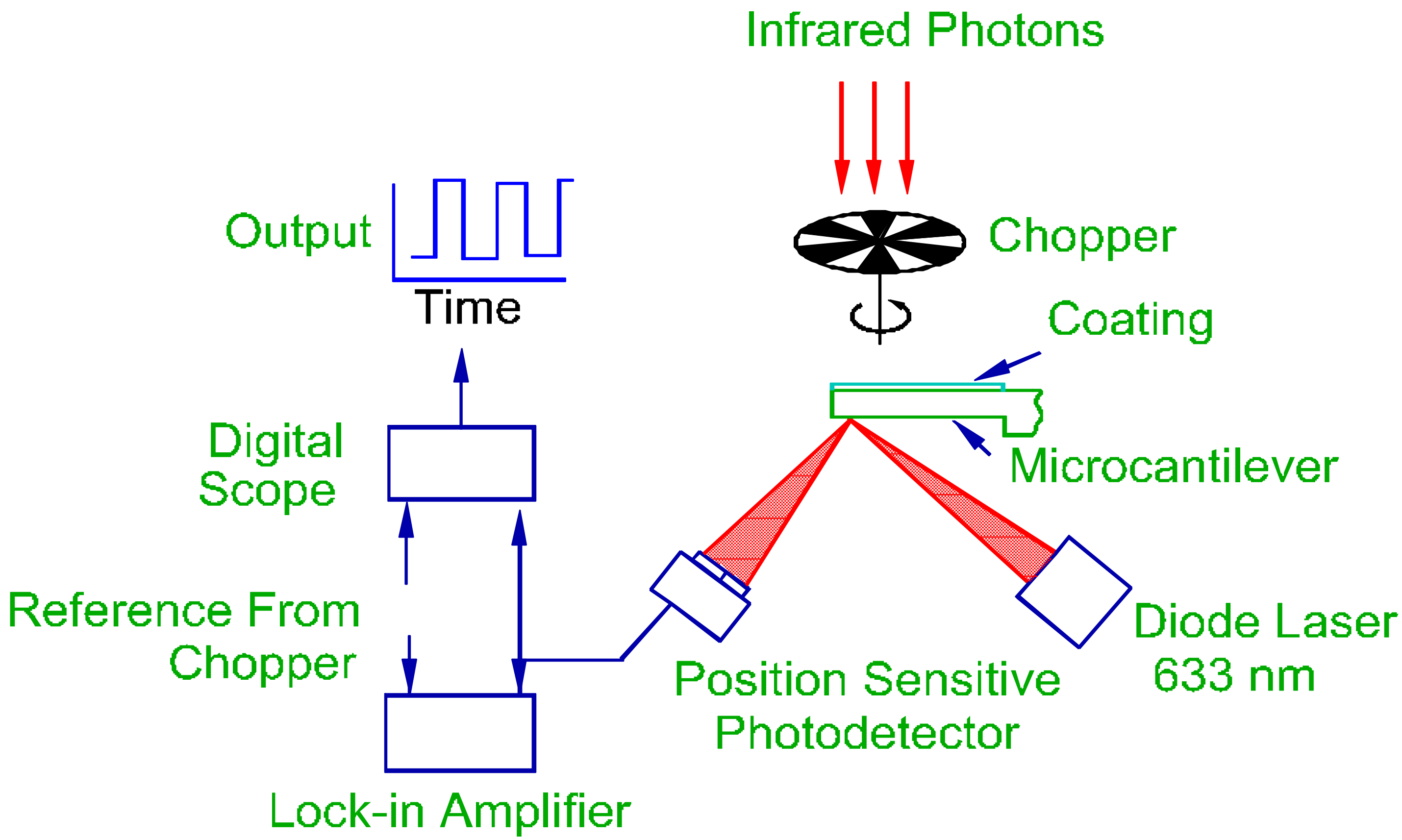




Micromechanical Device Modeling

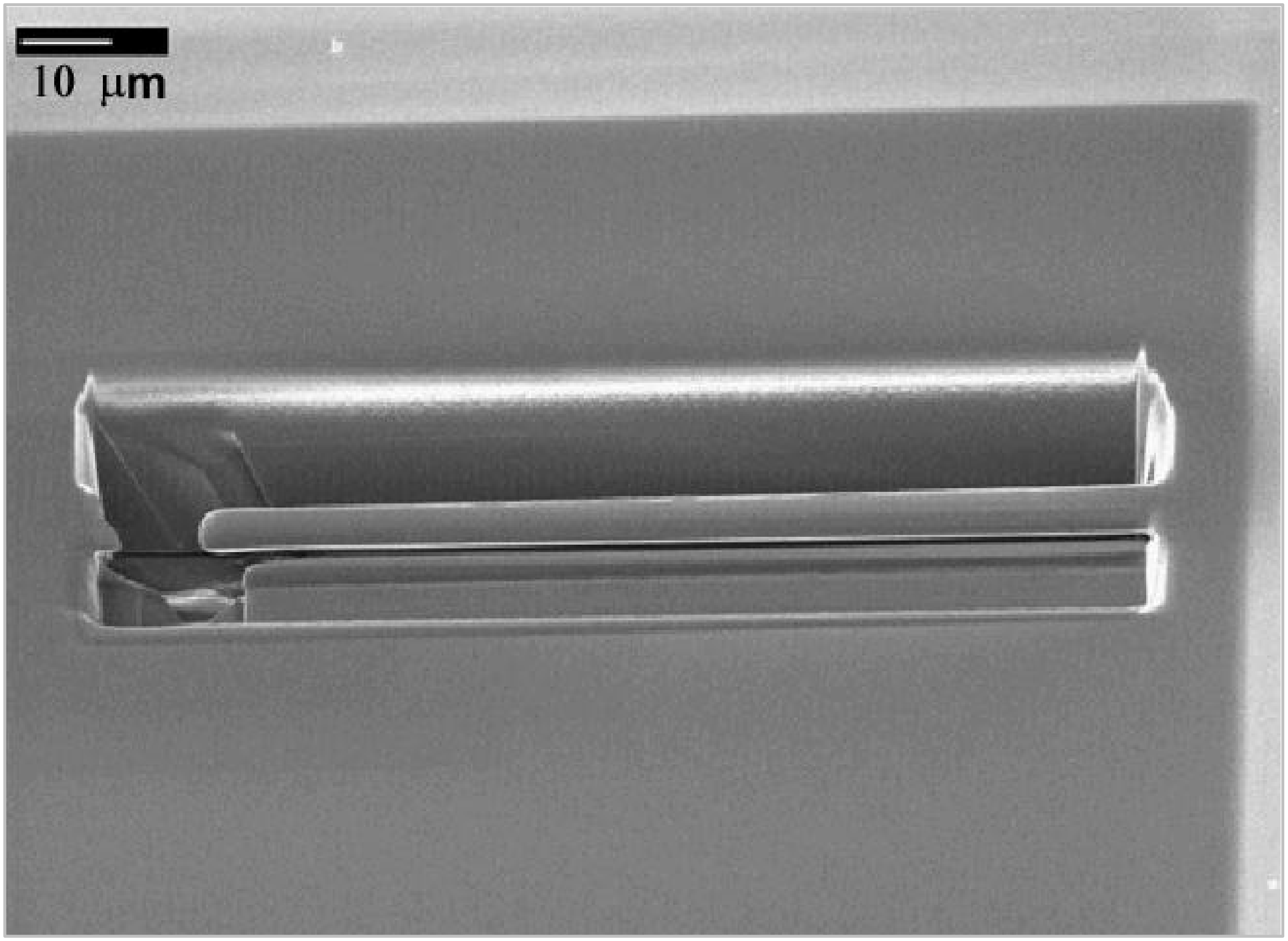


Experimental Setup

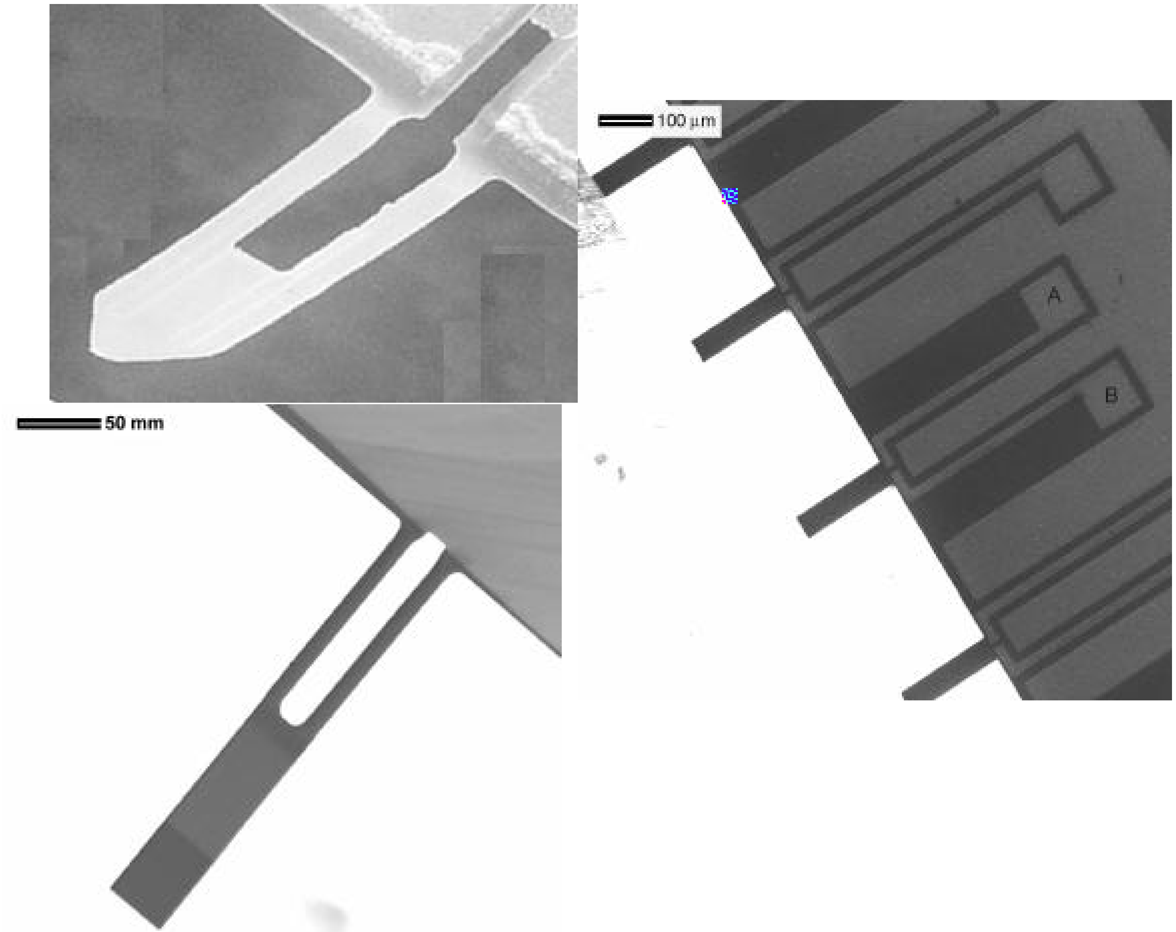


BENDING DETECTION METHODS: OPTICAL, PIEZORESISTIVE, PIEZOELECTRIC,CAPACITIVE,DIFFRACTIVE, AND TUNNELING

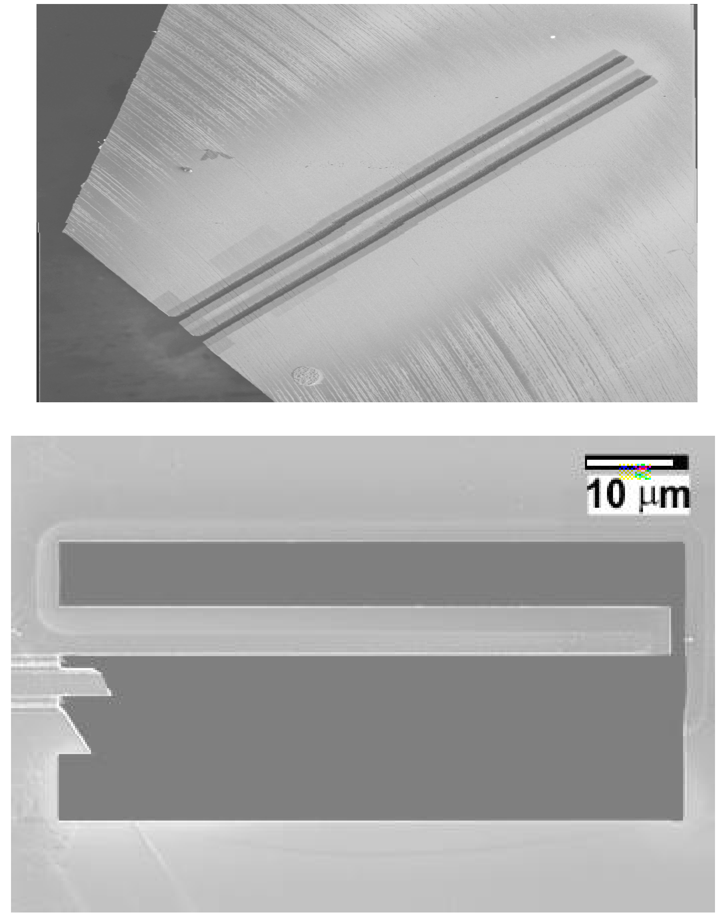
Initial Si Microstructure



Micromechanical Quantum or Thermal Detectors

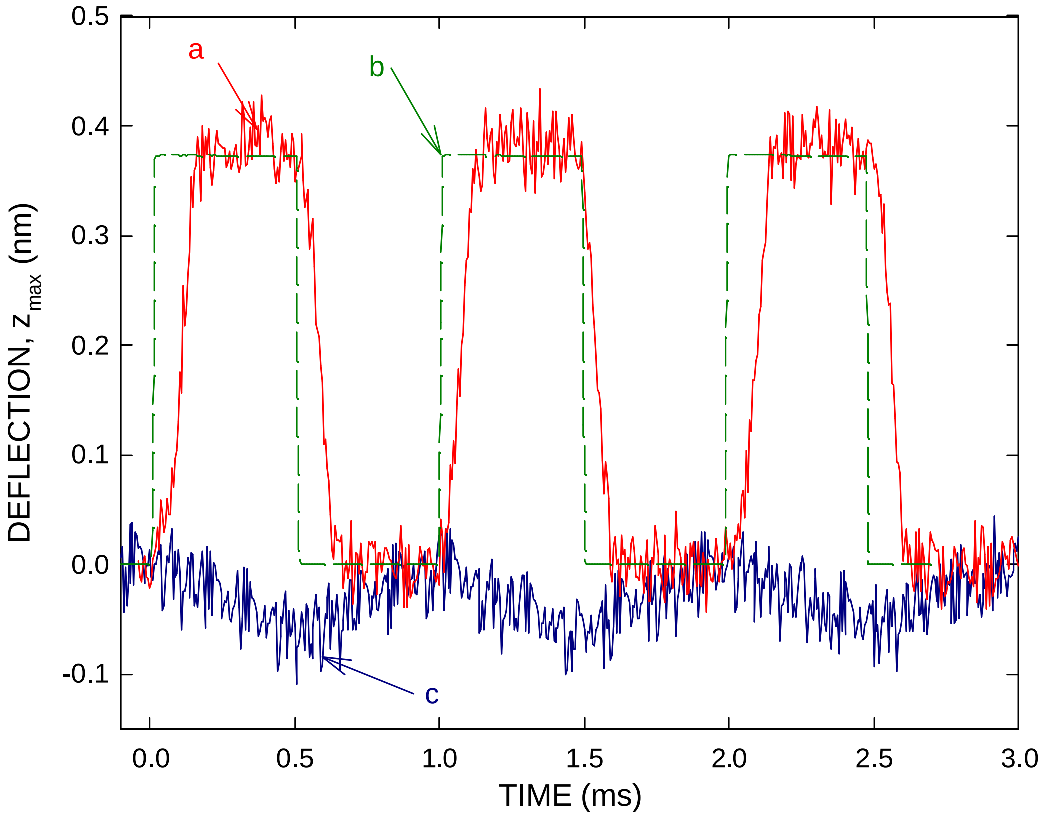


Piezoresistive Pt-Si photon detector



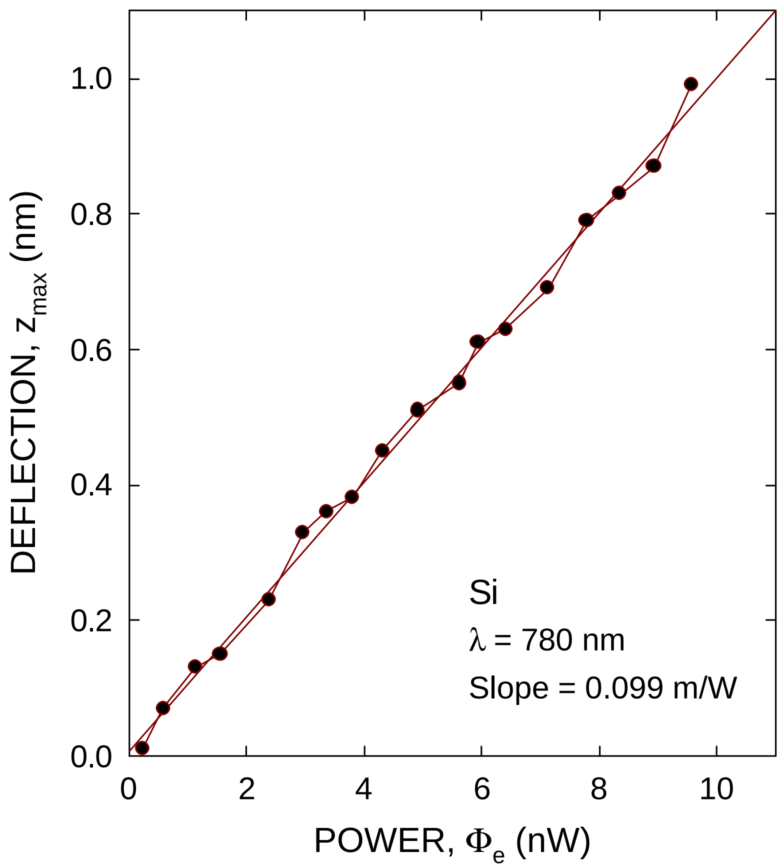
InSb cantilever photon detectors

Photo-induced Bending of Si Microstructures



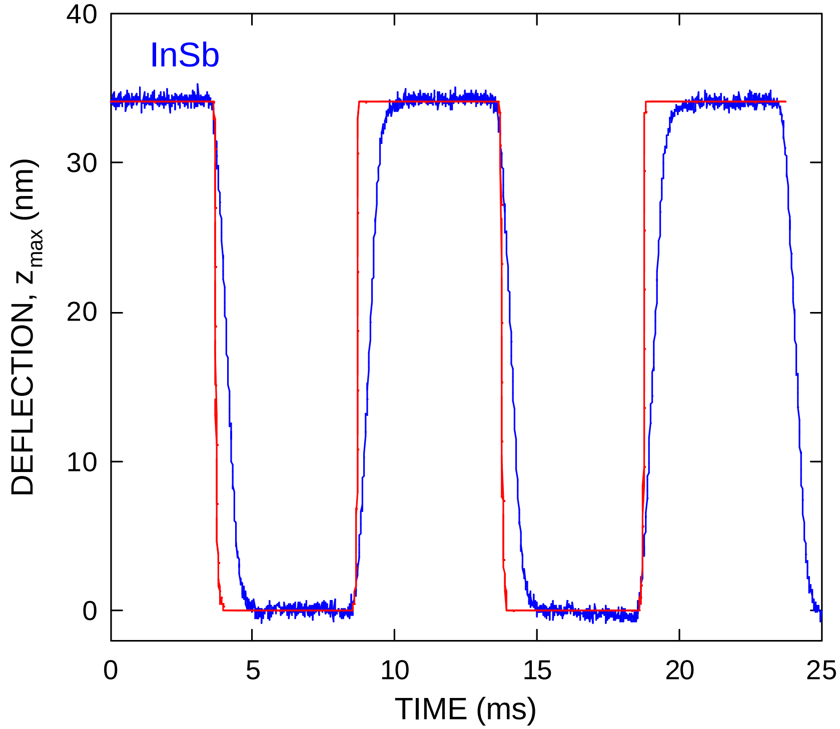
Si photon detector

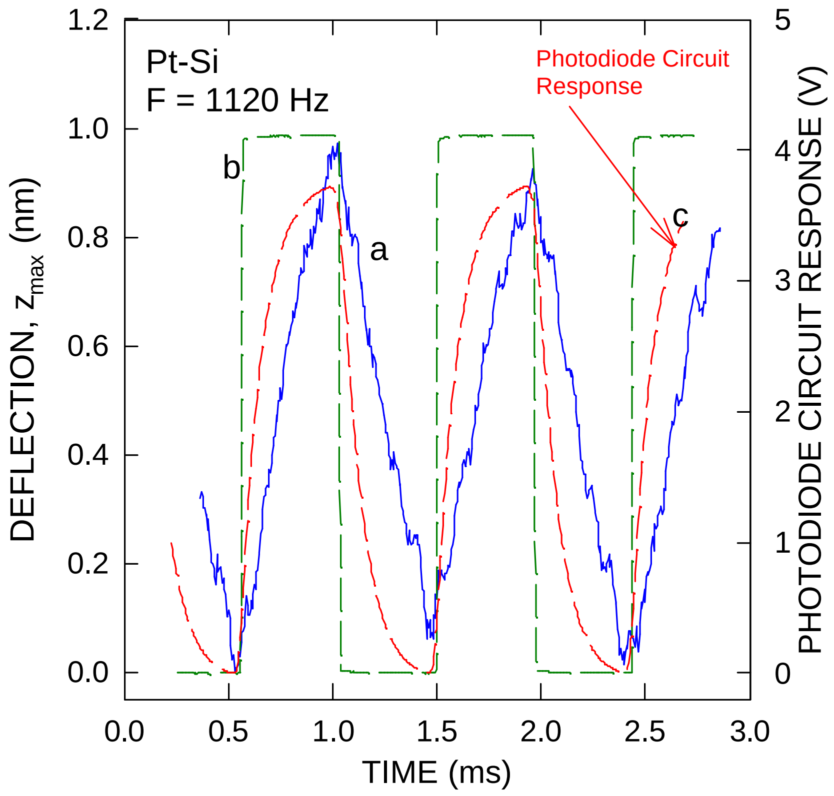
Deflection Responsivity



Si photon detector

Photo-induced Bending from Blackbody Radiation (l > 1.1 mm)

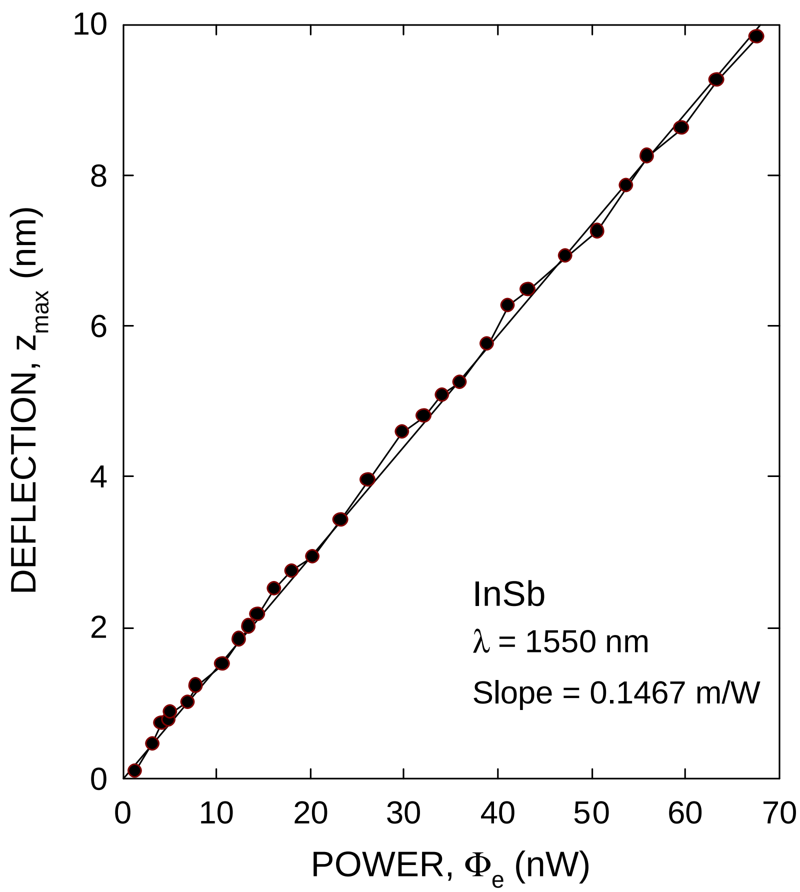


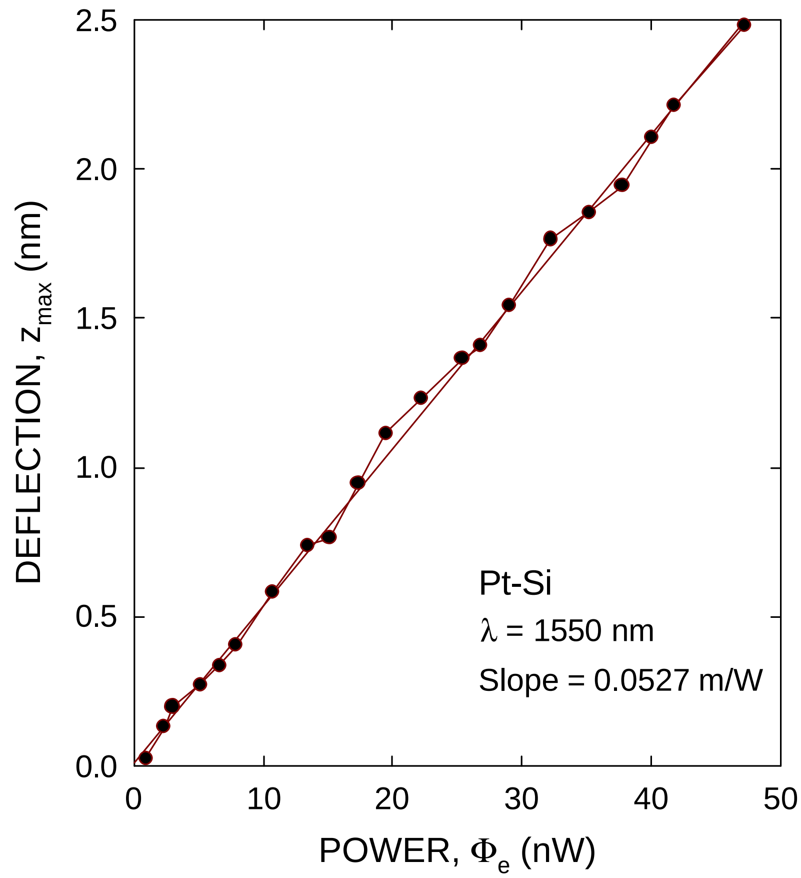


InSb photon detector

Pt-Si photon detector

Deflection Responsivity

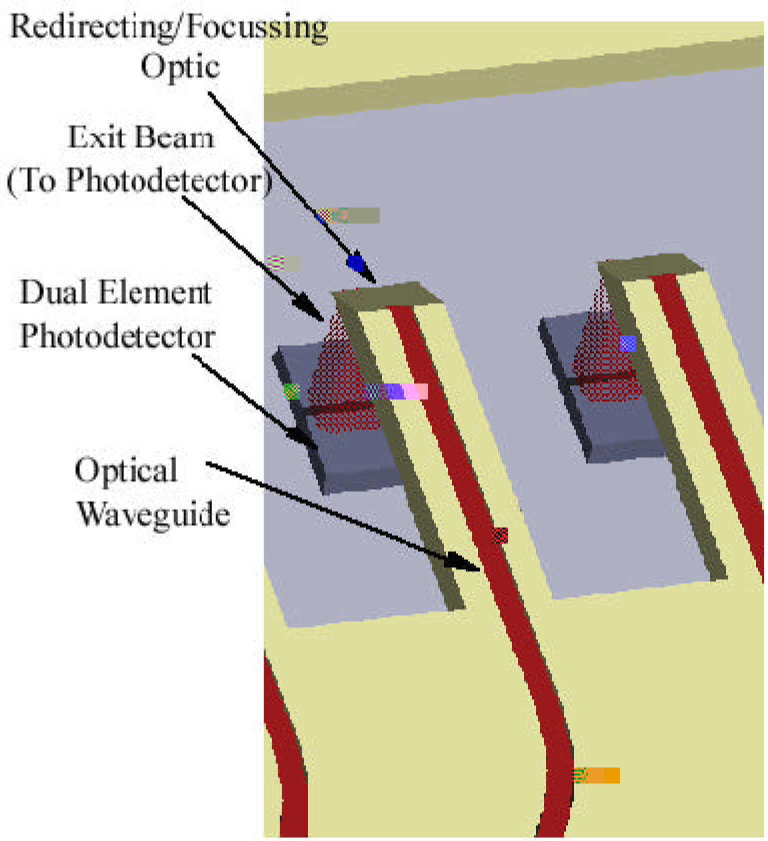


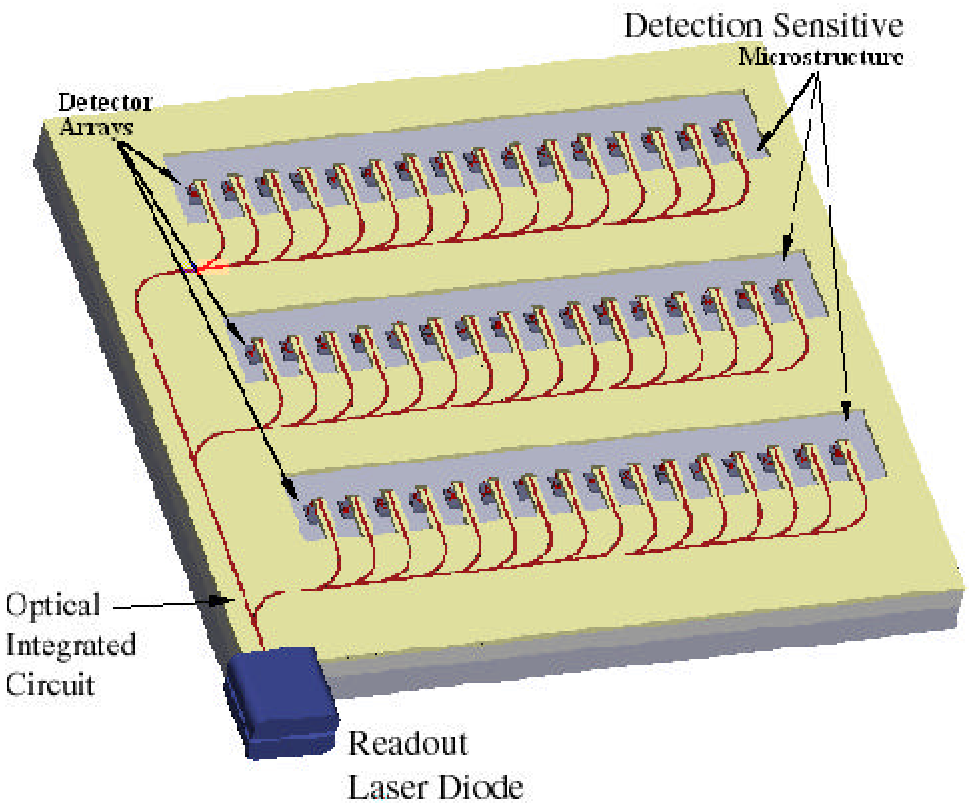


InSb photon detector

Pt-Si photon detector

Microposition Detection for Large Arrays





Acknowledgment of Funding Agencies

Summary/Conclusions

- Demonstrated detection of infrared photons using photo-induced stress and internal photo-emission in semiconductor microstructures.
- Photon detection mechanism allows room temperature infrared imaging
- Semiconductor microstructures respond to photons with energies above the bandgap via a photo-induced mechanical stress.
- Deflection (bending) of micromechanical structures depends linearly on photo-induced stress.