Sand2006-4550C

# *MEMS PACKAGING*

**Andrew Oliver, Ph.D.**
**Principal Member of the Technical Staff**
**Sandia National Laboratories**
**Albuquerque, New Mexico**
**adolive@sandia.gov**
**505 845-7931**

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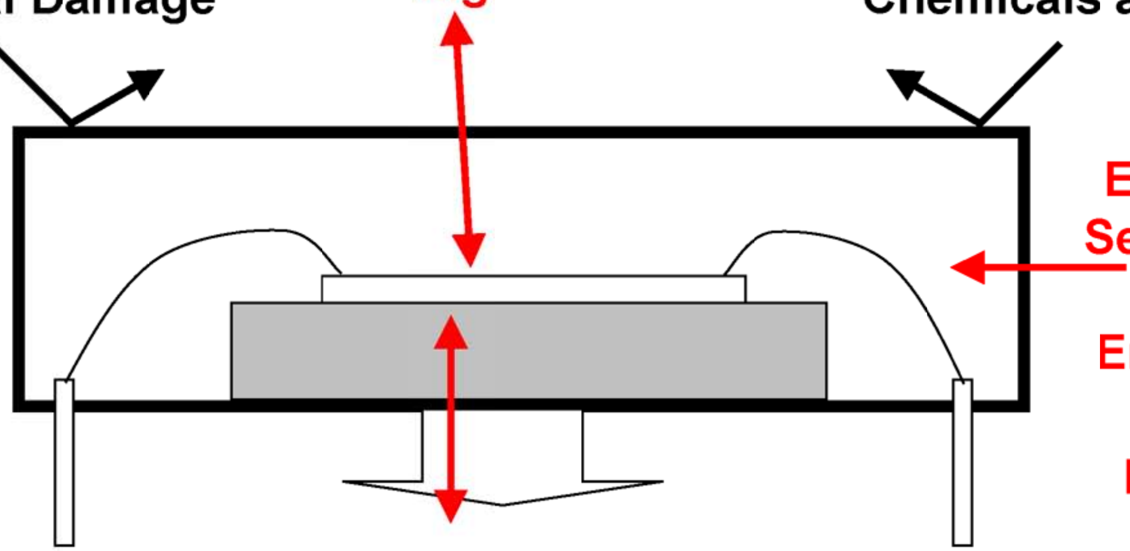
# GOAL OF MEMS PACKAGING

**Protect From Mechanical Damage**

**Optical Devices Need to let Light in and Out**

**Protect Chip From Chemicals and Moisture**

**Microfluidic devices have Fluids coming in and out**



**Environmental Sensors need to let the Environment in (dust, dirt, pollution, …)**

**Remove Heat Generated By The Chip**

**Get Electrical Signals and Power to/from IC**

**Don’t Limit Performance**

**Low Cost**

# *LAST YEAR*

- Some of you heard me talk last year
- This talk is intended to be complementary to last years talk
- It covers MEMS packaging techniques that are not used by the integrated circuit industry

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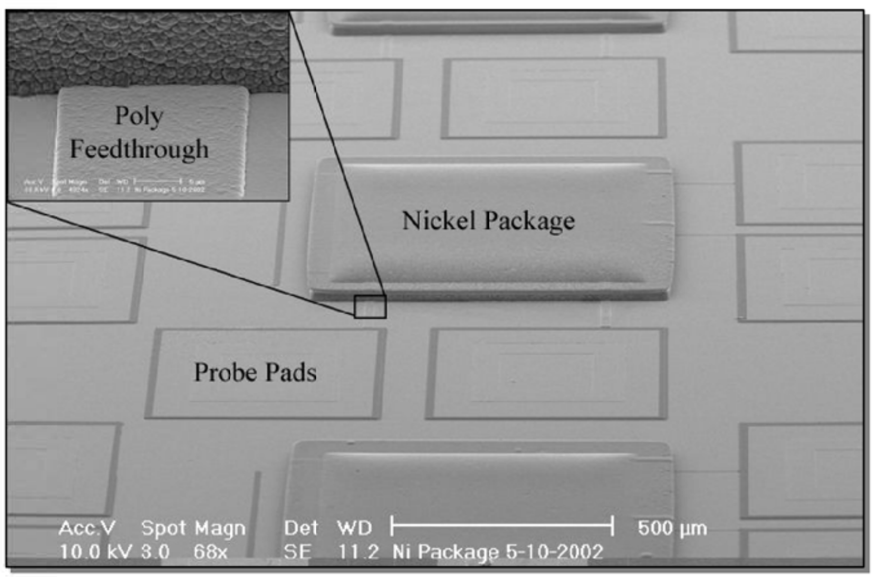
# OUTLINE

- Integrated Package
- Wafer Bonding
  - Fusion
  - Anodic
  - Glass frit
  - Thermocompression
  - Solder
- MEMS Packaging Issues

# INTEGRATED PACKAGES

- Formed during the fabrication process
- Using fabrication equipment (evaporators, LPCVD furnaces, lithography etc.)
- Not formed by using assembly techniques

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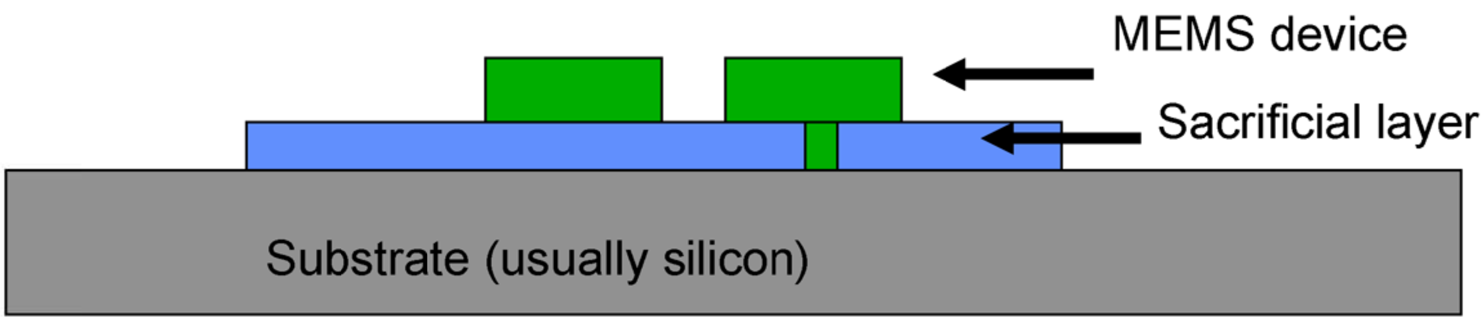
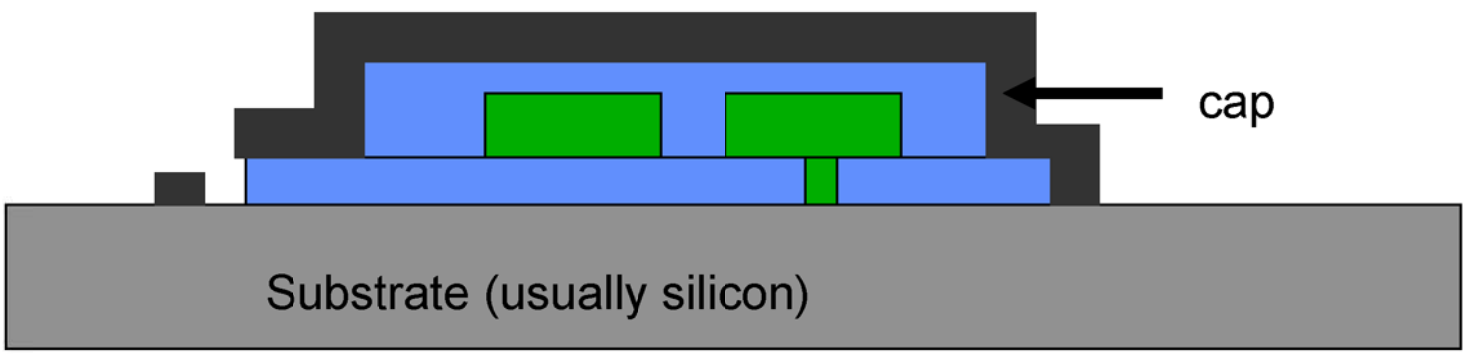
# *INTEGRATED PACKAGE*

- **Protected volume (package?) is formed during the fabrication process**
- **Step 1: The MEMS device (generally a surface micromachine) is fabricated**
- **Step 2: A cap or cover and sacrificial layer is formed over the MEMS device**
- **Step 3: The MEMS device is released (sacrificial layer removed) through a hole in the cover**
- **Step 4: The hole in the cover is sealed**

# *INTEGRATED PACKAGE (SIDE VIEW)*




1 MEMS device




2 Deposit sacrificial layer and cap

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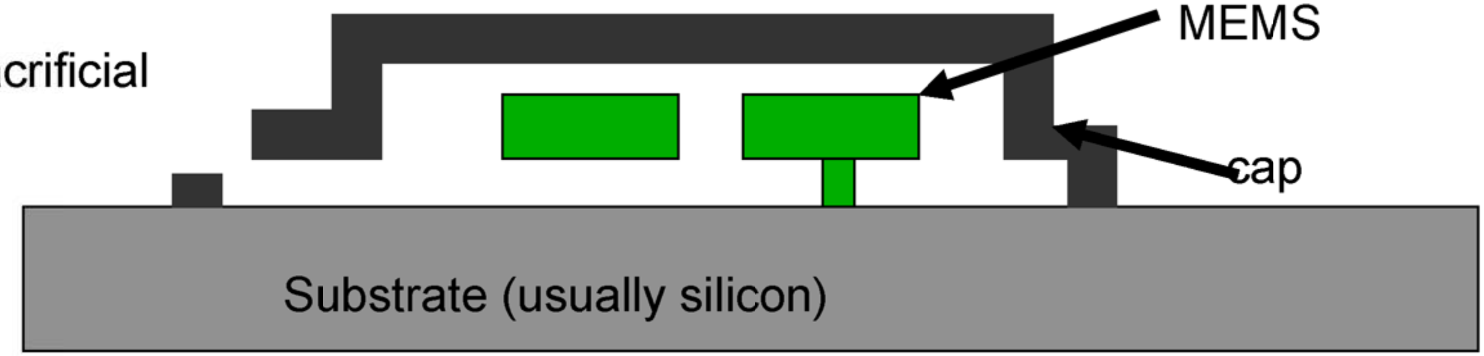
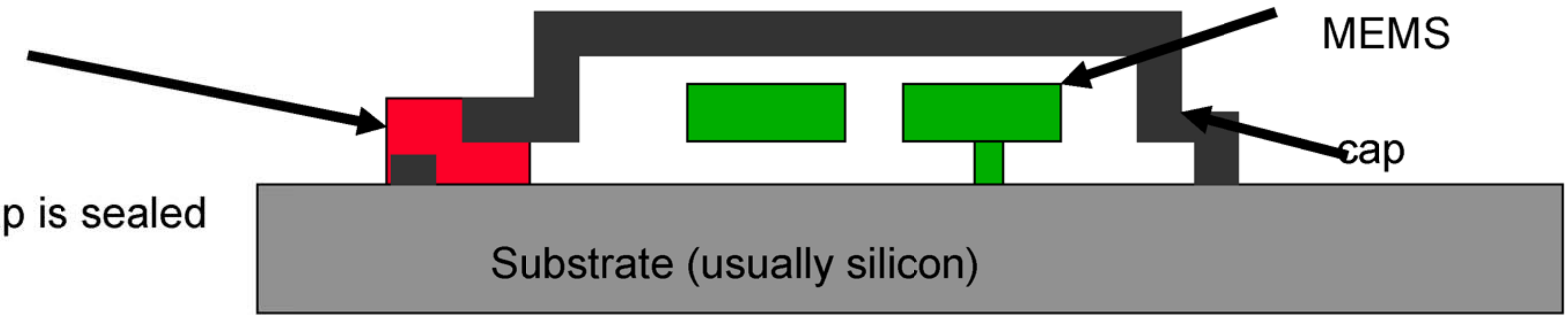
# INTEGRATED PACKAGE

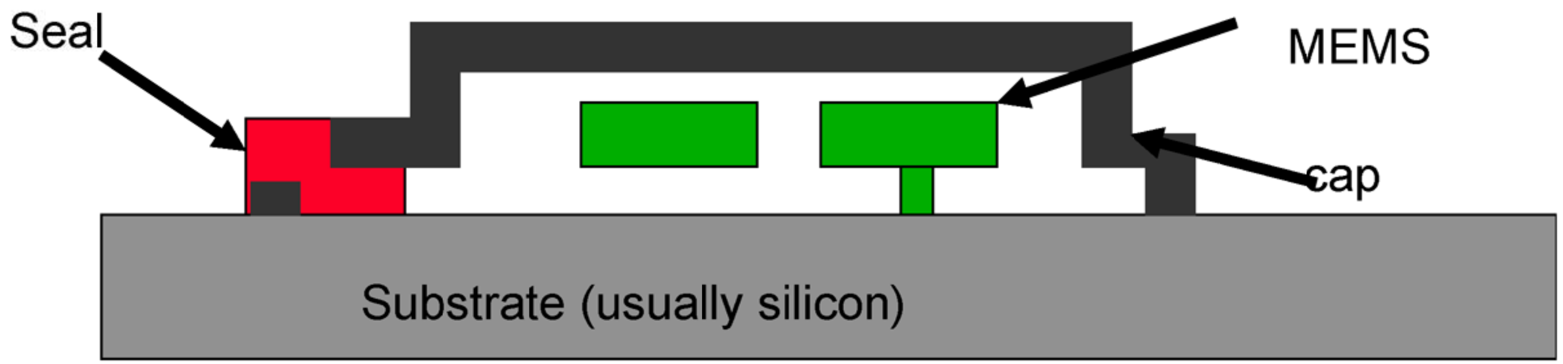
3 Removal of sacrificial layer



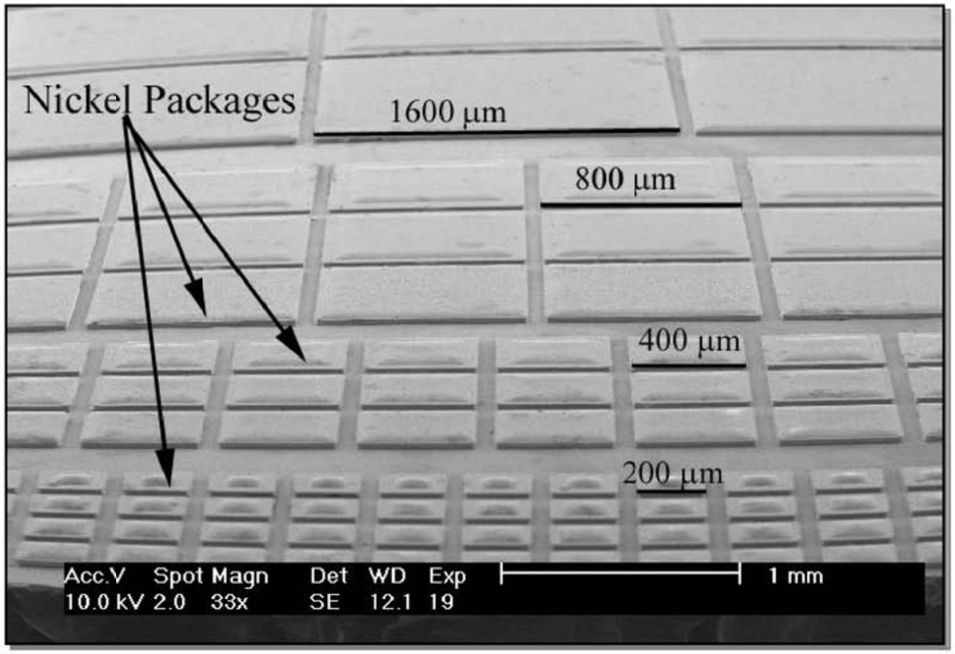

4 Cap is sealed

# INTEGRATED PACKAGE



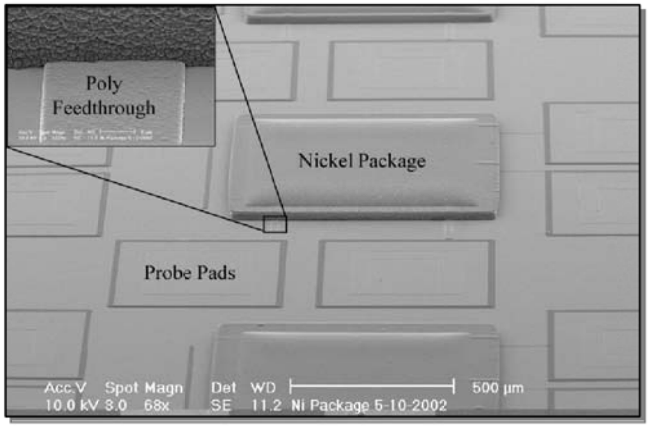

- **Materials used in integrated packages**
  - **Polysilicon lids and MEMS, silicon dioxide sacrificial layer, sealed in LPCVD furnace**
  - **Silicon nitride lid and polysilicon MEMS, silicon dioxide sacrificial layer sealed in LPCVD furnace**
  - **Permeable polysilicon lid (no hole to seal)**
  - **Aluminum or other metal has been evaporated or sputtered to seal the hole in the cover**

# *INTEGRATED MEMS PACKAGE*

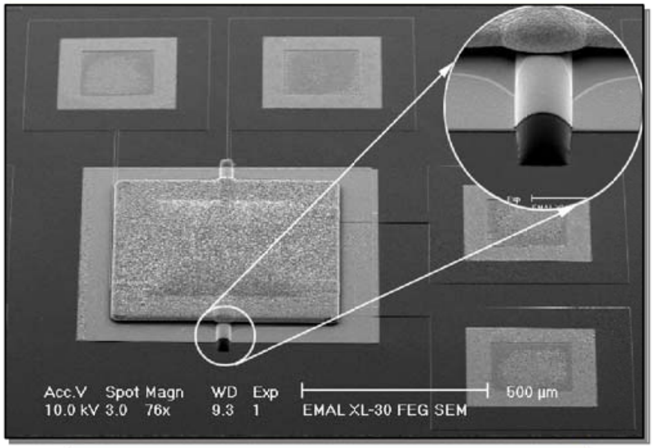



Electroplated nickel packages prior to sealing – note the variety of geometries possible

800μmX800μm package takes~2.5 hours to clean and release




Electrical Feedthroughs




Fluidic Access Port

Brian Stark, U of Michigan

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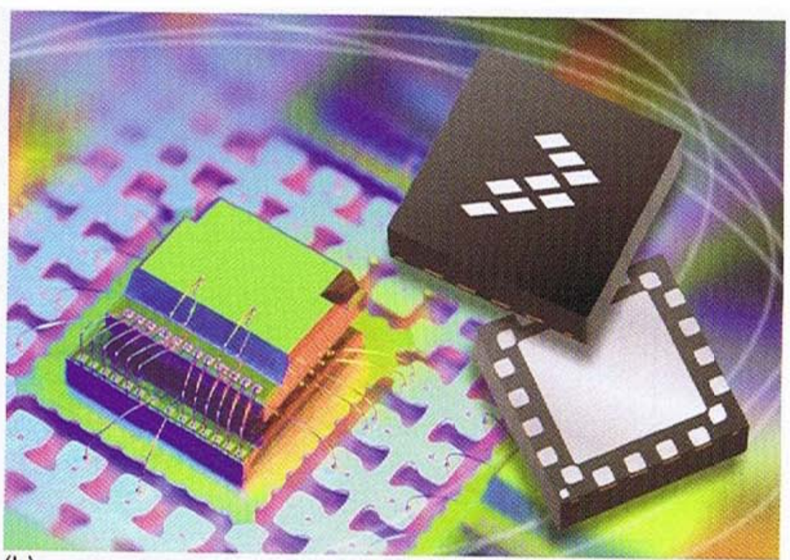
# *OUTLINE*

- Integrated Package
- **Wafer Bonding**
  - Fusion
  - Anodic
  - Glass frit
  - Thermocompression
  - Solder
- MEMS packaging issues

# *WAFER BONDING*

- Wafer bonding is a process that has been compared to alchemy
- Very dependent on surface finish and surface conditions (cleaning)
- In principle (not in practice), almost any materials can be bonded together if the surfaces are flat and clean enough and if the van der Waals forces are strong enough
- Bonding forces include van der Waals (dipole), capillary (water), and electrostatic.  These then can lead to covalent bond


(b)

- Wafer bonding provides a cover that protects the MEMS device
- This process is often used in high volume manufacturing

Devices from Freescale Semiconductor
MEMS:Applications M. Gad-el_Had ed.

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# WAFER BONDING CONSIDERATIONS

- Particle/defect coverage
- Wafer warpage
- How to get lines out
- Temperature
- Force
- Processing considerations
- Types of wafers used

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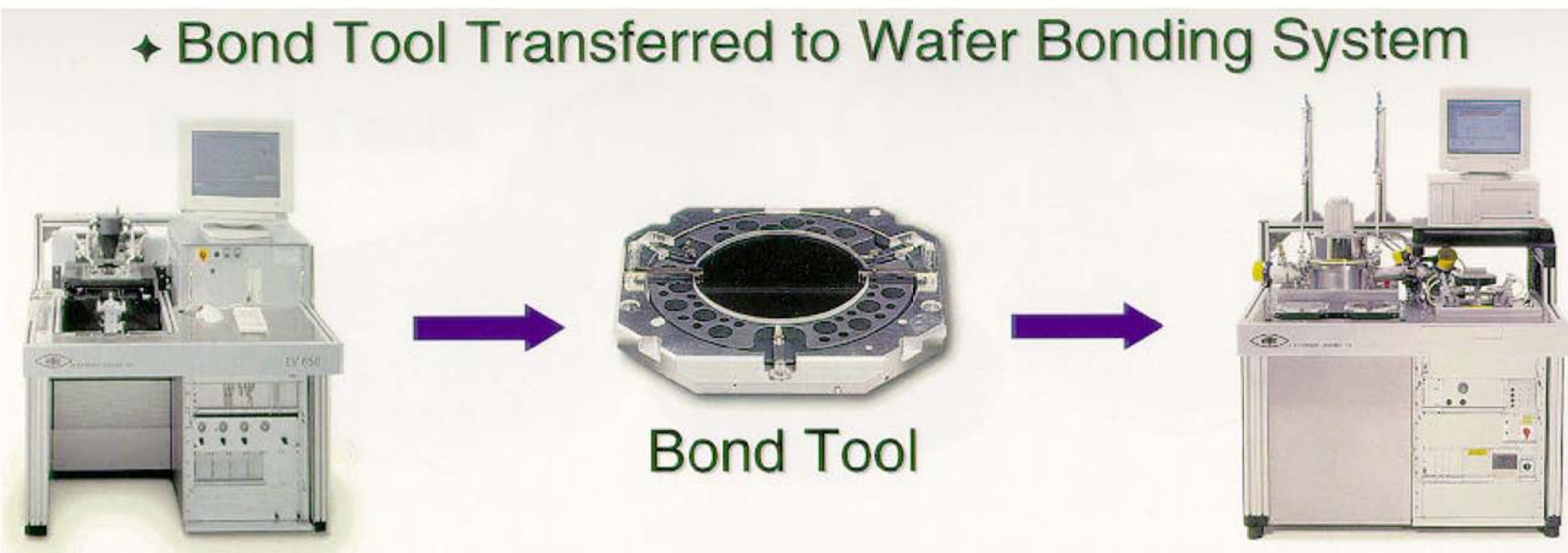
# *OVERVIEW OF BONDING METHODS*

| Bonding Method | Temperature | Hermeticity |
|---|---|---|
| Epoxy | Low | No |
| Eutectic | Medium | Yes |
| Anodic | Medium | Yes |
| Fusion | Very High | Yes |
| Integrated Process | High | Yes |

From MEMS Packaging, Tai-Ran Hsu ed

# *BONDING EQUIPMENT*

- **2 processes**
  - **Alignment of the wafers**
  - **Bonding of the wafers together**
- **Wafer Aligner: Positions(±2μm) up to 3 Wafers Together In a Transport Fixture for Bonding**
- **Bonder: Accepts Fixture and Bonds Wafers Using Heat, Pressure, or Voltage**
- **Bonding Methods: Anodic bonding; Silicon Direct; Epoxy; Glass Frit; Thermocompression; Solder**



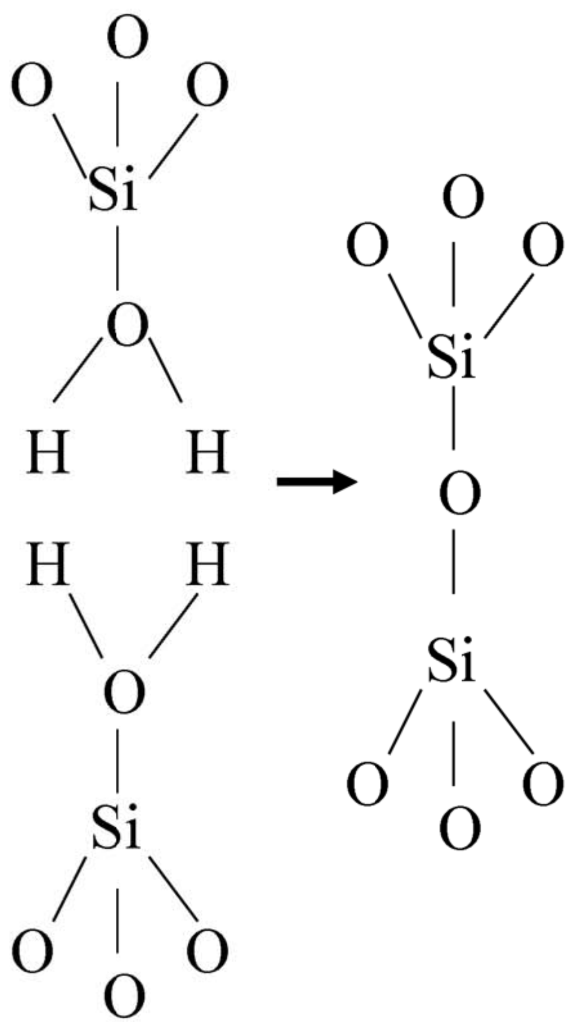

EV Group Bond System

# FUSION BONDING

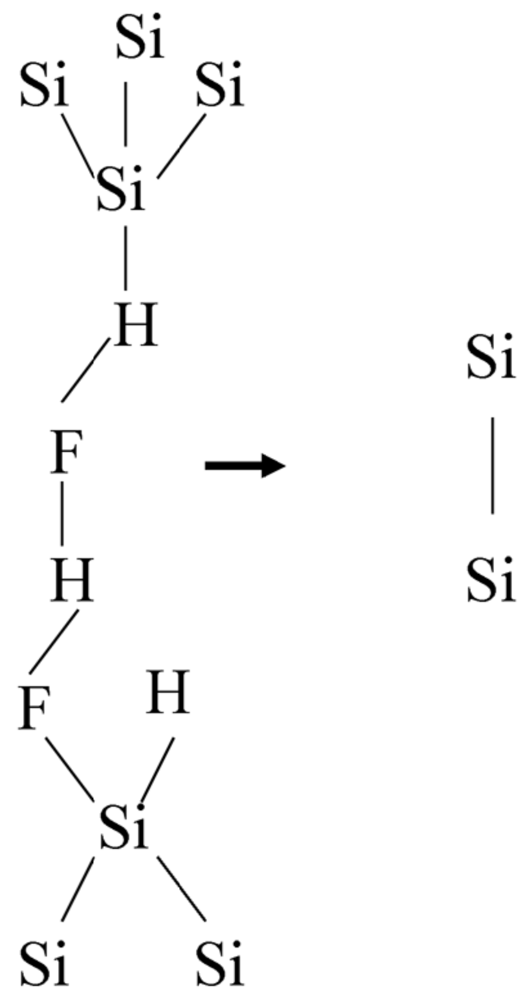
- Needs very smooth surfaces (5Å roughness) NO PARTICLES
- Hydrophilic or hydrophobic surfaces (surface preparation VERY important)
- Hydrophilic via boiling nitric acid dip, $H_2O_2$:$H_2SO_4$, and/or $O_2$ plasma
- Hydrophobic via RCA clean and HF dip (less common)
- Both surfaces are brought into contact at room temperature, and then annealed at 800-1100 C
- Bond strengths about 10-20 MPa
- Besides MEMS applications include
  - Silicon on Insulator (SOI)
  - Replacement for epitaxy (bonding instead of growing)

# BONDING MECHANISMS FOR HYDROPHILLIC AND HYDROPHOBIC SILICON

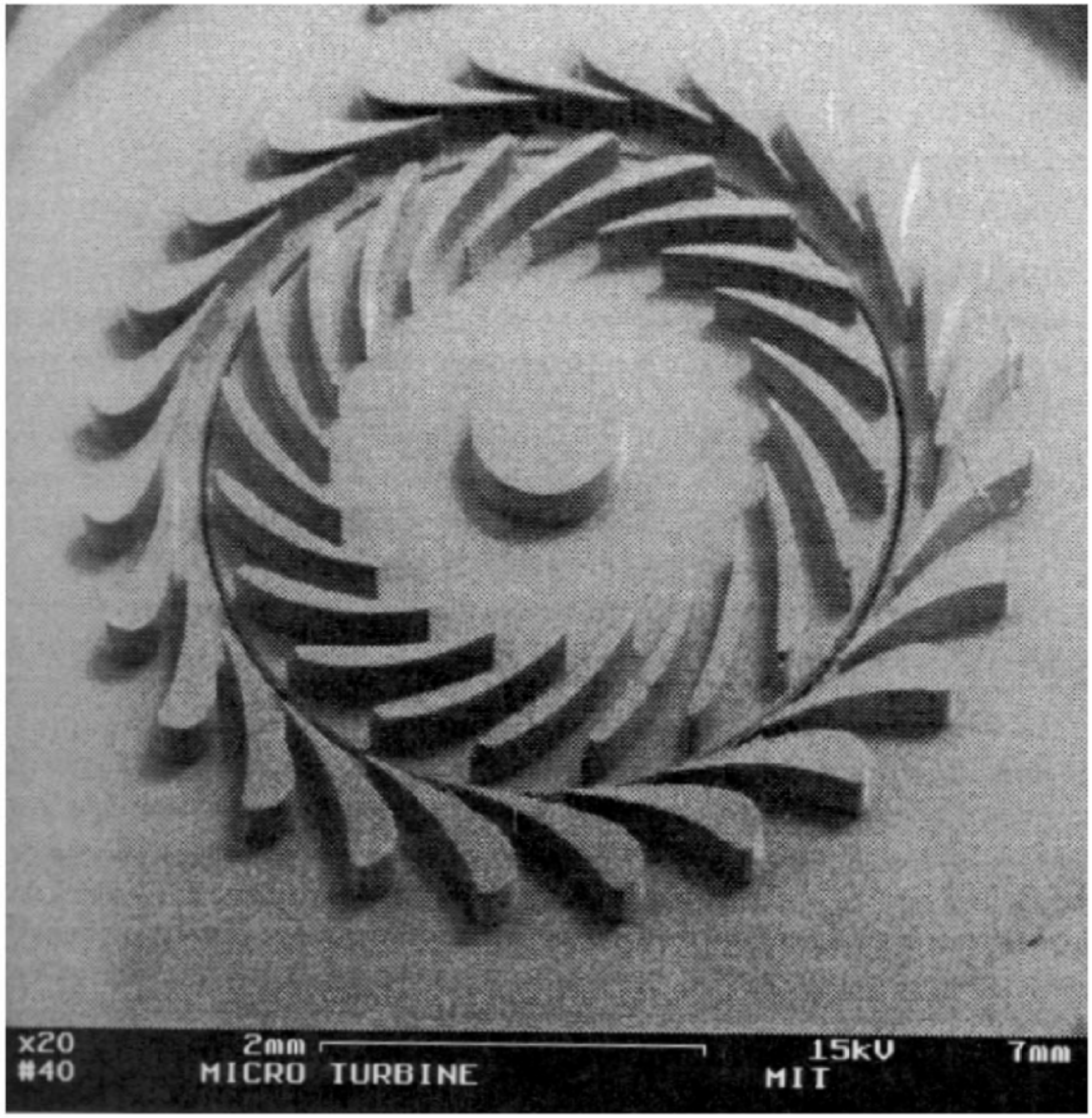
## HYDROPHILIC



## HYDROPHOBIC



# MIT FUSION BONDED µTURBINE




M. Schmidt, MIT

# *PLASMA ACTIVATED BONDING*

- Plasma activated bonding can reduce the temperature required for fusion bonding to room temperature
- However, the surfaces must be extremely flat and clean
- See Suss Microtec and Ziptronix among others for more information  www.suss.com www.ziptronix.com

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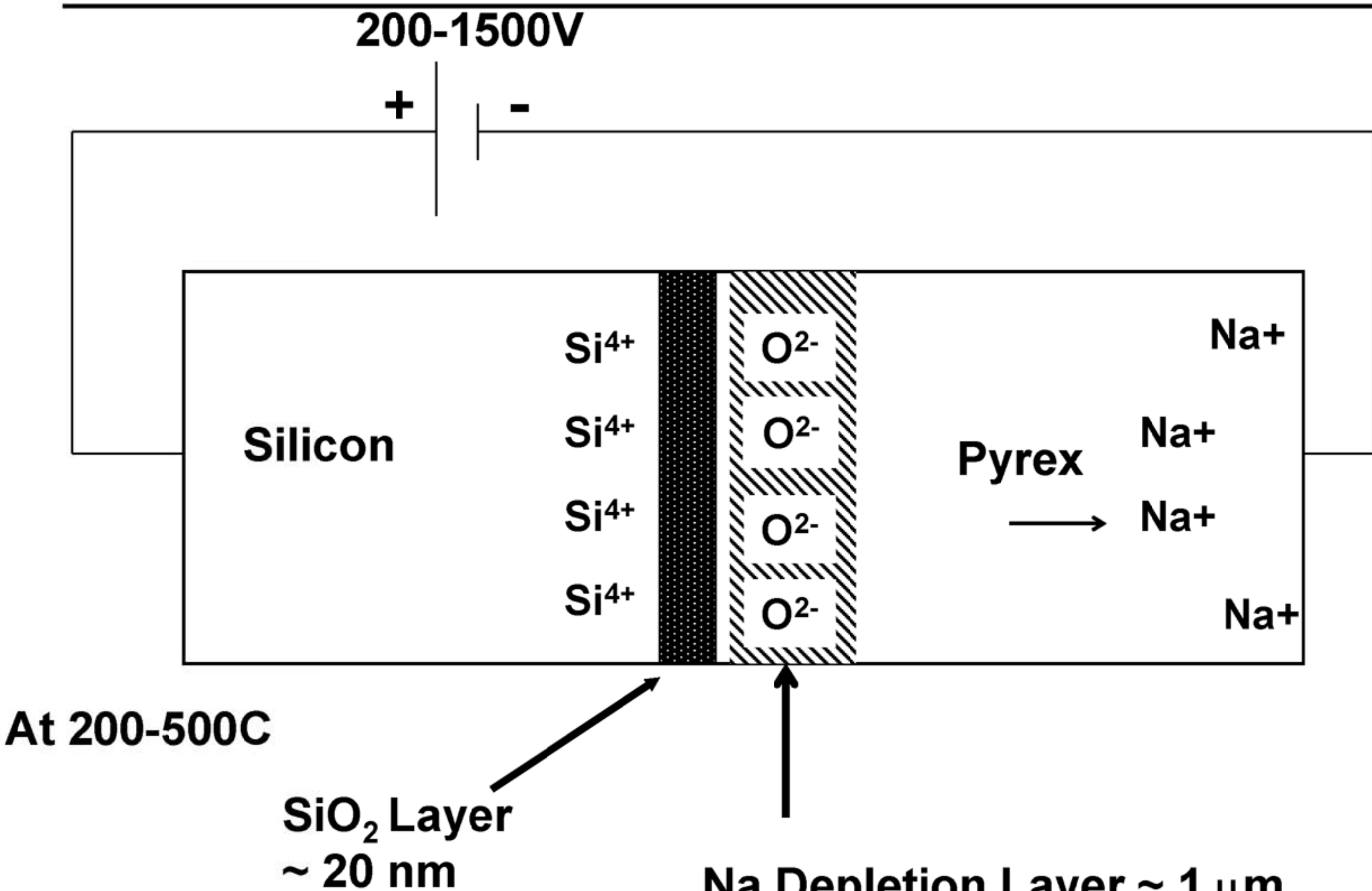
# *ANODIC (ELECTROSTATIC) BONDING*

- **Is done at lower temperatures than fusion bonding 200-500C**
- **Will only work between selected materials (Al, W, $Si_3N_4$, Cr, Ti, $SiO_2$, Si, and glass with mobile ions)**
- **Glass used is typically borosilicate pyrex (Corning 7740) but some other glasses will work**
- **Depending on temperature and voltage will bond over rougher surfaces than fusion bonding (between 50 nm and 1 µm)**
- **You can bond over feedthroughs, steps and particles**
- **Silicon and pyrex have closely matched TCEs**

# *ANODIC BONDING MECHANISM*

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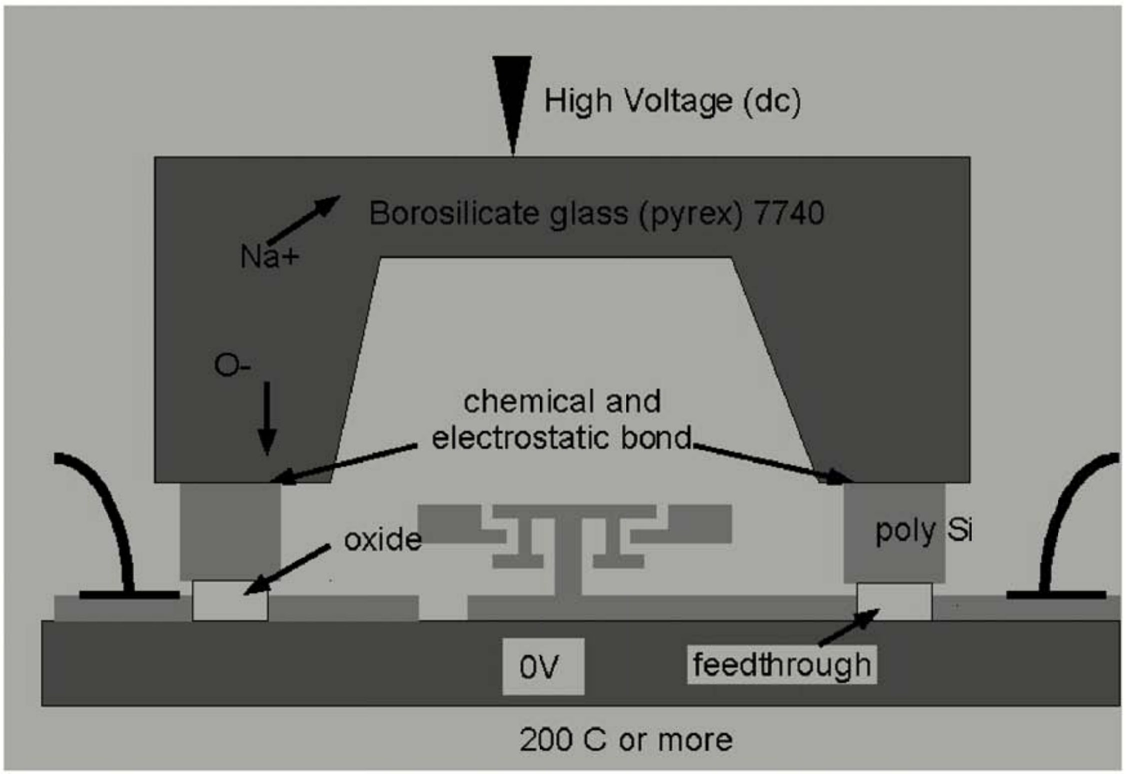
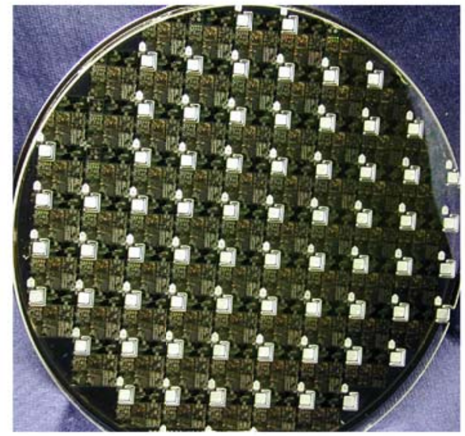
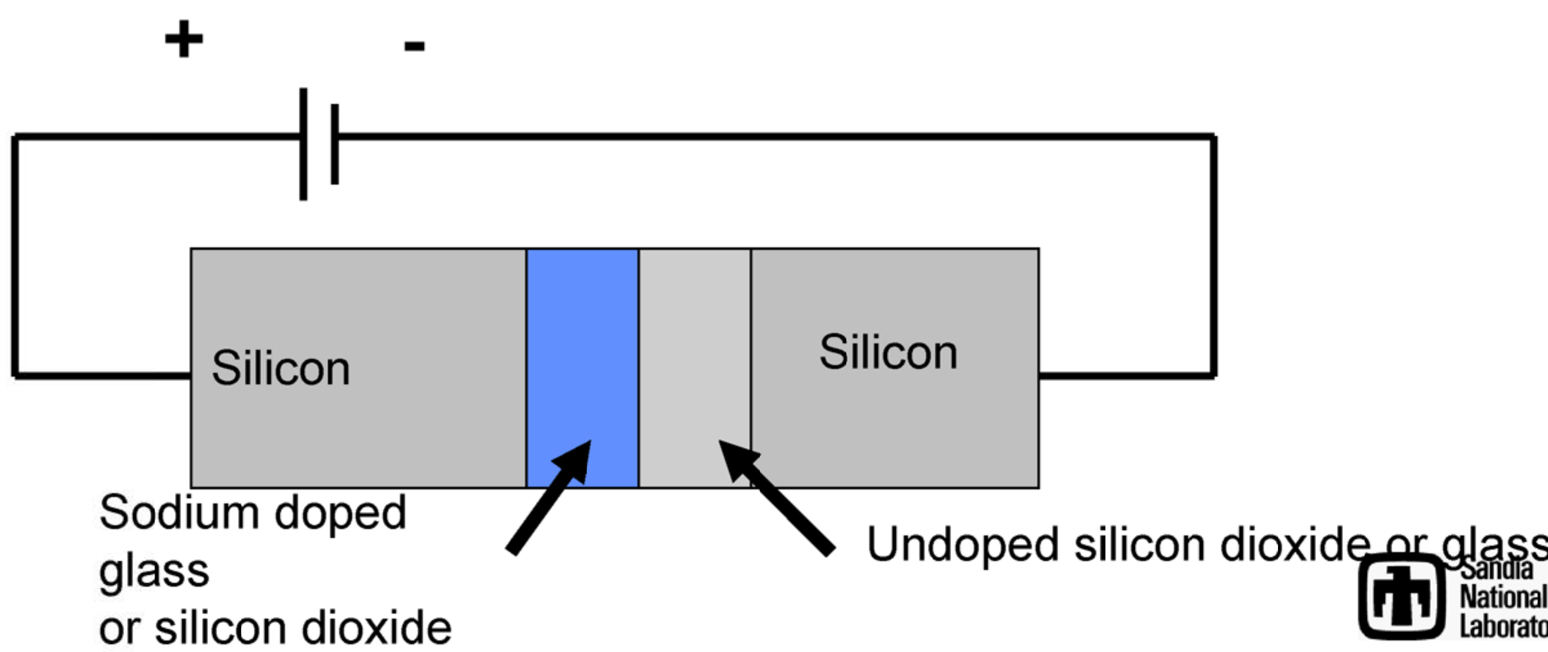
# SURFACE MICROMACHINE WAFER LEVEL PACKAGING



## *ANODIC BONDING WITH THIN FILMS*

- **Thin films of either silicon dioxide or glass doped with sodium**
- **Can be used to bond silicon to silicon or other non glass substrates**
- **Uses a higher temperature and longer bonding time than regular anodic bonding**



# *GLASS FRIT*

- **Does not use high voltages**
- **Uses moderate temperatures**
- **Will not short out metallic signal lines**
- **Robust and reliable bonding technique**
- **Limited requirement for planarity because the glass frit will deform**

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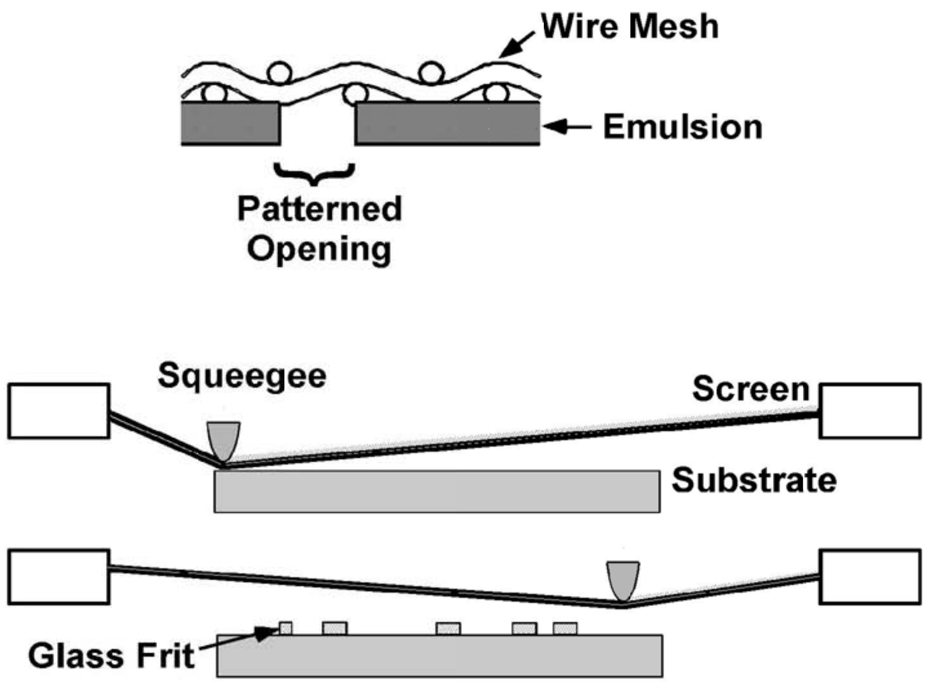
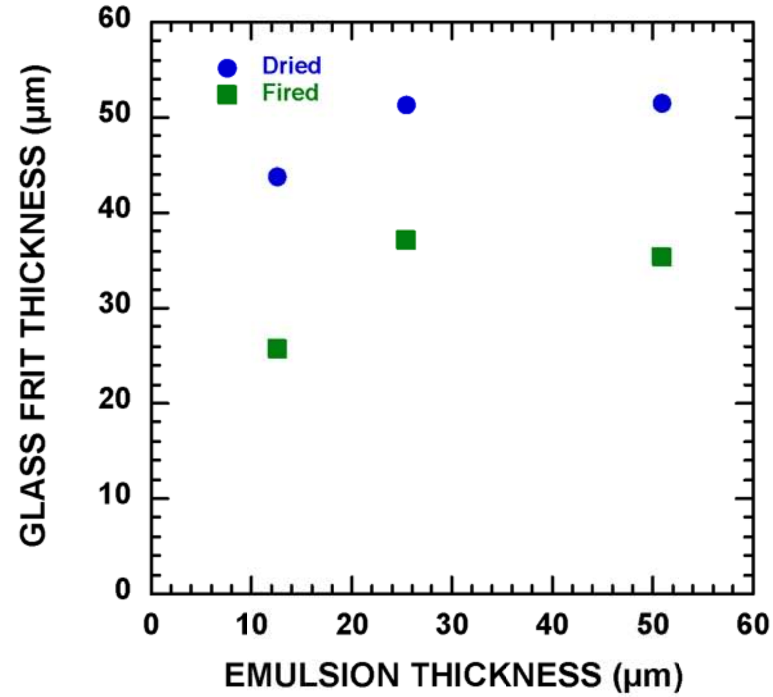
# GLASS FRIT SCREEN PRINTING




- Photopatterned Screen for Bond Ring Patterning: No Lithography
- Stainless Steel Screen 200 mesh, 45 °angle
- Wire Diameter 40.64 µm
- Emulsion Thicknesses from 12.5 to 50.8 µm
- Glass Frit Paste FX11-036

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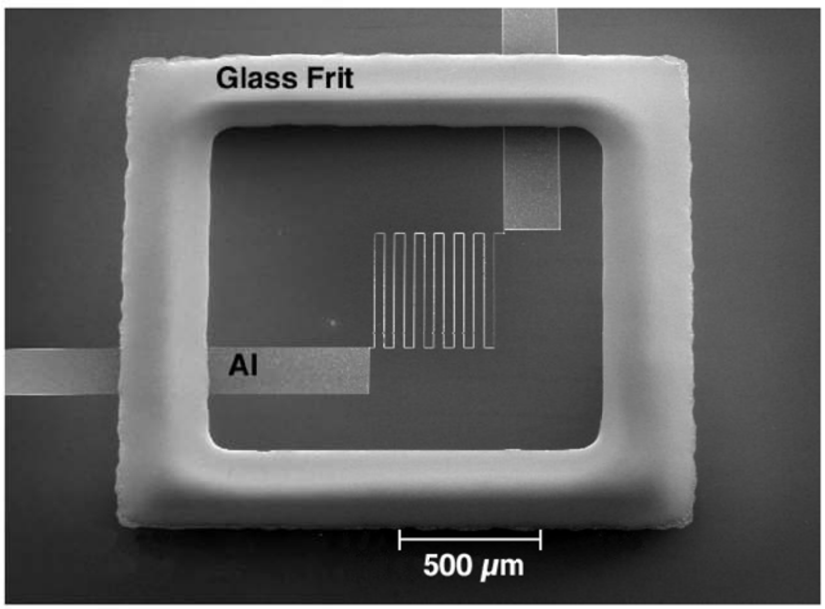
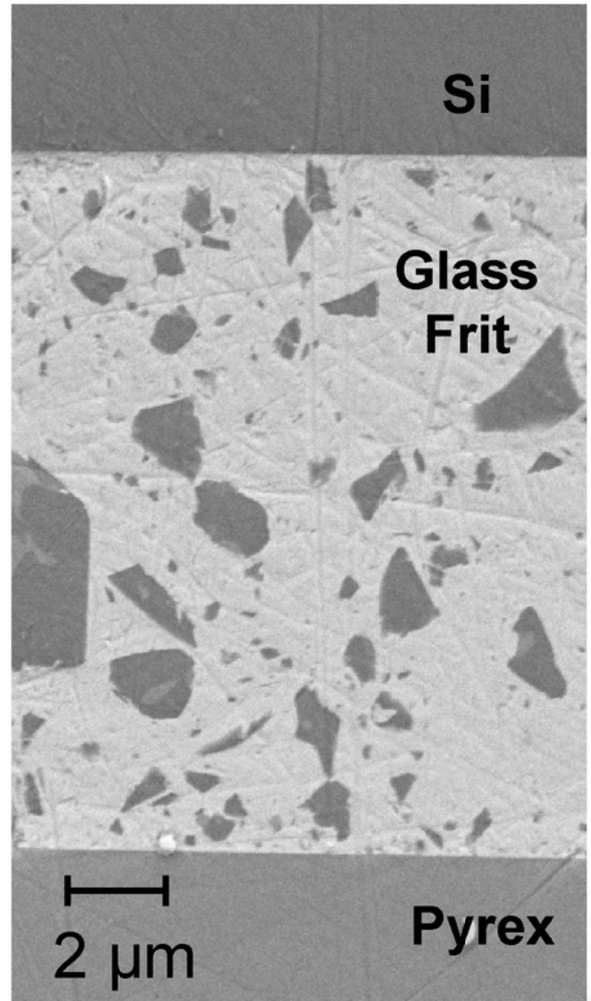
# GLASS FRIT BONDING

- Glass Frit has Refractory Fillers to Modify CTE
- 30 µm-thick Glass Frit on Si
- Bonding of Si to Pyrex at 450 °C for 10 min and 1000 N
- Good Coverage Over Topologies

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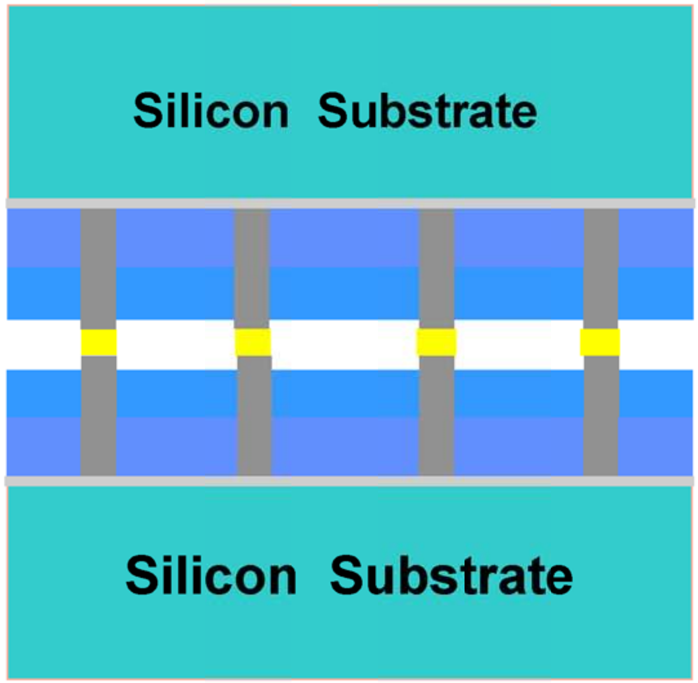
# *THERMOCOMPRESSION GOLD TO GOLD BONDING*




- Provides a conductive interconnection of two substrates
- More difficult process because the gold does not compress more than a few thousand Angstroms

# *EPOXY BONDING*

- Low Temperature, 150 C or less
- Strong, shear 7-15 MPa shear
- Can be electrically conductive or insulating
- Easy to integrate as a last process step
- Shellcase is using epoxy bonding commercially http://www.shellcase.co.il

# *SOLDER BONDING*

Courtesy of Hymite
www.hymite.com

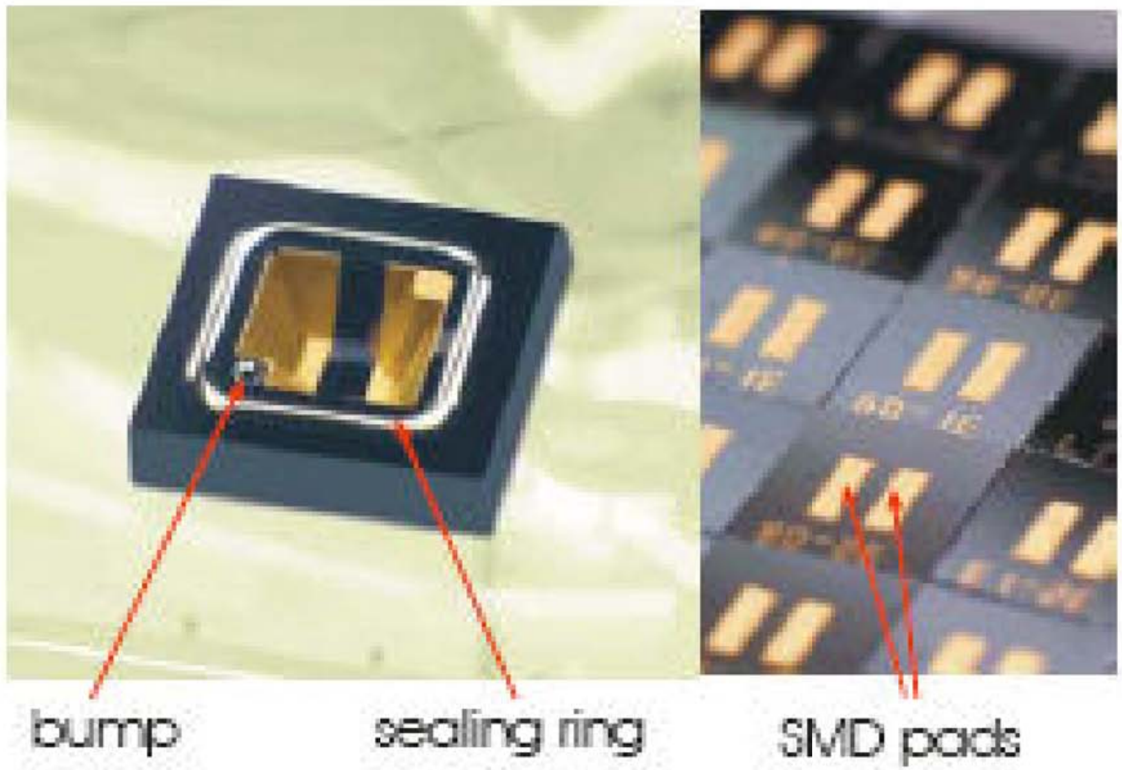
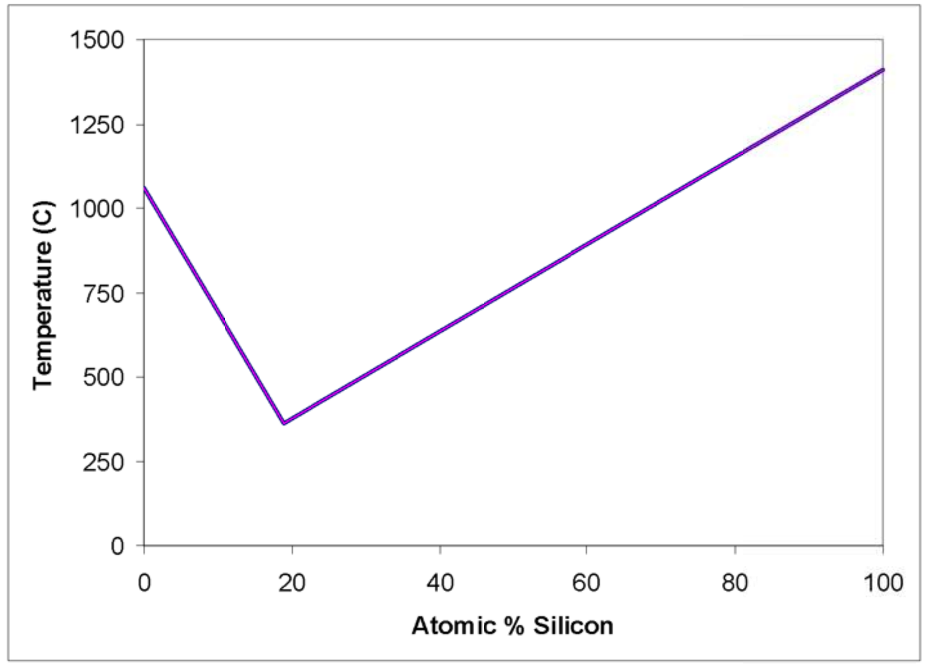



Figure 1 HyCap® cavity side with AuSn sealing ring and bump (left) and HyCap® back side after assembly (right)

- **Works with most types of solders**

# AU:SI EUTECTIC BONDING

- Gold and silicon liquefy into each other
- Sensitive to chemical contamination
- Sensitive to temperature that are too high or low
- Bonding process often require scrubbing
- Sensitive to oxygen in atmosphere
- Sensitive to time at temperature
- Very good thermal conductivity
- Good electrical conductivity
- Good mechanical strength

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# *OUTLINE*

- Integrated Package
- Wafer Bonding
  - Fusion
  - Anodic
  - Glass frit
  - Thermocompression
  - Solder
- **MEMS Packaging Issues**

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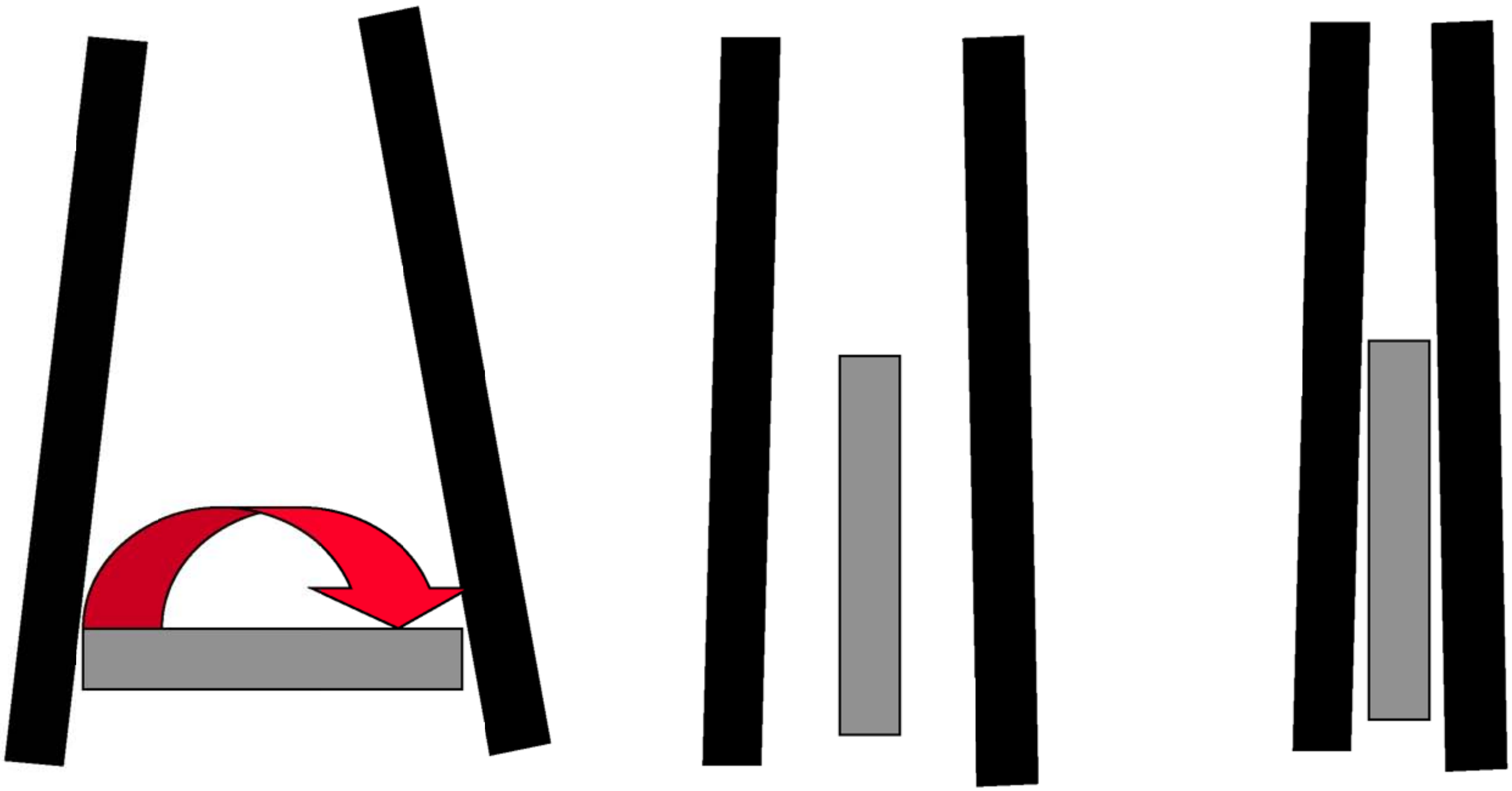
# *MEMS SPECIFIC PACKAGING*

- There are a couple of packaging techniques that are MEMS specific
- However, most MEMS packaging is borrowed from other sources
- However, the considerations of particles, mechanical damage, non standard films, outgassing, and stiction, are unique to MEMS

# MEMS HANDILING WITH TWEEZERS



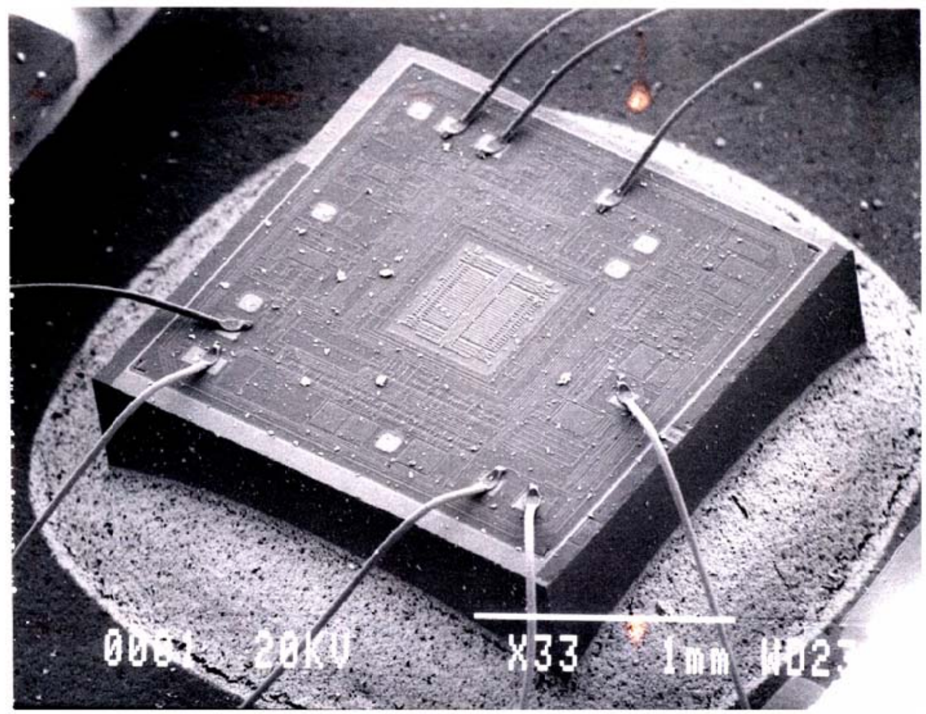
Not a good mass production technique, but works OK for prototypes

1 2 3

Your device is smashed

# MEMS DIE ATTACH

- **Outgassing and temperature are concerns**
- **Solder — Eutectic Au/Si (370°C), Au/Sn (280°C)**
- **Epoxies (70-80% Ag, silica filled)**
  - **Typical cure 150°C, 30-60 minutes**




Epoxy Die Attach
Analog Devices ADXL-50

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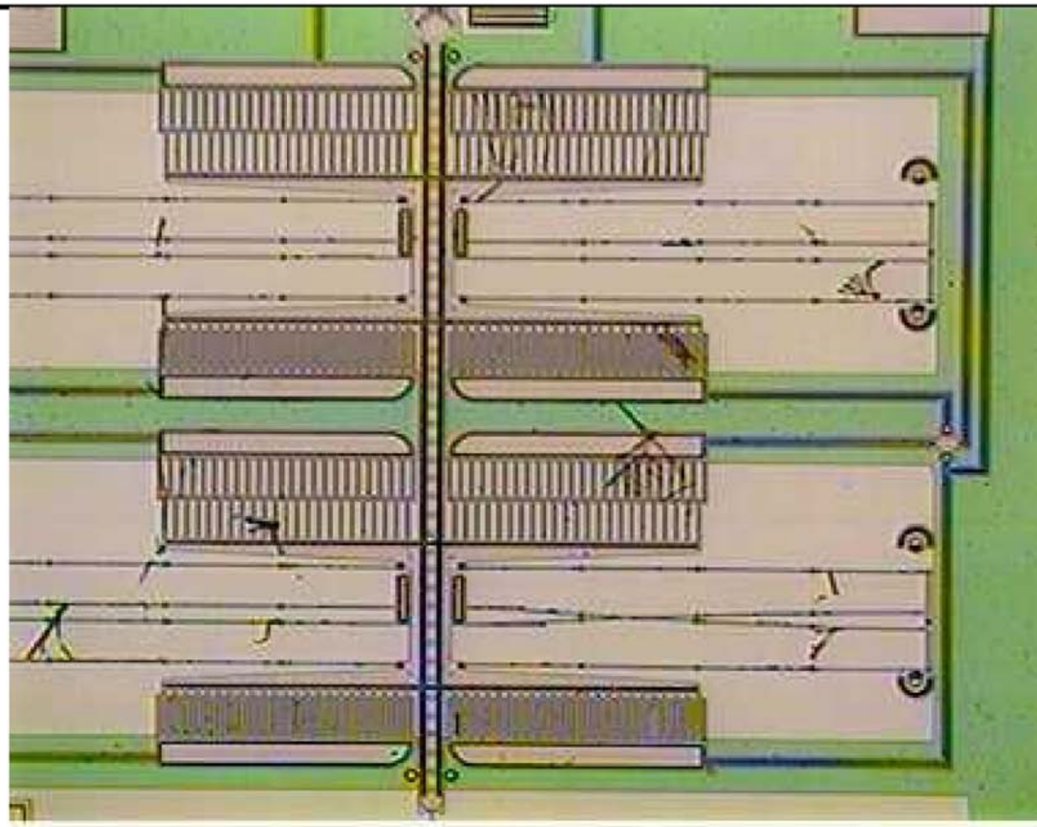
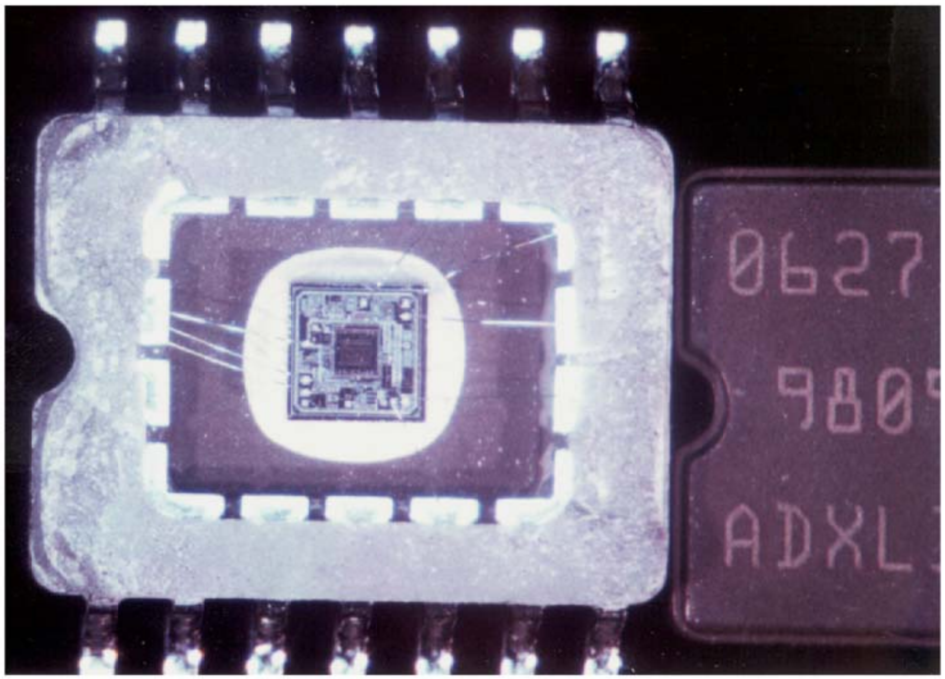
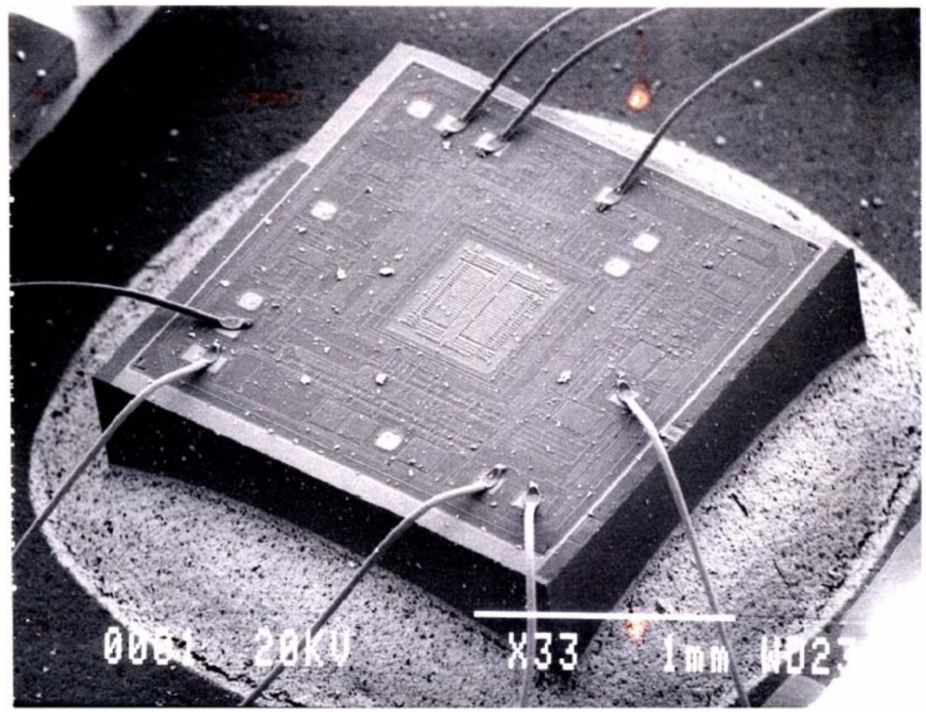
# PARTICLES AND MEMS



- Unlike ICs, MEMS with moving parts must be packaged in a particle free environment

# PACKAGED SURFACE MICROMACHINE

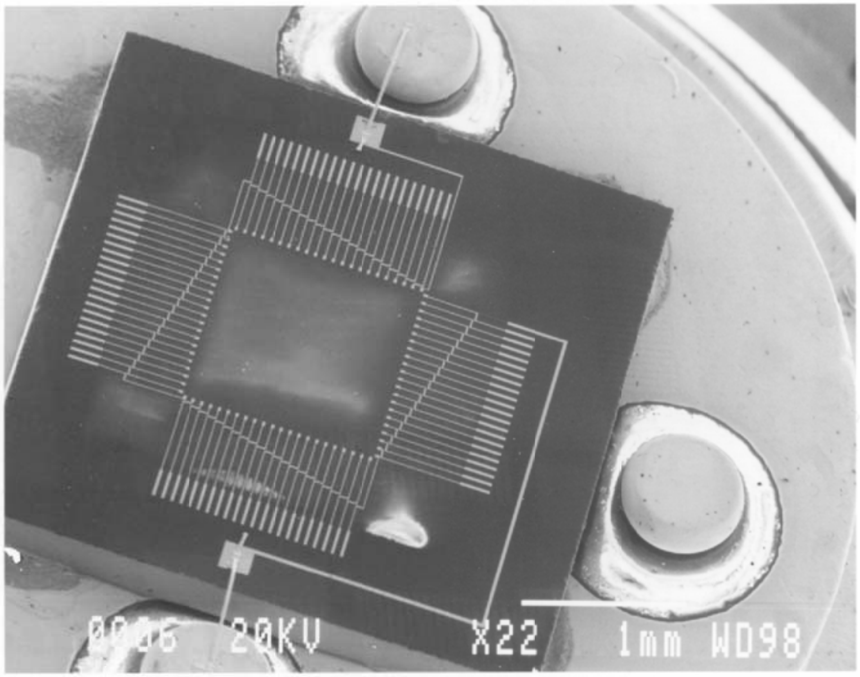



- **Hermetic ceramic package**

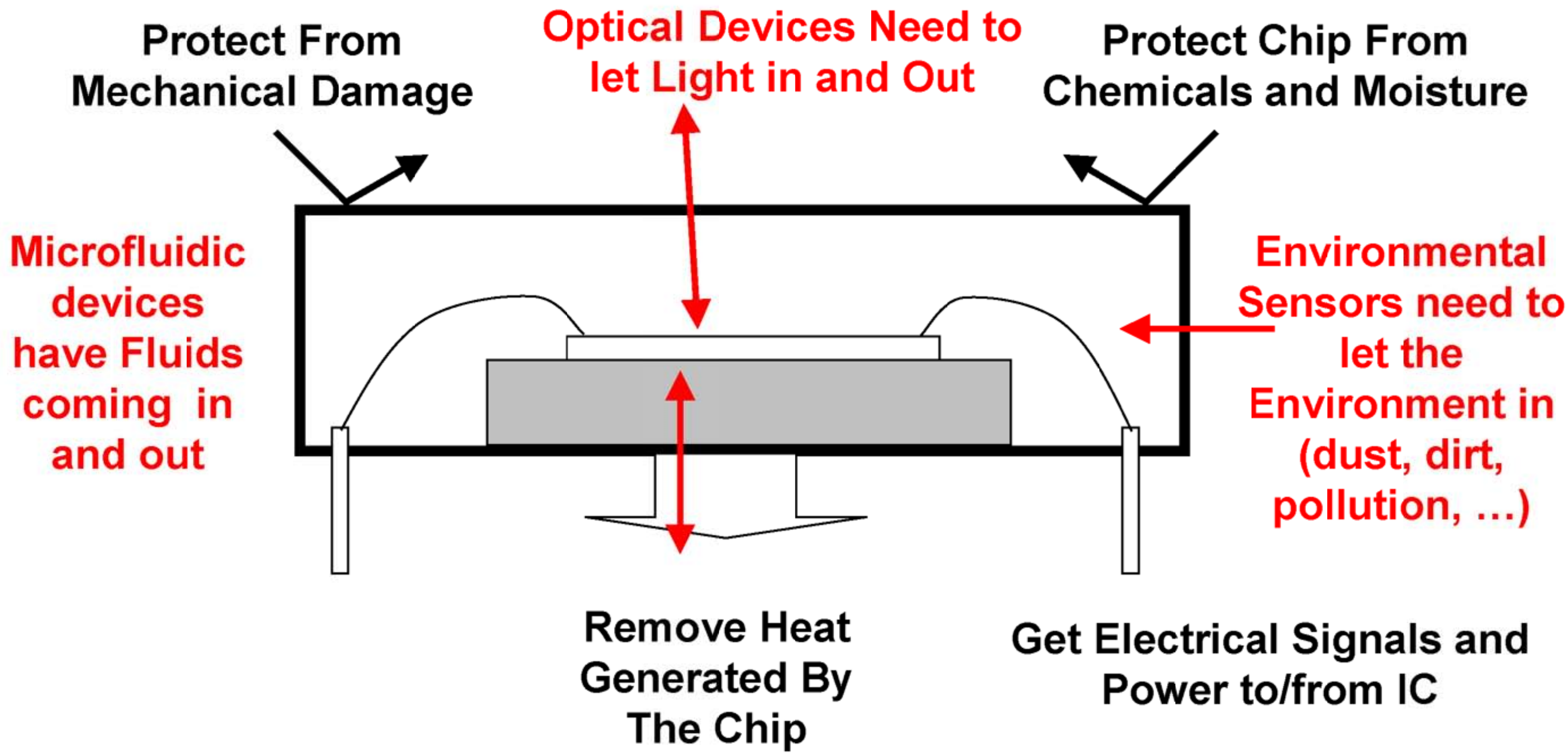
Analog Devices ADXL-50

# *MEMS PACKAGING EXAMPLE*




- **S150 bulk micromachined infrared detector from Dexter Research Center**
- **Welded TO can package with optical window**
- **Proprietary infrared absorbing layer (black)**

# GOAL OF MEMS PACKAGING




Don't Limit Performance

Low Cost

- So how do we get chemicals in?

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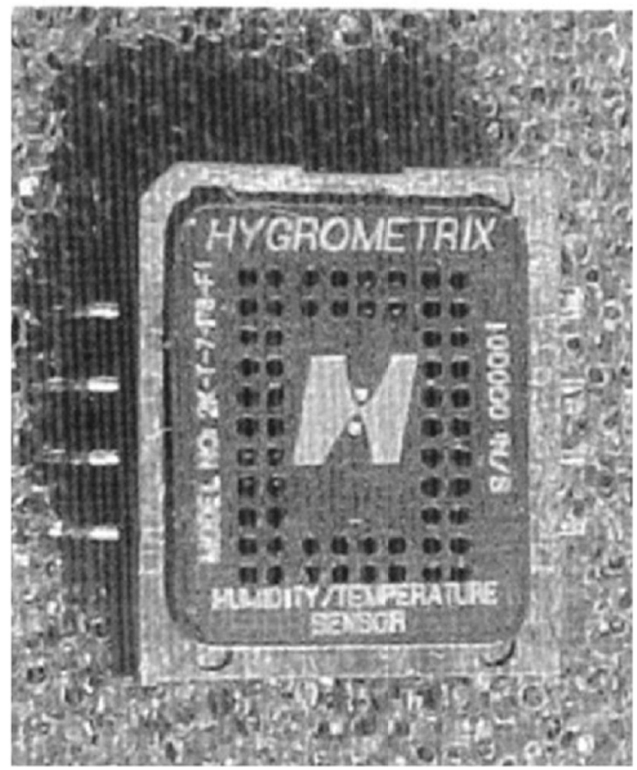
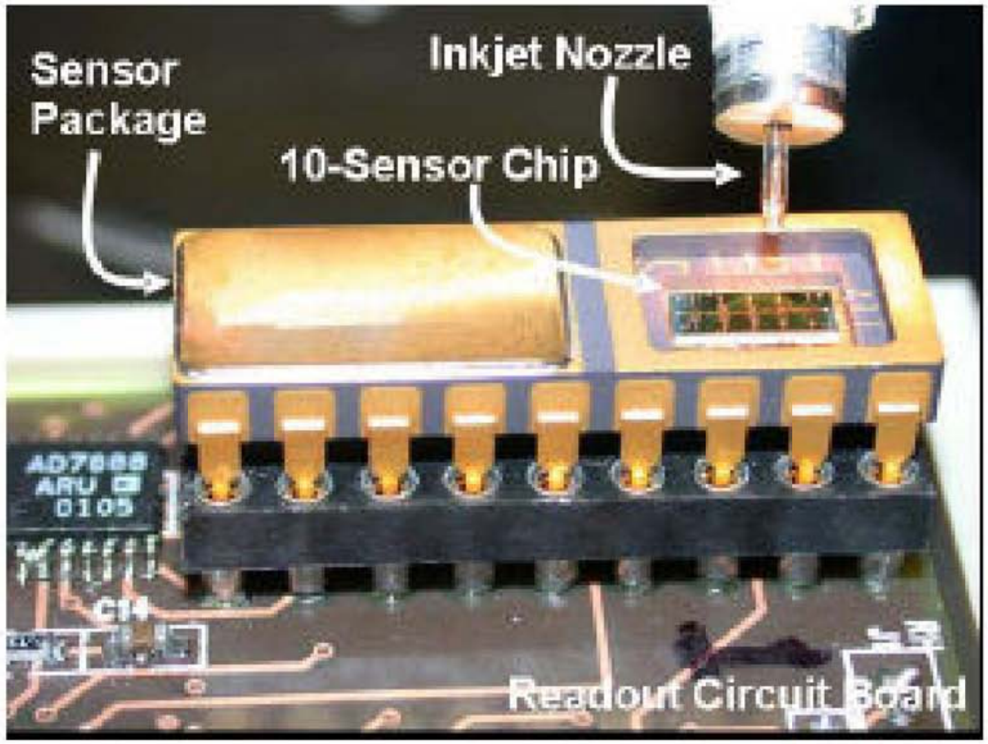
# ENCAPSULATION

- Most sensors do not use fancy encapsulation schemes to protect them from the environment
- The Hygrometrix humidity sensor uses holes in the package lid



# SEACOAST SENSOR




- **Sensor is protected by a fine screen**
- **Readout chip is hermetically sealed**

# *ENCAPSULATION*

- Many readout circuits in chemical sensors are protected
- Especially in liquid sensor applications these encapsulates must have very good adhesion
  - 2 part epoxies must have no bubbles (vacuum aeration)
  - Silicone rubbers
    - Moisture resistant
    - Good adhesion
  - Parylene (thermoplastic polymer)
    - Vacuum deposited
    - Conformal coating
  - Wafer bonding
    - Hermetic and expensive and perhaps high temperature

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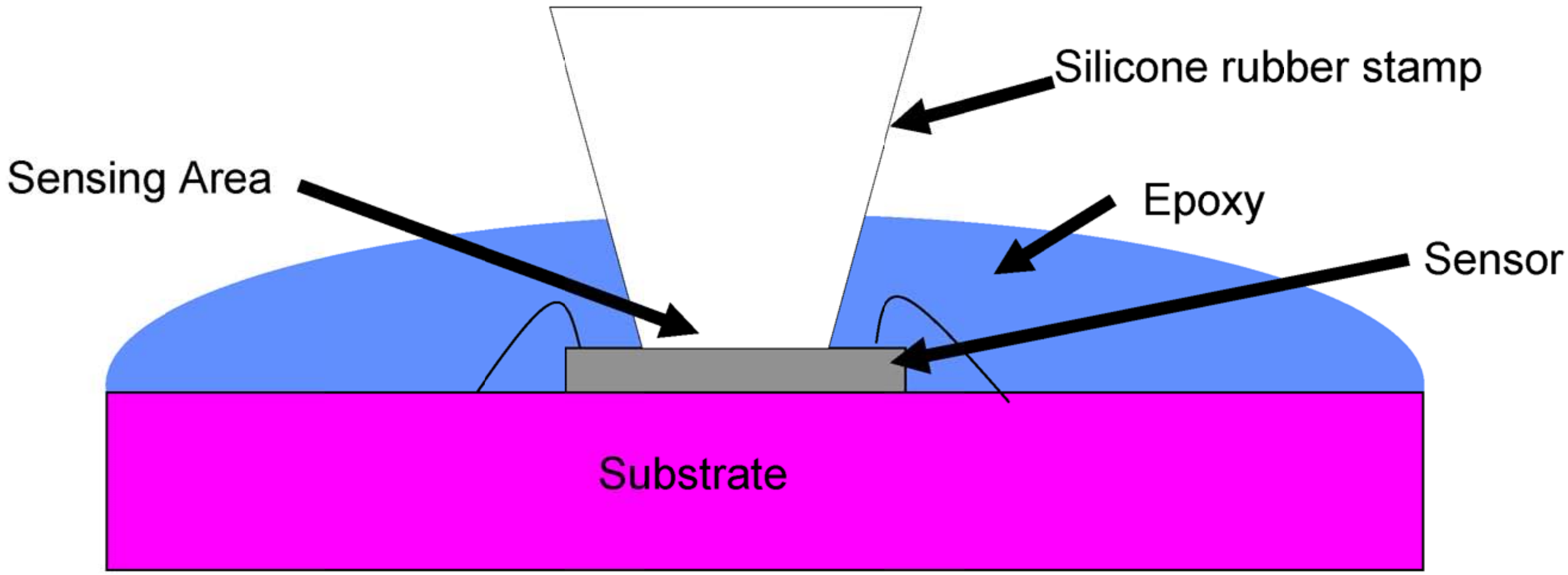
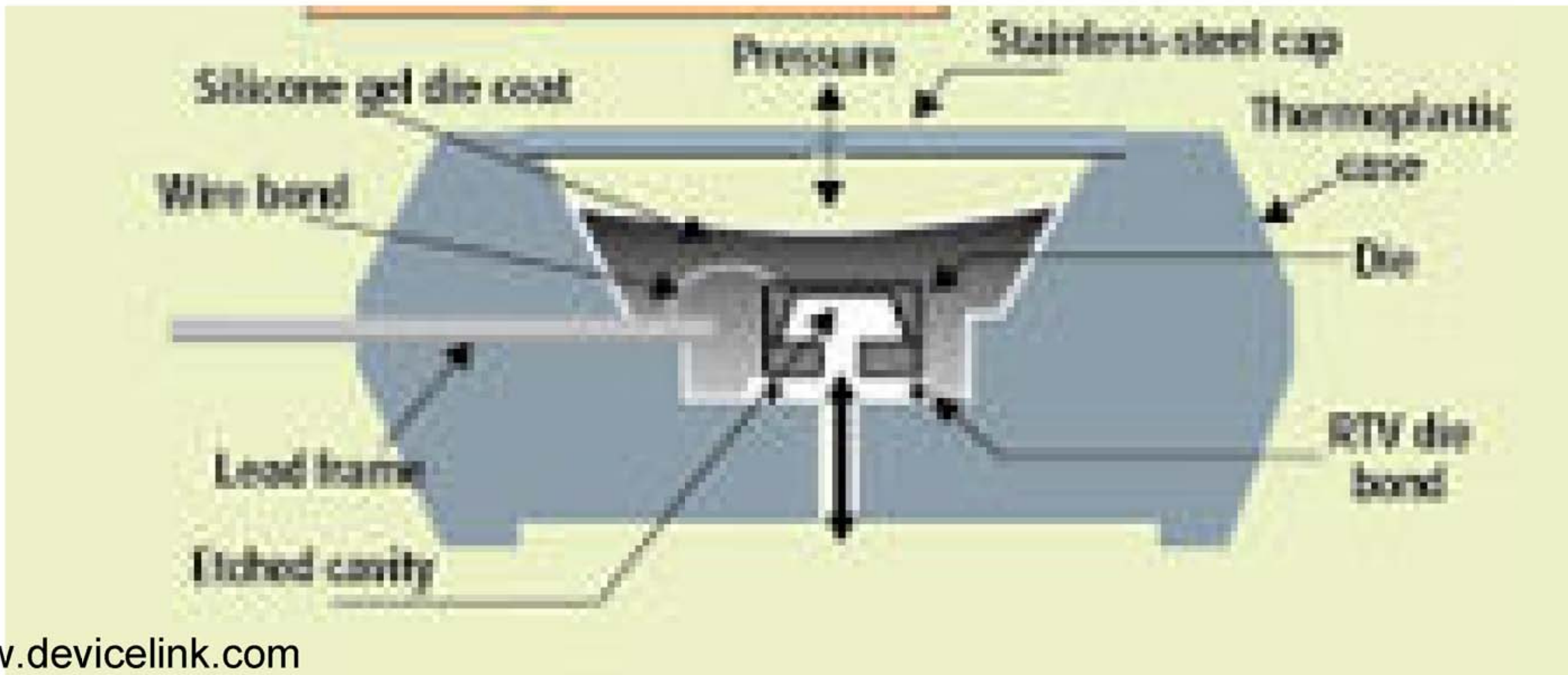
# STAMP ENCAPSULATION METHOD



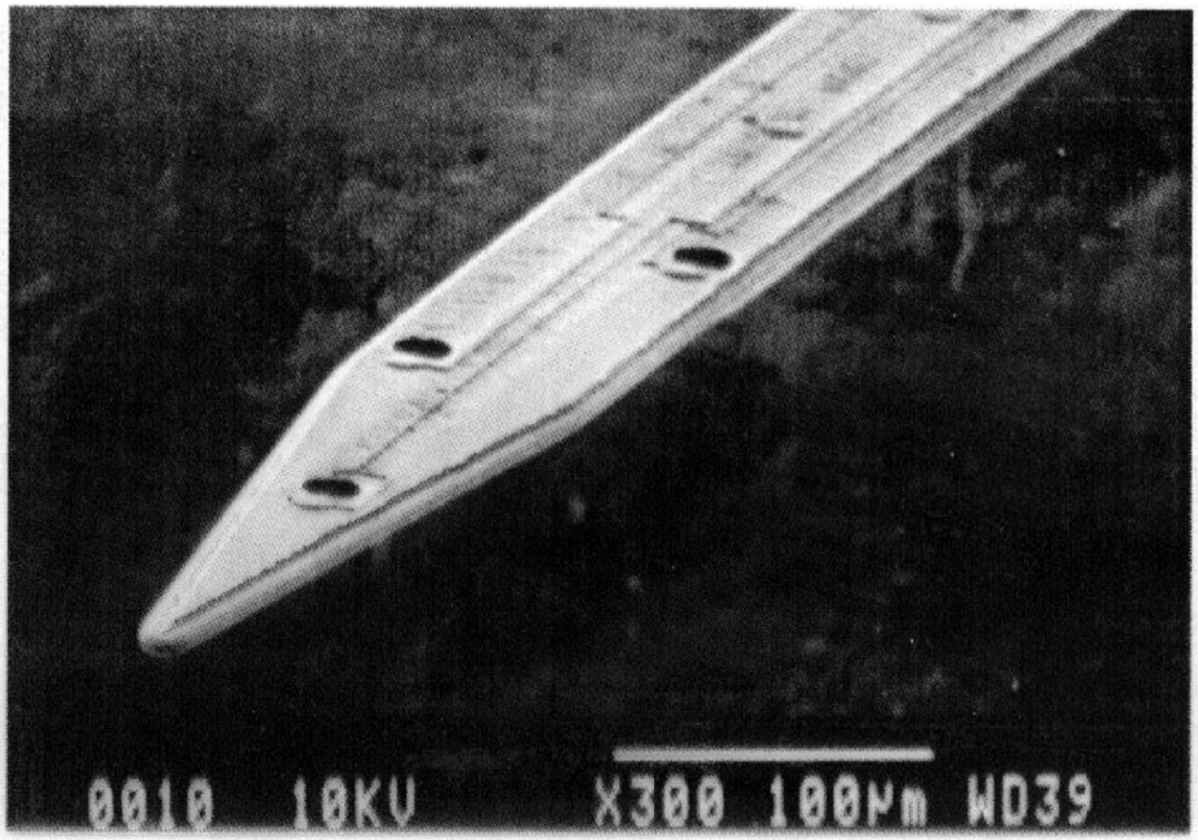
# *PACKAGING OF AN AUTOMOTIVE PRESSURE SENSOR*

- **Sensor element is isolated from the medium**
- **Other types of pressure sensors are bonded or fabricated on the backside of the steel cap**




www.devicelink.com

# SOME DEVICES ARE THEIR OWN PACKAGE




**Neural Probe**

**JK Chen, the University of Michigan, now with the University of New Mexico**

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# MEMS PACKAGING CONCLUSIONS

- No general solution typically custom
- Based on IC packaging
- Surface micromachines require special handling, surface films, and protection from particles
- The main issue with MEMS packaging is that it is application specific
- In contrast, IC packaging is not application specific and has 40 years of experience behind it.

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# *REFERENCES*

- MEMS Packaging Tai-Ran Hsu, ed. Chapters 2 and 3
- Microsystem Packaging by R. Tummala
- Plasma activated fusion bonding information at
  - www.suss.com
  - www.ziptronix.com
- Other vendors include
  - http://www.evgroup.com/

# *ACKNOWLEDGEMENTS*

- **Much of this information came from a course I taught at the University of New Mexico on packaging**
- **Other information came from Dr. Ted Dellin at Sandia who co-taught an internal Sandia packaging course with me in 2004 and 2006**
- **Special thanks to Jon Custer, Helena Chan, Brian Stark, JK Chen, Lauren Rohwer, and Melissa Collins whose work is represented here and who provided some of the pictures**