Optical Basics _MEMS

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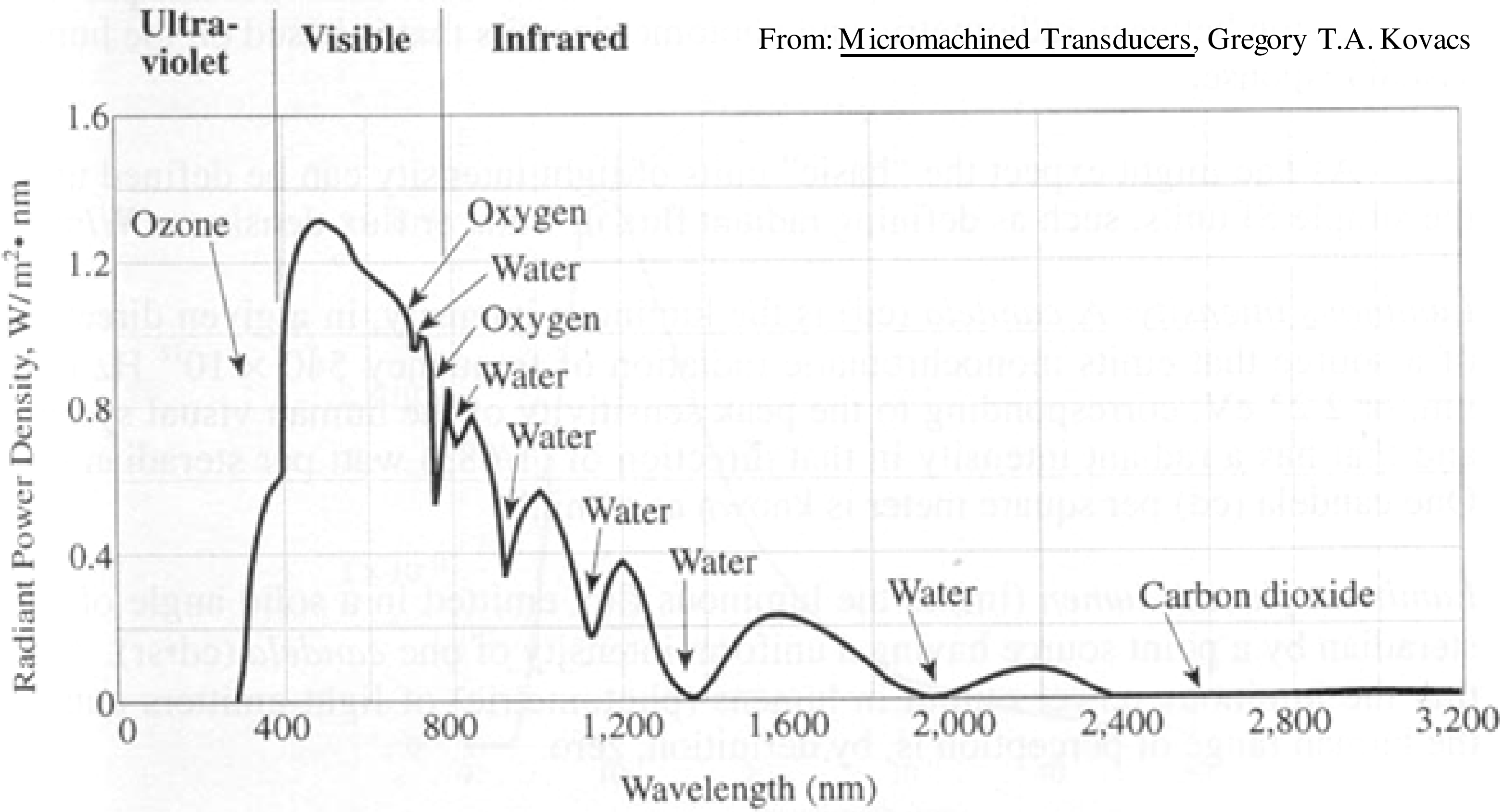
4-2-2013 Optical_Basics_MEMS.ppt

OUTLINE

Light Sources
Light Detectors
Optic Components
Mirrors
Light Emissive Devices
Light Modulators
References
Homework

SPECTRICAL DISTRIBUTION OF SOLAR RADIANT POWER

From: Micromachined Transducers, Gregory T.A. Kovacs



Spectral distribution of solar radiant power density at sea level, showing the ozone, oxygen, water, and CO_2 absorption bands. After Benson (1992).

BLACK BODY, AM0 AND AM1.5

From: Solar Cells, Martin A. Green, Prentice Hall

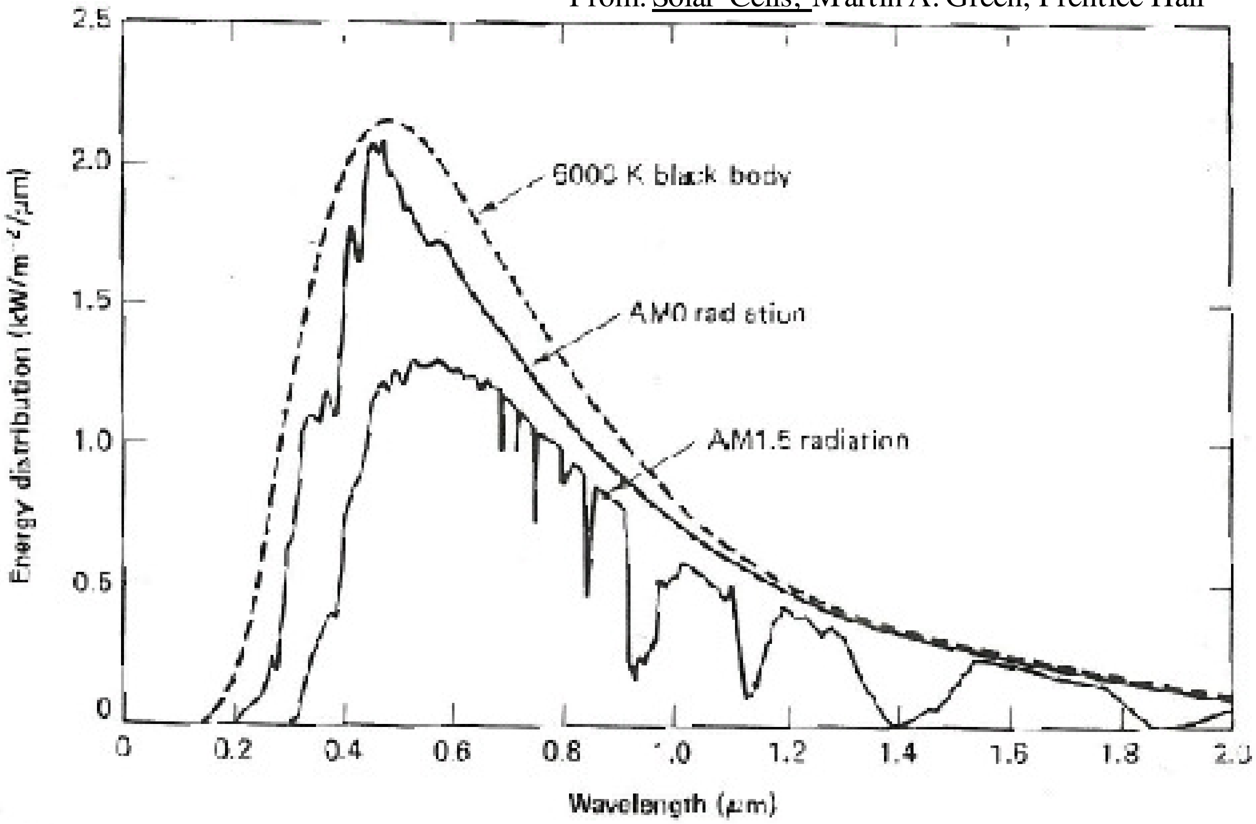
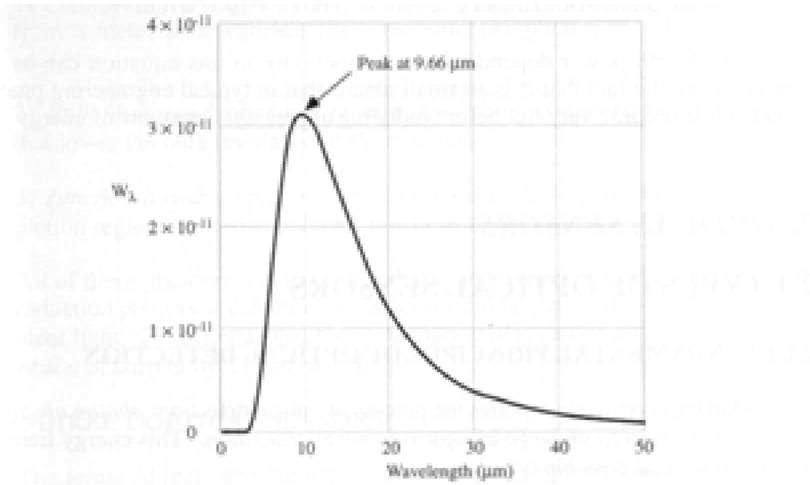


Figure 1.3. Spectral distribution of sunlight. Shown are the cases of AM0 and AM1.5 radiation together with the radiation distribution expected from the sun if it were a black body at 6000K.

BLACK BODY RADIATION

From: Micromachined Transducers, Gregory T.A. Kovacs



Plot of W_λ versus λ (μm) for a 300 K (room temperature) object assuming ε = 1 (human body temperature corresponds to a peak at ≈ 9.4 μm).

$$W_\lambda = \frac{\varepsilon(\lambda)\, 2\pi h c^2}{\lambda^5} \frac{1}{\left(e^{\frac{hc}{\lambda k T}} - 1\right)} \quad \text{in W/m}^2$$

From: Solar Cells, Martin A. Green, Prentice Hall

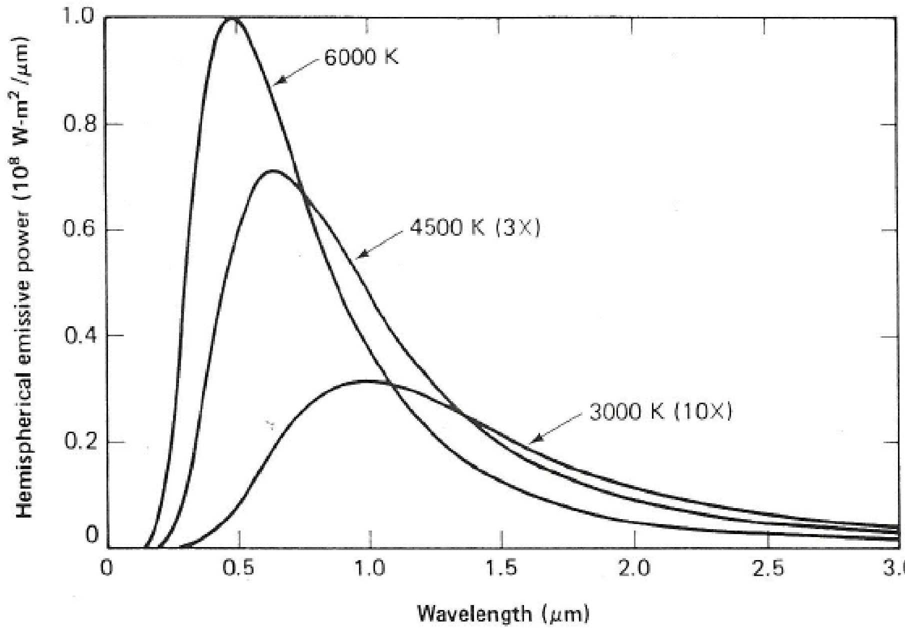
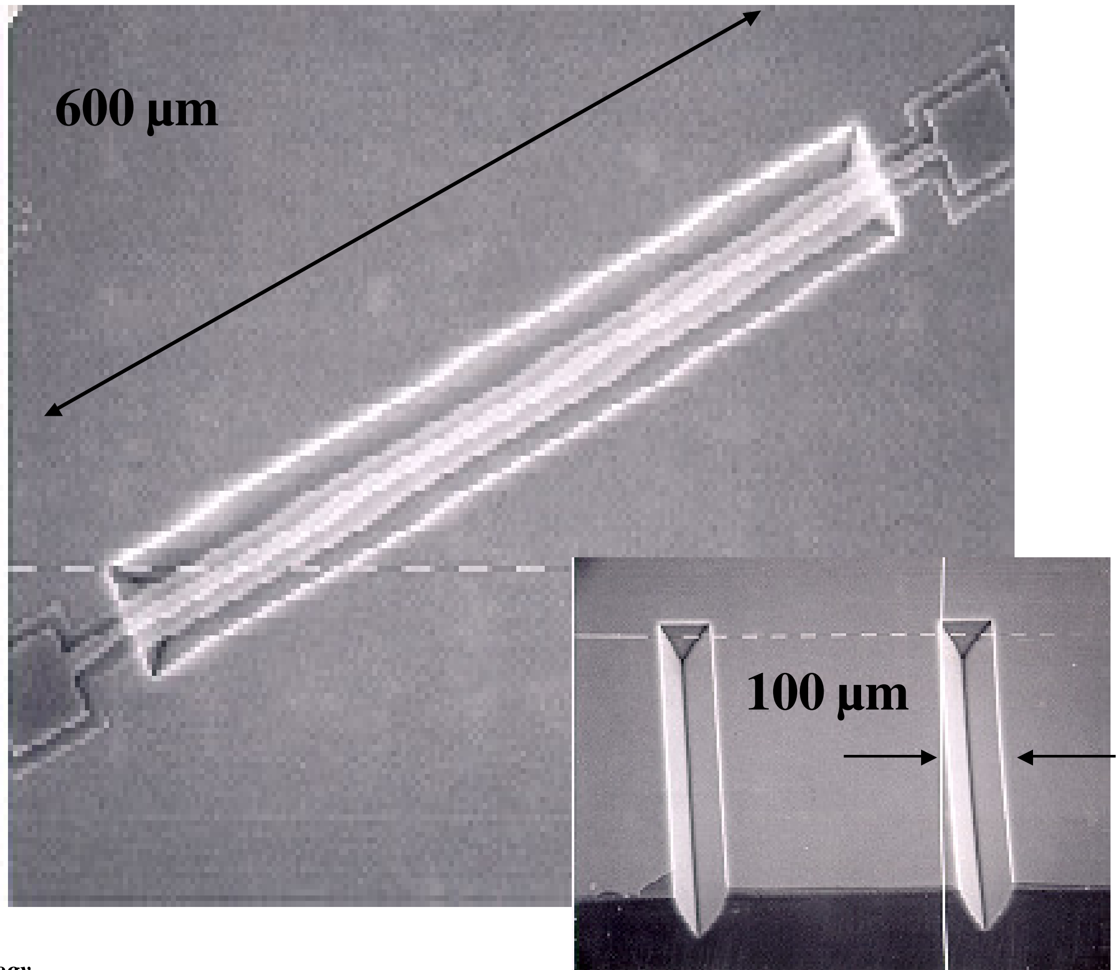


Figure 1.1. Planckian black-body radiation distributions for different black-body temperatures.

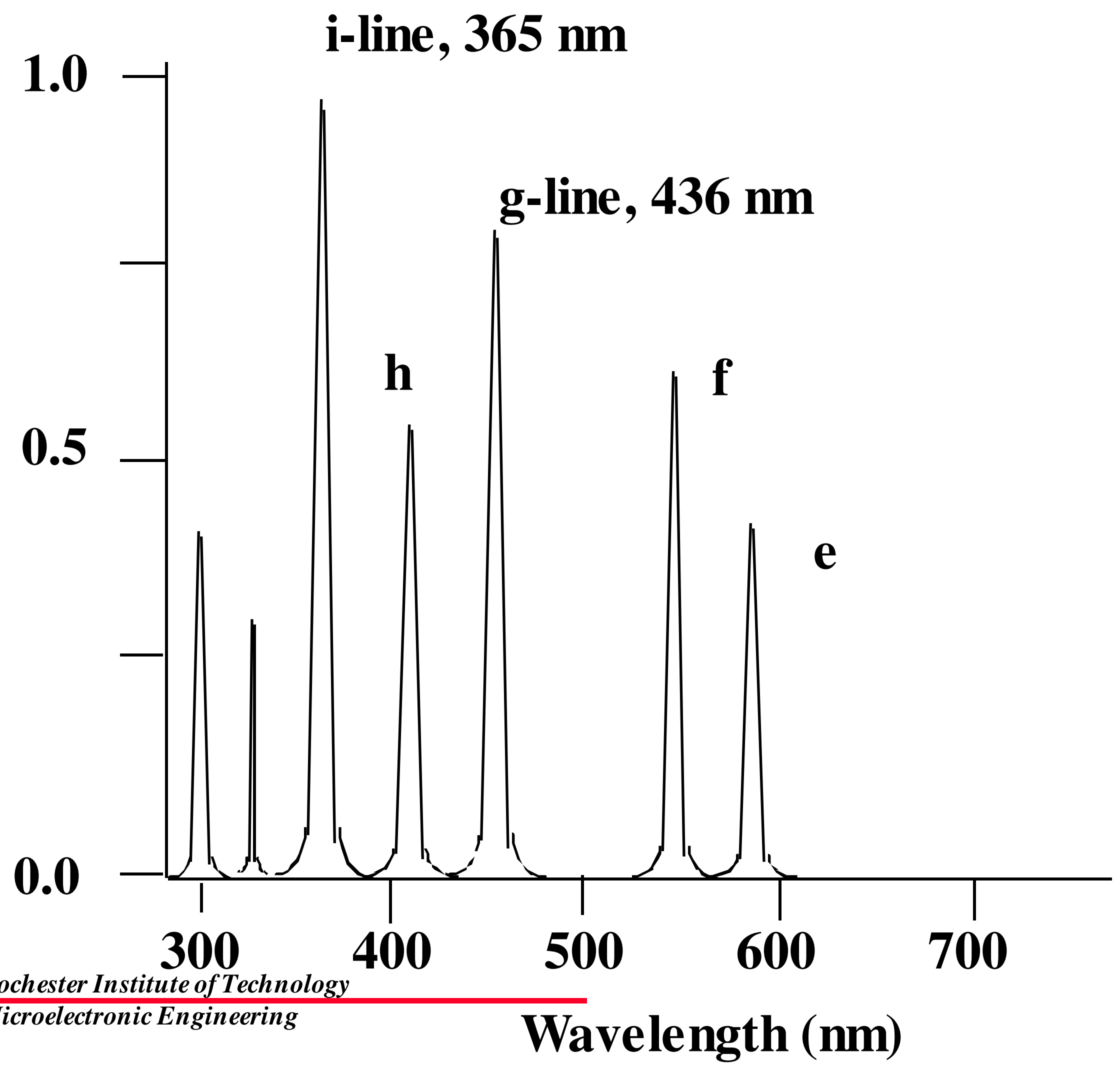
HOT FILIMENT "BLACK BODY" LIGHT SOURCES

Dave Borkholder
Senior project 1993

MOVIE

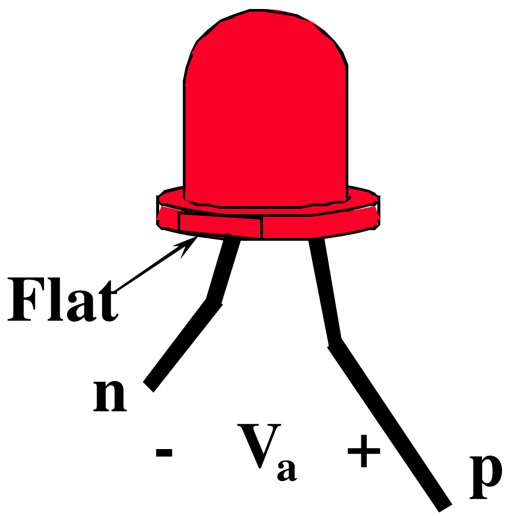


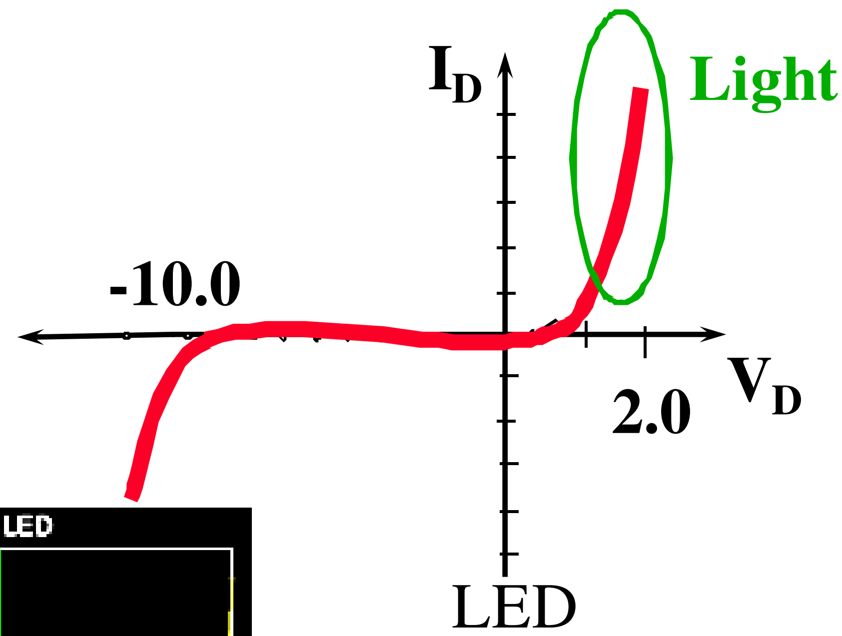
EMISSION SPECTRA OF THE Hg VAPOR BULB

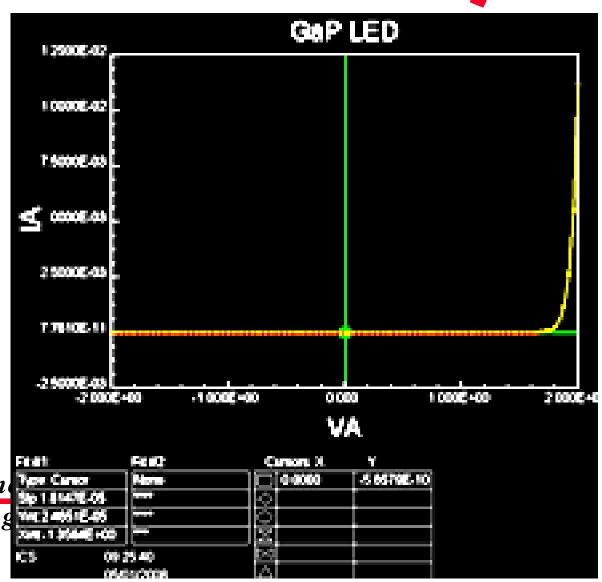


LED IV CHARACTERISTICS

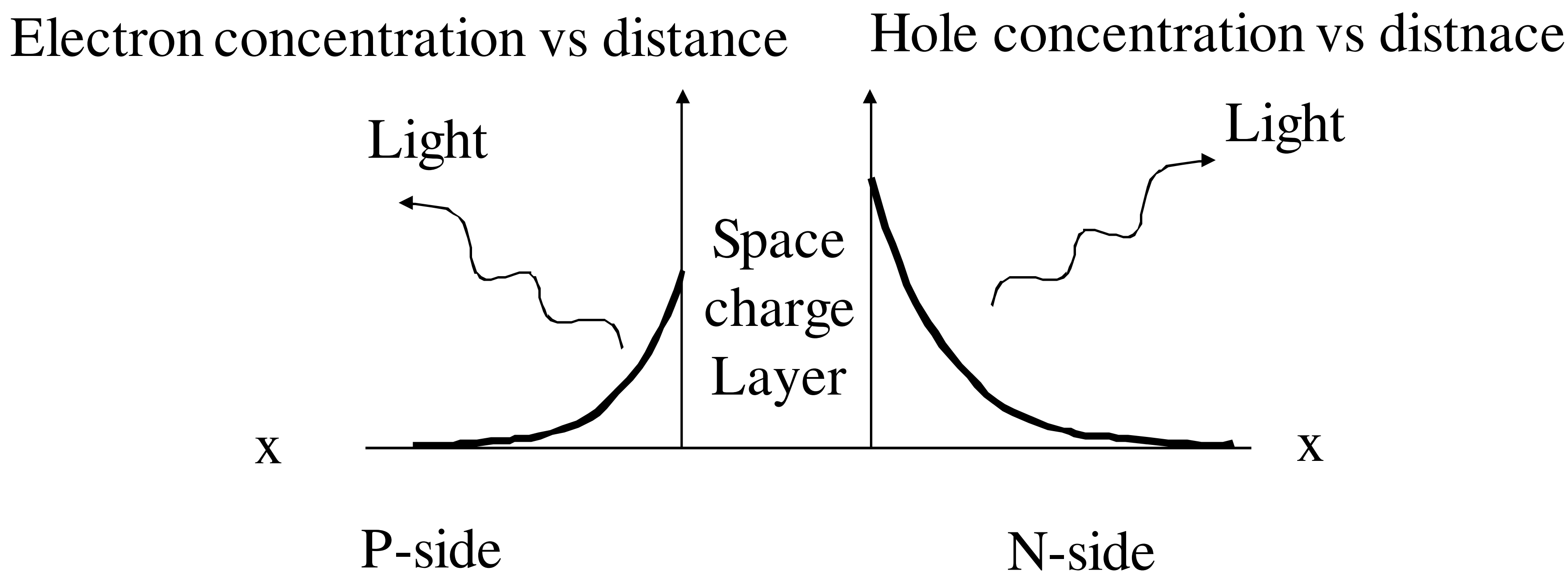
Light Emitting Diode -LED







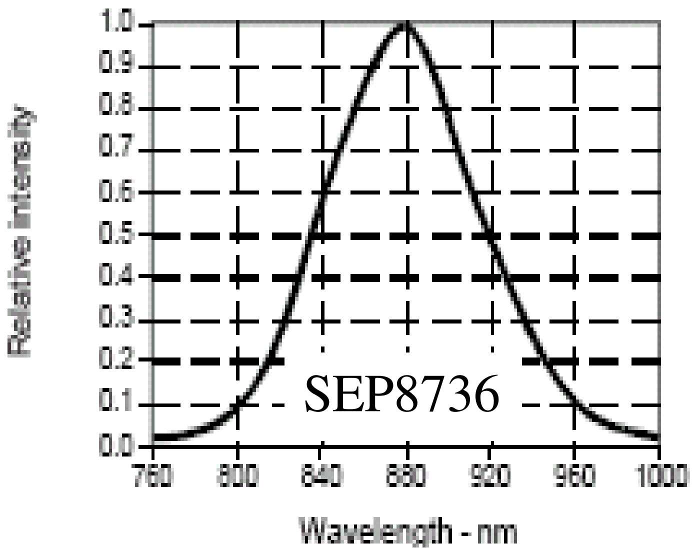
LIGHT EMITTING DIODES (LEDs)

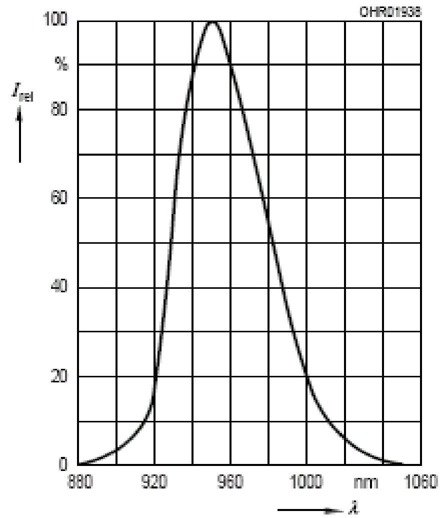


In the forward biased diode current flows and as holes recombine on the n-side or electrons recombine on the p-side, energy is given off as light, with wavelength appropriate for the energy gap for that material. $\lambda = h\ c\ /\ E$

h = Plank's constant
c = speed of light

LEDs





SFH4110

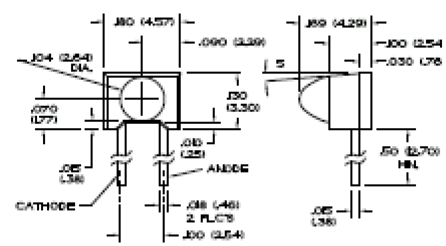
SEP8736

AlGaAs Infrared Emitting Diode

OUTLINE DIMENSIONS in inches (mm)

Tolerance 3 plc decimals ±0.005(0.12)

2 plc decimals ±0.020(0.51)



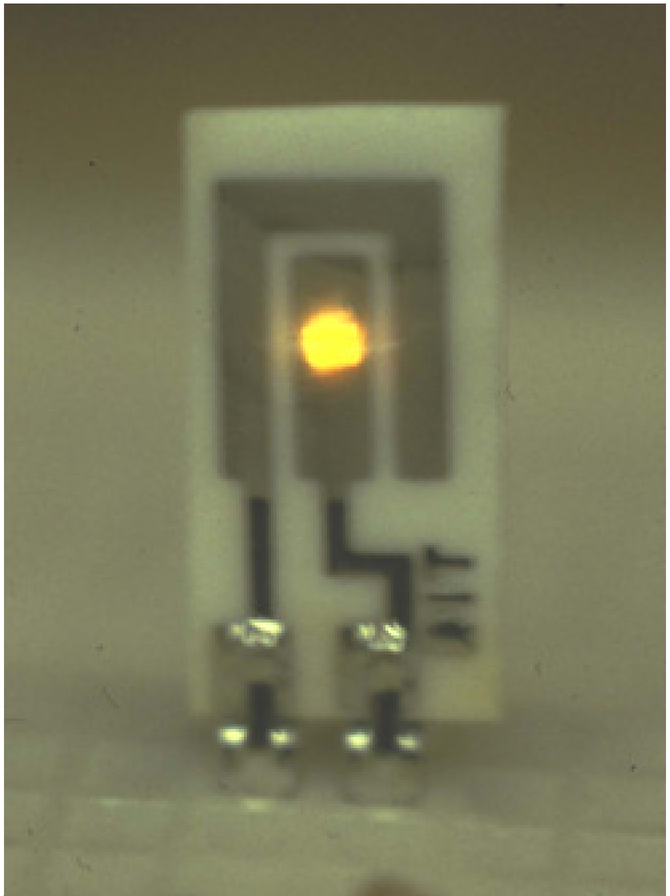
ELECTRICAL CHARACTERISTICS (25°C unless otherwise noted)

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	TEST CONDITIONS
Irradiance (1)	H				mW/cm²	I_F=20 mA
SEP8736-001		0.5				
SEP8736-002		1.2		3.0		
SEP8736-003		1.7				
Forward Voltage	V_F			1.7	V	I_F=20 mA
Reverse Breakdown Voltage	V_{BR}	3.0			V	I_R=10 µA
Peak Output Wavelength	λ_P		880		nm	
Spectral Bandwidth	$\Delta\lambda$		80		nm	
Spectral Shift With Temperature	$\Delta\lambda_P/\Delta_T$		0.2		nm/°C	
Beam Angle (2)	Ø		10		degr.	I_F=Constant
Radiation Rise And Fall Time	t_r, t_f		0.7		µs	

Notes

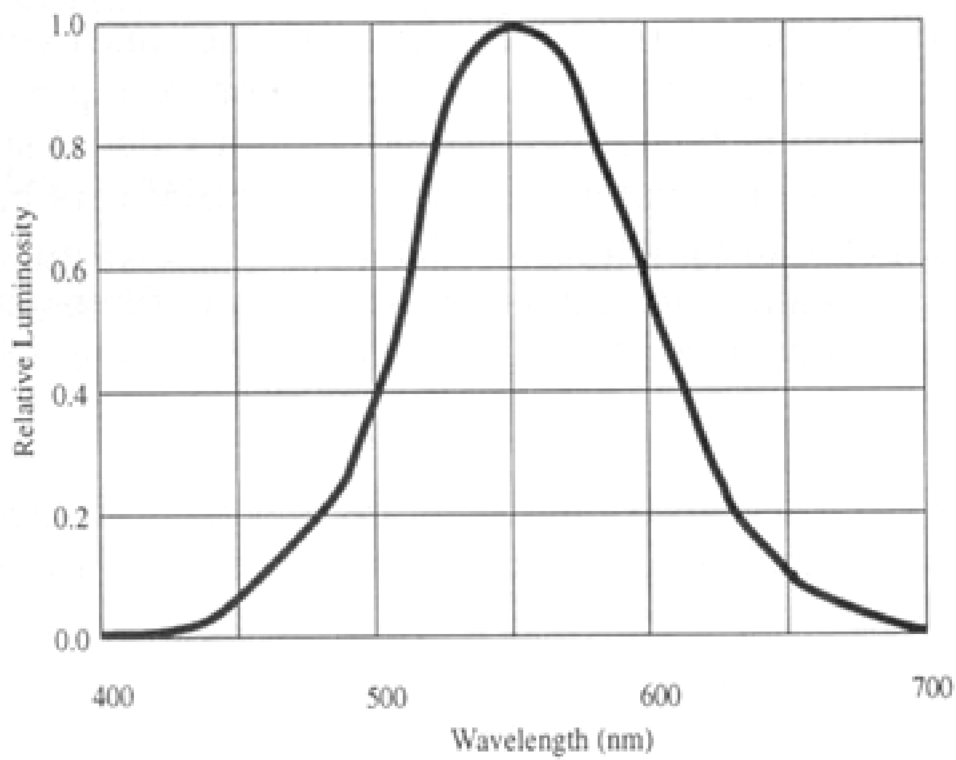
1. Measured in mW/cm² into a 0.104 (2.64) diameter aperture placed 0.500(12.7) from the lens tip.
2. Beam angle is defined as the total included angle between the half intensity points.

RIT'S FIRST LED



GaP wafers with n-type epilayer, add gold metal, dice and wire bond to RIT thick film ceramic package.

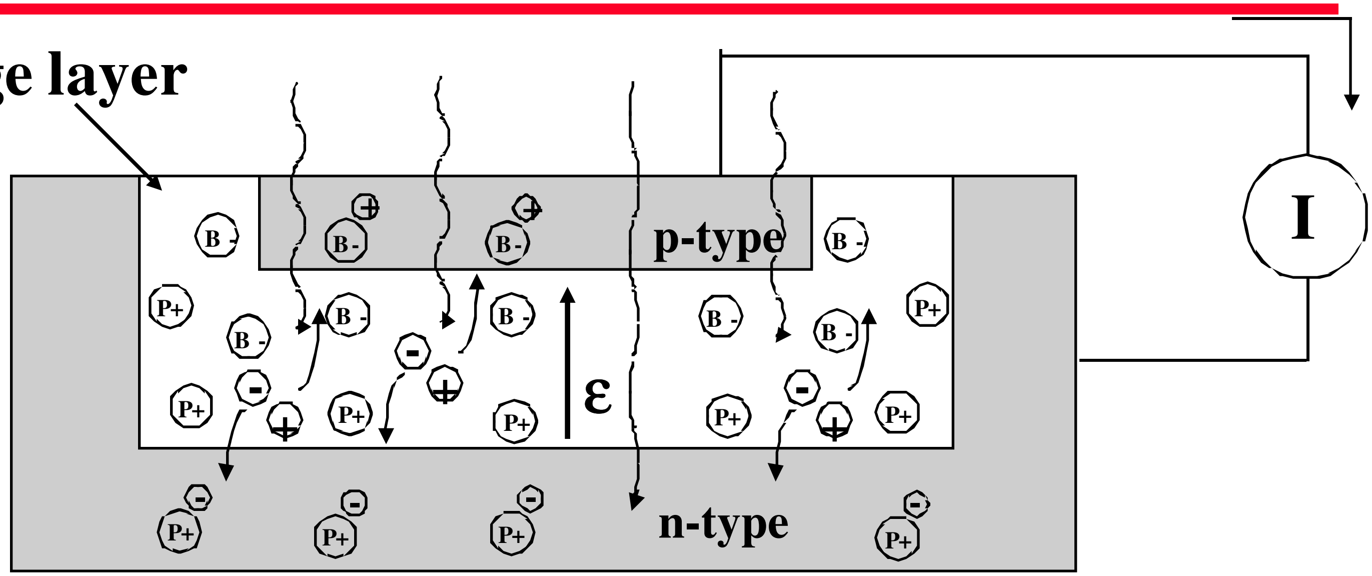
RELATIVE LUMINOSITY VS WAVELENGTH

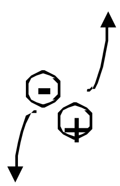


Human eye perceives 550nm (green-yellow) as the brightest, the relative luminosity of other colors is give above

PHOTODIODE

space charge layer





electron and hole pair

Phosphrous donor atom and electron

Ionized Immobile Phosphrous donor atom

Ionized Immobile Boron acceptor atom

Boron acceptor atom and hole

Rochester Institute of Technology
Microelectronic Engineering

WIDTH OF SPACE CHARGE LAYER

Width of space charge layer depends on the doping on both sides and the applied reverse bias voltage and temperature.

ROCHESTER INSTITUTE OF TECHNOLOGY PN.XLS
MICROELECTRONIC ENGINEERING 4/13/2011

CALCULATIONS FOR PN JUNCTION (ELECTROSTATICS) DR. LYNN FULLER

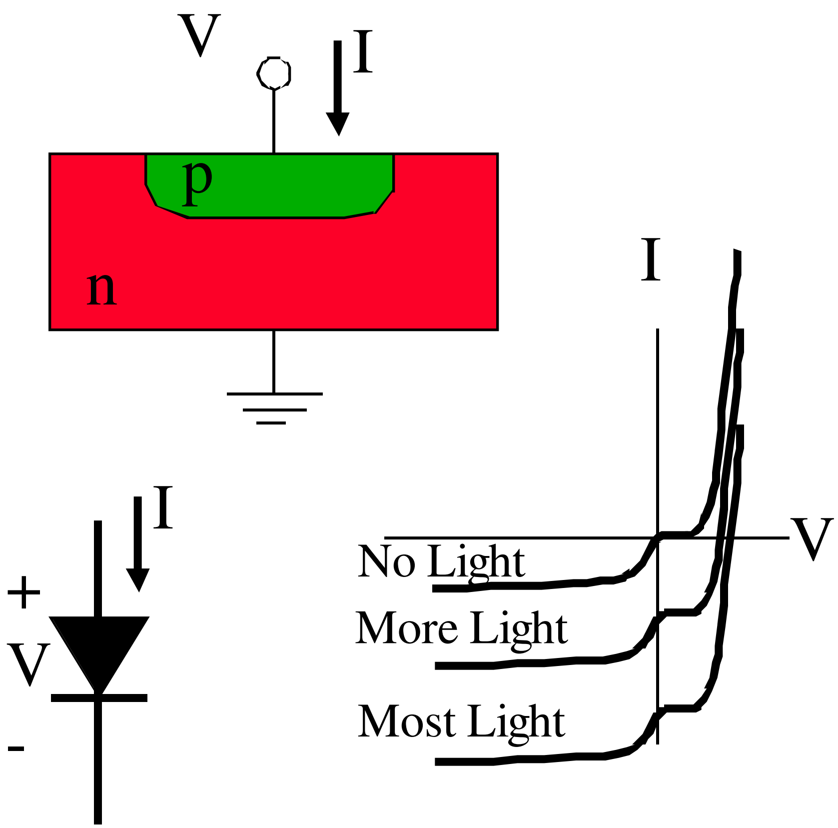
To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

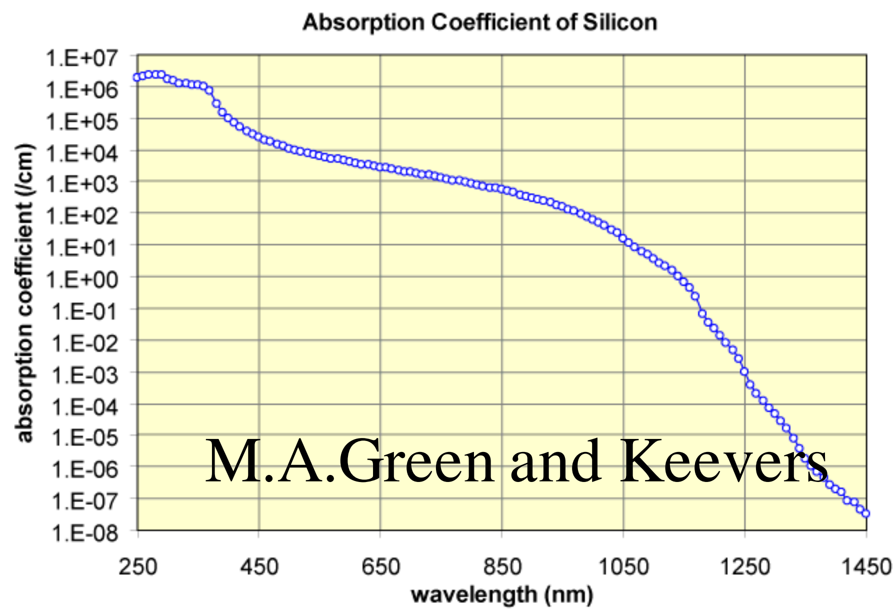
CONSTANTS			VARIABLES			
K	1.38E-23	J/K				
q	1.60E-19	Coul	Temp=	300	°K	
Eg	1.12	eV				
εo	8.85E-14	F/cm	Nd =	1.00E+16	cm-3	
εr	11.7		Na =	5.00E+14	cm-3	
ni	1.45E+10	cm-3				
Breakdown E	3.00E+05	V/cm	Vr =	0	Volts	Reverse Bias Voltage

CALCULATIONS:

Eg = Ego - (aT^2/(T+B)	1.075	eV
ni^2 = A T^3 e^(-Eg/KT/q)	9.84E+20	cm-6
KT/q =	0.0259	Volts
Vbi = (KT/q) ln (NaNd/ni2)	0.58	Volts
W = [(2ε/q)(Vbi+Vr)(1/Na +1/Nd)]^0.5	1.25	µm
W1 = W[Nd/(Na+Nd)]	1.19	µm
W2 = W[Na/(Na+Nd)]	0.06	µm
Eo = -[(2q/eoer)(Vbi+Va)(NaNd/(Na+Nd)]^0.5	-9.23E+03	V/cm
Cj' = eoer/W	8.26E-09	F/cm2

ADSORPTION VERSUS DISTANCE





$\phi(x) = \phi(0)\ \exp^{-\alpha\ x}$

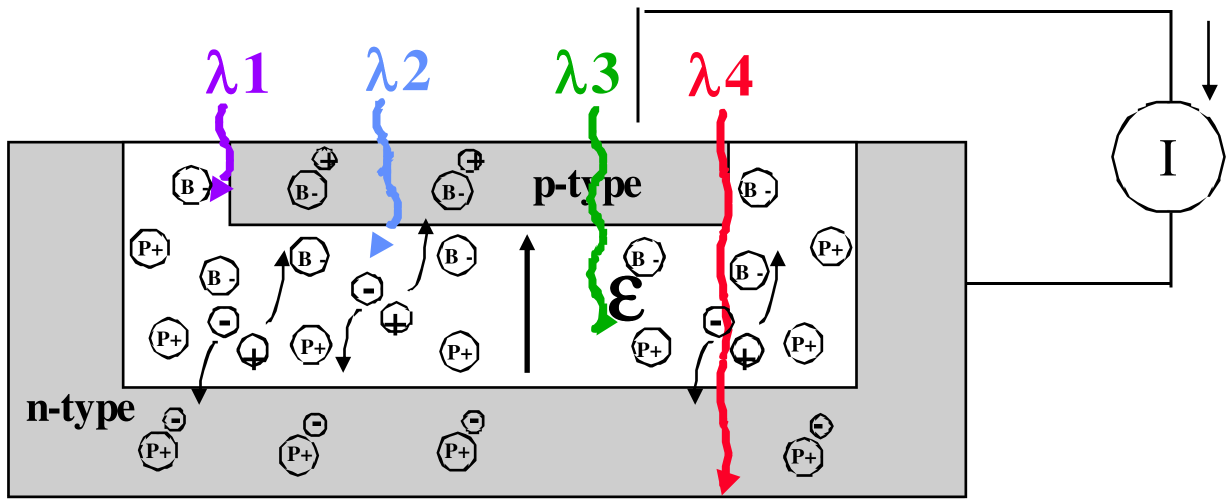
Find % adsorbed for Green light at x=5 µm and Red light at 5 µm

CHARGE GENERATION vs WAVELENGTH

E = hν = hc / λ

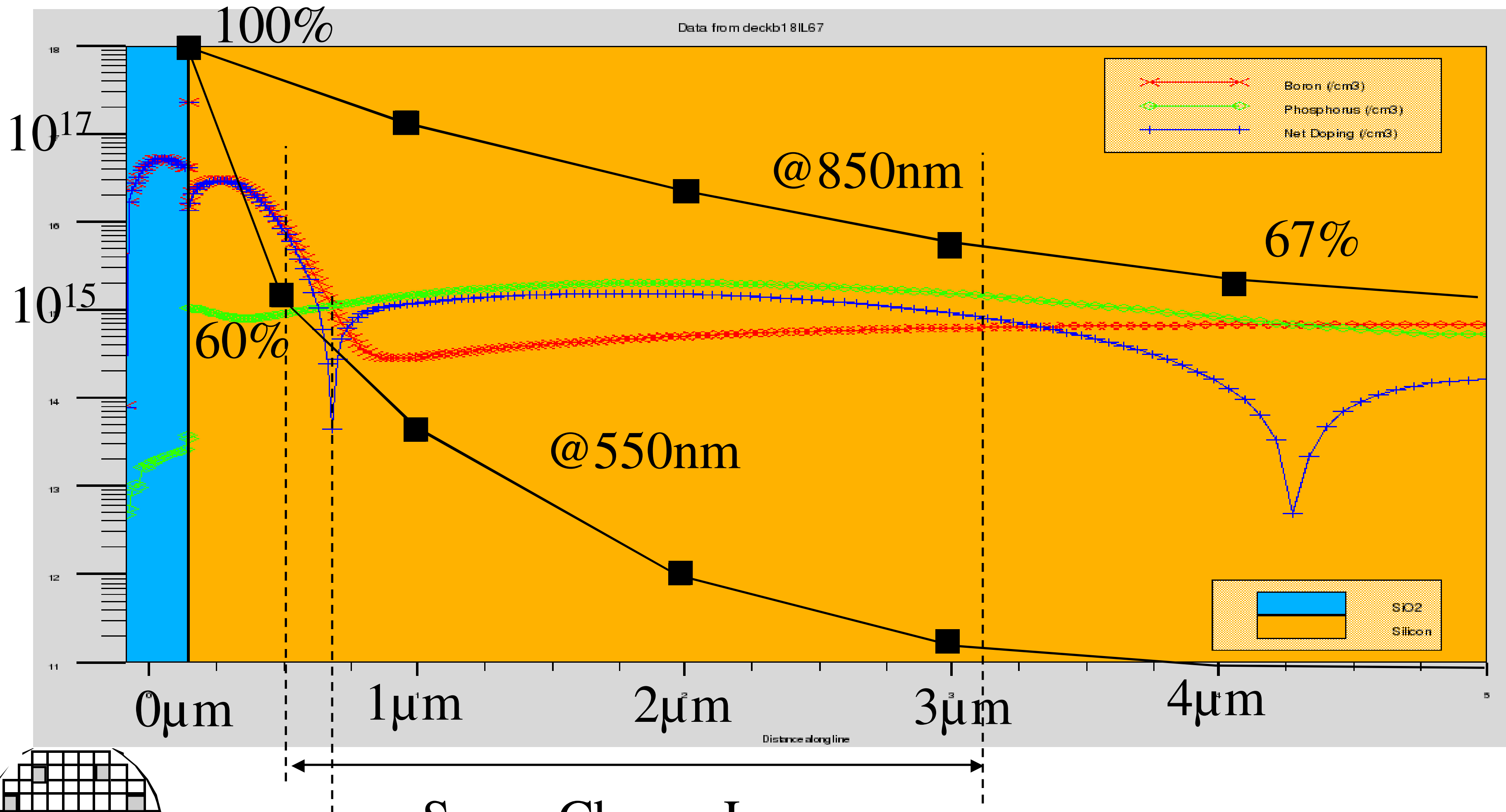
h = 6.625 e-34 j/s
= (6.625 e-34/1.6e-19) eV/s

E = 1.55 eV (red)
E = 2.50 eV (green)
E = 4.14 eV (blue)



To generate e-h pair in silicon we need E ≥ Egap
E ≥ 1.12 eV

PN JUNCTION DESIGN FOR PHOTO DIODE



CHARGE GENERATION IN SEMICONDUCTORS

$$E = h\nu = hc / \lambda$$

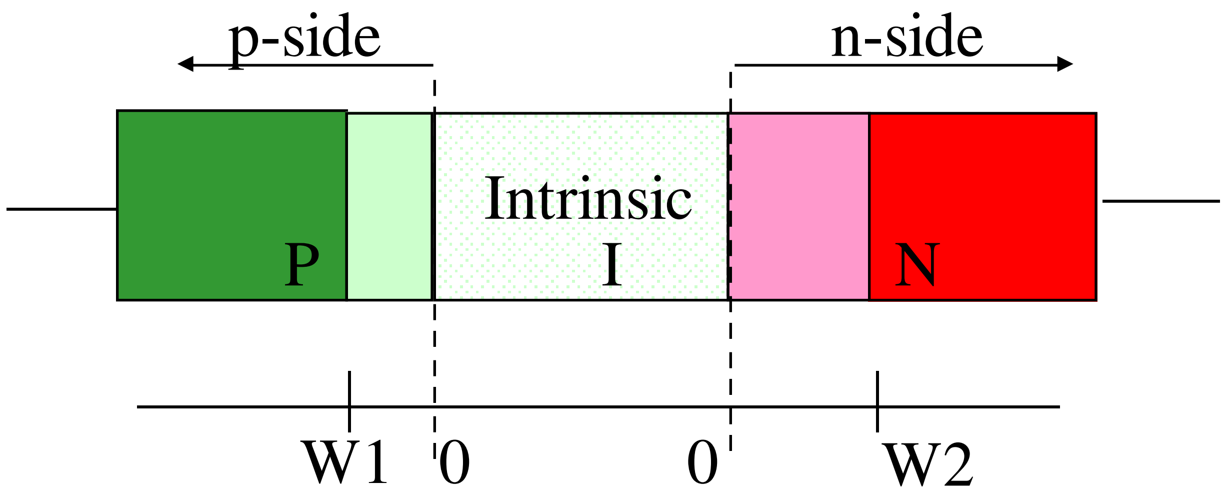
What wavelengths will not generate e-h pairs in silicon. Thus silicon is transparent or light of this wavelength or longer is not adsorbed?

From: Micromachined Transducers, Gregory T.A. Kovacs

Semiconductor	Bandgap (eV) 300 K	Bandgap (eV) 0 K	λ_{max} (μm) 300 K
BN	7.500	-	0.165
C	5.470	5.480	0.227
ZnS	3.680	3.840	0.337
GaN	3.360	3.500	0.369
ZnO	3.350	3.420	0.370
Alpha-SiC	2.996	3.030	0.414
CdS	2.420	2.560	0.512
GaP	2.260	2.340	0.549
BP	2.000	-	0.620
CdSe	1.700	1.850	0.729
AlSb	1.580	1.680	0.785
CdTe	1.560	-	0.795
GaAs	1.420	1.520	0.873
InP	1.350	1.420	0.919
Si	1.120	1.170	1.107
GaSb	0.720	0.810	1.722
Ge	0.660	0.740	1.879
PbS	0.410	0.286	3.024
InAs	0.360	0.420	3.444
PbTe	0.310	0.190	4.000
InSb	0.170	0.230	7.294
Sn	-	0.082	15.122 @ 0 K

Table of various semiconductors in order of increasing λ_{max}. From Sze (1981).

PIN, AVALANCE PHOTODIODES (APD)

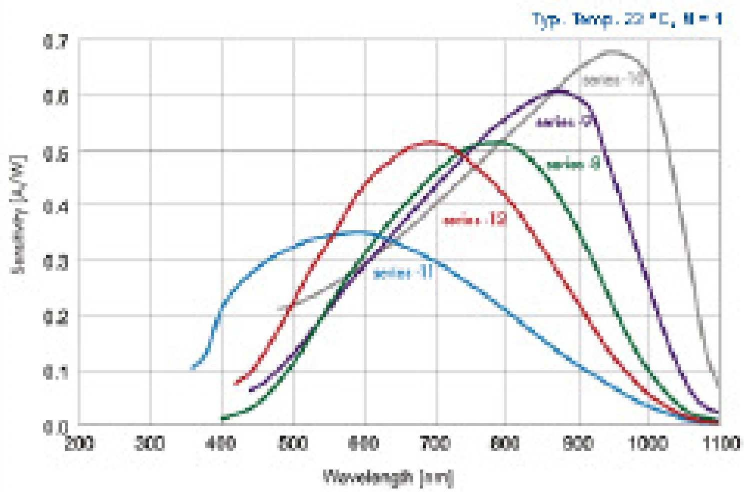


PIN and Avalance photo diodes (APD) are made with an intrinsic (almost zero doping) layer between the N and P layers. The depletion layer is increased by the width of the Intrinsic layer. Avalance diodes are the same structure but used with large reverse bias (>100 volts) that creates large electric field in the space charge layer that can accelerate the electrons to velocities high enough to cause ionizing collisions giving a multiplication of carriers. Each photon can generate hundreds of electron hole pairs.

PIN, AVALANCE PHOTODIODES (APD)

Si Avalanche Photodiodes (APD)

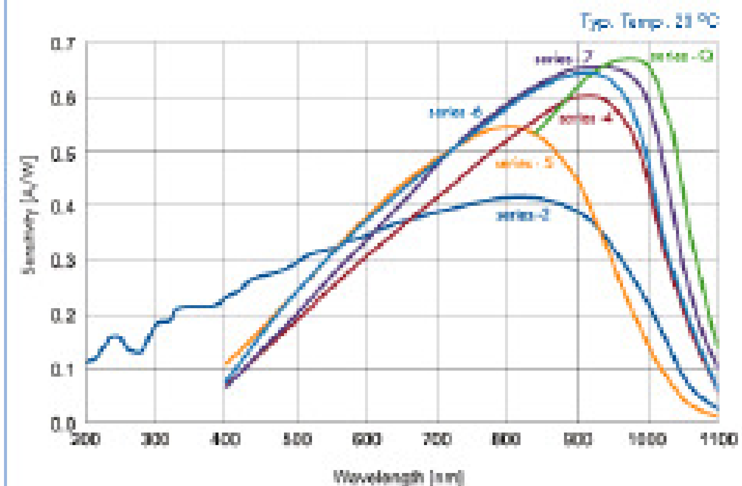
Spectral Sensitivity



Are high speed, high sensitivity photodiodes with an internal gain mechanism and high gain bandwith product with a spectral response range between 300 nm and 1100 nm

Si PIN Photodiodes

Spectral Sensitivity



Optimised for high UV-response, low dark current, high shunt resistance, very low capacitance, etc. ideal for high performance and standard applications like x-ray detection , scintillation detectors and more... Spectral response range between 190nm and 1100nm.

Position Sensing Photodiodes (PSD)

Single and Dual –Axis PSD´s with high position resolution and high linearity

Quadrant Photodiodes

Small Gap, excellent uniformity, low dark current, high shunt resistance, high resolution

www.silicon-sensor.com

PHOTOMULTIPLIER

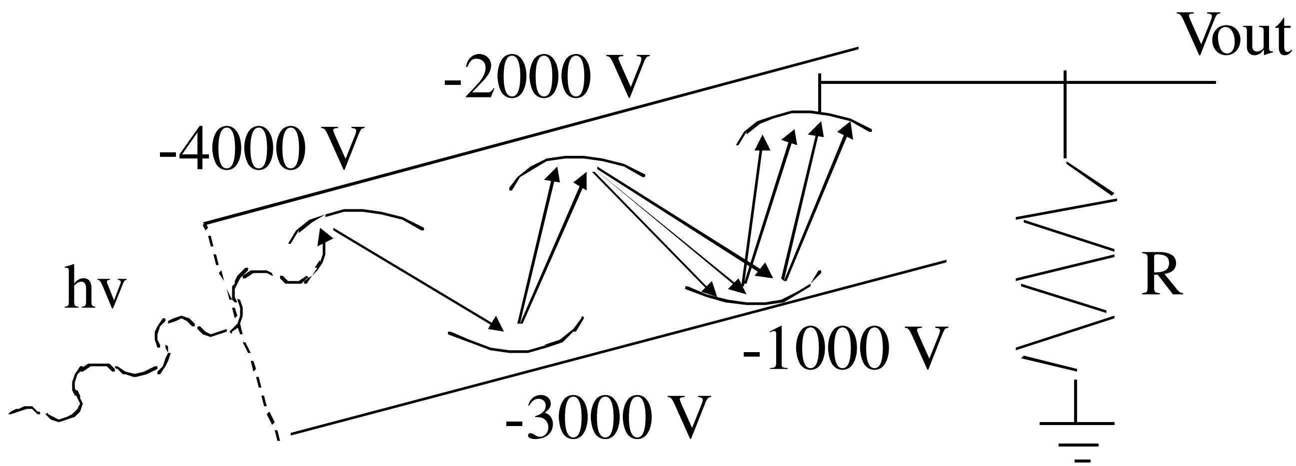


Photo Multiplier Tube (low work Function)

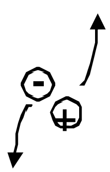
CHARGE COLLECTION IN MOS STRUCTURES

$E = h\nu = hc / \lambda$

h = 6.625 e-34 j/s
= (6.625 e-34/1.6e-19) eV/s

E = 1.55 eV (red)
E = 2.50 eV (green)
E = 4.14 eV (blue)

electron and hole pair



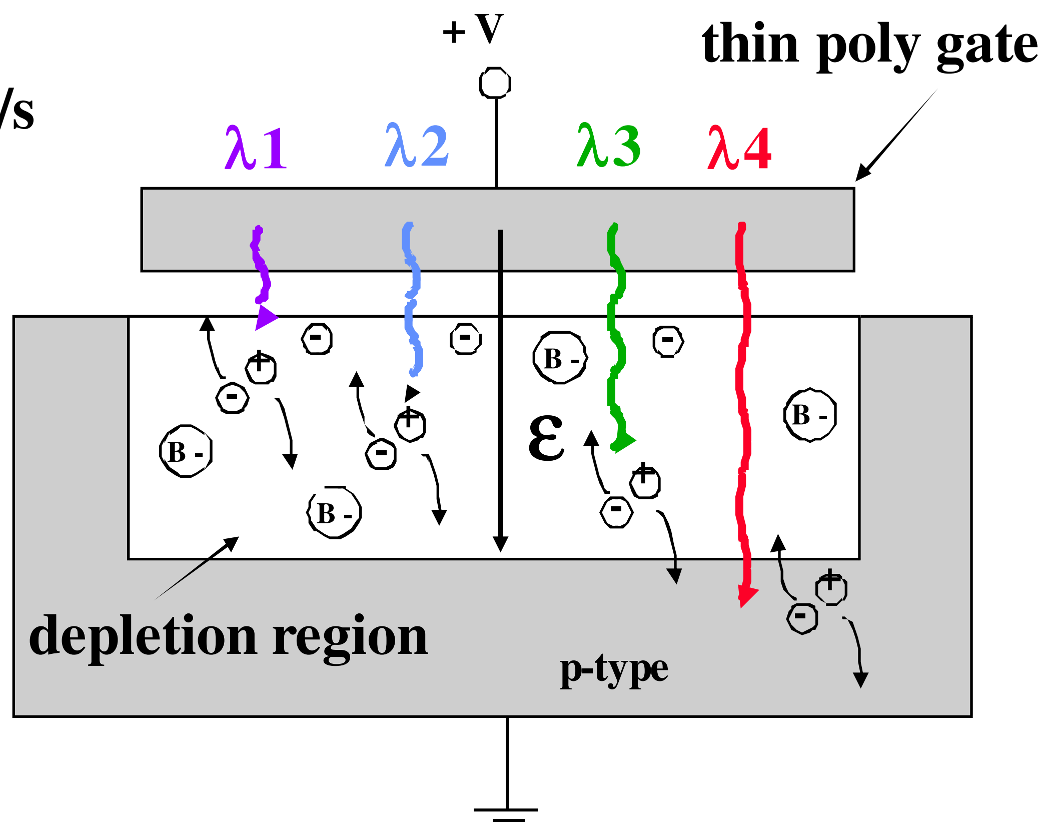


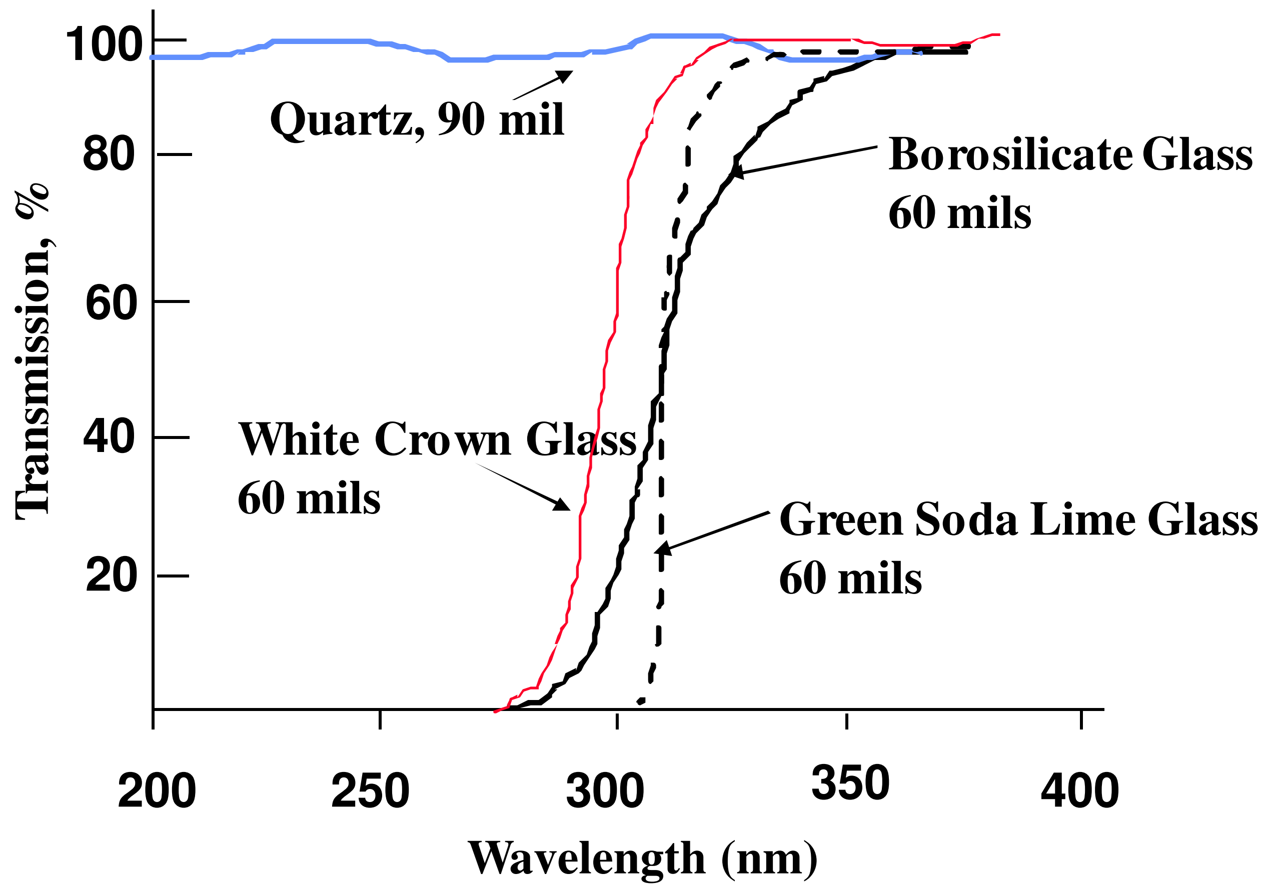
PHOTO DETECTORS

From: Micromachined Transducers, Gregory T.A. Kovacs

Device Type	Gain	Response Time (s)	Typical Temperature
Photomultiplier	> 10^{6}	10^{-7} to 10^{-9}	300 (sometimes cooled)
Photoconductor	1 to 10^{6}	10^{-3} to 10^{-8}	4.2 to 300
Metal-Semiconductor-Metal Photodetector	1 or less	10^{-10} to 10^{-12}	300
p-n Photodiode	1 or less	10^{-6} to 10^{-11}	300 (sometimes cooled to 77 K)
p-i-n Photodiode	1 or less	10^{-6} to 10^{-9}	300
Metal-Semiconductor Diode	1 or less	10^{-9} to 10^{-12}	300
Avalanche Diode	10^{2} to 10^{4}	10^{-10}	300
Bipolar Phototransistor	10^{2}	10^{-6} to 10^{-8}	300
Bipolar Photo-Darlington	10^{4}	10^{-5} to 10^{-6}	300
Field-Effect Phototransistor	10	10^{-7}	300
CCD Cell (Metal-Insulator-Semiconductor Capacitor)	1 or less	10^{-5} to 10^{-8}	300 (sometimes cooled)

Gains and response times of some typical photodetectors (some are optimistic!). After Sze (1981). Note that the CCD cell, and some extrinsic photoconductors, are integrating detectors, and thus the response time figures can be somewhat misleading.

TRANSMISSION PROPERTIES OF OPTICAL GLASS



SOLAR CELL TUTORIAL

SOME TERMS AND DEFINITIONS:

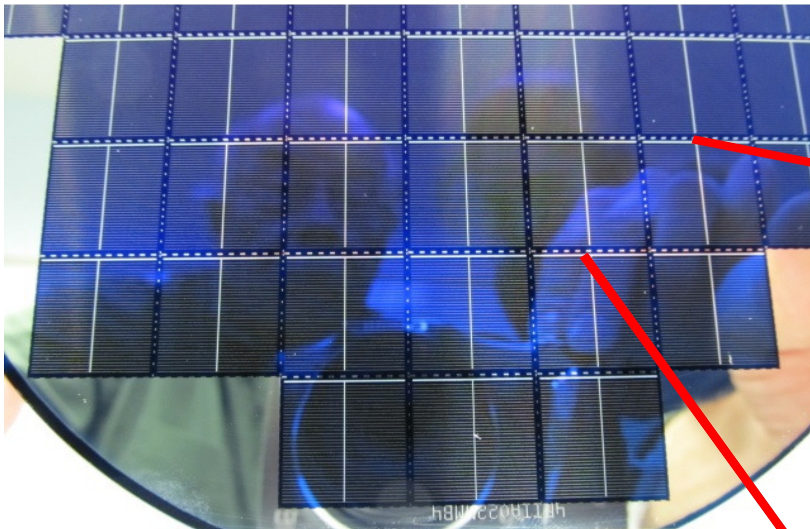
Air Mass – amount of air between sun and solar cell. In space AM=0 at the equator at noon AM=1, if the sun is arriving at an angle θ , AM=1/cos θ . AM1.5 is the standard for most solar cell work in USA and gives a sum total of 1000w/m2 over the entire spectrum of wavelengths from 0.2um to 2.0um

Efficiency is the ratio of the power out of a solar cell to the power falling on the solar cell (normally 1000w/m2 with the AM1.5 spectrum) Since Si solar cells can not absorb much of the infrared spectrum from the sun, and other factors, typical efficiencies are limited to 26-29% for basic silicon solar cells.

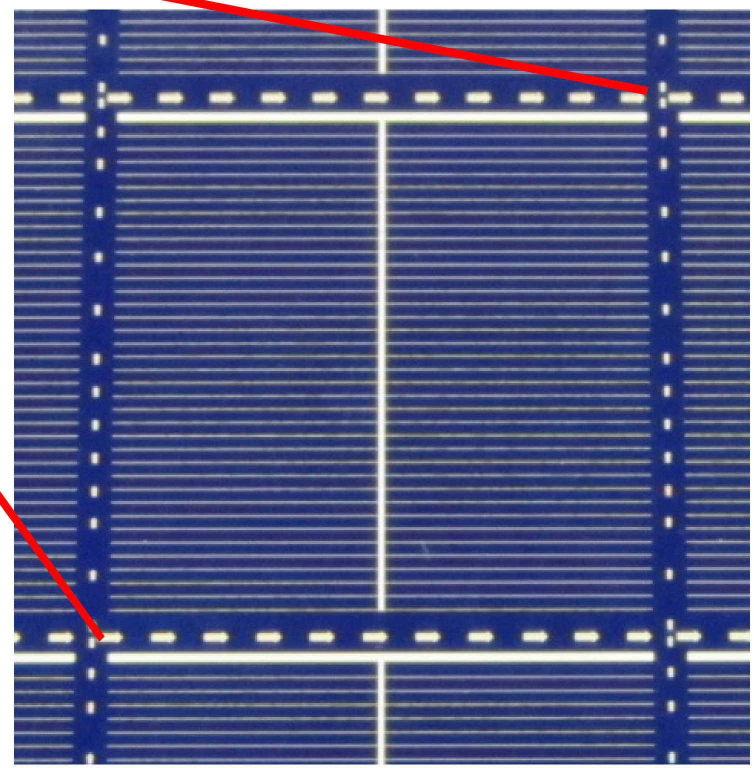
Quantum Efficiency – normalized ratio of electrons and holes collected to photons incident on the cell at a single wavelength, given in %.

FF – Fill Factor, a figure of merit, the “squareness “ of the diode I-V characteristic in 4^{th} quadrant with light falling on the cell.

SOLAR CELL

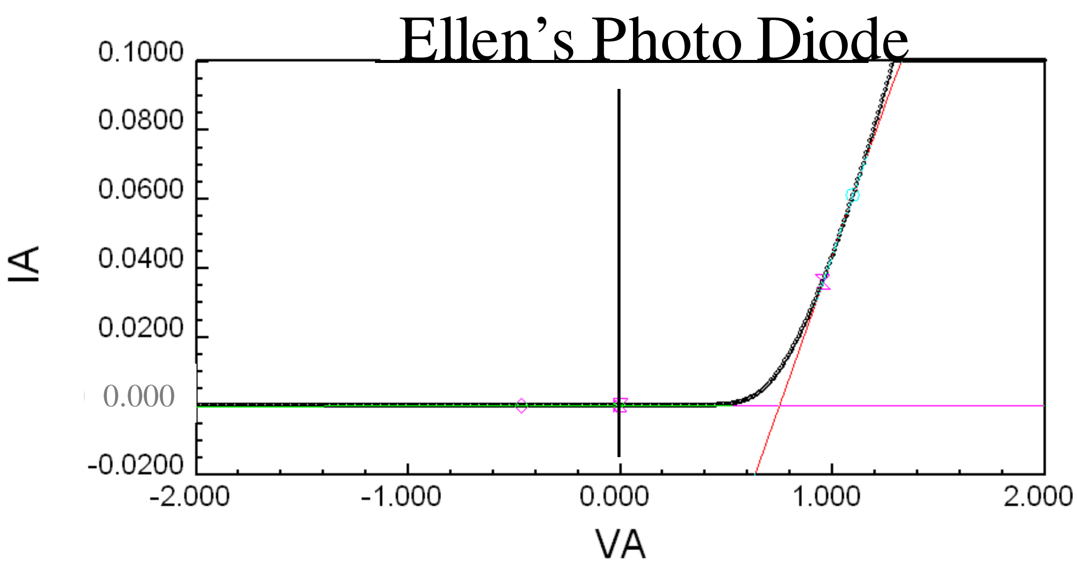


16000um x 16000um



Ellen Sedlack 2011

I-V CHARACTERISTICS OF SOLAR CELL



Conditions:

Swp: SMU1
Start: -2.00000 V
Stop: 2.00000 V
Step: 8.00000m V
Pts: 501

Con: SMU2
Val: 0.00000 V

Fit #1:

Type: Cursor
Slp:0.08492m
Yint:0.80462u
Xint:-9.47468m

Fit #2:

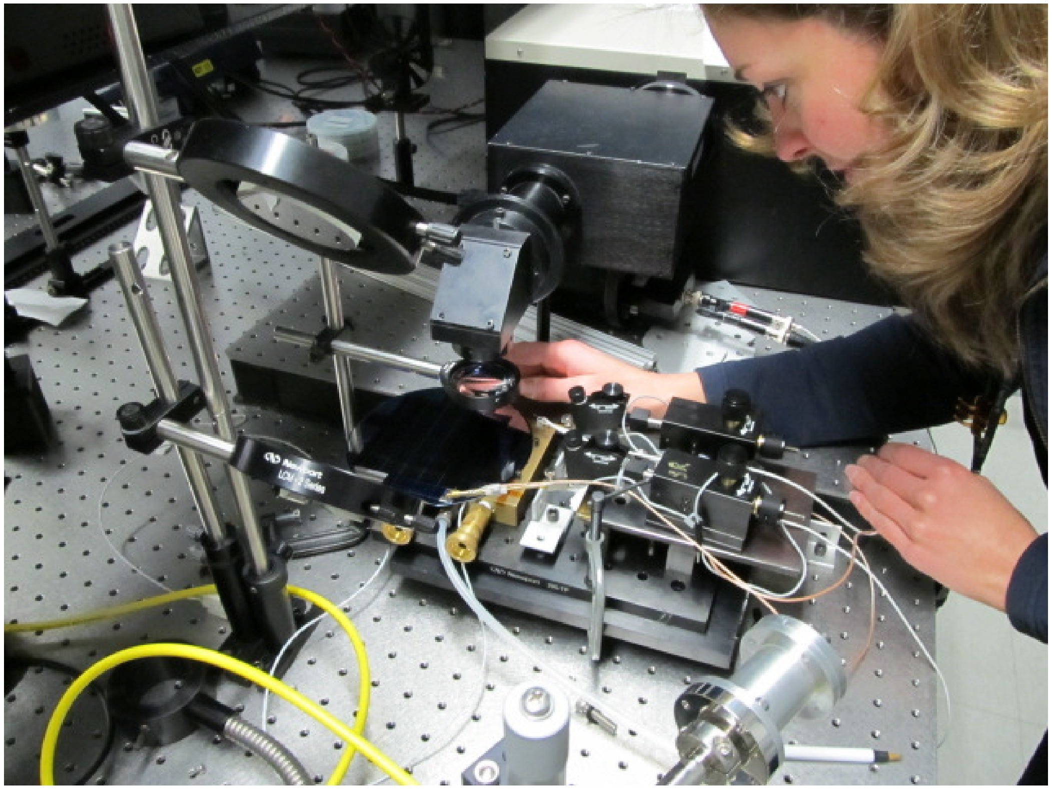
Type: Cursor
Slp:0.17331
Yint:-0.12898
Xint:0.74425

Cursors:	X	Y
□	8.00000m	1.48400u
◇	-0.47200	-0.03928m
○	1.09600	0.06096
⌛	0.95200	0.03601
⋈	0.00000	-0.12275u
△		

ICS 10:39:05
04/05/2011

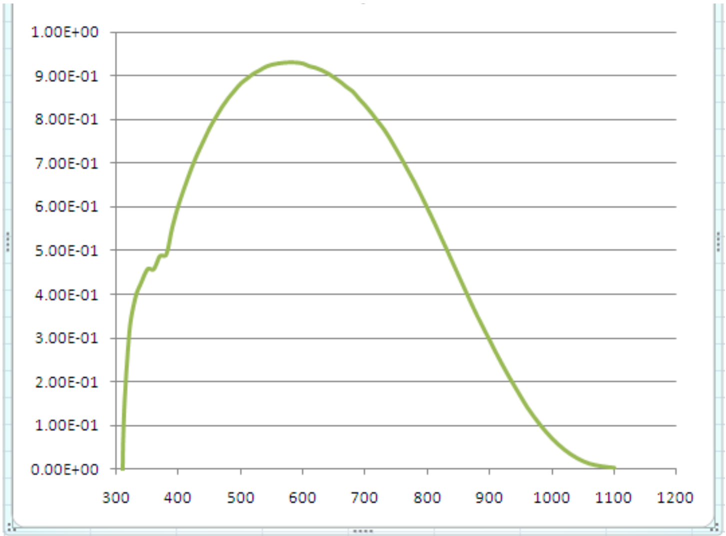
Von = 0.6 volts
Rseries = 1/slope = 1/0.129
= 7.75ohms
Is = 1.48uA (in room light)

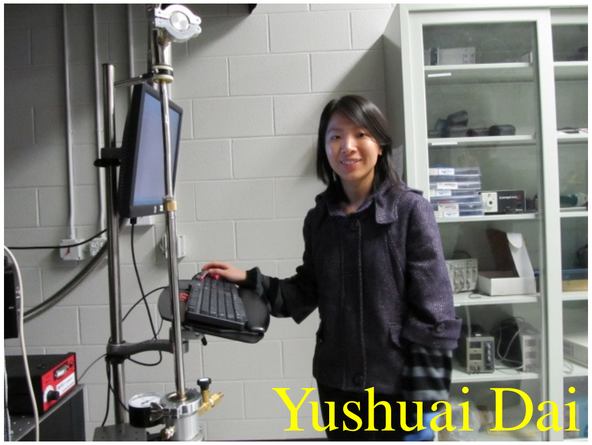
SOLAR CELL – QUANTUM EFFICIENCY



Ellen Sedlack 2011

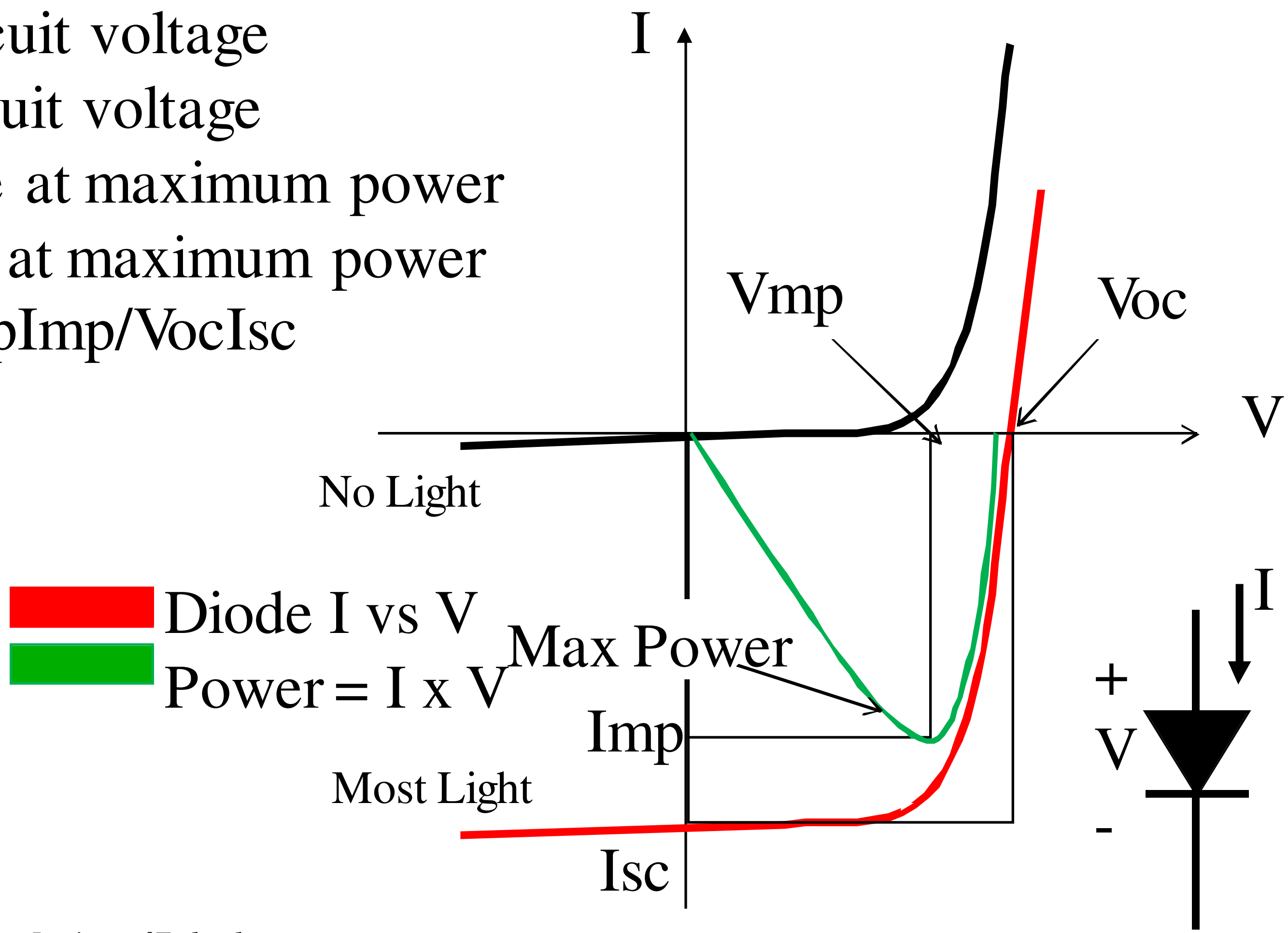
93% between 550nm and 650nm





SOLAR CELL TUTORIAL

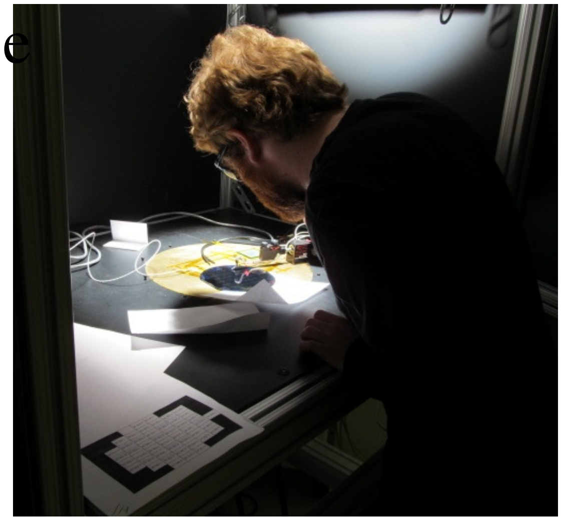
Voc - open circuit voltage
Isc – short circuit voltage
Vmp – Voltage at maximum power
Imp – Current at maximum power
FF – FF = VmpImp/VocIsc

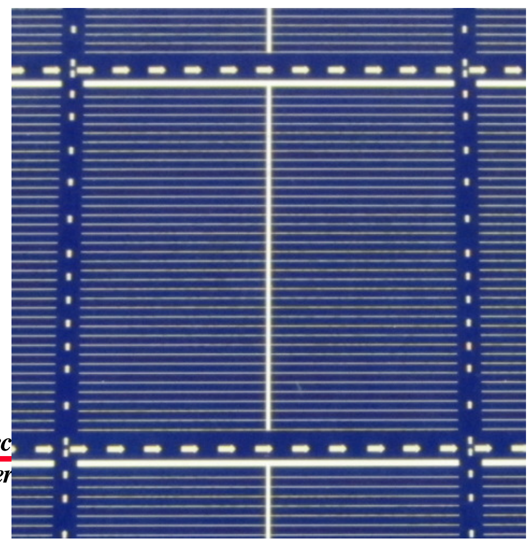


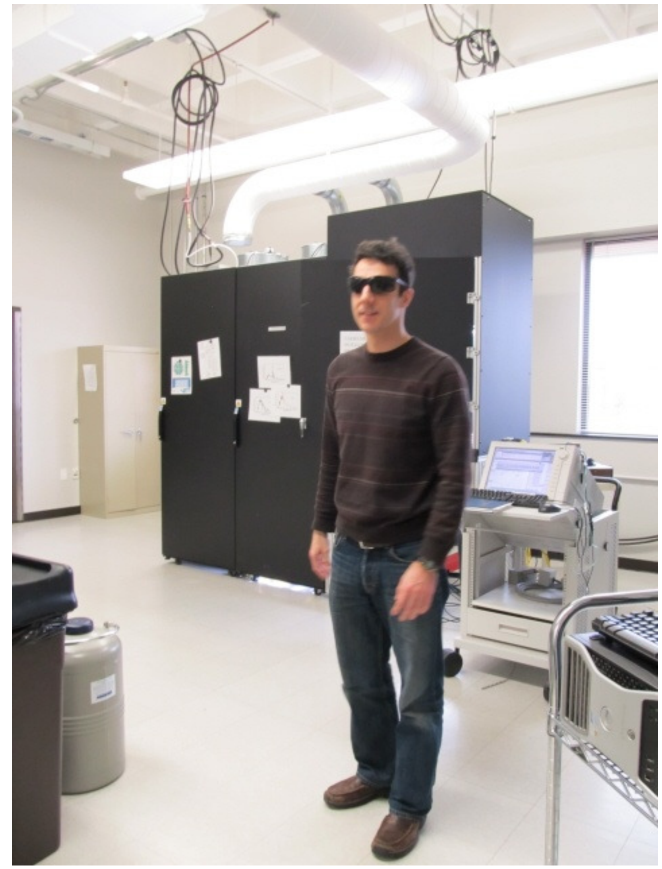
SOLAR CELL – POWER EFFICIENCY

AM 1.5 Light Source

Zachary Bittner







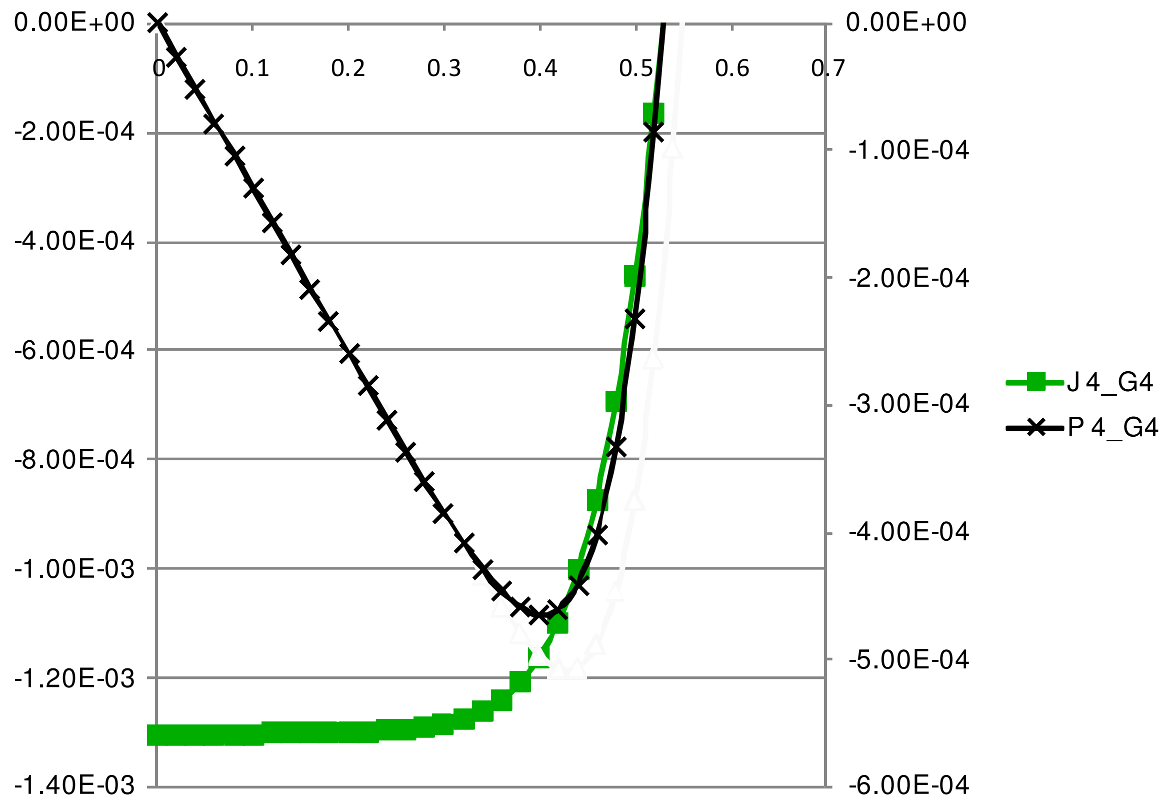
Ivan Puchades

Rochester Institute of Tec
Microelectronic Engineer

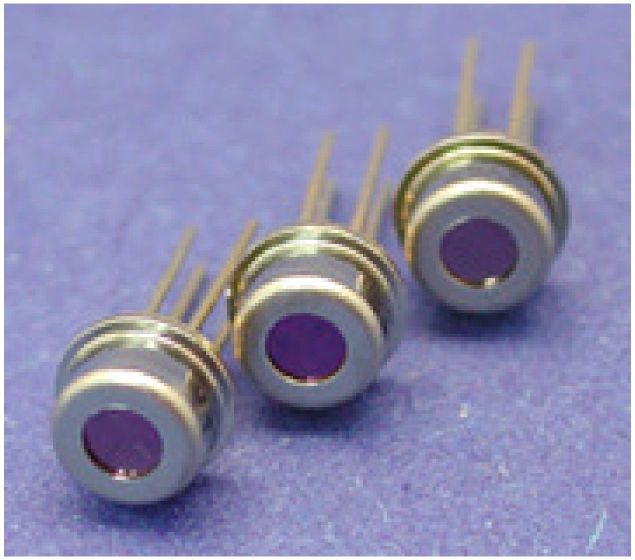
POWER, EFFICIENCY, Isc, Voc

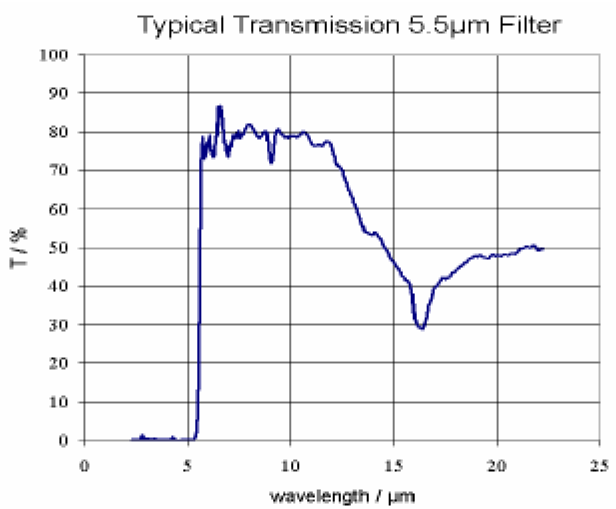
Setting	Spot size (	Cell size (c	Current	J (A/cm2)	Irradiance (mW/cm2)	
2.25x @ma	1.267	**0.25**	2.77E-04	1.11E-03	3.39	

Column1	**P 4_G5**	**P 4_G4**
Pmax	-5.06E-04	-4.65E-04
Jmax	-1.21E-03	**-1.160E-03**
Vmax	0.42	**0.380**
Jsc	-1.30E-03	-1.30E-03
Voc	5.60E-01	**0.540**
FF	69.8%	62.8%
efficiency	-15%	-14%



THERMOPILE SENSOR



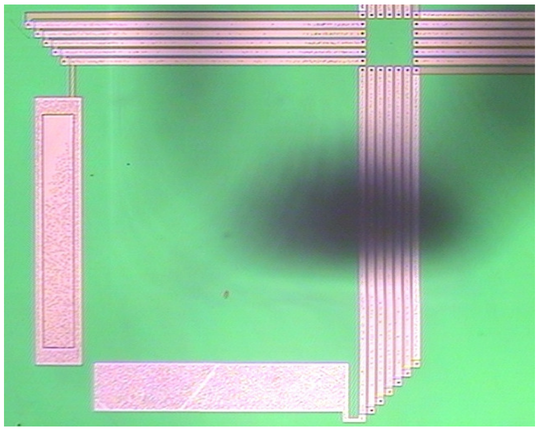


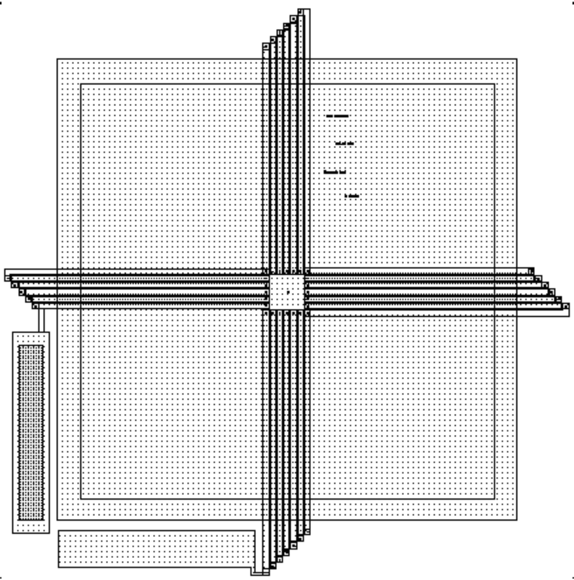
HMS Z11 – F5.5

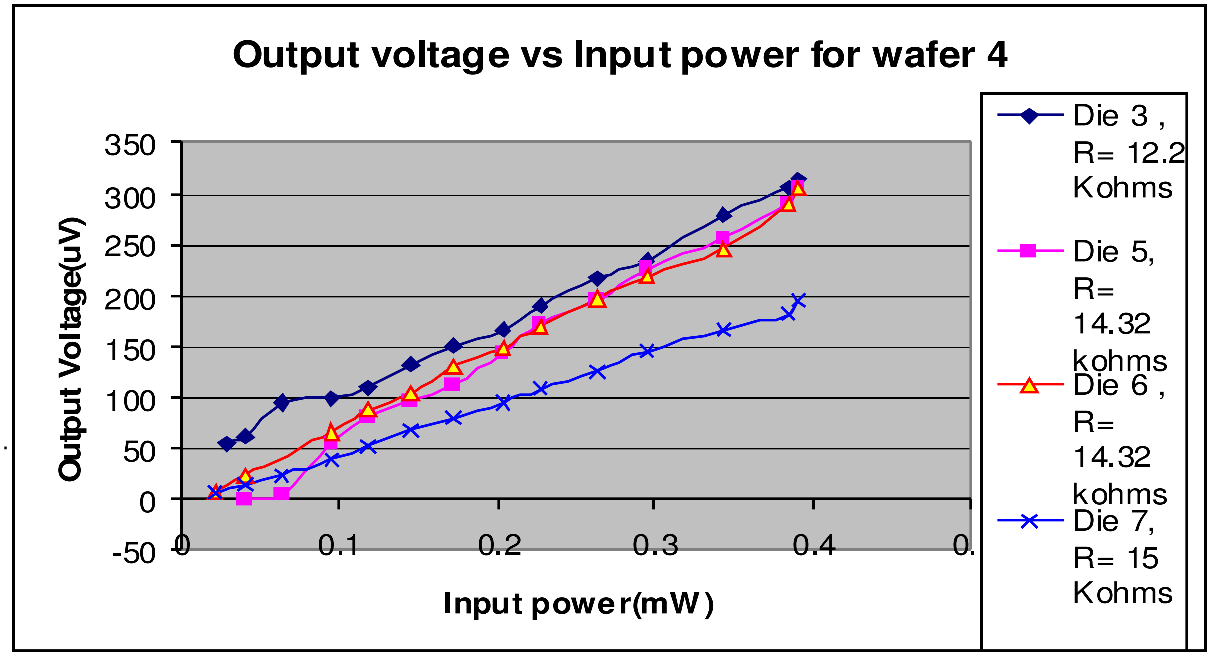
Thermopile				
Parameter	**Typical Value**	**Unit**	**Condition**	**Remark**
Element Size	0.6 x 0.6	mm²		Active area
Voltage Response	13	Vmm²/W		
Sensitivity	36	V/W	Tobj=373K Tamb=298K	
Thermopile Resistance	86	kΩ	25°C	
TC of Thermopile Resistance	20	ppm	Operating temp. range	
Thermopile Noise	38	nV/√Hz	25°C	
Detectivity	$5.6 \cdot 10^7$	cm√Hz/W		
Time Constant	<6	ms	63%	

www.heimannsensor.com

RIT THERMOPILE SENSOR

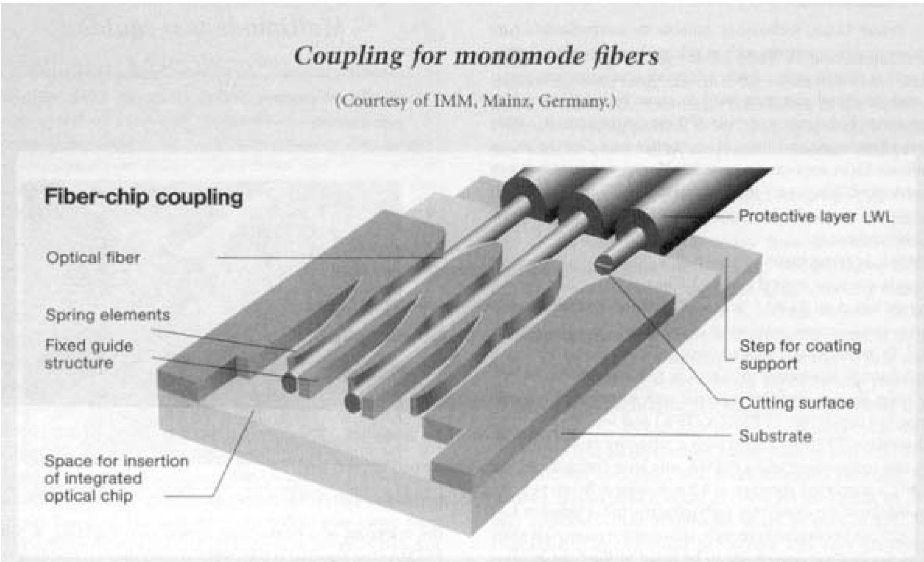






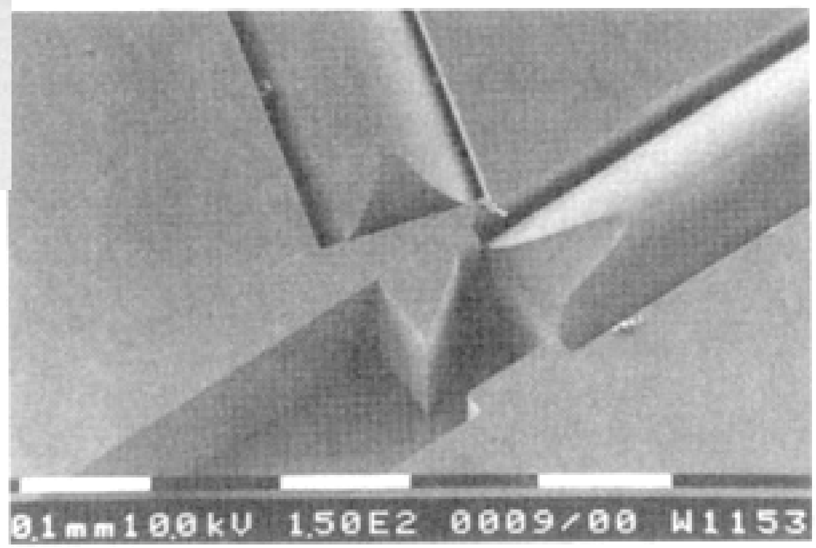
Usha Kuppuswamy, 2005

FIBER OPTIC COMPONENTS

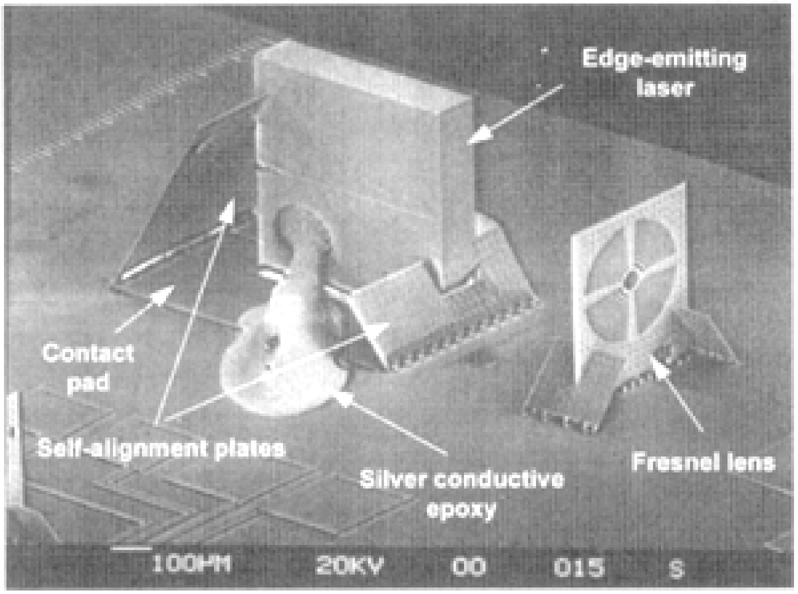


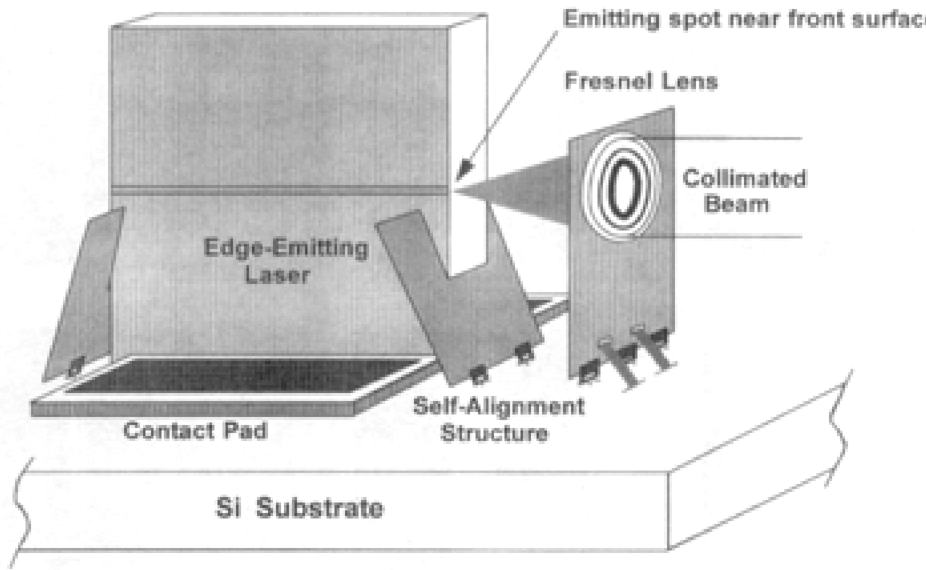
Fiber coupling
(1 × 2 beam splitter)

(Courtesy, KfK, Karlsruhe, Germany.)

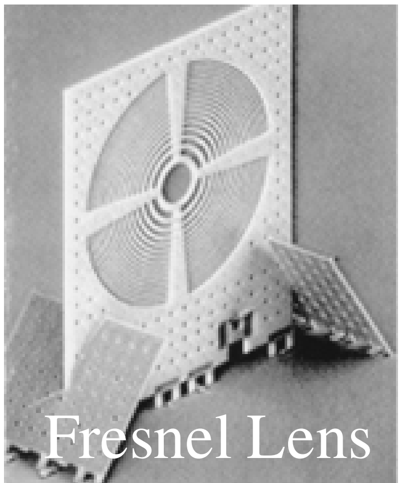


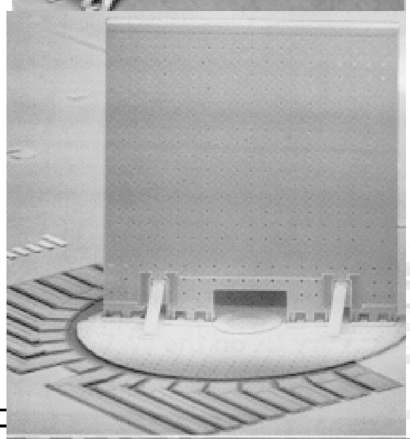
LASER AND FRESNEL LENS

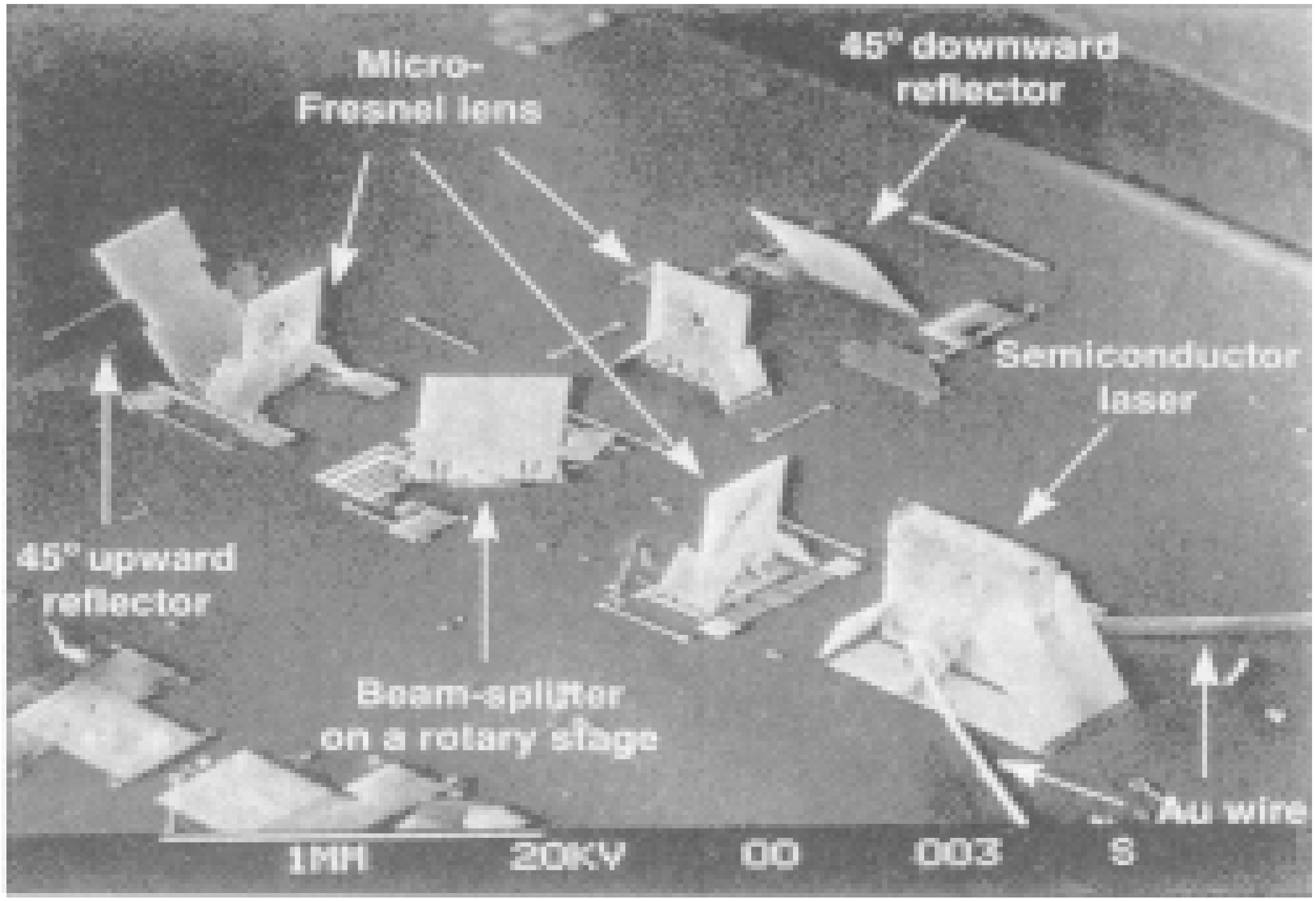




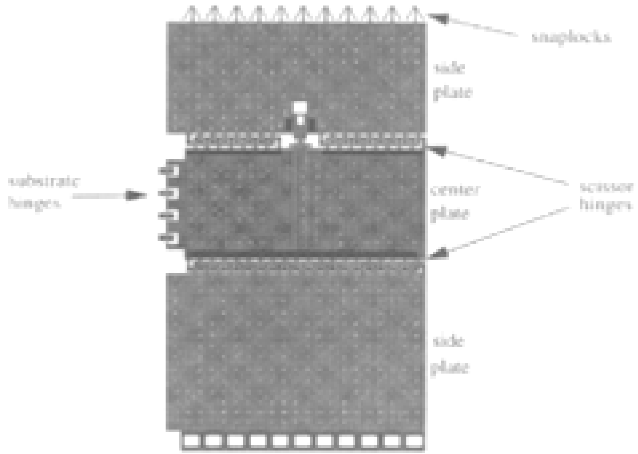
OPTICAL SYSTEM

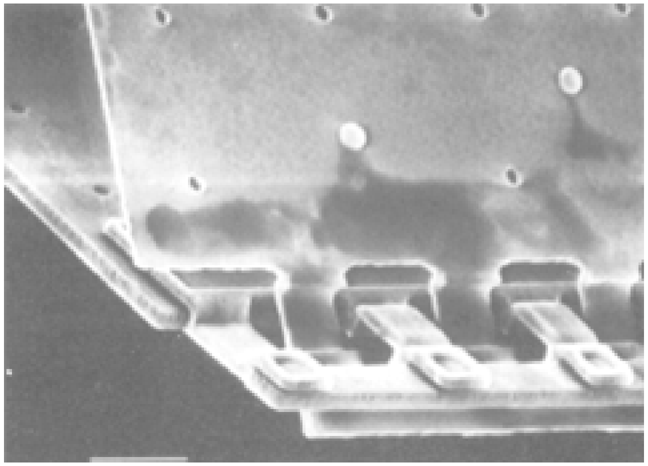


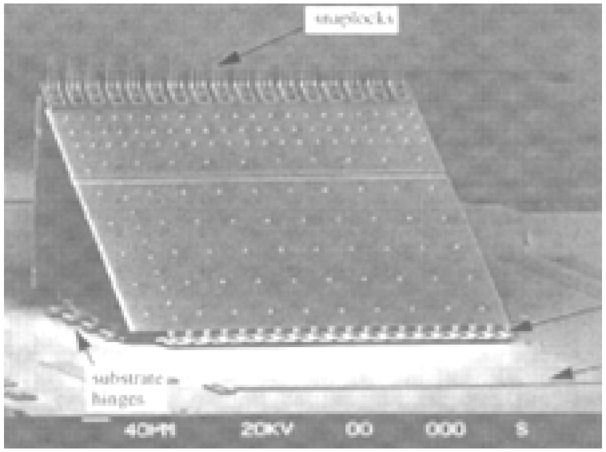


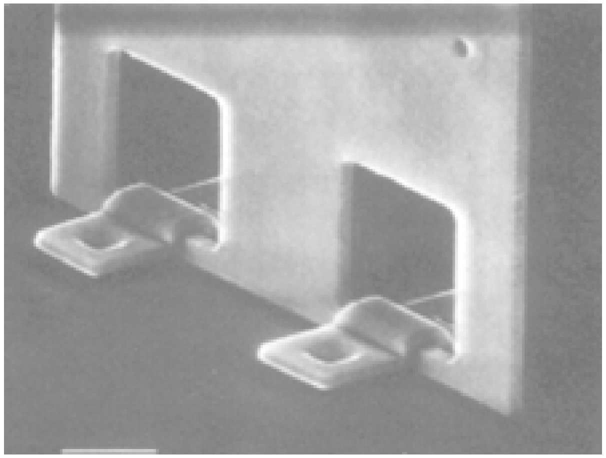


HINDGE









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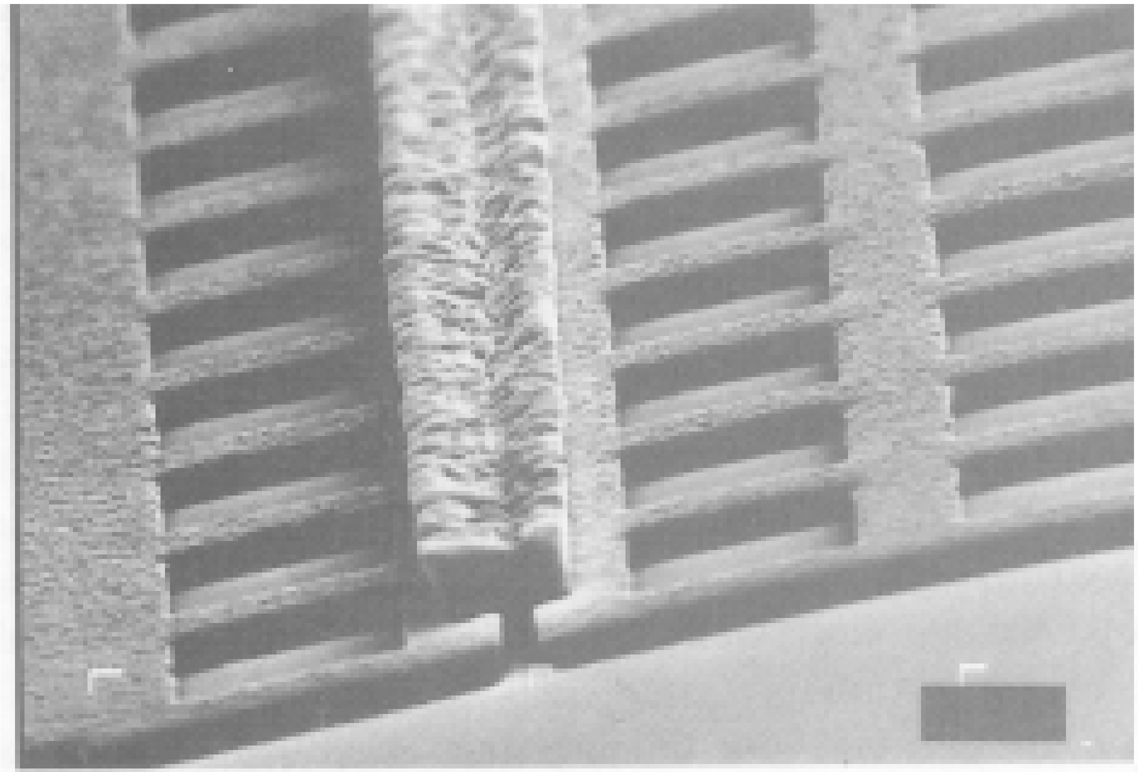
SELF ASSEMBLY



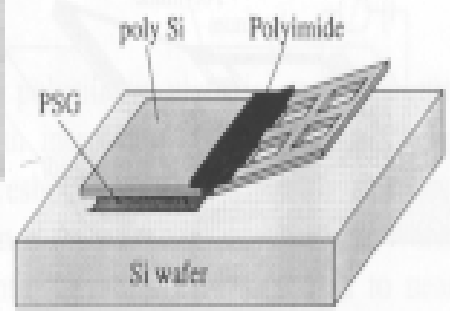
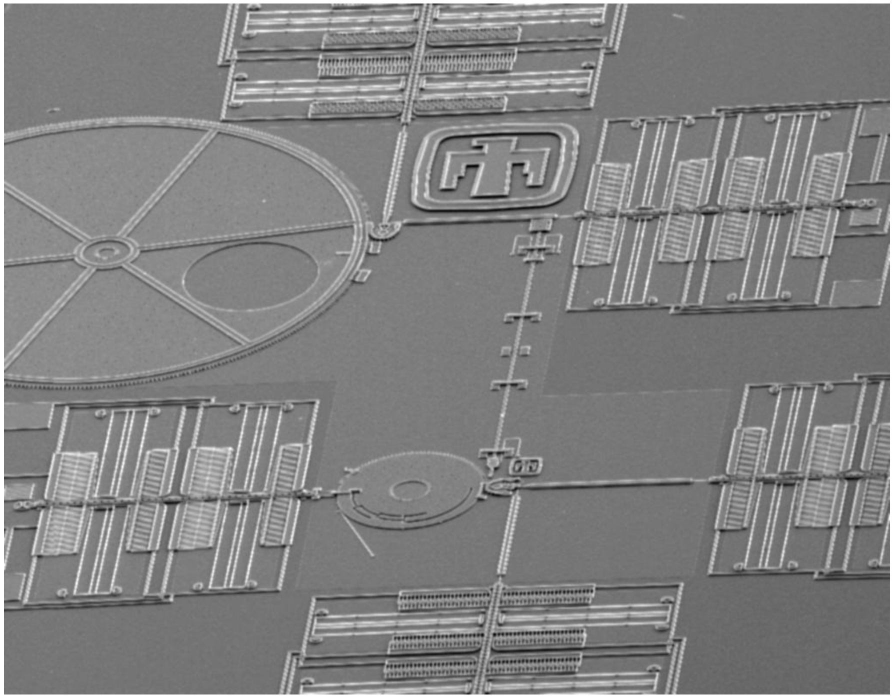
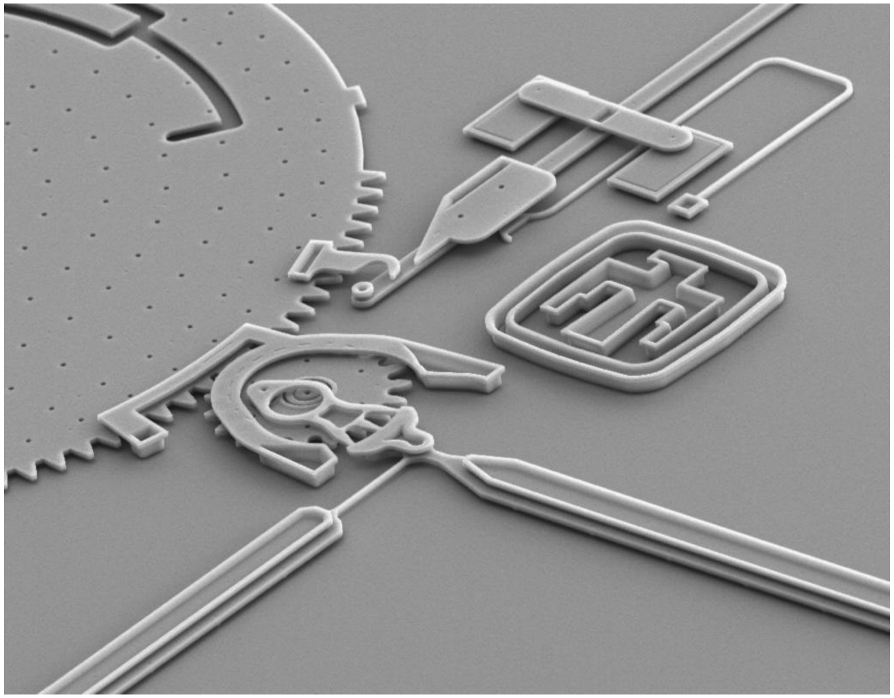


Fig. 2. Basic model of the external skeleton. Three-dimensional structure is constructed by bending along the polyimide hinges.

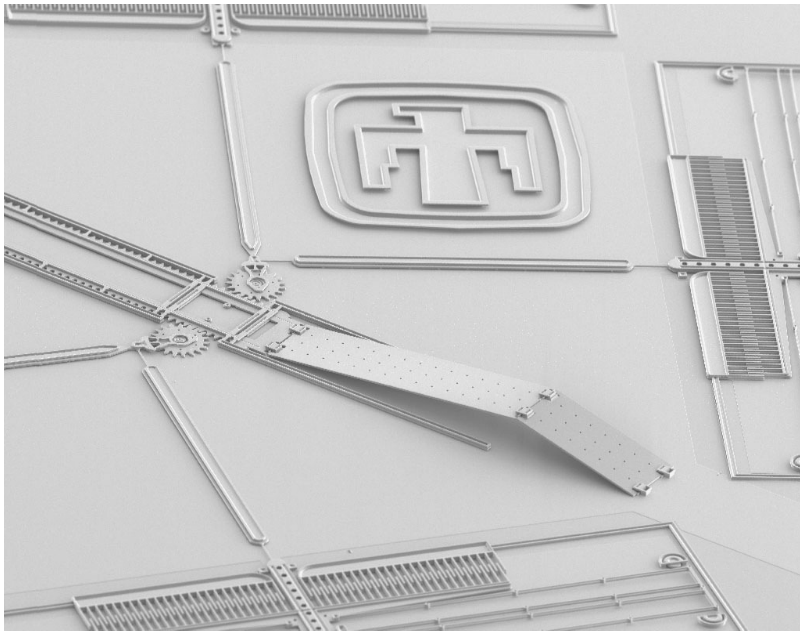
ELECTROSTATIC COMB DRIVE

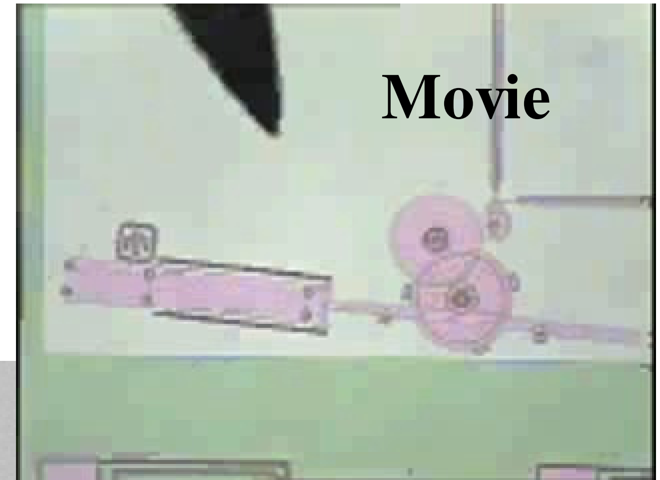


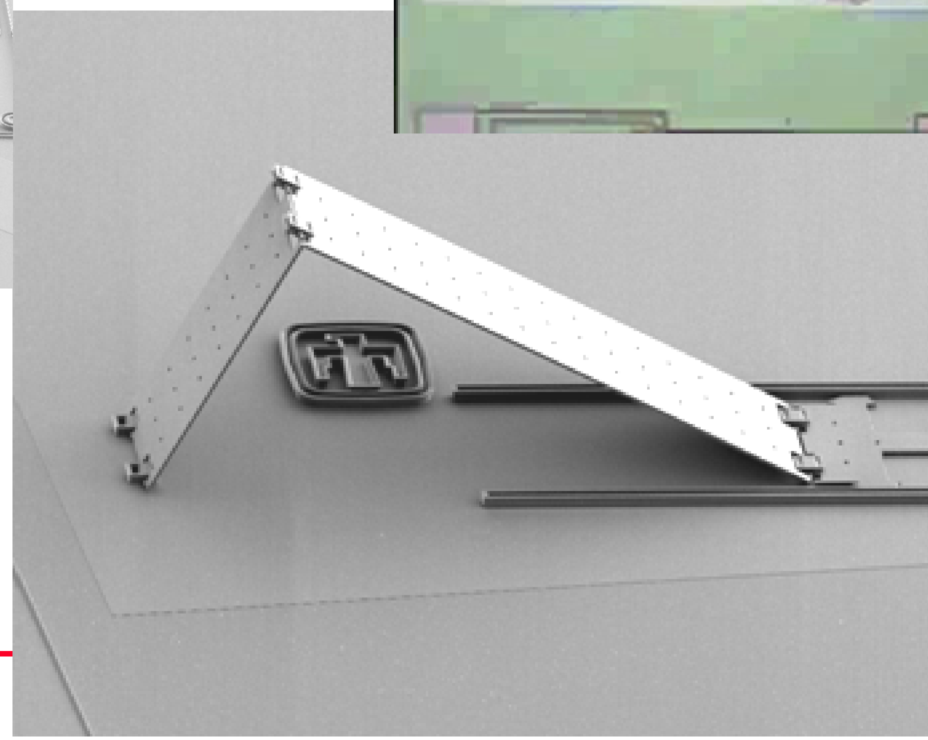


Movies at www.sandia.gov

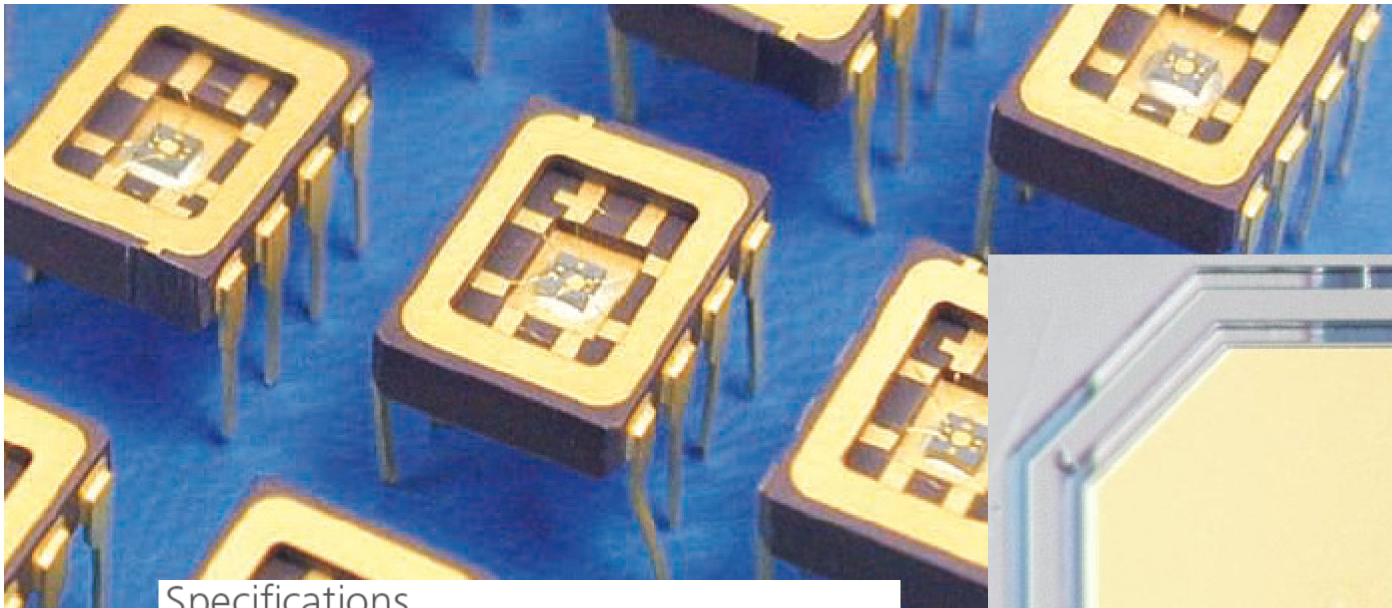
ELECTROSTATIC COMB DRIVE MIRROR





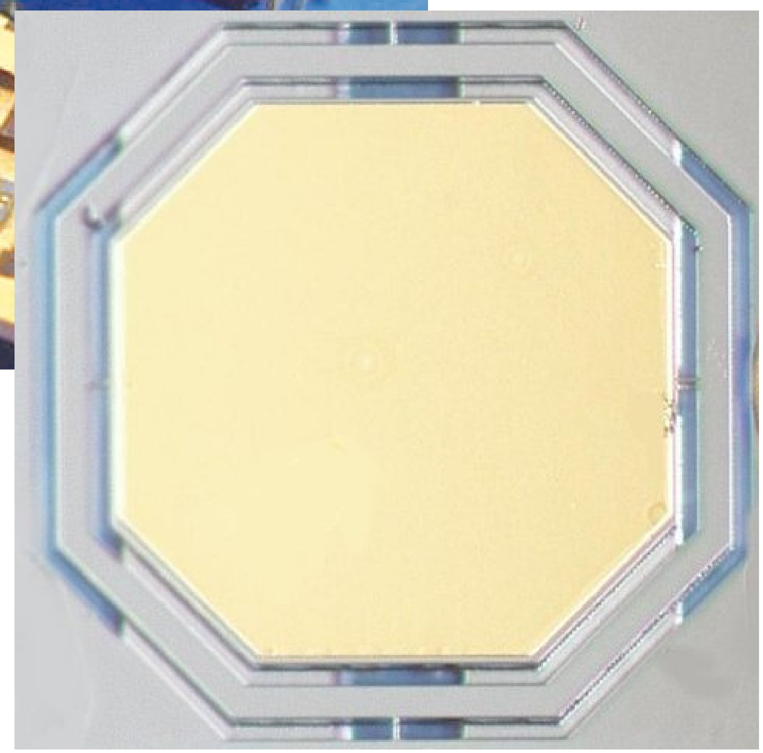


ELECTROSTATIC MIRROR



Specifications

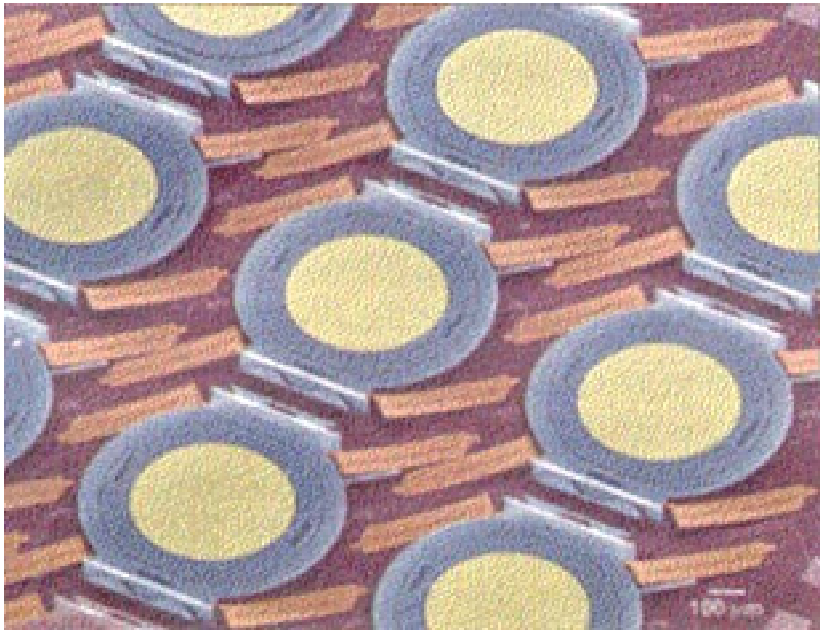
Mirror size:	520 µm across
Reflective area:	510 µm across
Shape:	Octagonal
Mirror thickness:	13 µm
Surface roughness:	< 8 Å rms
Surface reflectivity:	> 95% at 630 nm (gold)
Bias voltage:	35 to 55 Volts
Drive voltage:	0 to 110 Volts (0 to 2X Bias)
Resonant rotation frequency:	outer axis 1.3 kHz, inner axis 1.8 kHz
Operating Temperature:	0 to 50 °C
Radius of Curvature:	> 0.4 meters within operating temperature
Product number:	029157

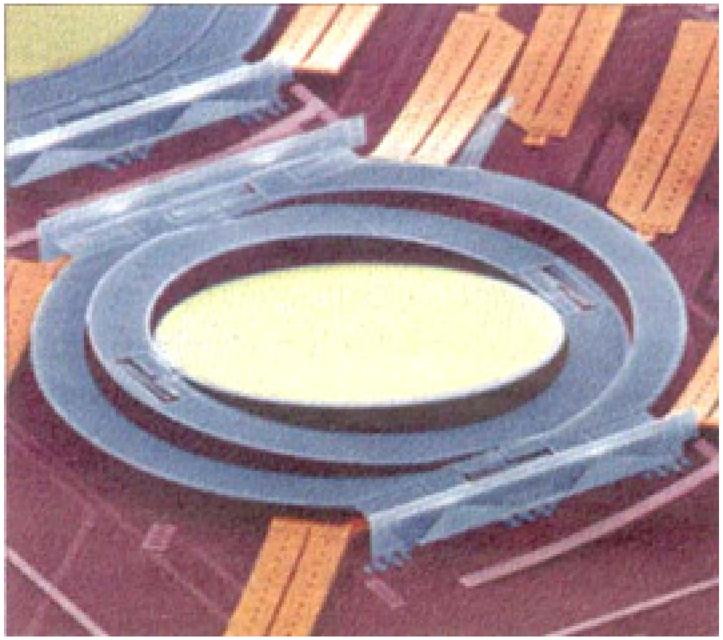


www.memsoptical.com

MIRRORS

MOEMs - Micro Optical Electro Mechanical Systems

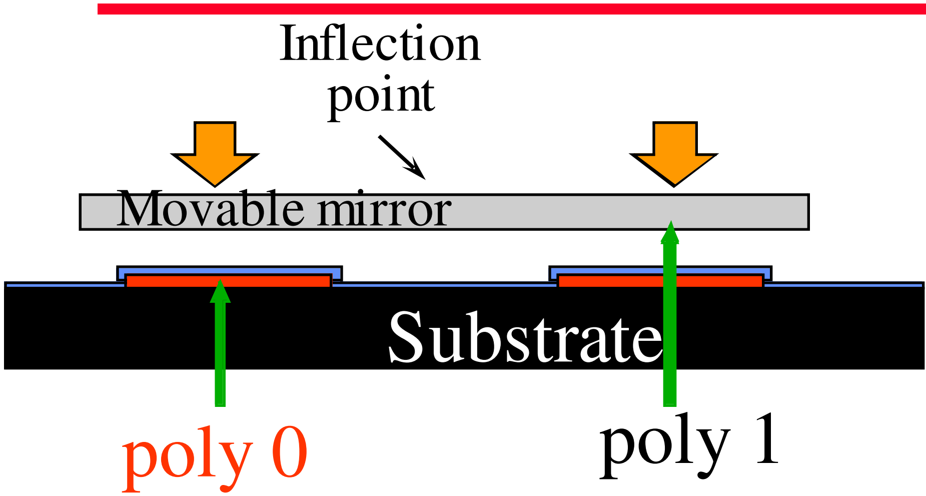


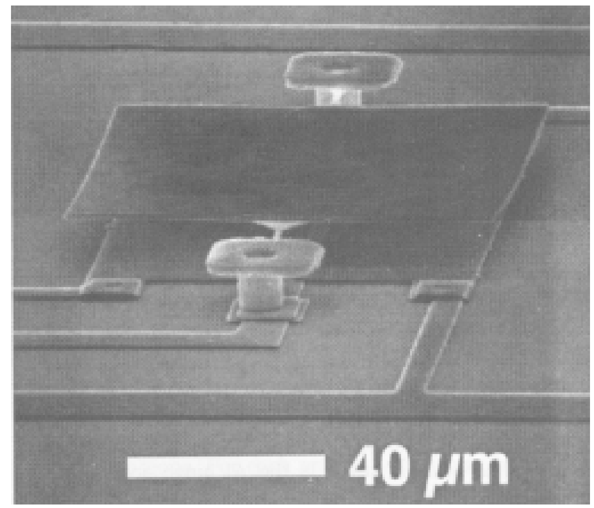


Lucent Technologies –

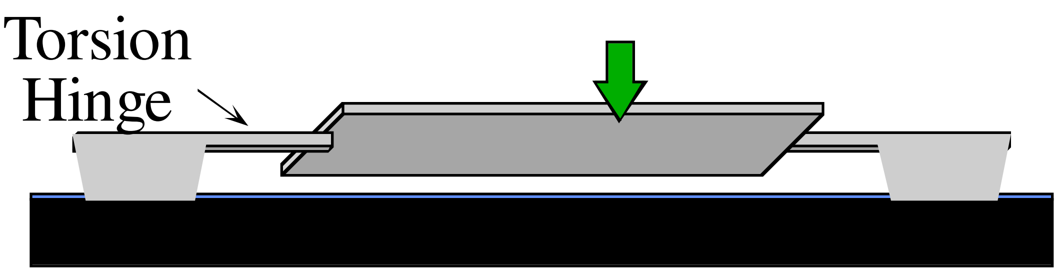
Lambda router, 256 mirror fiber optic multiplexer

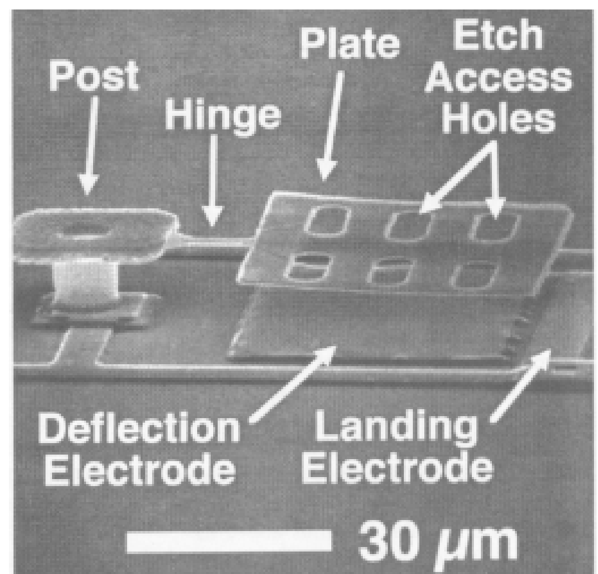
TORSION - MIRROR



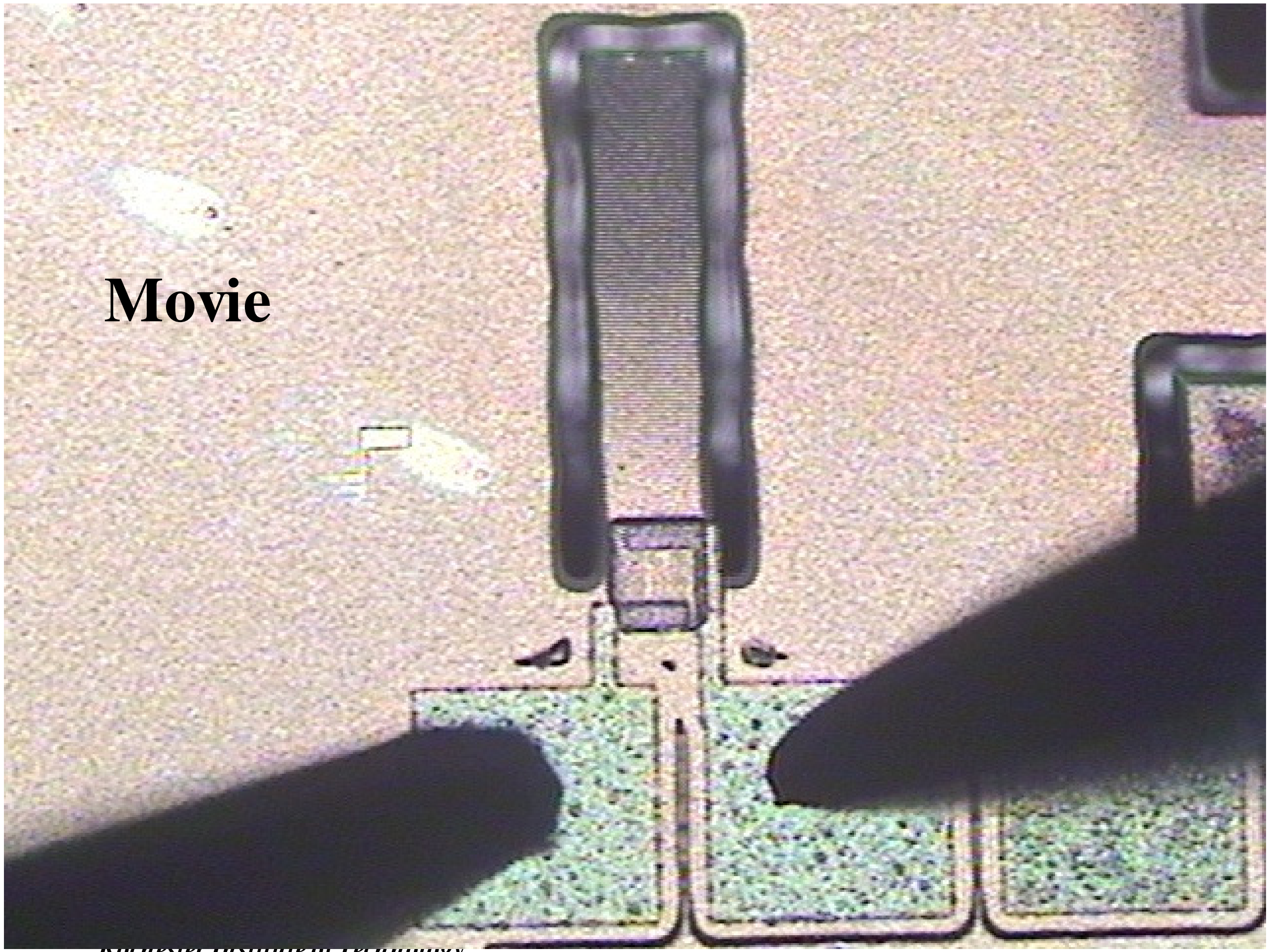


Micro-mirror Perspective View



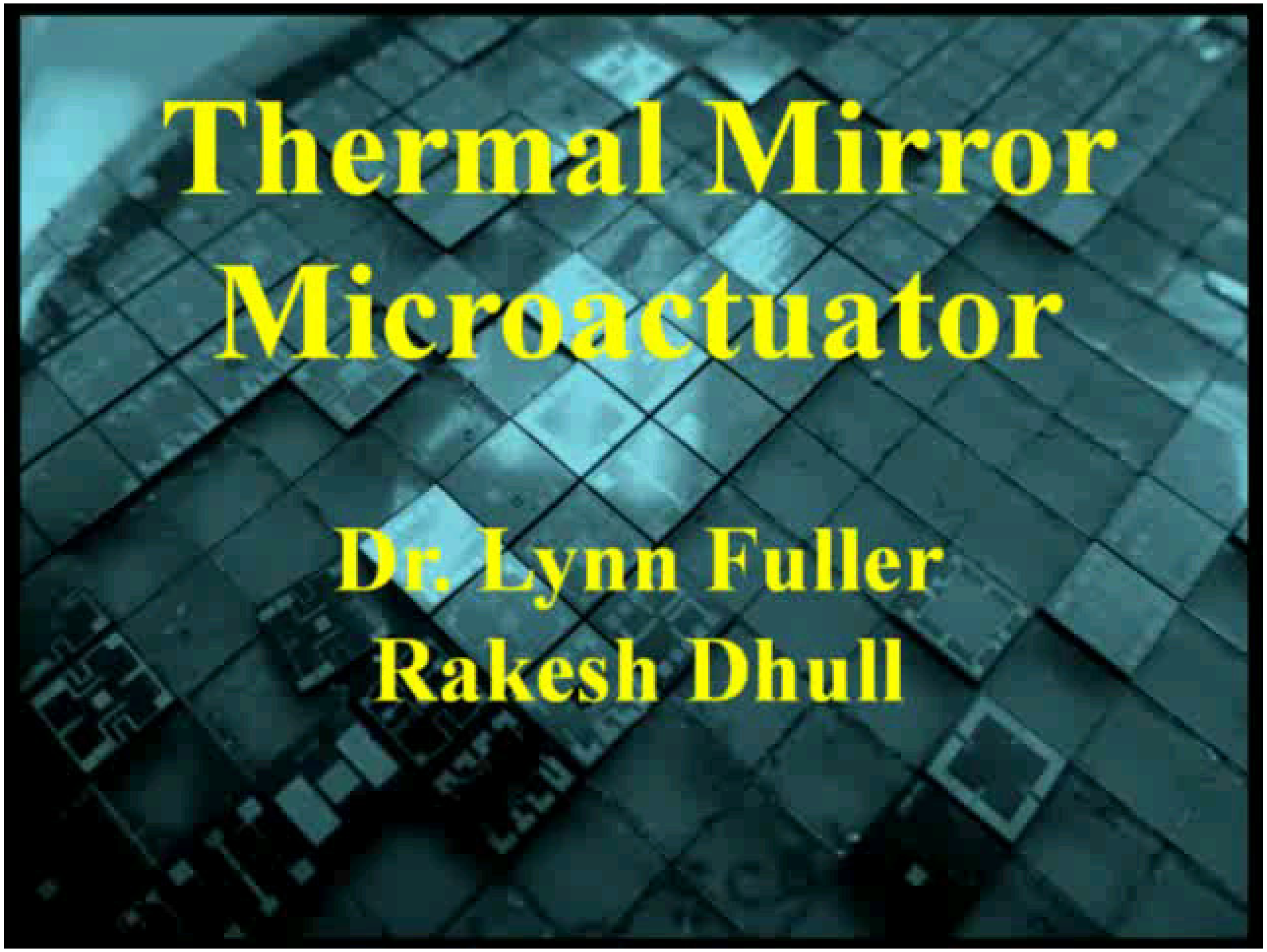


POLYIMIDE ON HEATER

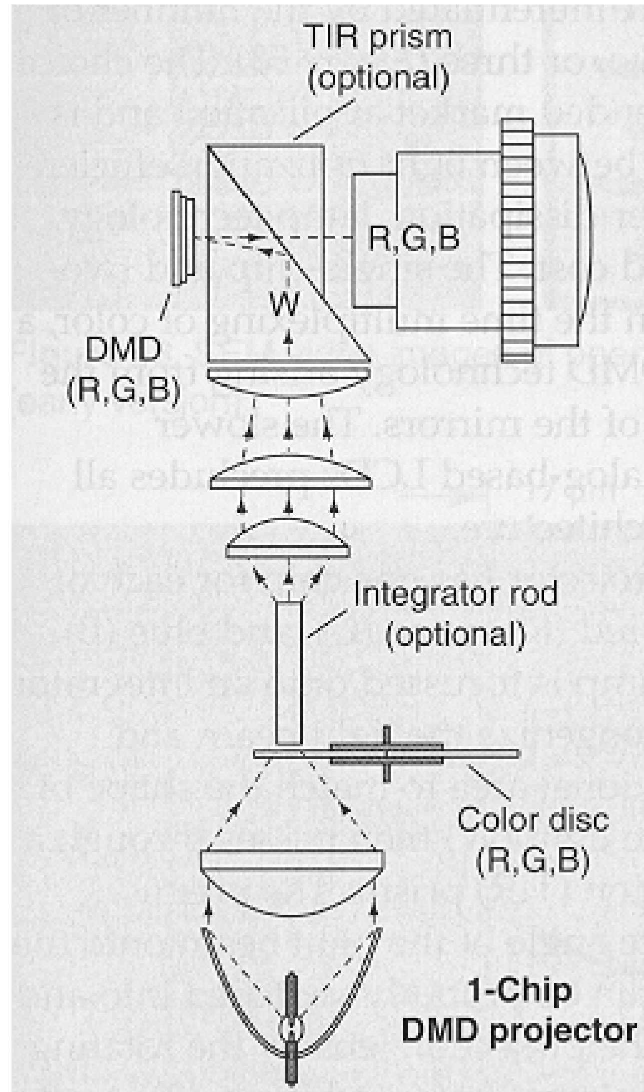


Jeremiah Hebding

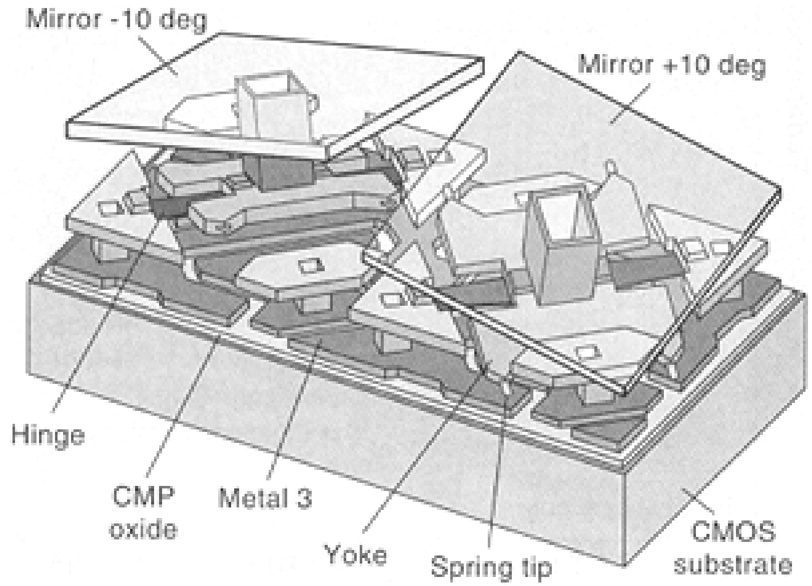
THERMALLY ACTUATED MEMS MICRO MIRROR

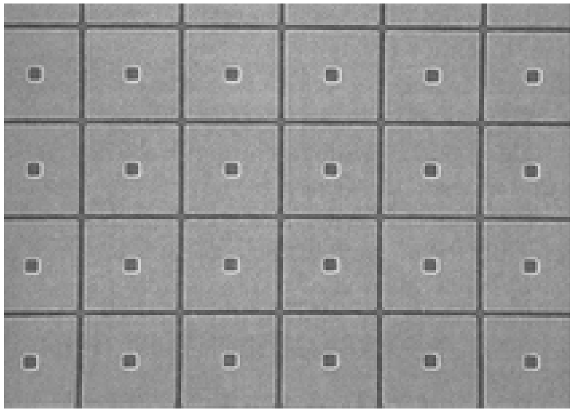


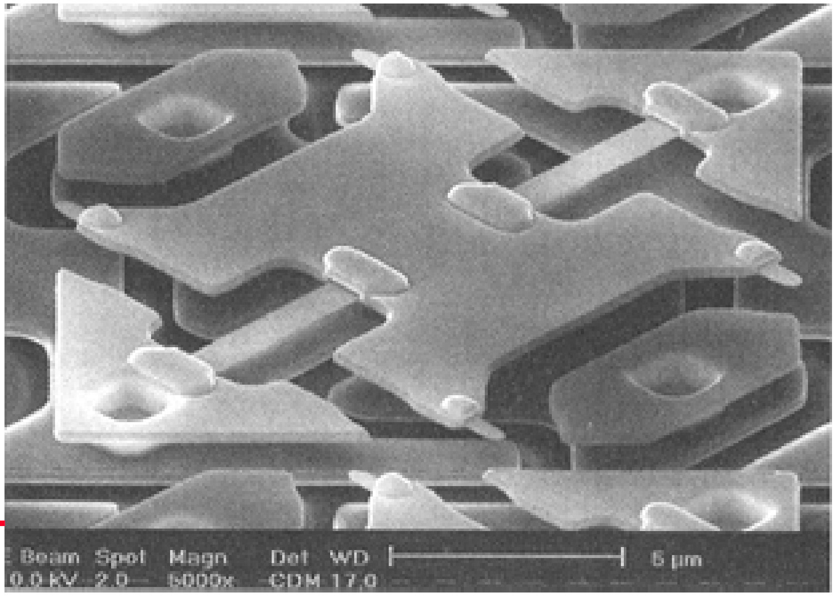
DIGITAL MIRROR LIGHT PROJECTION SYSTEM



TORSIONAL MIRRORS







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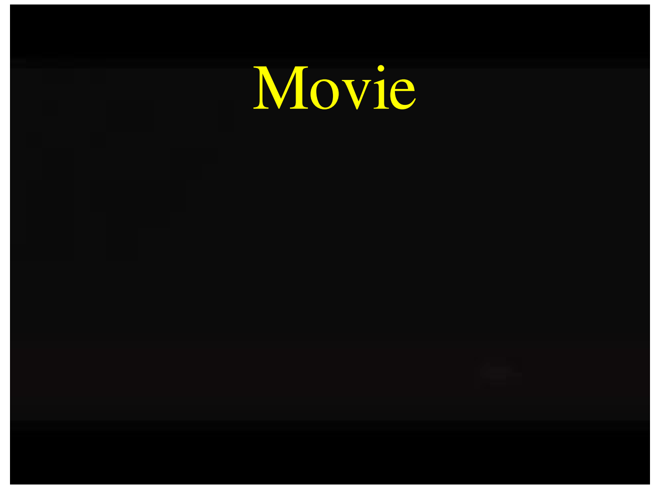
TI MICROMIRROR PROJECTOR

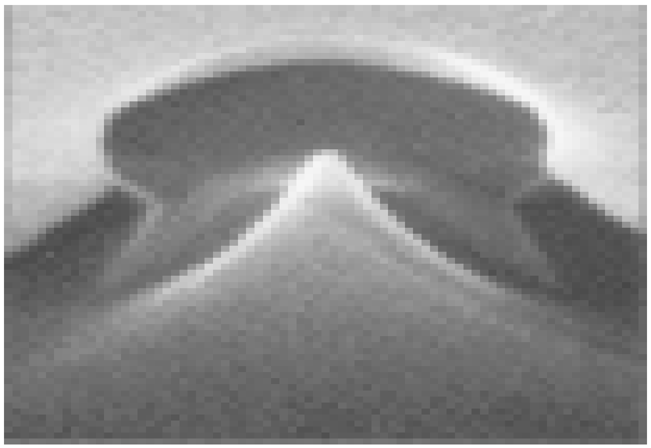
TEXAS INSTRUMENTS DIGITAL PROJECTION PRODUCTS

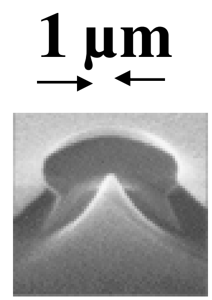


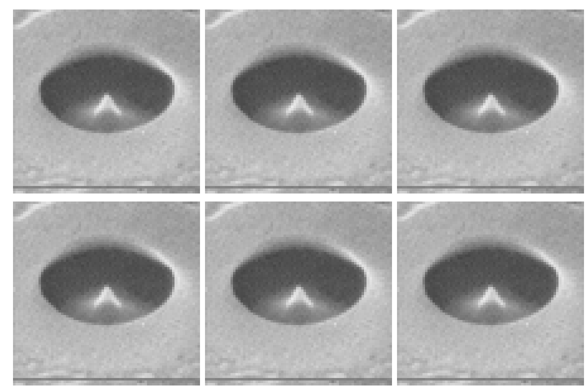
www.TI.com

DXtreme PRO1

FIELD EMISSION TIPS FOR FLAT PANNEL DISPLAYS

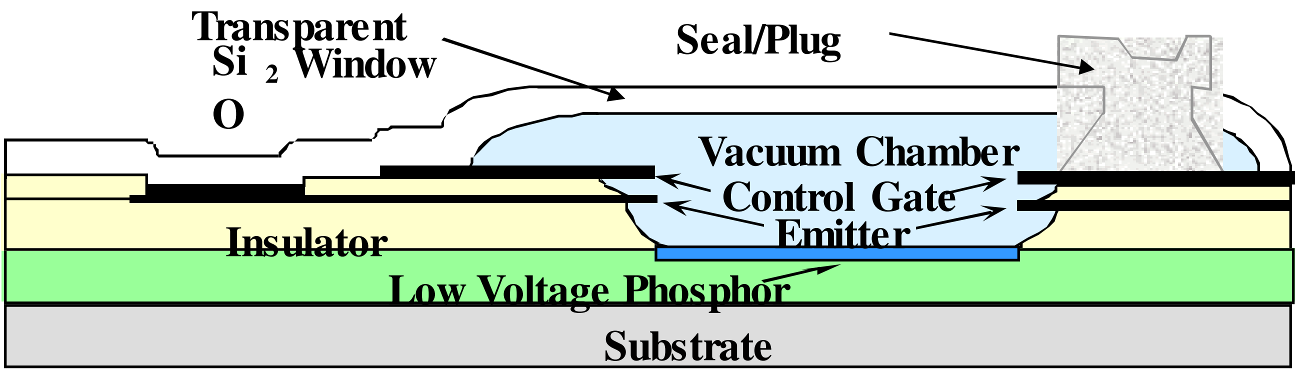






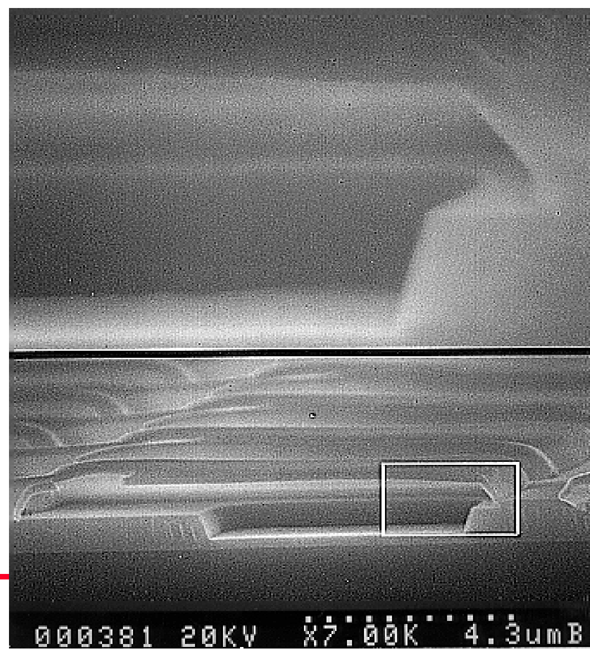
Alex Raub, 1995, now at National Semiconductor Santa Clara, CA

FIELD EMISSION FLAT PANNEL DISPLAYS

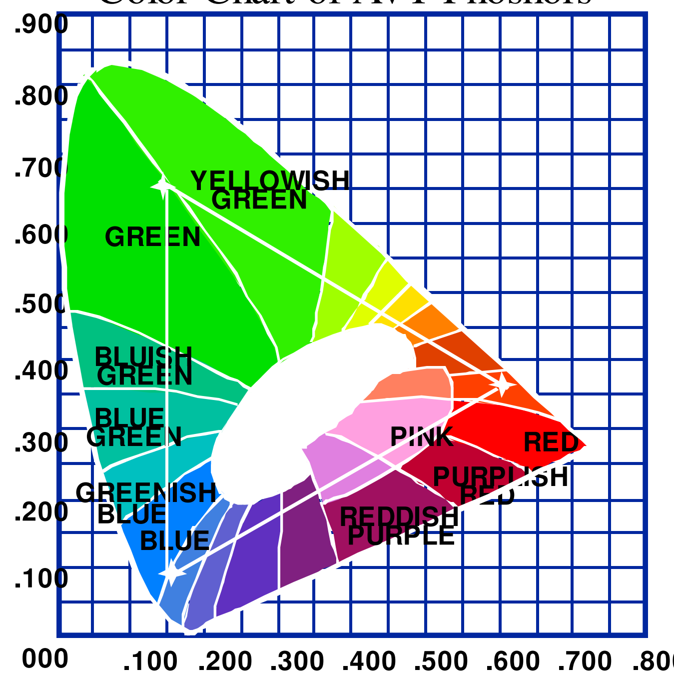


Integrated Phosphor Field Emission Device

Micro-encapsulated Chamber



Color Chart of AVT Phoshors



REFLECTIVE MECHANICAL LIGHT MODULATOR

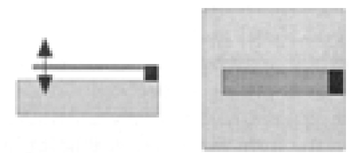
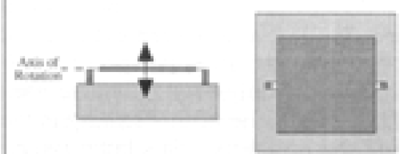
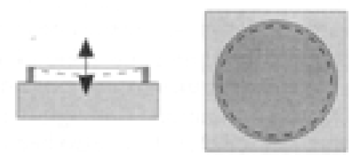
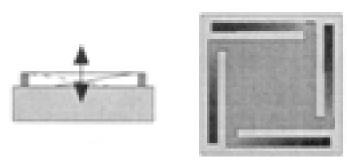
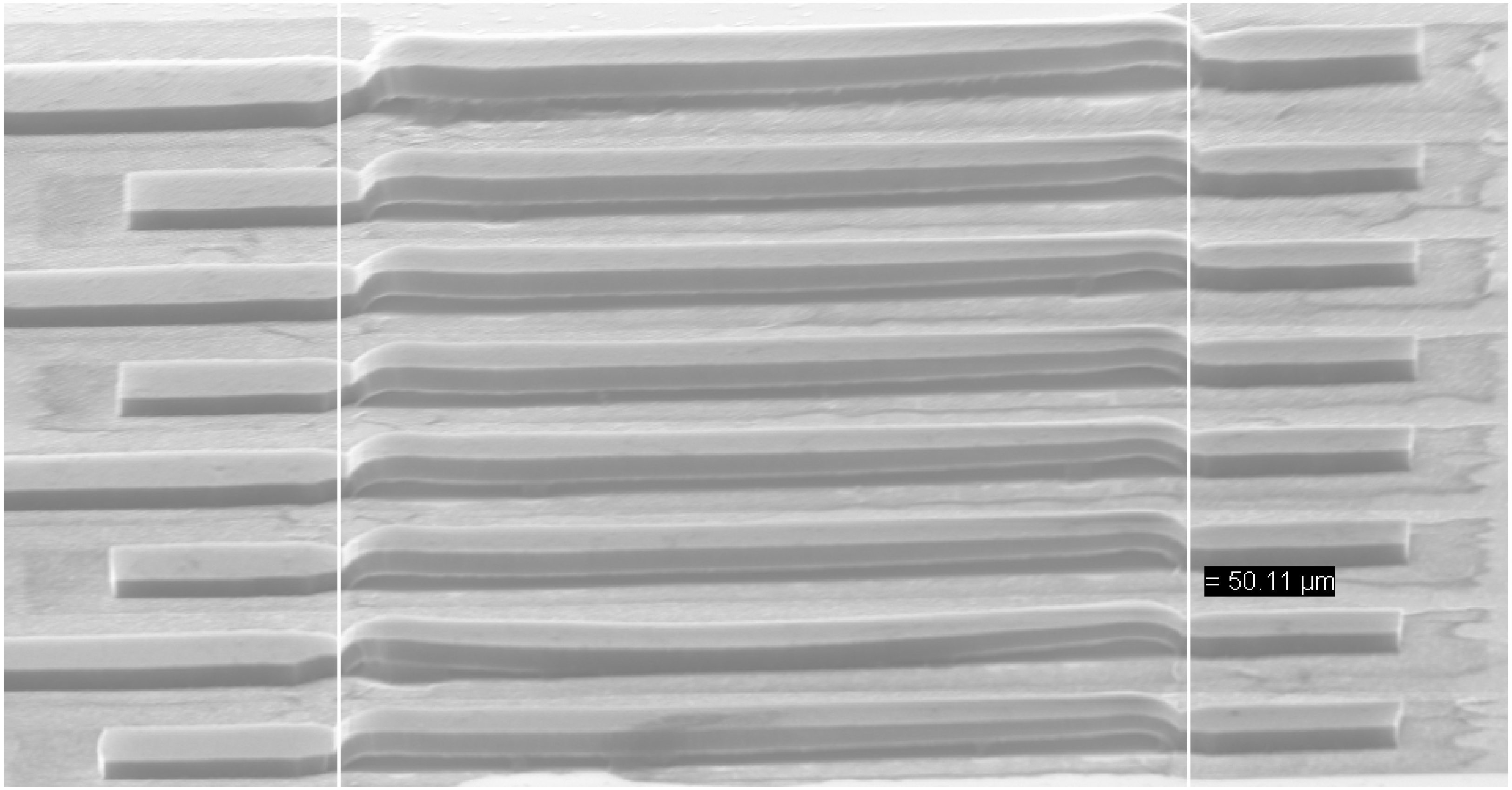
Modulator Type	Motion	Side and Top Views
Cantilever Beam	Bending	
Torsional Plate	Rotation about Torsion Axis	
Membrane	Drumhead	
Suspended Plate	Vertical	

Table comparing four basic surface micromachined reflective mechanical light modulator designs. Each design has different sensitivities to geometries, thin-film properties, squeeze-film damping, etc.

RIT LIGHT MODULATOR - SENIOR PROJECT



Sushil Shakya

REFERENCES

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2. Fundamentals of Microfabrication, Marc Madou, CRC Press, LLC, 1997.
3. Scientific Measurement Systems, Inc., 2527 Foresight Circle, Grand Junction, CO 81505-1007.
4. Micromachined Transducers, Gregory T. A. Kovacs, McGraw-Hill, 1998
5. Solar Cells, Martin A. Green, Prentice-Hall

HOMEWORK – OPTICAL BASICS FOR MEMS

1. If the human body is thought of as a black body light source. What types of optical detector will be able to sense a human by sensing its IR emission? Explain.

2. Look up the Texas Instruments Digital Light Projector products. What is the cost of a developer kit for some of their projection products.

3. Visit the following web sites and discuss one product of interest for each. www.silicon-sensor.com
www.heimannsensor.com
www.oceanoptics.com
www.memsoptical.com