Presented at the COMSOL Conference 2009 Boston

Design and Optimization of An All Optically Driven Phase Correction MEMS Device using FEA

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Outline

- Introduction and working principle
- Micro mirror (Structural Mechanics, Electrostatics module)
- Photodiode (Electrostatics, Conduction-Convection module)
- Wafer fusion (Thermal-structural module)
- Conclusion and future work

Introduction

Astronomy

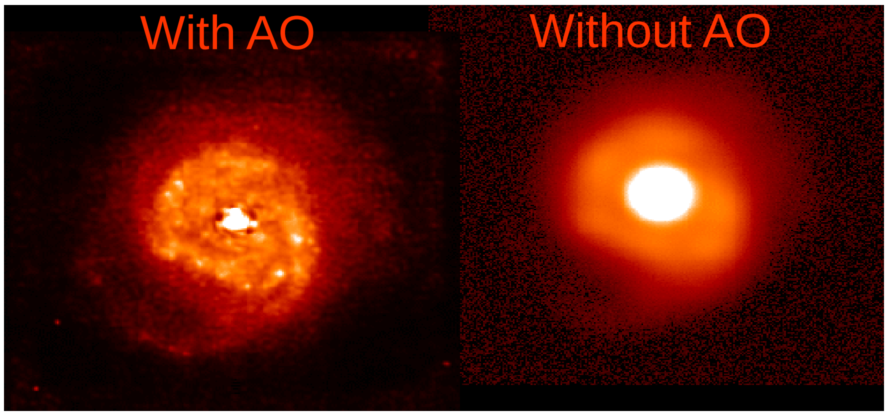


Image Credit: Canada-France-Hawaii Telescope. Starburst galaxy NGC7469

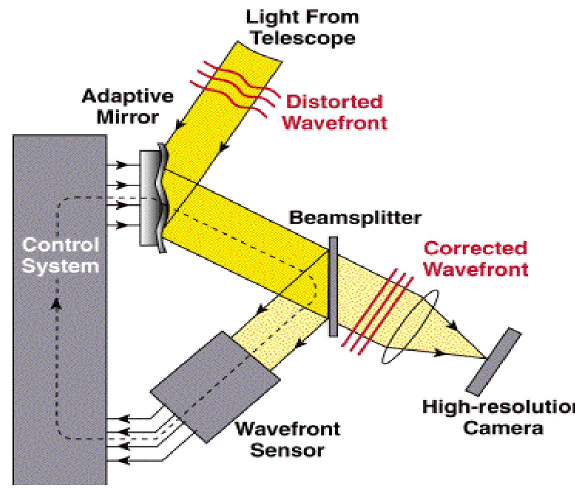


image credit: Center for Adaptive Optics

Medical Imaging (Human Retina)

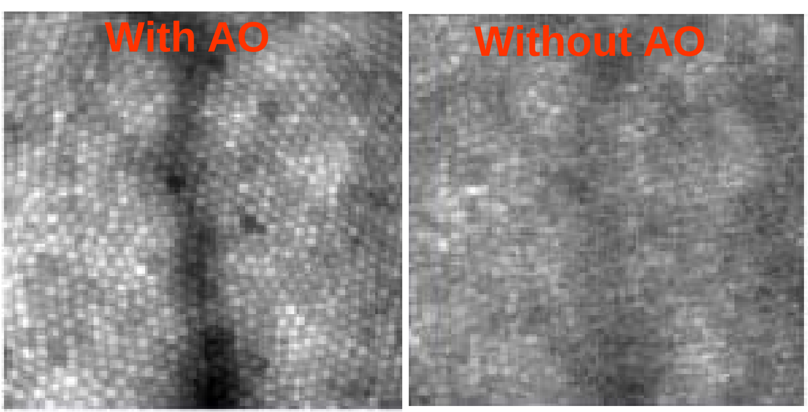
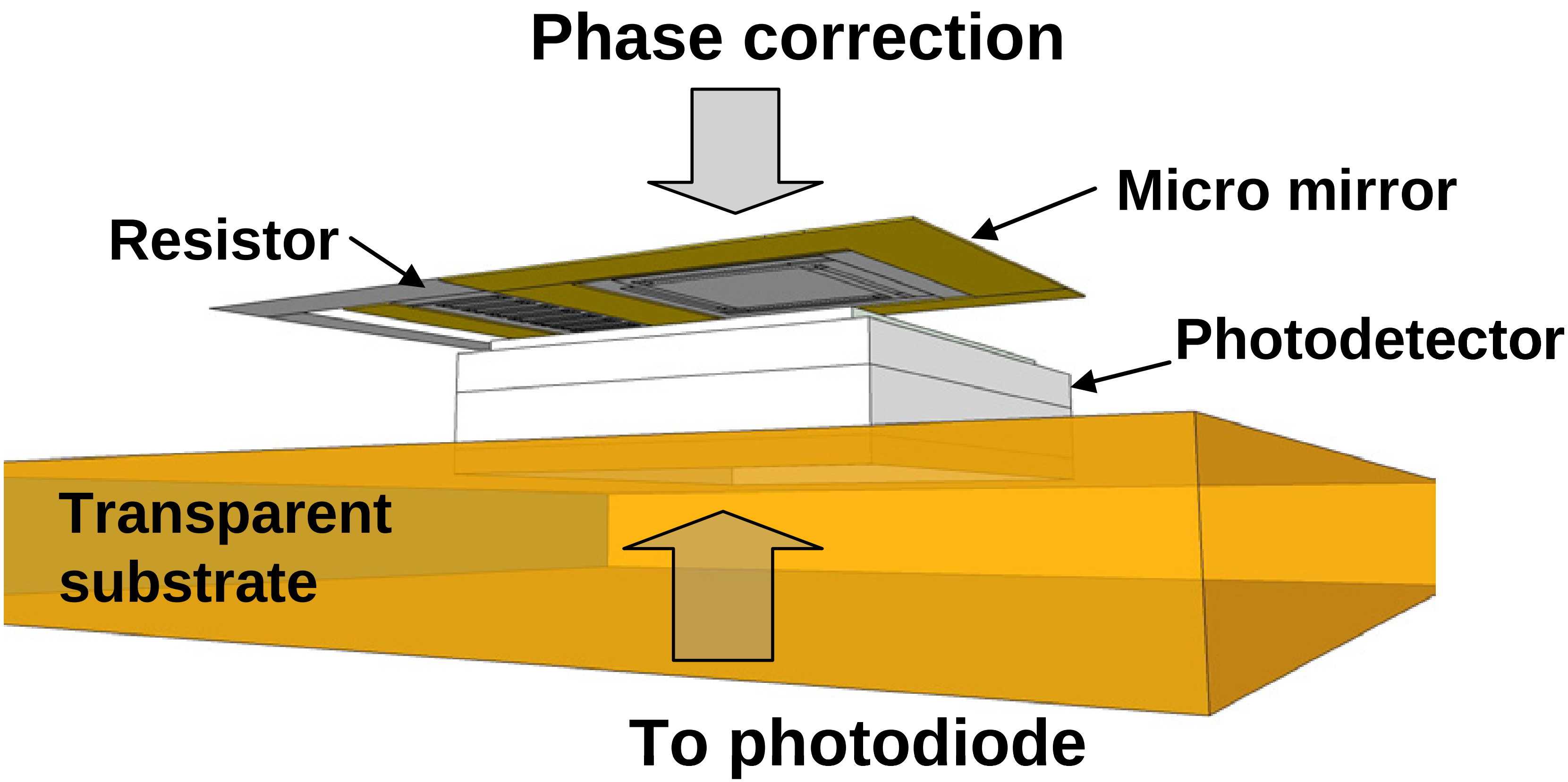


Image courtesy Center for Adaptive Optics.

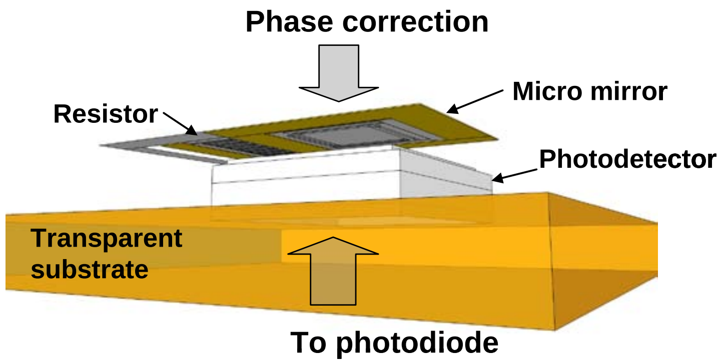
- **Wavefront aberration correction**
- **Spatial light modulators**
- **Moving MEMS mirrors for dynamic correction**

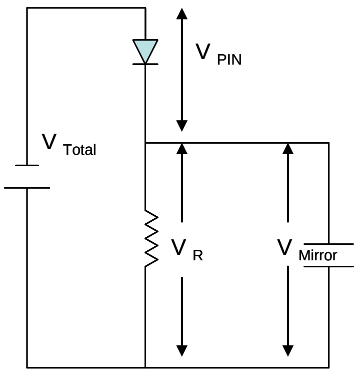
Device



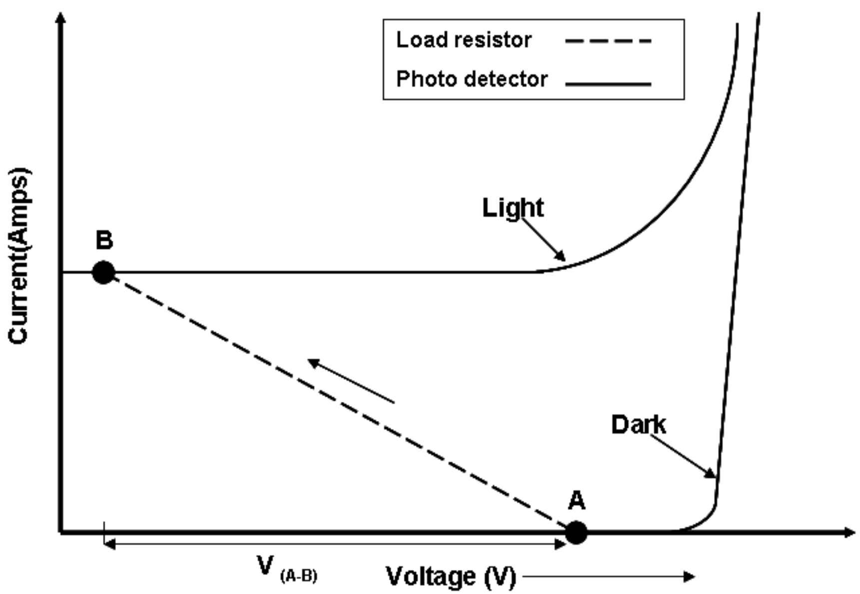
3-D Schematic of a single pixel of the MEMS device

Actuation Mechanism





Equivalent circuit



Operation points on the I-V curves

- Allows parallel addressing of large arrays
- Different material systems integrated
- TaN thin film resistors
- SiN mirrors
- GaAs detectors

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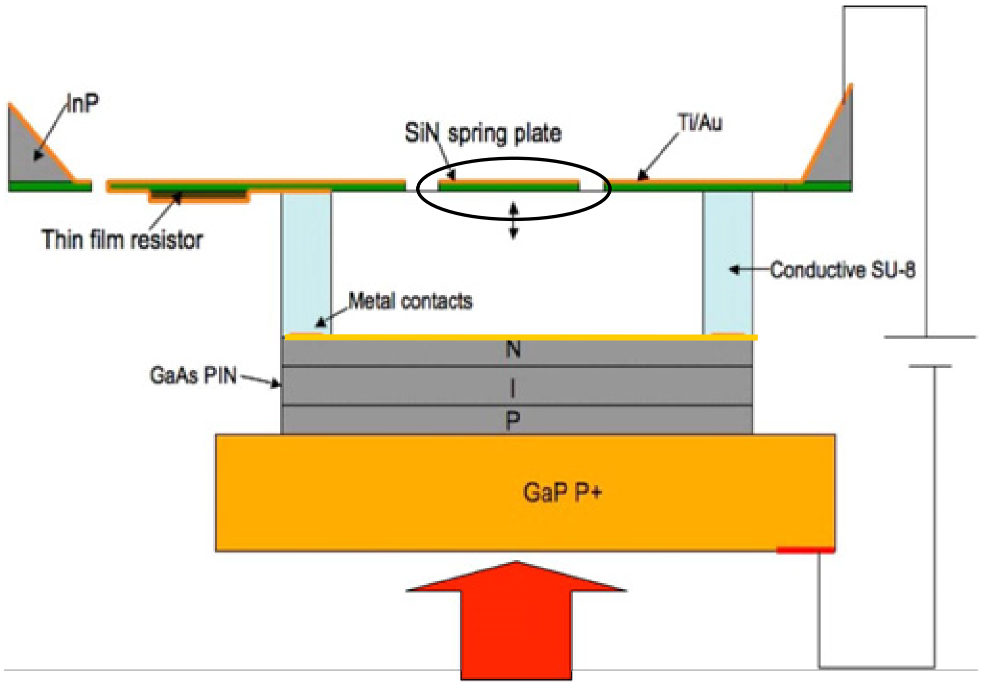
Design Parameters



2-D Schematic of a single pixel

Silicon Nitride mirrors

- **Low stress ➔ Low voltage actuation**
- **Displacement ≈ 1-2 microns**

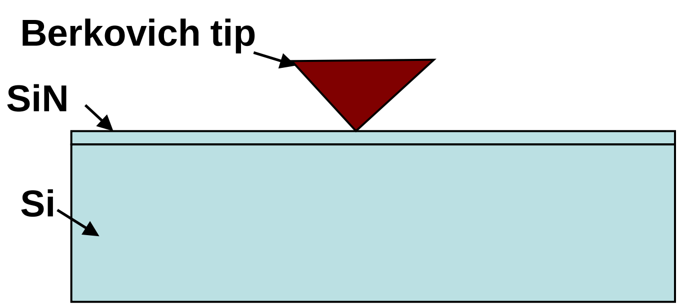
GaAs PIN diode

- **Low dark currents, high photo current**
- **Breakdown voltage to be higher than actuation voltage**

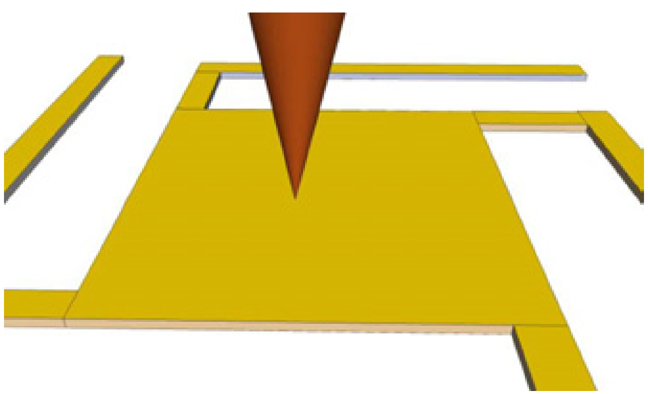
Wafer Fusion

- **High stress, high temperature**
- **Eliminate fixture failure**
- **Uniform bonding**

Silicon Nitride mirrors



Thin film indentation



Spring plate indentation

- PECVD low stress SiN films (≈23MPa residual stresses)
- Two layer interpolation method, to determine Y= 250-270MPa

- <u>Mechanical characterization</u>

* Indenter Studies, force vs displacement

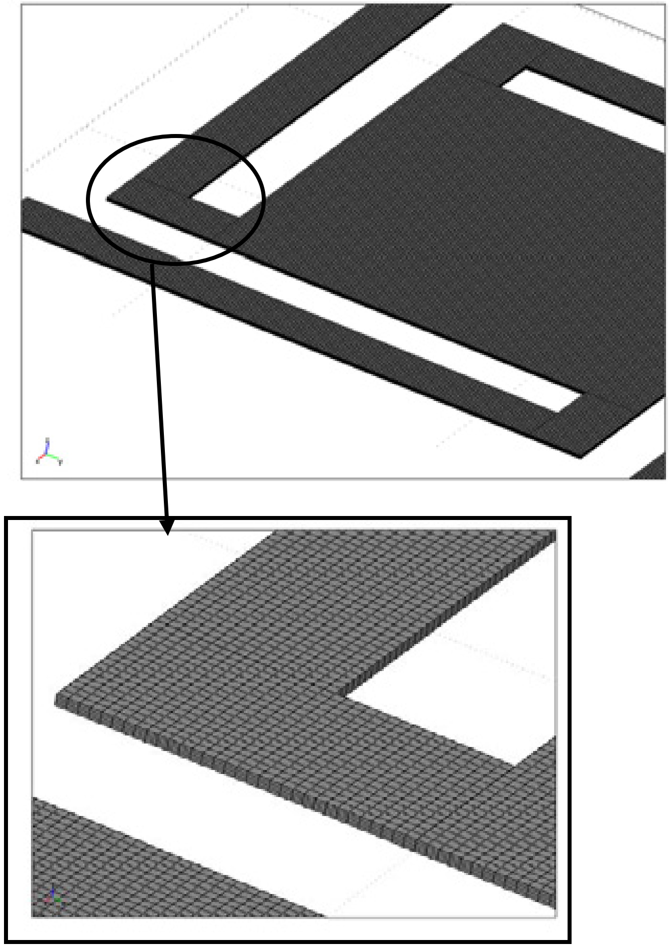
* COMSOL Structural mechanics

- <u>Optical characterization</u>

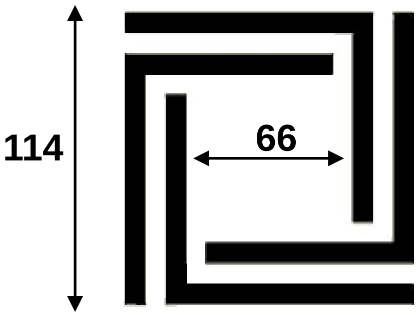
* Interferometer studies, voltage displacement

* COMSOL Electrostatics + Structural mechanics

Model



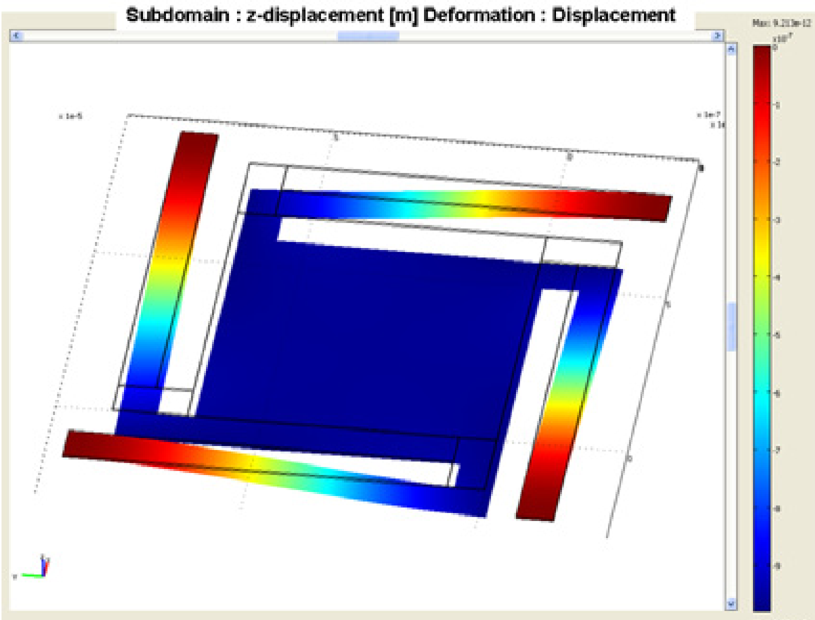
Close up of the mesh



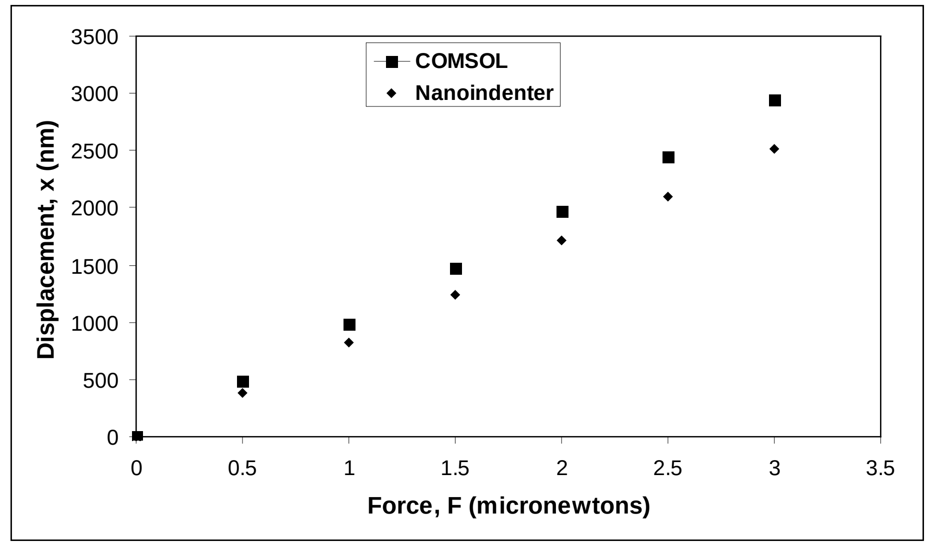
Mirror dimensions

- 500nm thickness
- Point load approximated by boundary load
- 0 to 5 micro newtons load
- 4 layer mapped mesh

Force vs Displacement



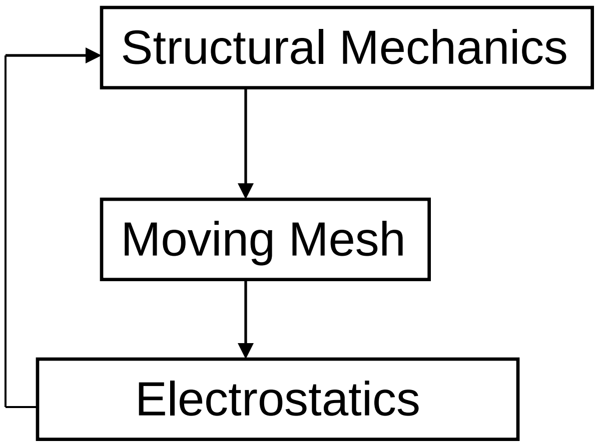
Simulation showing 980nm displacement for 1 μN face load

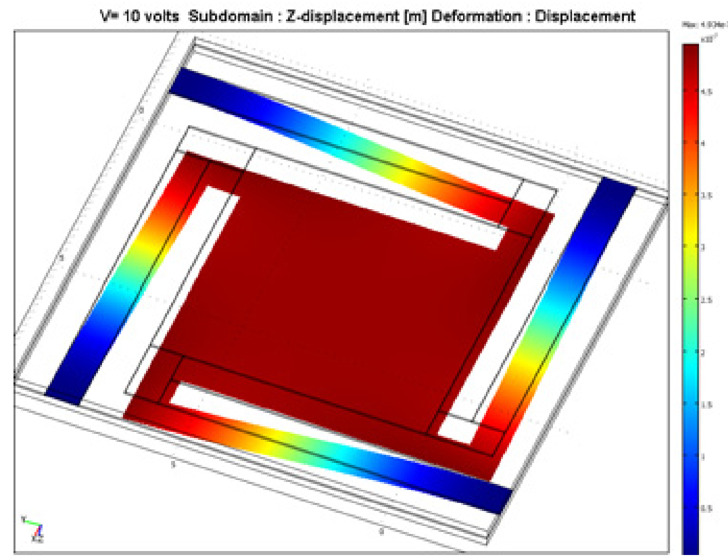


Plot showing the force vs displacement curve from COMSOL and Hysitron Nanoindenter

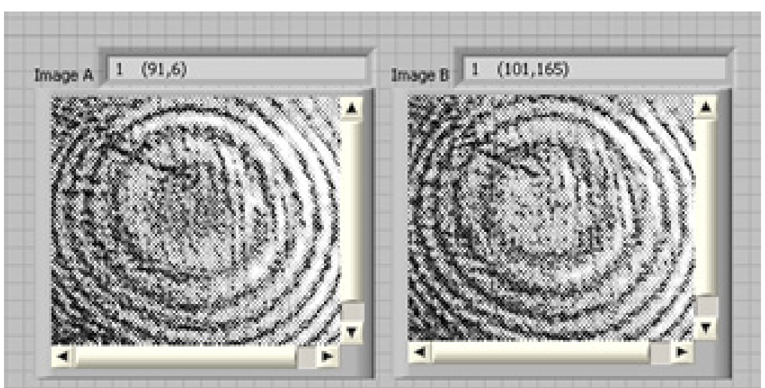
- **Spring constant ≈ 0.98 N/m**
- **Displacements upto 1.5 microns**
- **Max stress at the fixed arms**

Voltage vs Displacement

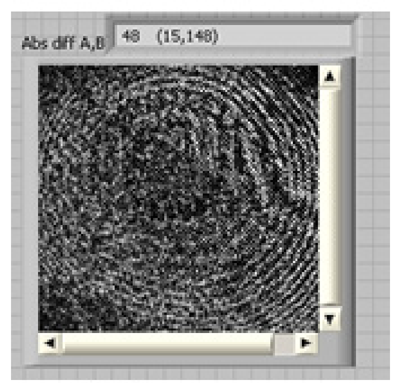




500nm displacement for 10volts



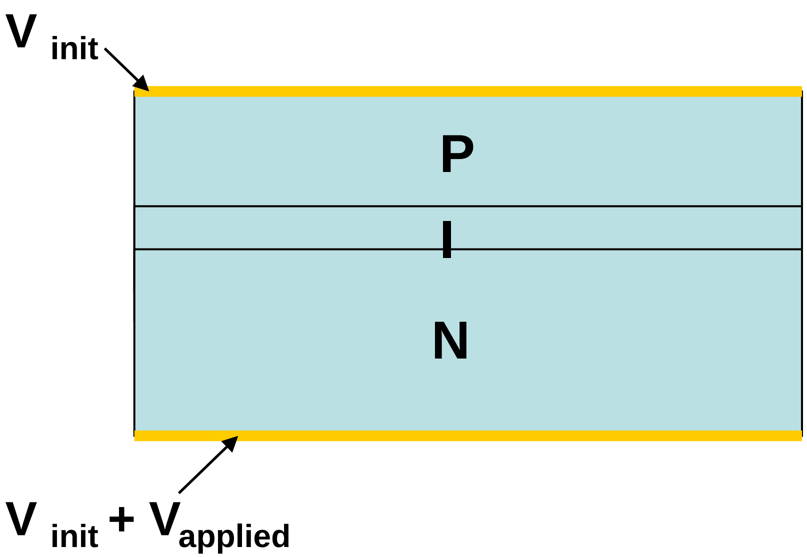
A (Dark) B (Light)



Difference

CCD images of captured fringes

GaAs Photodiode

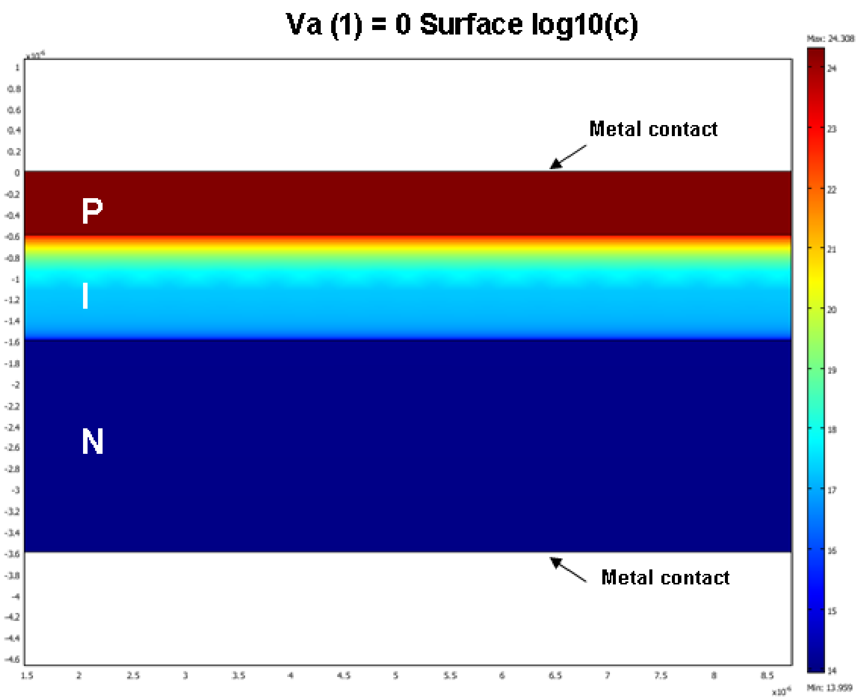


q	1.602e-19[C]	Elementary charge
T	300[K]	Room temperature
k	1.38e-23[J/K]	Boltzmanns constant
epsilonr	12.9	Rel. permittivity for GaAs
ni	1.45e13[1/cm^3]	Intrinsic concentration for GaAs
mun	8000[cm^2/(V*s)]	Electron mobility for GaAs
mup	400[cm^2/(V*s)]	Hole mobility for GaAs
Dn	k*T/q*mun	Electron diffusivity
Dp	k*T/q*mup	Hole diffusivity
taun	0.1[us]	Electron life time
taup	0.1[us]	Hole life time
NApmax	p*1e15[1/cm^3]	Maximum p-type doping
NDn	p*1e12[1/cm^3]	I layer n-type doping
NDnmax	p*1e15[1/cm^3]	Maximum n-type doping
Va	0[V]	Applied voltage
y1	-6.00E-07	
c1	q/(k*T)	
y2	-1.60E-06	
p	2000	

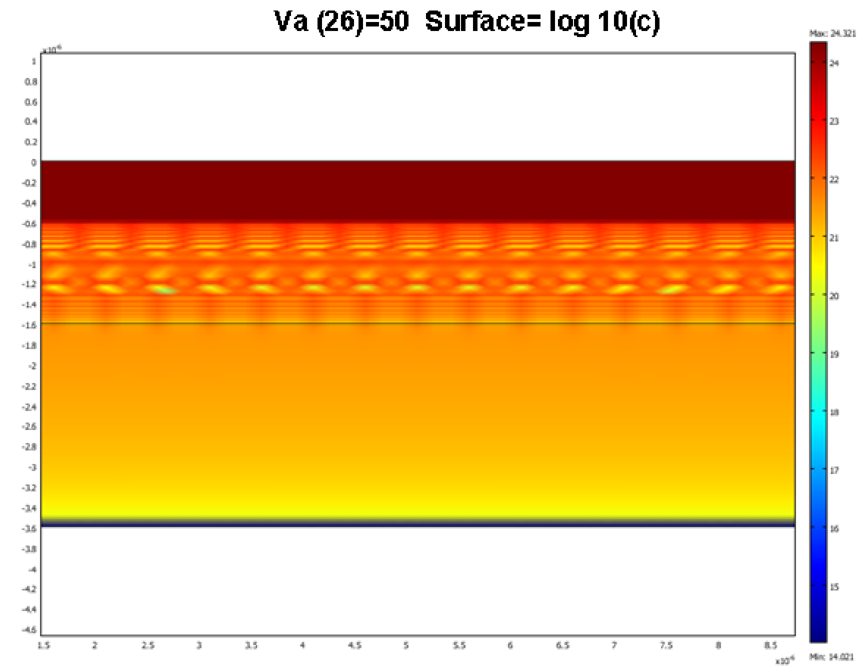
GaAs properties

- Uniform doping assumed
- Dopings ramped up
- Drift and diffusion solved using cond/conv module

Results

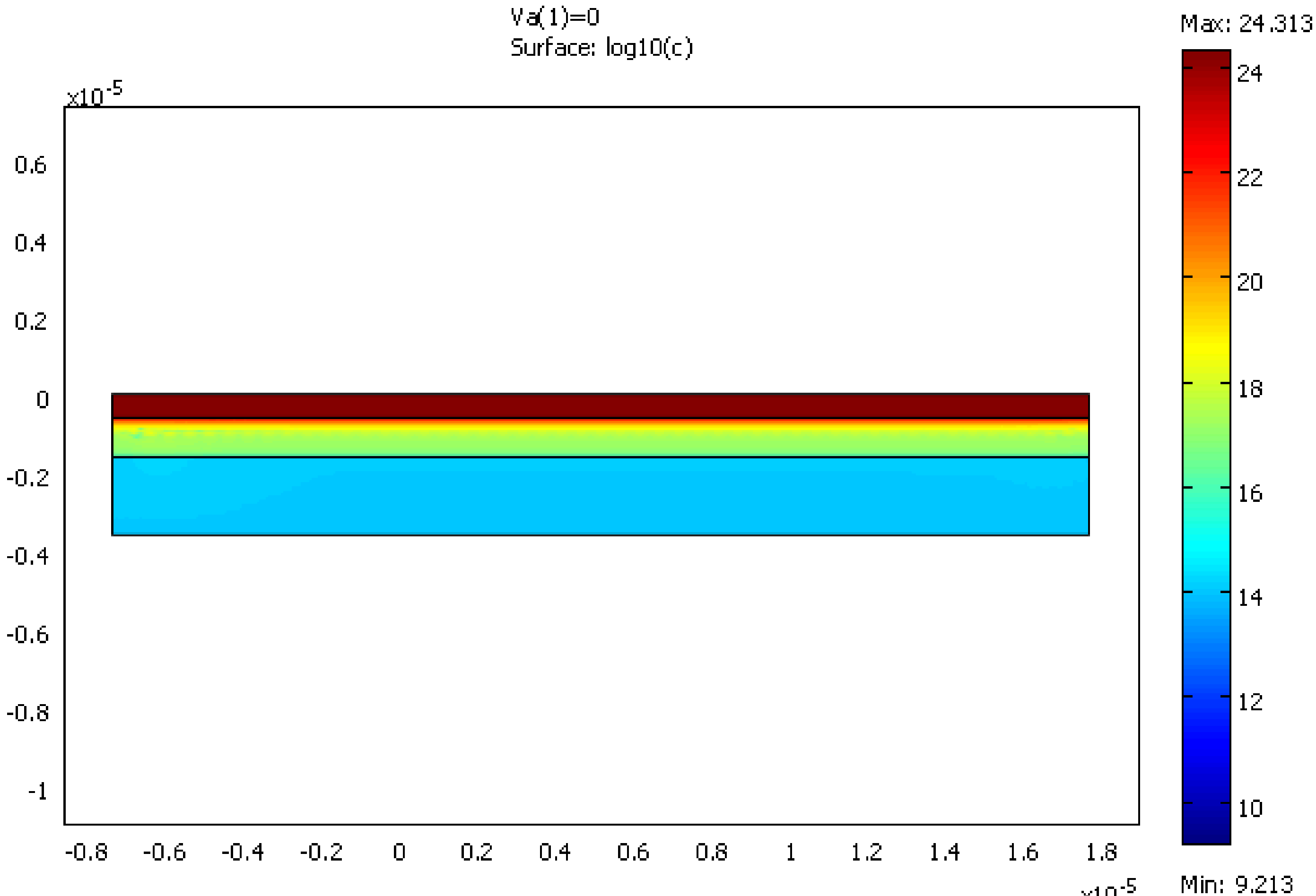


Hole distribution at equilibrium



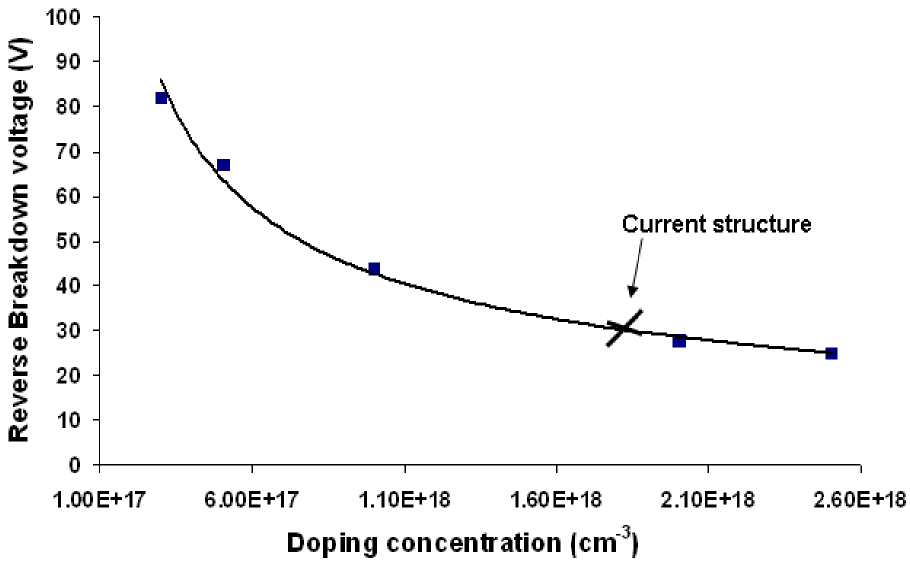
Hole distribution after breakdown

Results

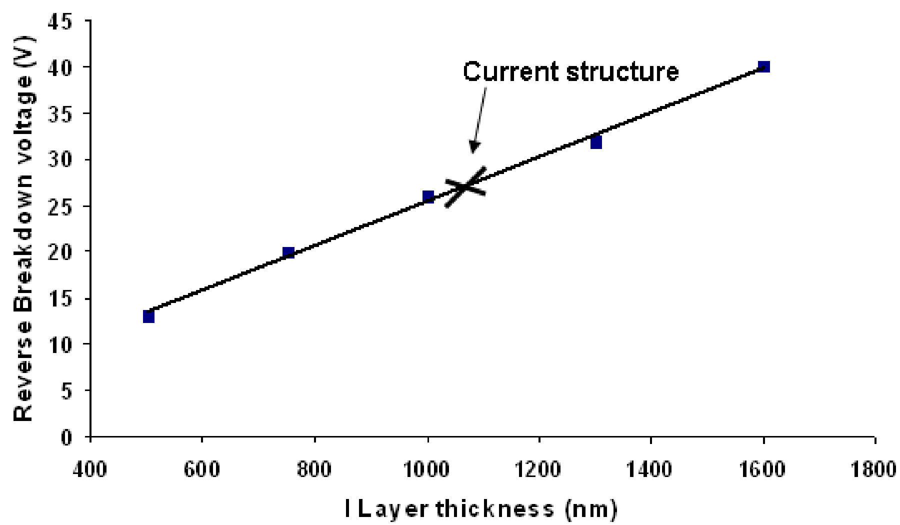


Animation showing breakdown ≈ 30 volts

Breakdown Studies



V_{BD} as a function of doping



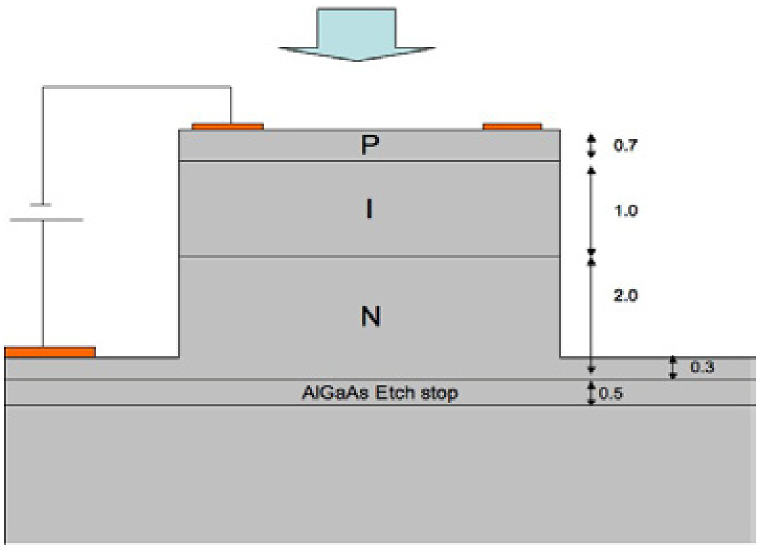
V_{BD} as a function of intrinsic layer thickness

<u>**Current design**</u>

P, N layer ≈1.8E1+8 cm^{-3} , I Layer ≈ E+15

I Thickness ≈ 1micron

Characterization



Schematic of ohmic contacts

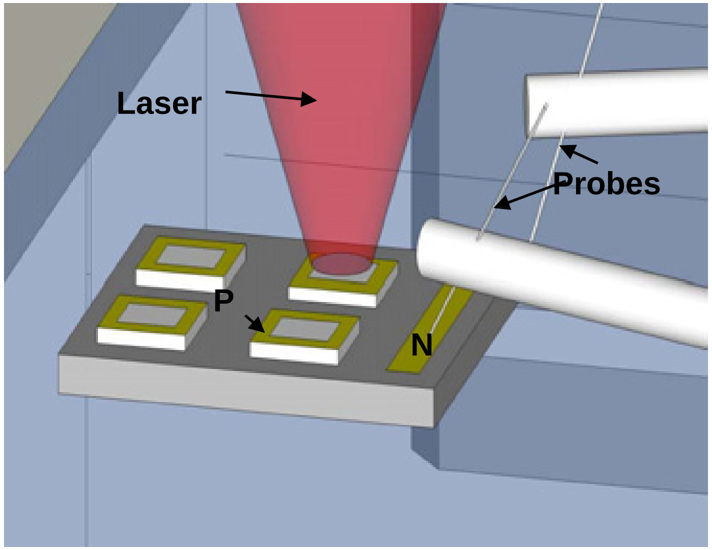
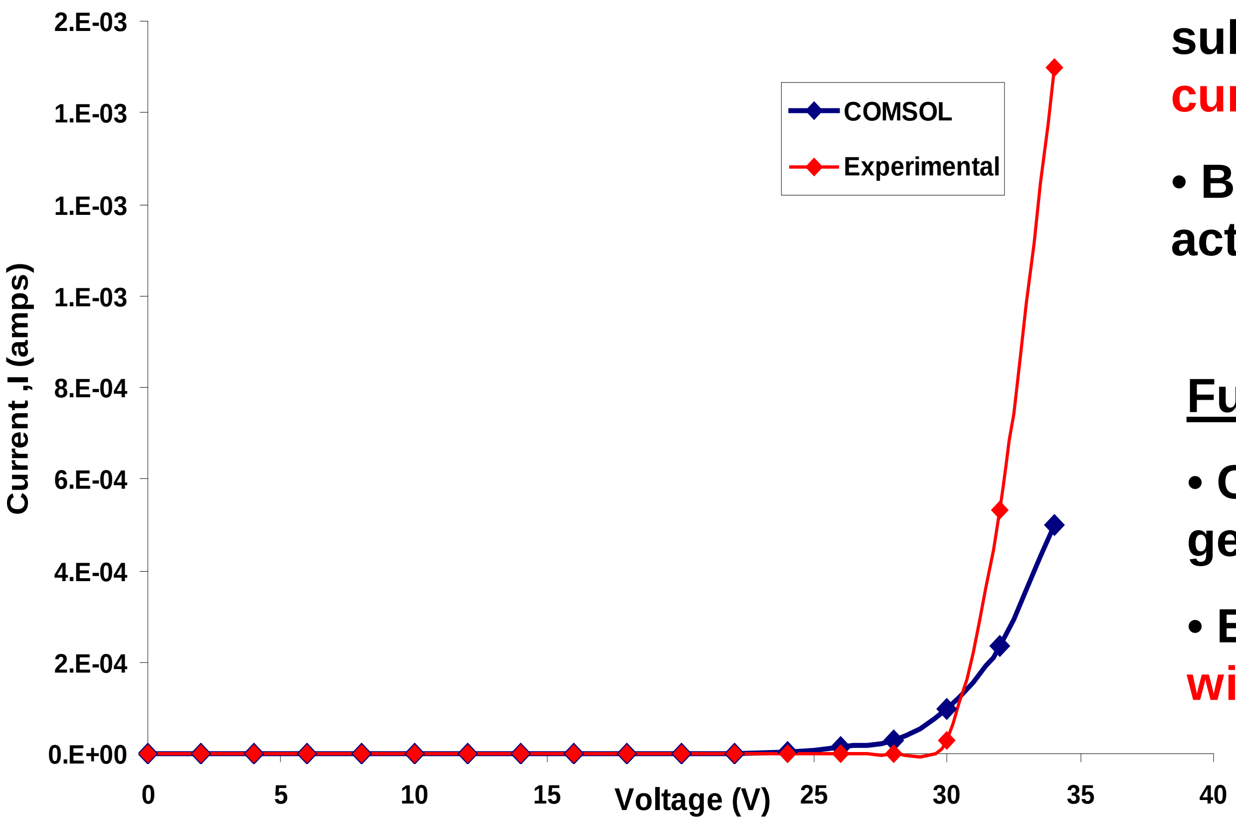


Photo response characterization setup

- Wet etch to form mesas
- Reverse biased ohmic contacts
- 300 micron width

Comparison

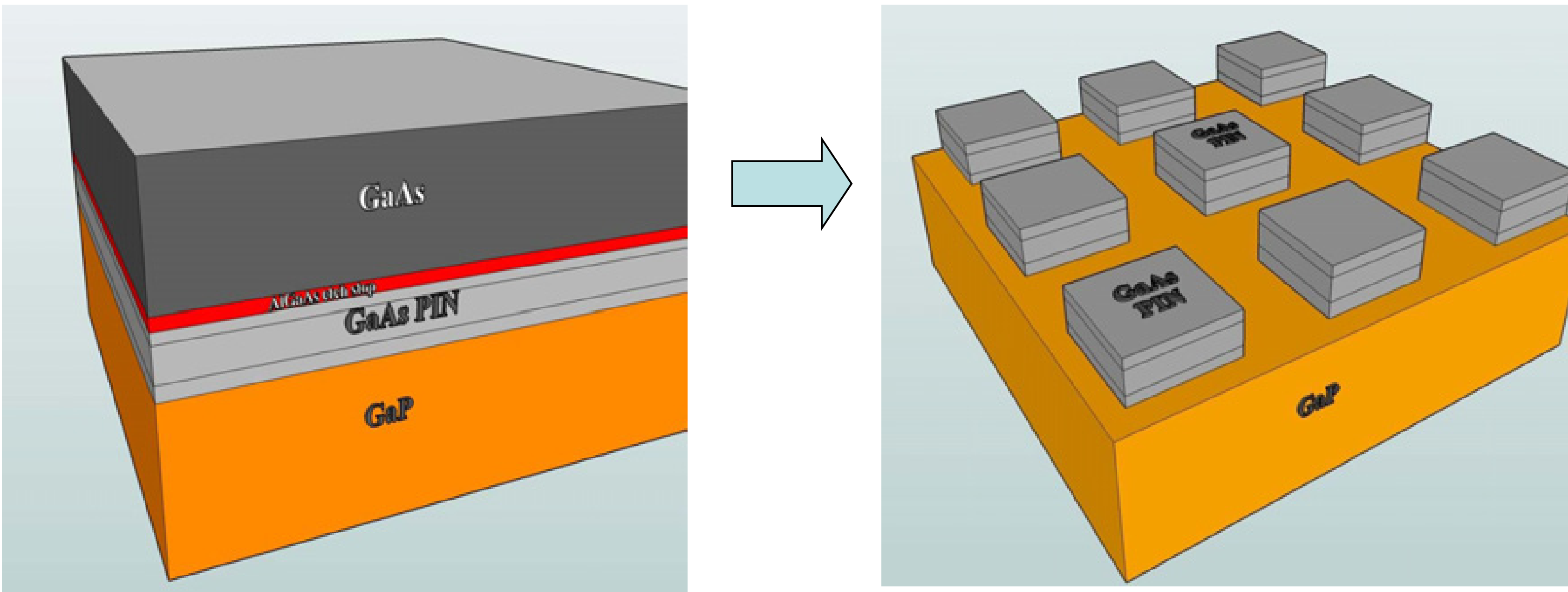


- **I-V extracted by subdomain integration of current density**
- **Breakdown abrupt in actual device**

Future studies

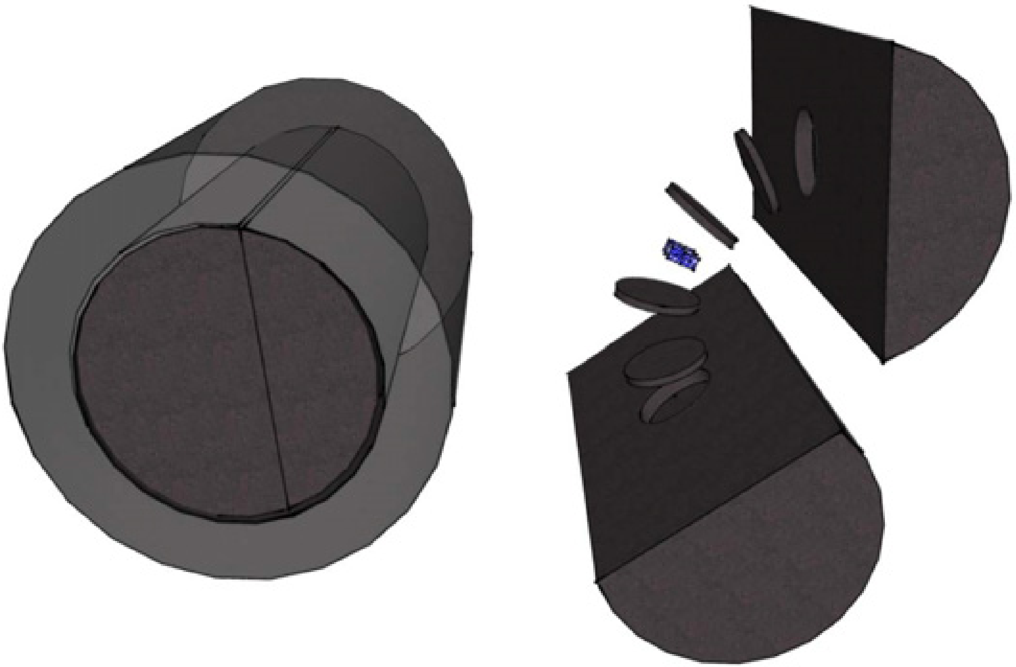
- **Coupling RF module to get photoresponse**
- **Effect of changing mesa widths**

Wafer Fusion



- ≈ 700 degrees C
- High pressure
- Custom designed fixture

Wafer Fusion



3-D Schematic of wafer fusion components

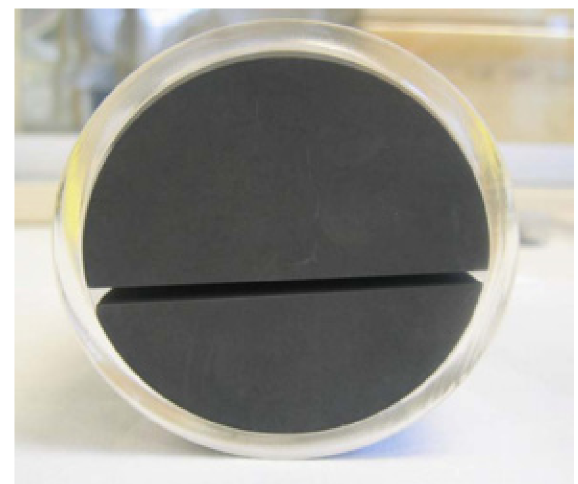
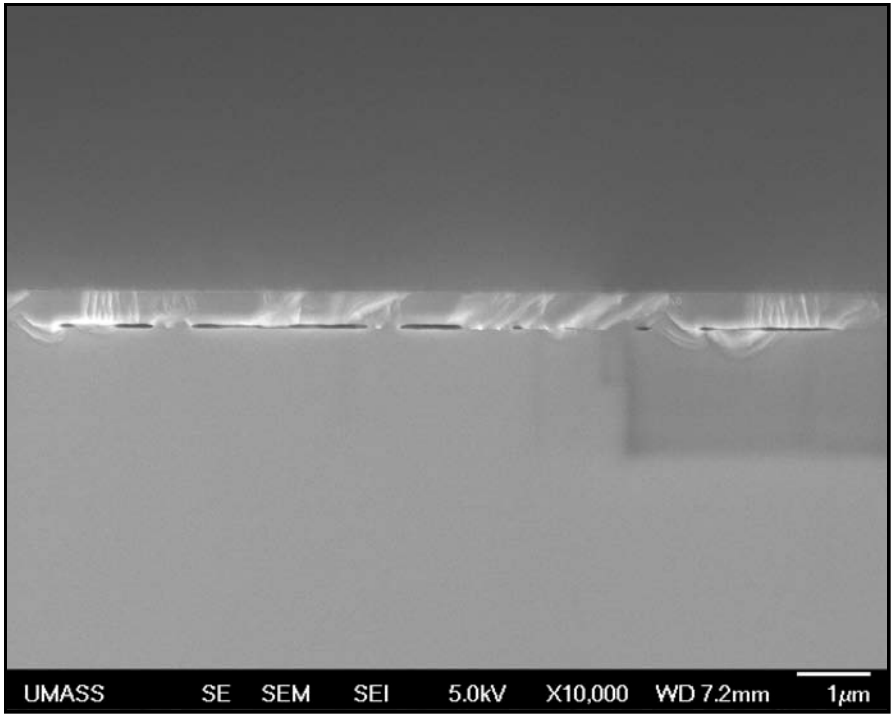
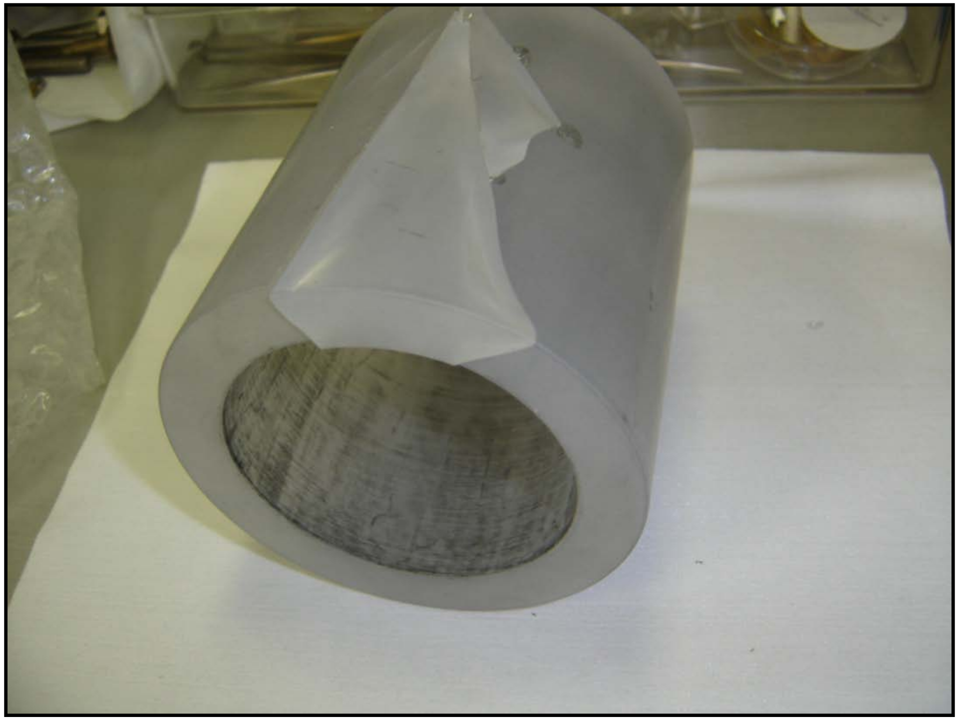


Photo of an assembled fixture

Problem

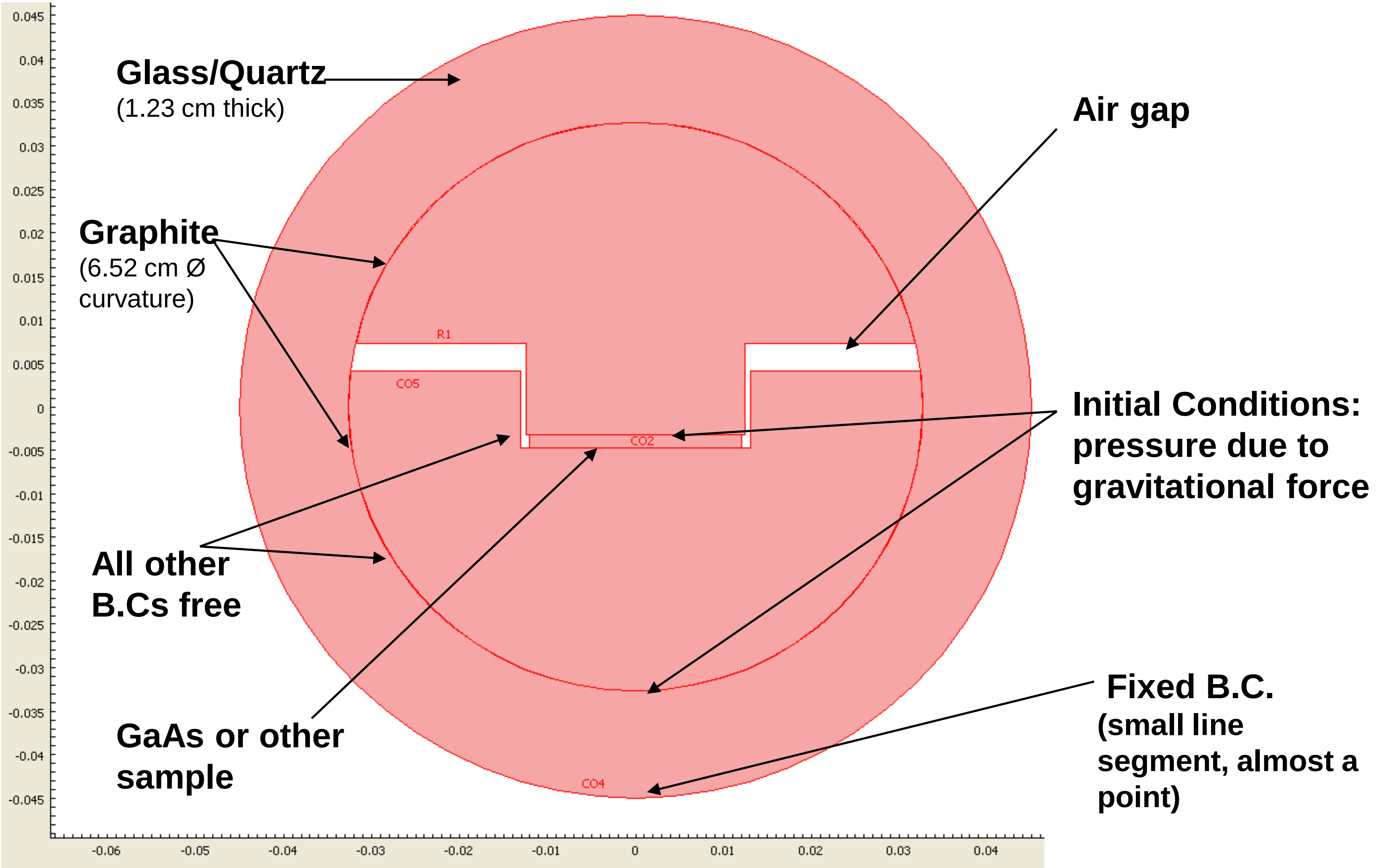


- *Non uniform bonding*
- *Defects*
- *Peeling off during wet etch*

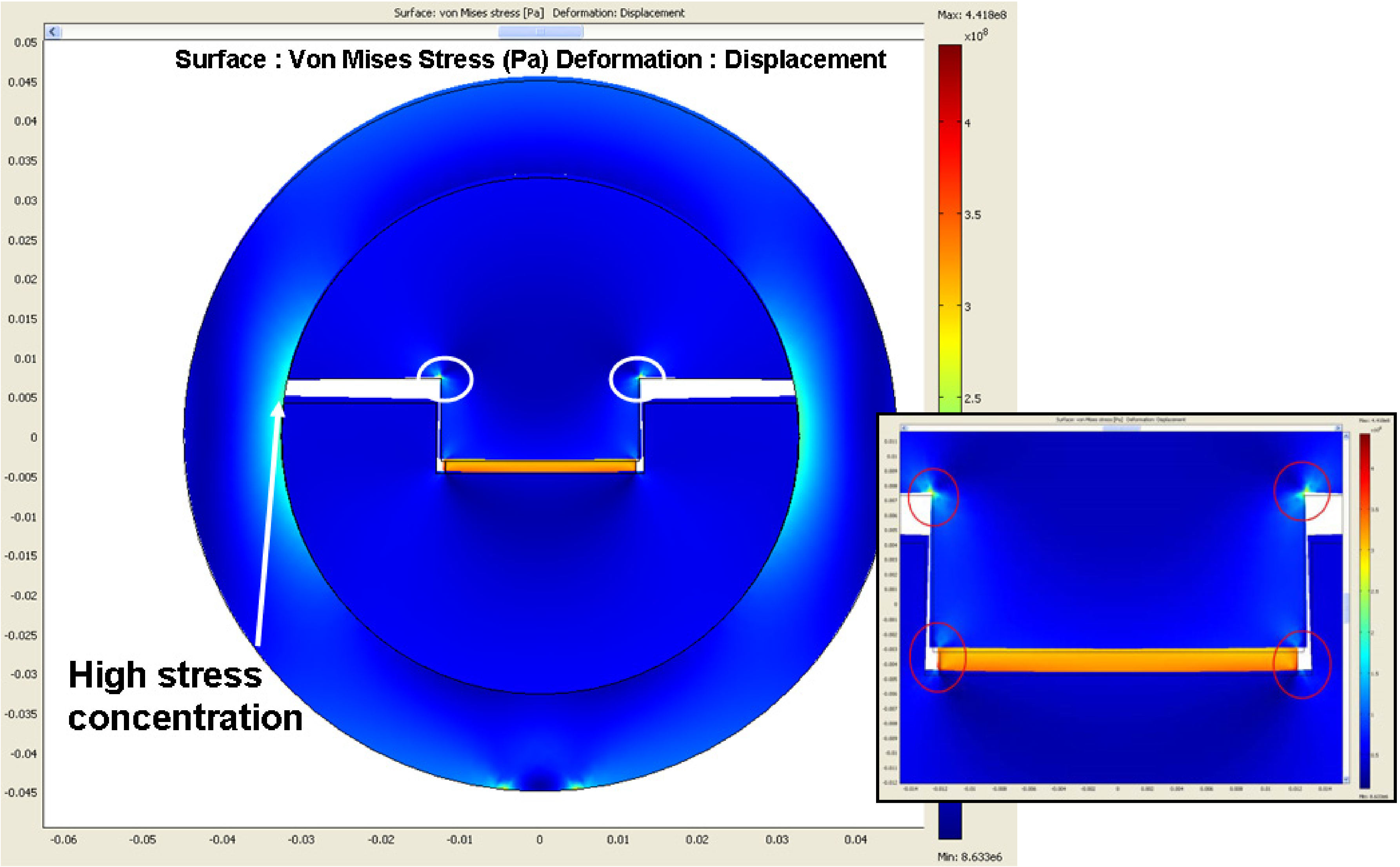


Thermal stress failure

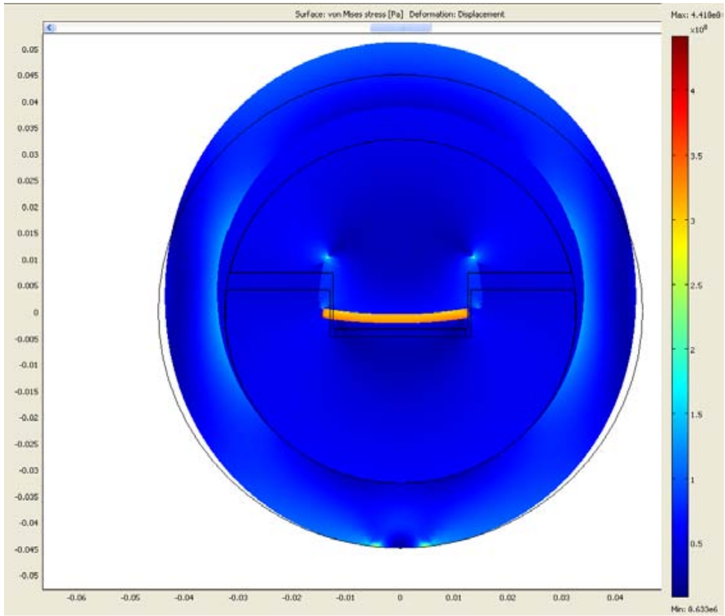
Original design



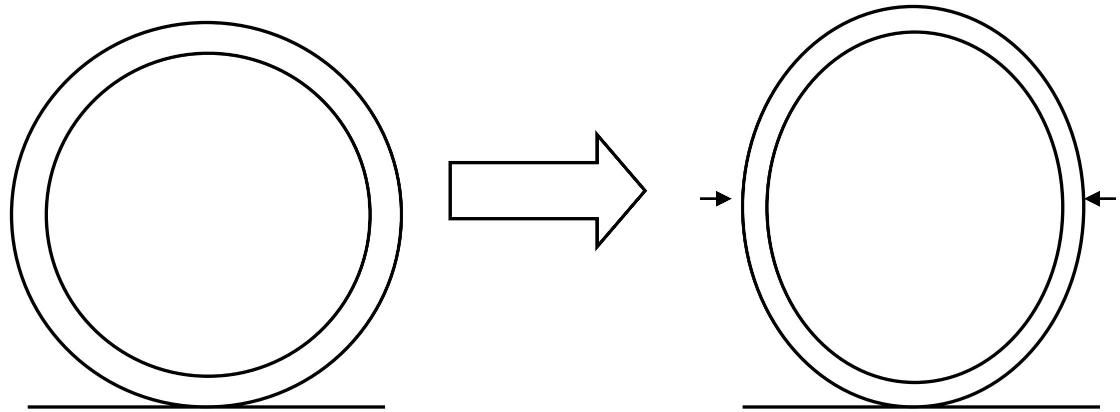
Stress distribution



Problem



Exaggerated deformation plot

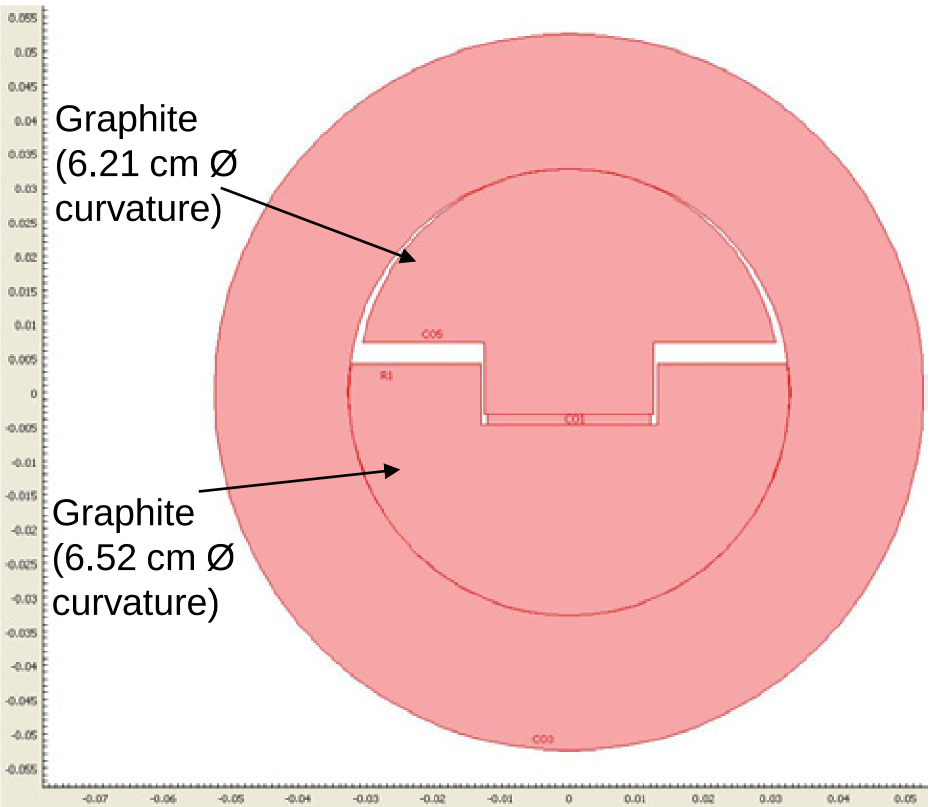


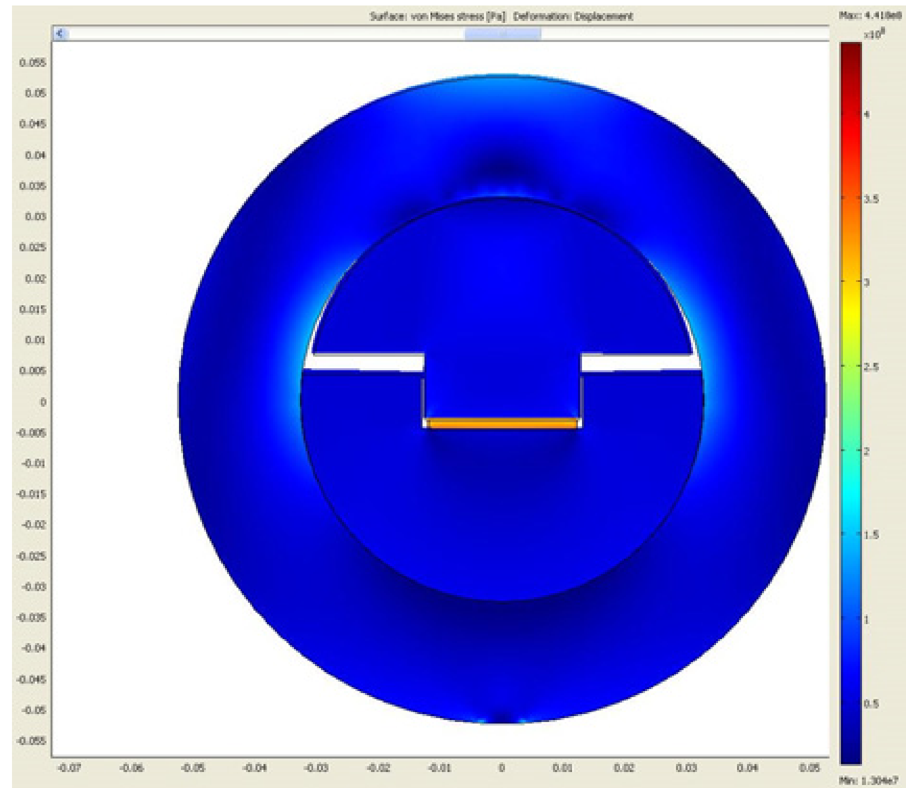
Room temperature

High temperature

- **Bottom end fixed**
- **Quartz tube tends to squeeze**
- **No room for expansion**

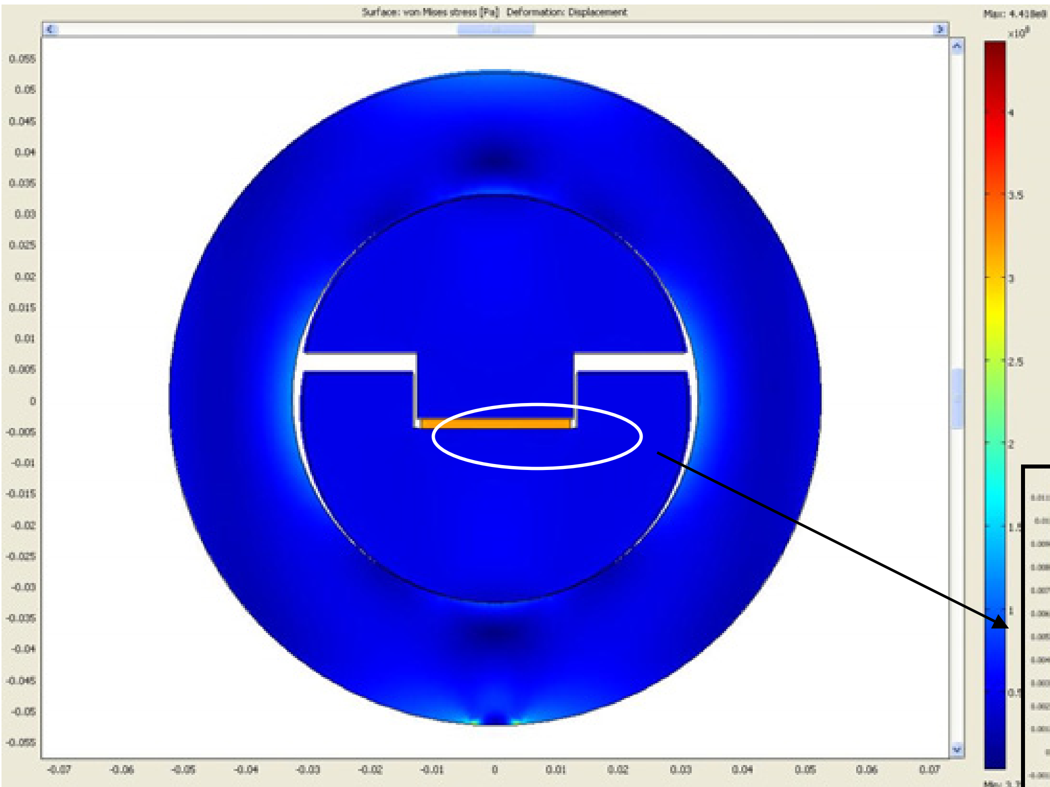
Design changes



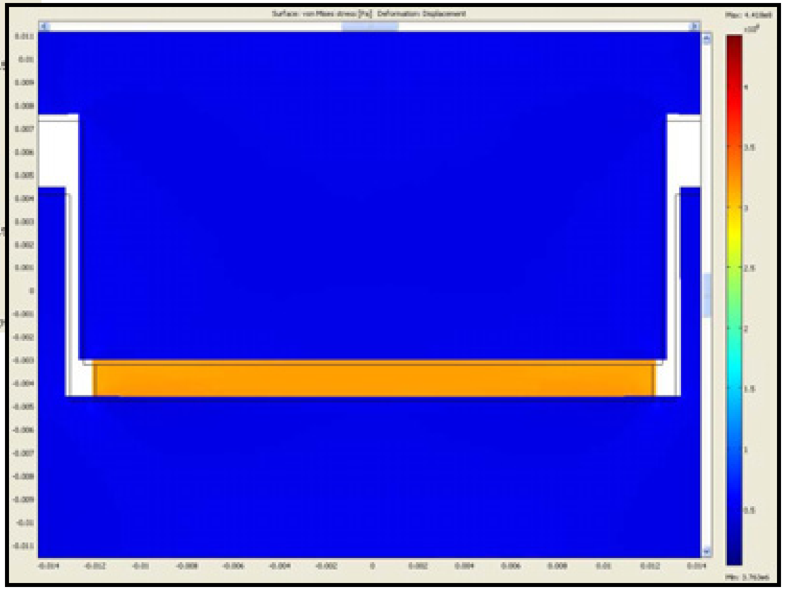


Top graphite radius of curvature reduced

Design changes

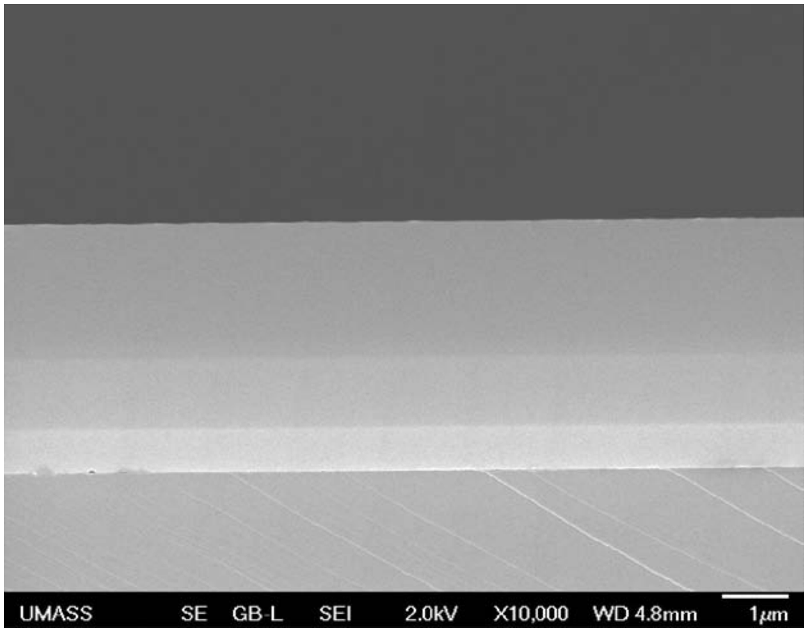


Uniform forces on the sample

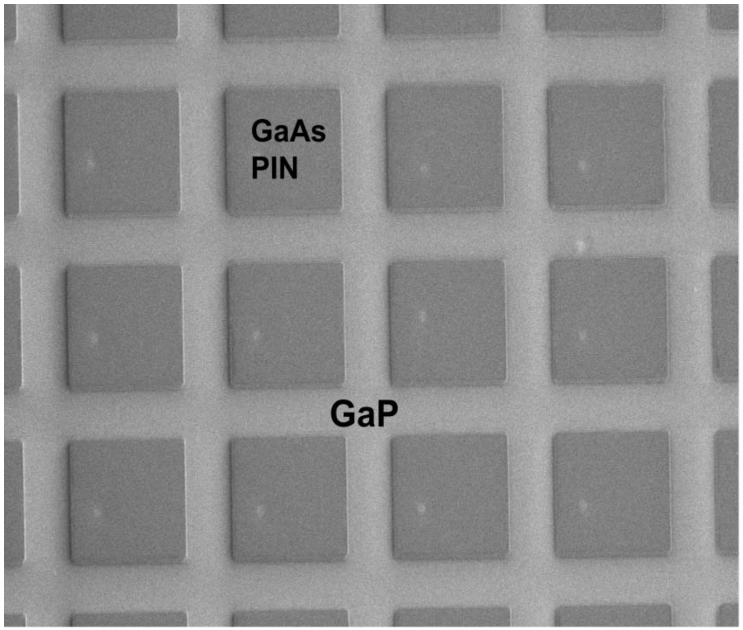


Both bottom and top graphite radius reduced

New Samples



SEM of GaAs/GaP bonded interface



PIN diodes transferred on GaP substrate

- **Cleaner bonding interfaces**
- **Eliminated quartz failure**

Conclusion & Future Work

Basic models developed :

to study the electrostatic actuation of spring plates

to study behaviour of our PIN diode structure

wafer fusion fixture

64 Bit workstation with 28Gb RAM

Future work :

- **Study effect of changing spring plate thickness**
- **Varying PIN diode dimensions, and photo response**

Acknowledgement

•**Work partially funded by United States Air Force**

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