Packaging Issues of MEMS Devices

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Presentation Outline

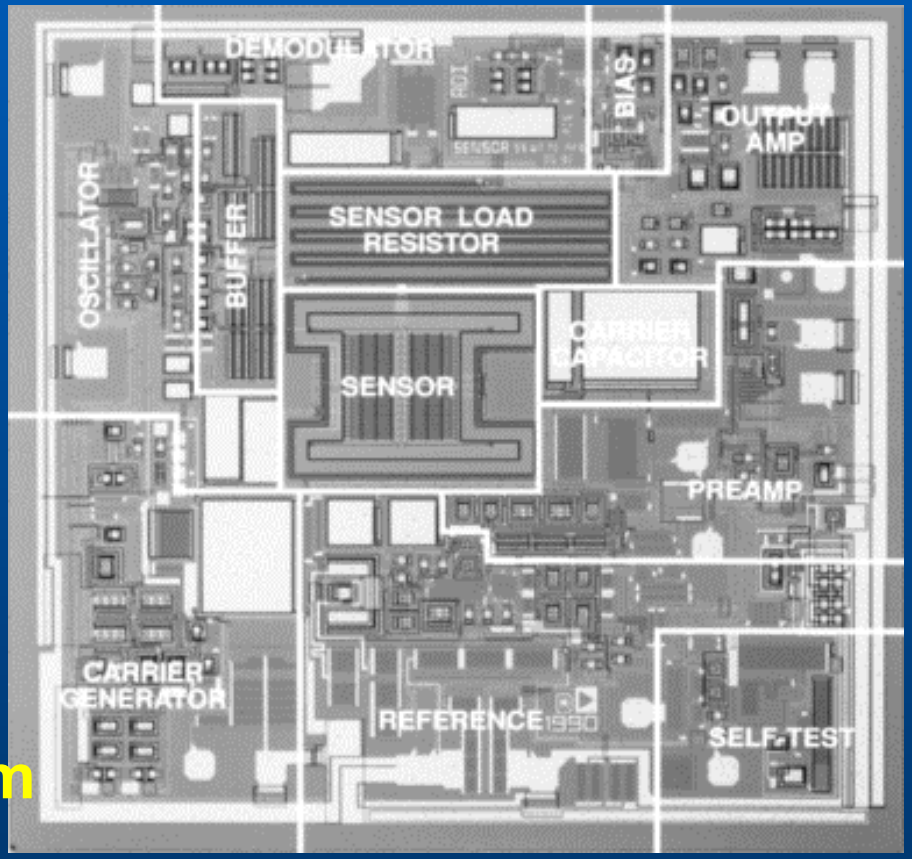
- MEMS Products & Packaging Issues
- Microelectronics Packaging
- MEMS Packaging Approaches
  - Integrated microfabrication processes
  - Water bonding processes
- Summary

Existing MEMS Products

Device	Year	Units (M)	Sale (M)	Comment
Blood Pressure	1998	20	22	price drop, sale flat
Auto MAP	2000	52	400	price dropping
Auto Accelerom.	2002	100	~400	price dropping
Auto Gyro	2002	20	~200	newer market
Ink-Jet Head	2002	470	8,400	huge market
Disk-Drive Head	2002	1,500	12,000	huge market
Head Positioner	2002	400	~800	new market
Displays	2000	1	300	High chip cost
Valves	2005	1~2	100	small market

MEMS Packaging Issues

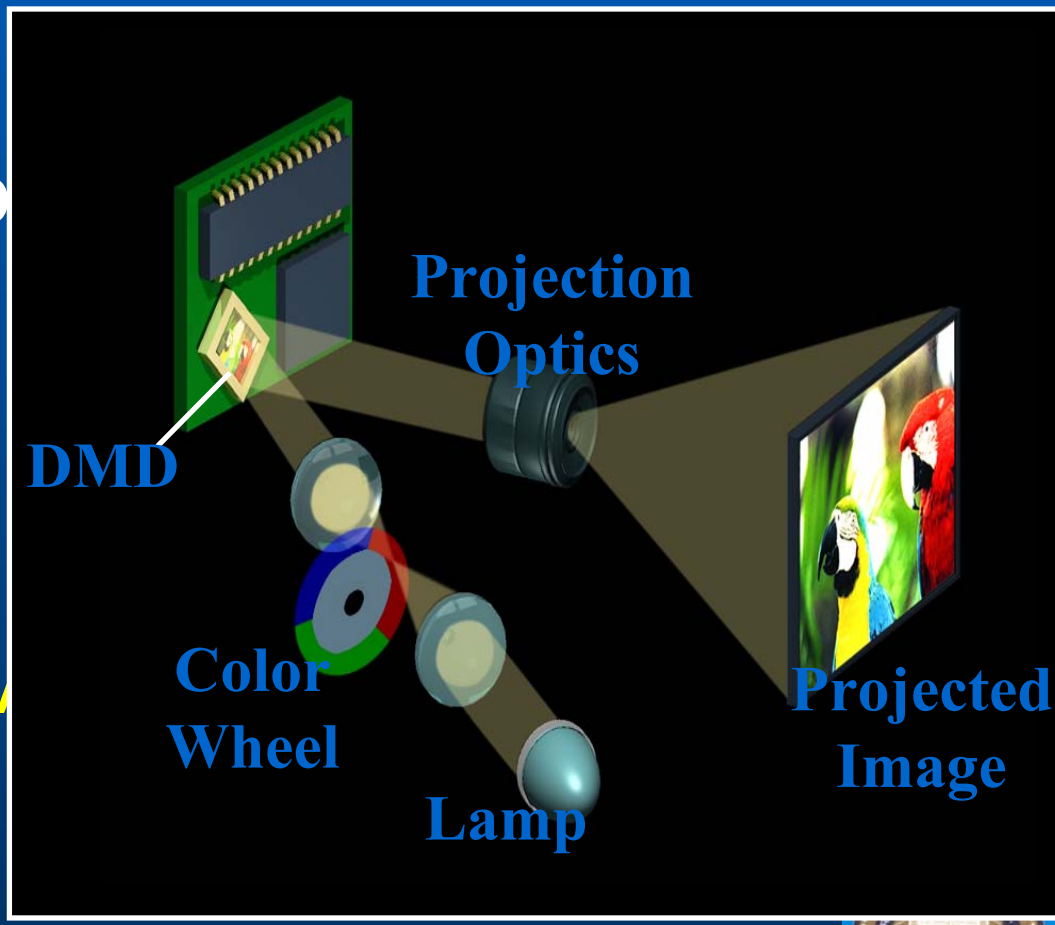
- **MEMS Accelerometer**
  - **Example: Surface-Micromachined Accelerometers by Analog Devices, Inc.**
- **Key Issues**
  - **Free standing microstructures**
  - **Hermetic sealing, Vacuum**
  - **Temperature sensitive microelectronics**



ADXL50 by Analog Devices, Inc.

Example – Optical MEMS

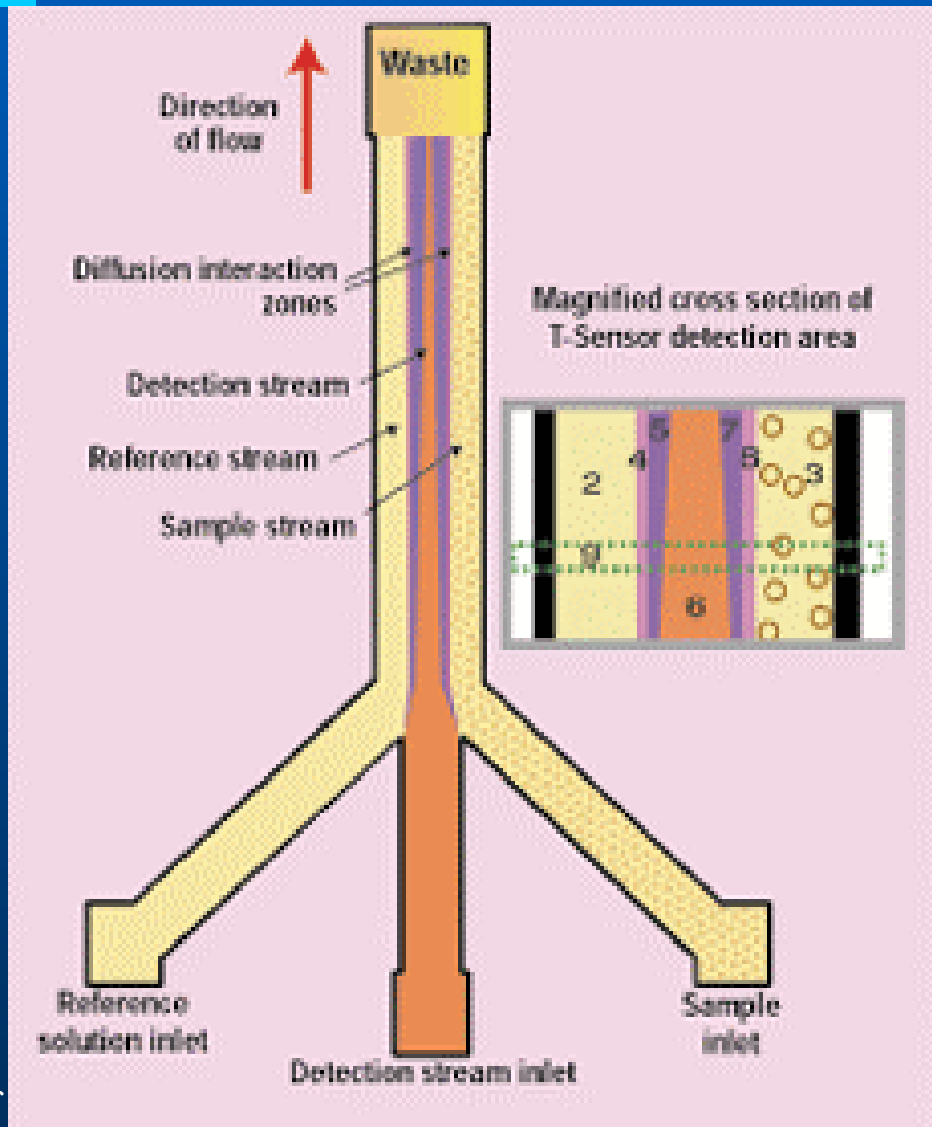
- **Optical MEMS**
  - **Example: surface-micromachined DMD by Texas Instrument**
- **Key Issues**
  - **Free standing microstructures**
  - **Hermetic sealing**
  - **Temperature sensitiv microelectronics**



TI's DMD™ Chip for Projection Display

Example – BioMEMS & Microfluidics

- **Microfluidics**
  - **Example: diffusion-based sensor by Micronics Inc.**
- **Key Issues**
  - **Micro-to-Macro interconnector**
  - **Good sealing**
  - **Temperature sensitive materials**



Micronics Inc.'s T sensor

Example – RF MEMS

- **MEMS Relay**
  - **Example: micromachined RF relay by Omron with a needle (1 billion operation, 0.5 msec)**
- **Key Issues**
  - **Free standing microstructures**
  - **Hermetic sealing**
  - **Vacuum encapsulation ?**

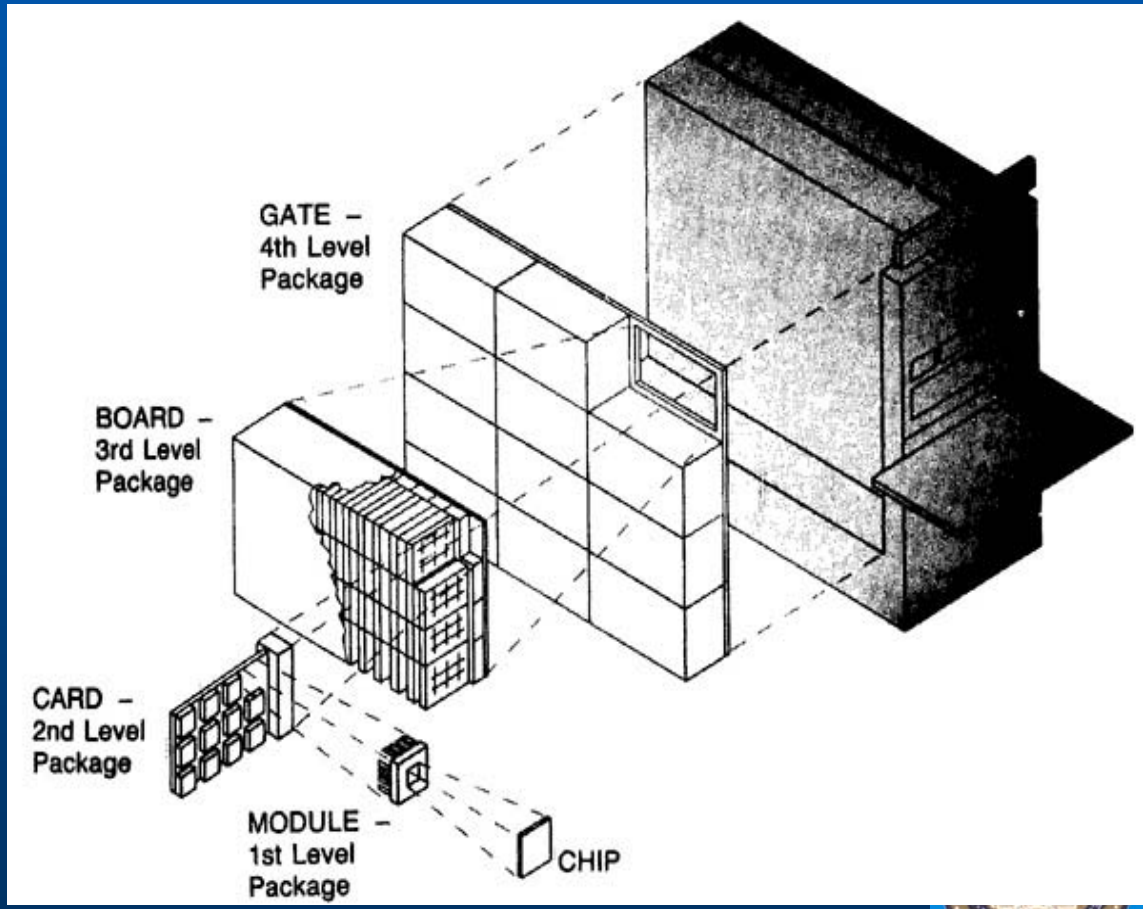
Omron's MEMS RF relay

IC and MEMS Packaging

- **IC Packaging**
  - **well-developed (dicing, wire bonding ...)**
  - **30% to 95% of the whole manufacturing cost**
- **MEMS Packaging**
  - **specially designed packaging processes**
  - **difficult due to moving structures, chemicals ...**
  - **the most expensive process in micromachining**

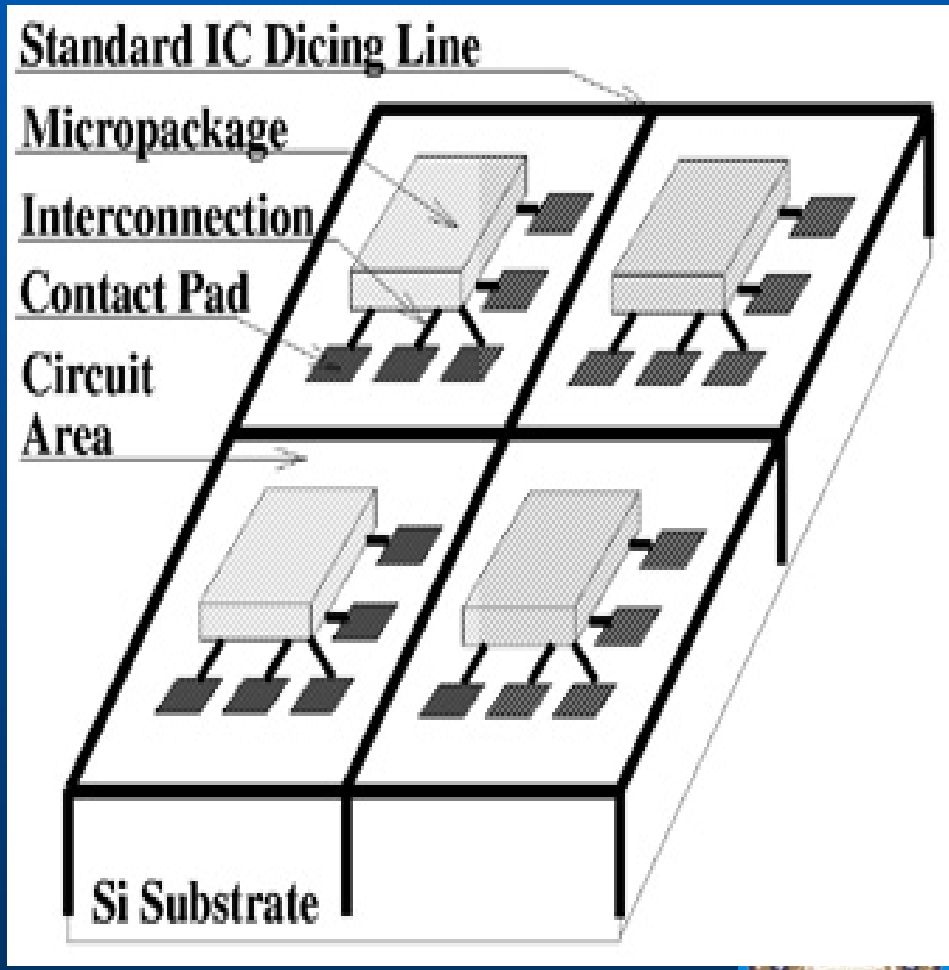
Microelectronics Packaging

- **Electronic Package Hierarchy**
  - **Chip**
  - **Module (1st level)**
  - **Card (2nd level)**
  - **Board (3rd level)**
  - **Gate (4th level)**



Approach

- To adopt IC packaging processes as much as possible
- To protect MEMS devices and follow IC packaging processes
- **Encapsulations** (caps) are required



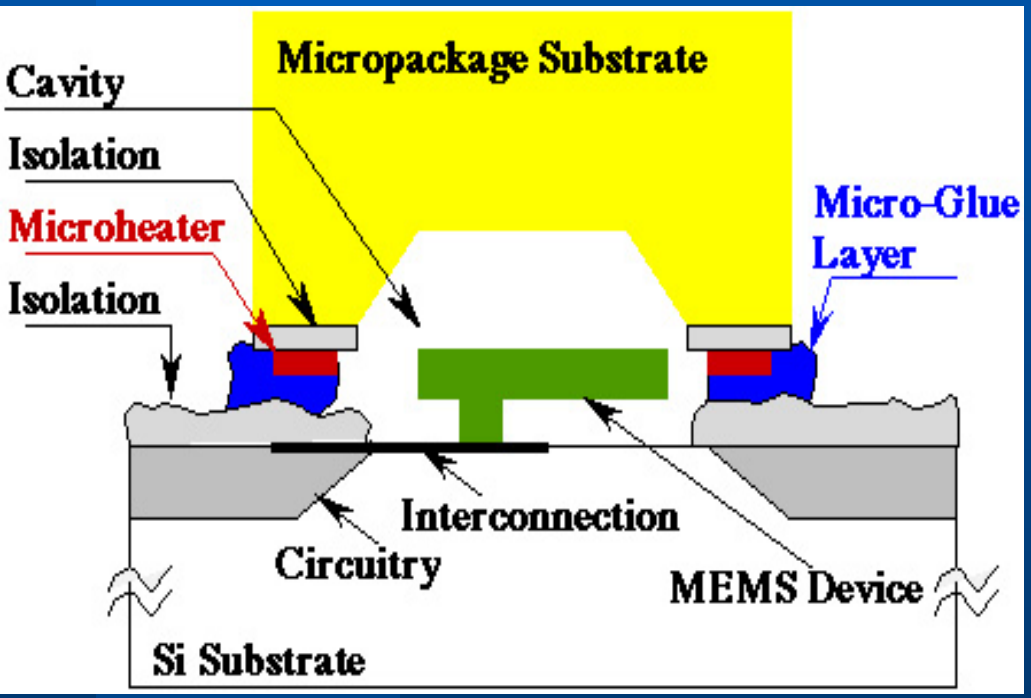
NSF CAREER Award, Division of Electrical & Communication Systems, 5/98-4/2002
Rated No. 1 in the panel

MEMS Post-Packaging

- **MEMS Packaging Processes**
  - **Integrated Processes**
    - Highly process dependent, not versatile
    - Not suitable for post-processing
  - **Wafer Bonding Processes**
    - Need high temperature which may damage microelectronics or temperature sensitive MEMS materials
    - Require very smooth and flat surfaces
- **Localized Heating & Bonding Processes**
  - **Localized Eutectic, Fusion bonding and others**

Massively Parallel Post-Packaging

- **Innovative Approach**

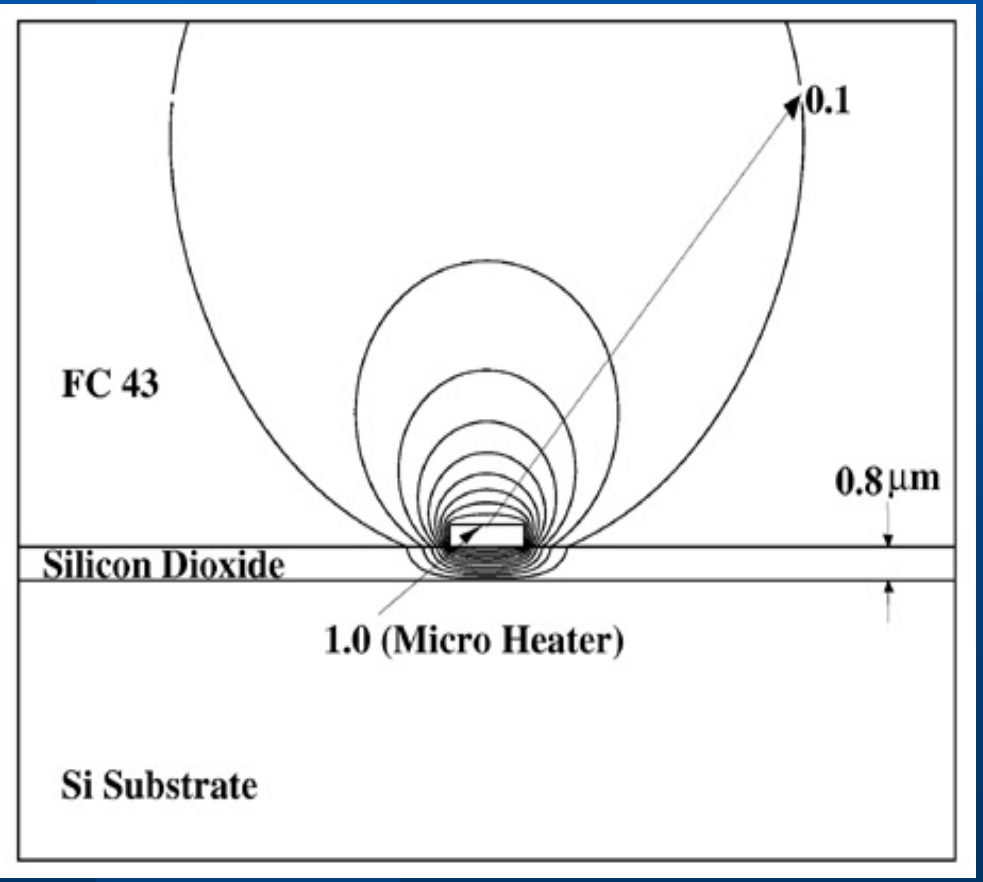


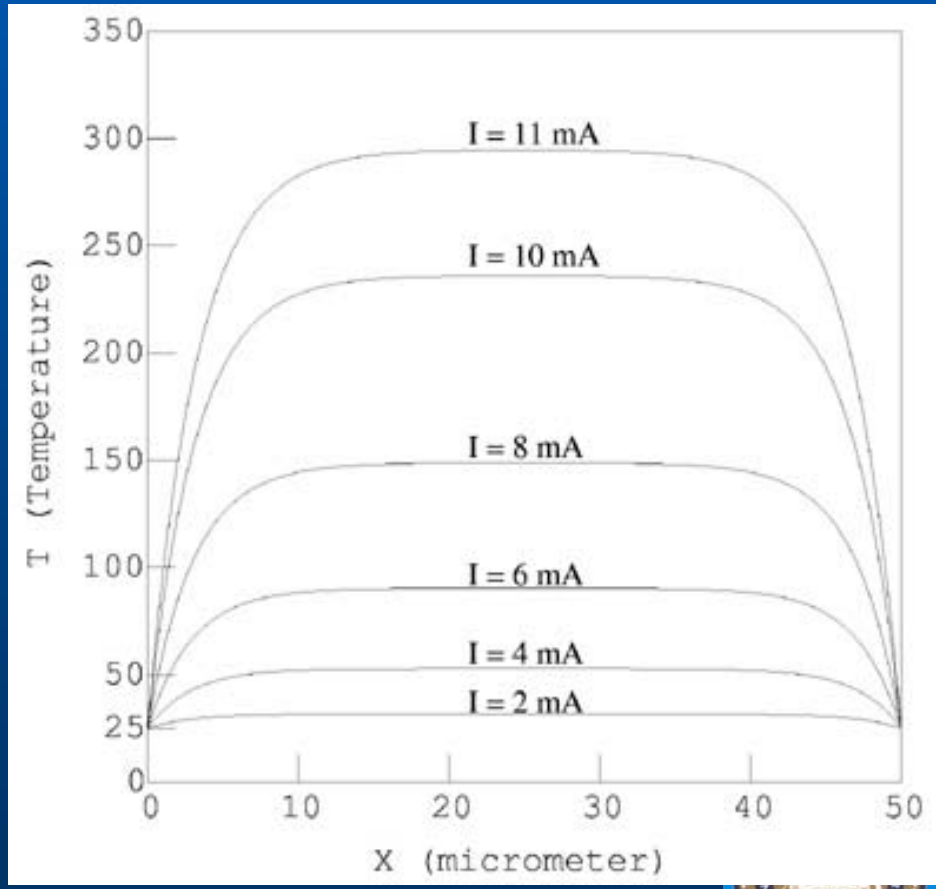
- **Industrial Participants**

  - Analog Devices Inc.
  - Motorola Inc.
  - Delco Electronics Corp.
  - Honeywell Inc.
  - Ford Motor Company
  - SiTek Inc.
  - ...

Rationale: Localized Heating

- High temperature is **confined**
- Temperature is **controllable**



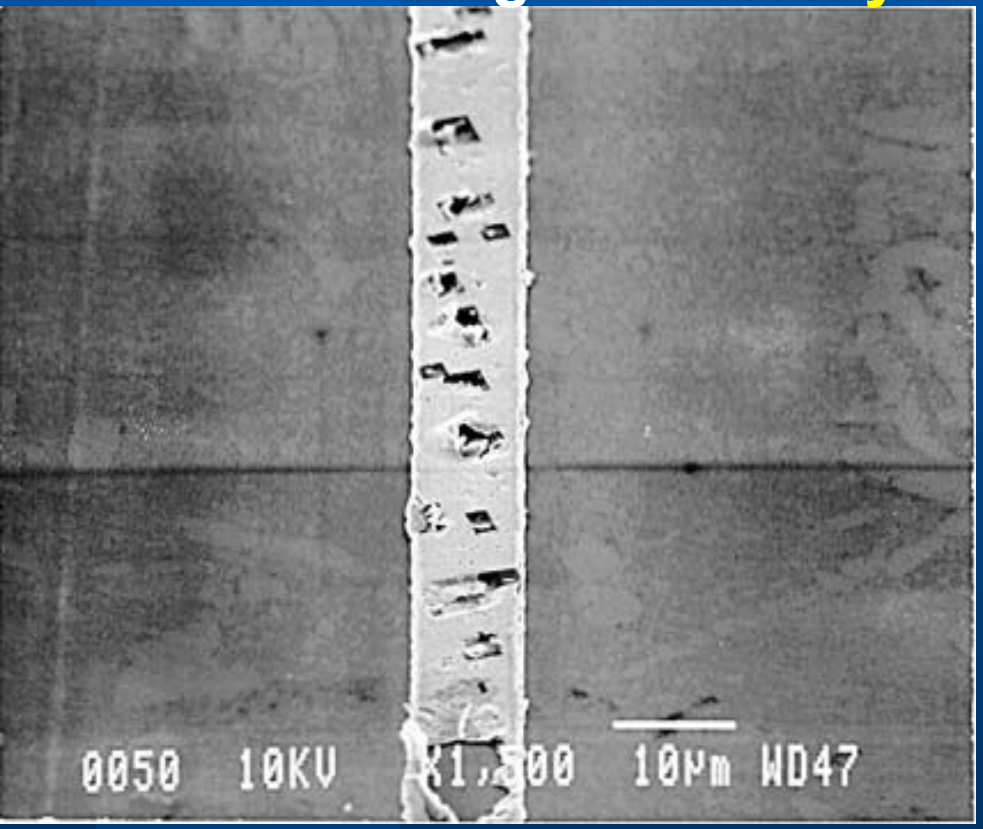


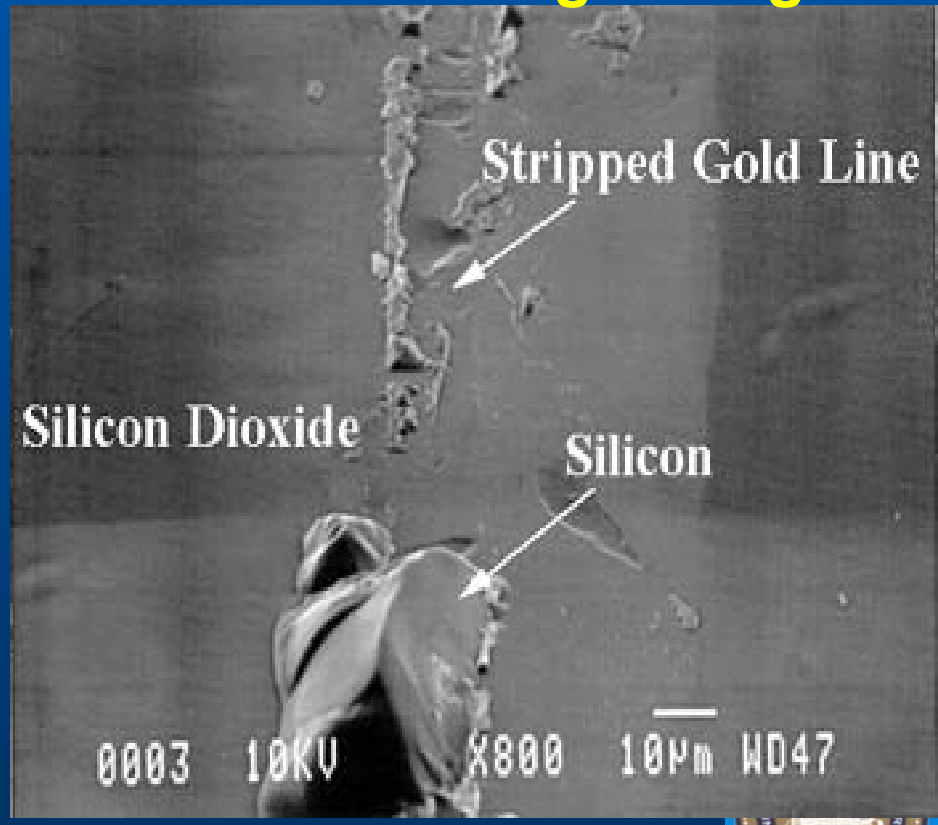
Lin, Cheng and Najafi, Japanese Journal of Applied Physics, Vol. 11B, pp. 1412-1414, 1998

Localized Eutectic Bonding

Surface +

- Conventional oven, Si-Au eutectic bonding - uniformity??
- Localized eutectic bonding excellent bonding strength

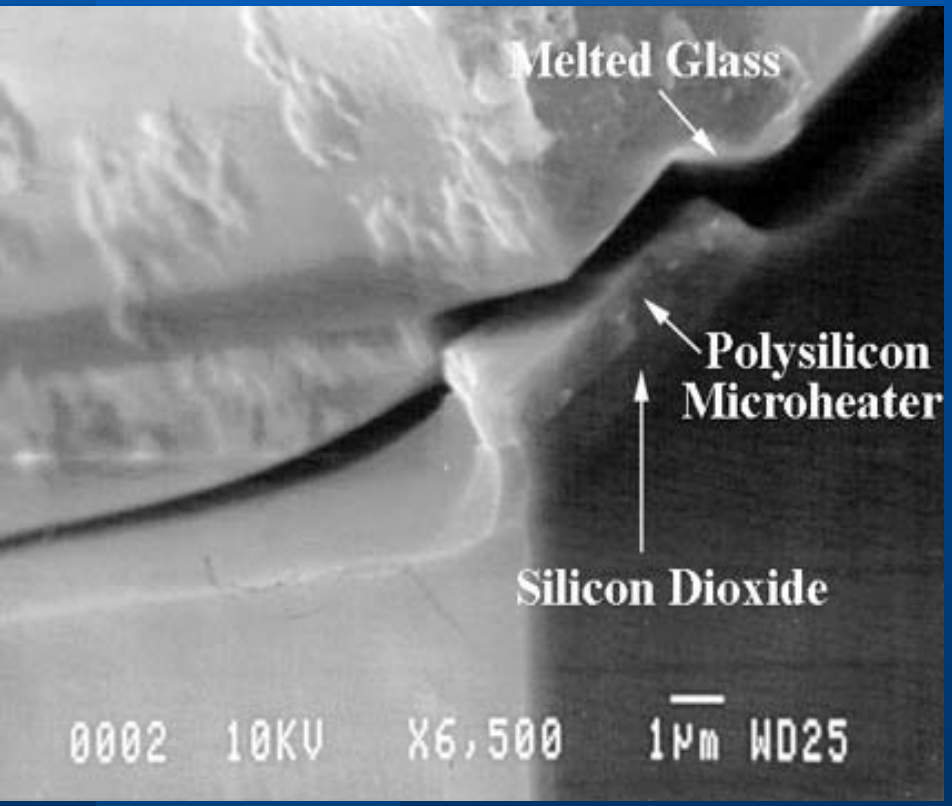


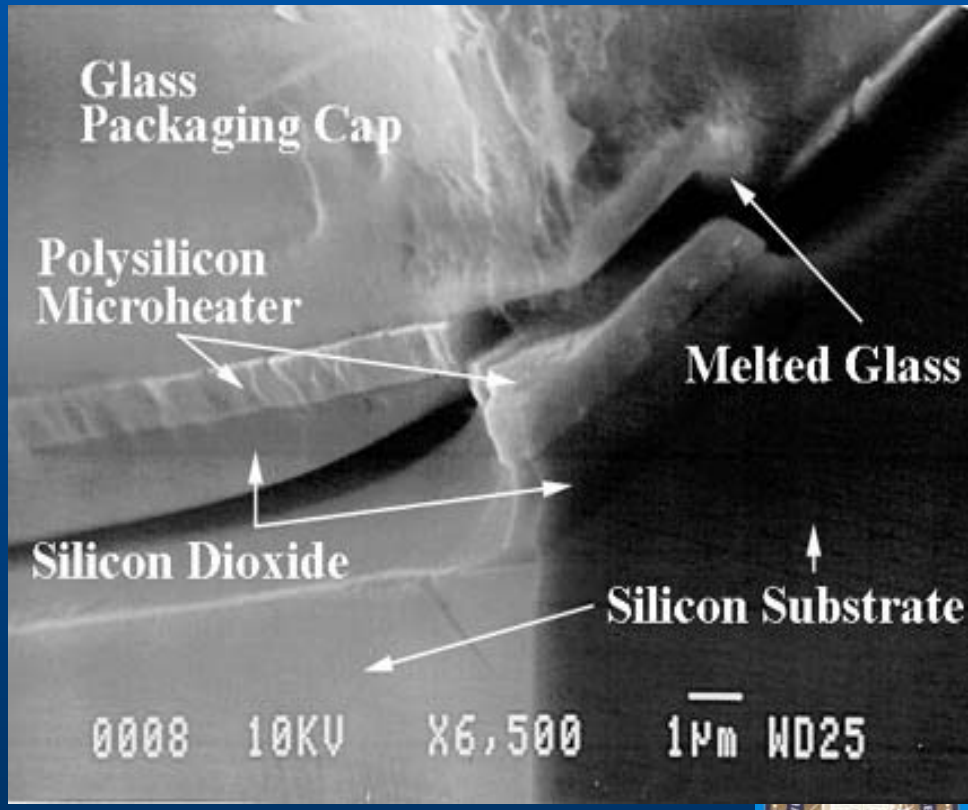


Localized Fusion Bonding

Surface +

- Silicon-to-glass fusion bonding - heater disappeared
- After HF dipping excellent bonding result

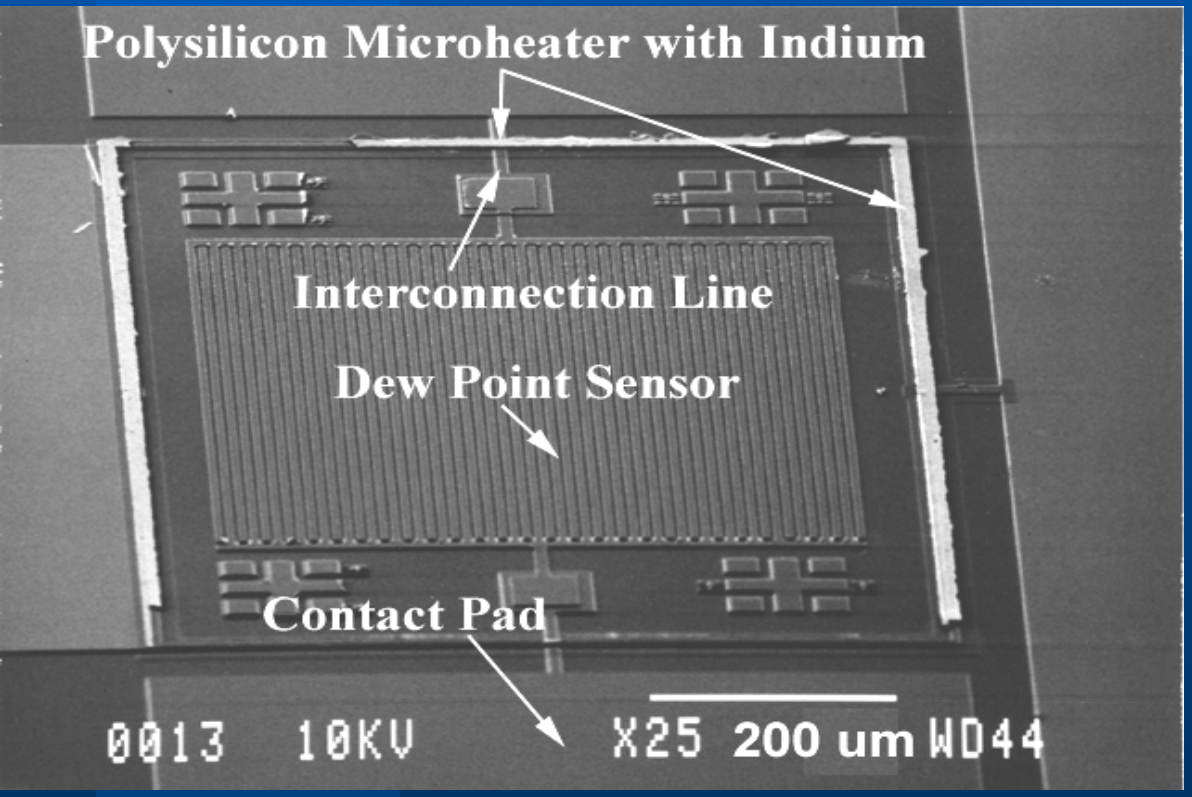


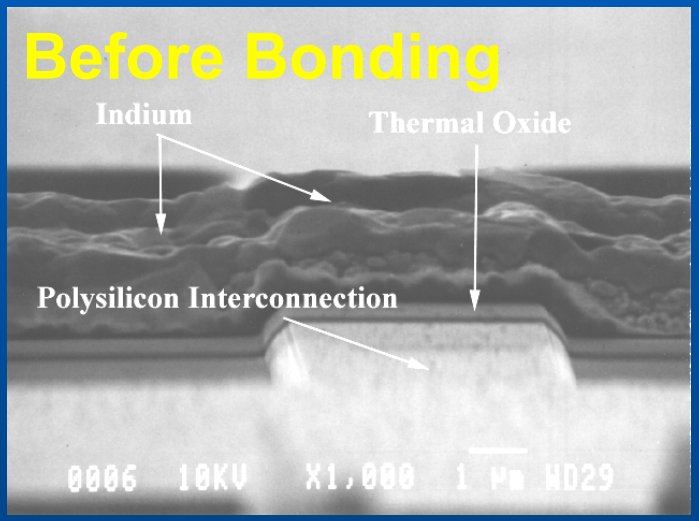


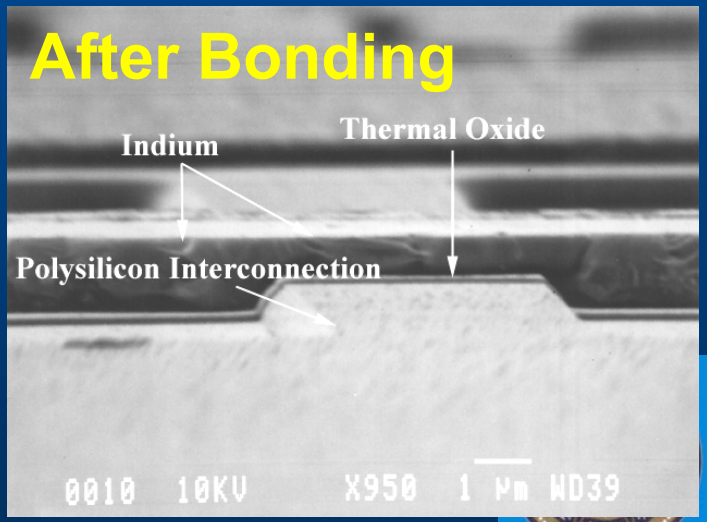
Localized Solder Bonding

Surface +

- Indium solder as intermediate layer - Al Dew Point Sensor



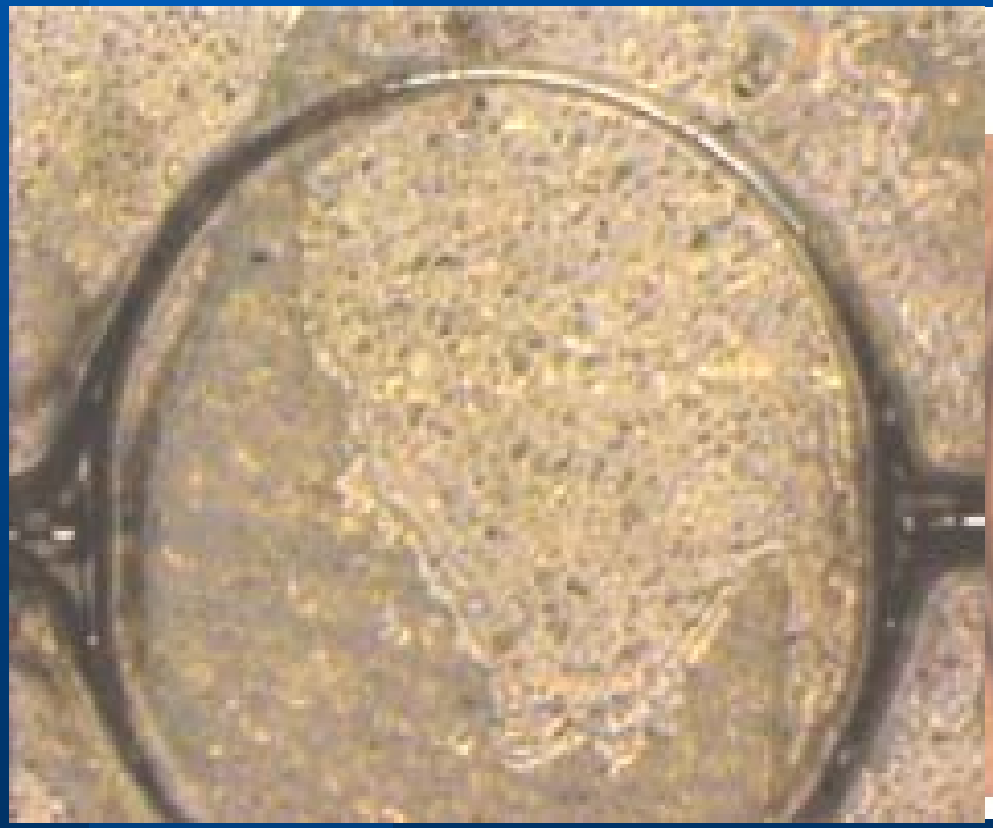


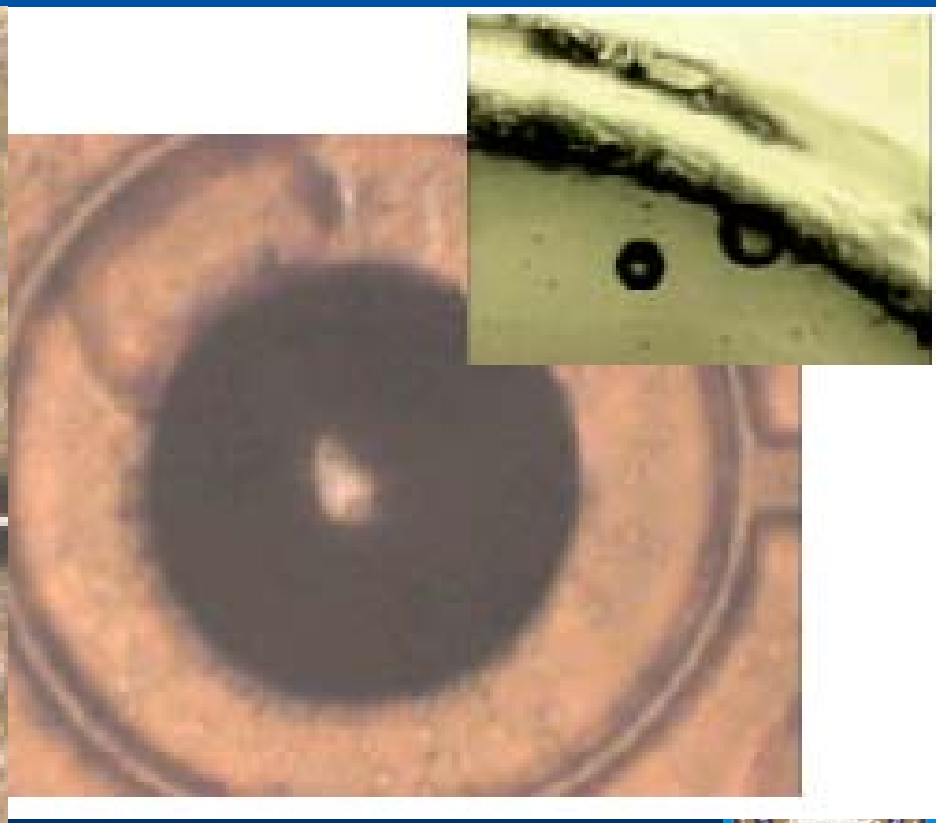


Localized Plastics Bonding

Surface +

- **Plastics to Silicon, to Glass and to Plastics bonding**
- **Direct encapsulation of liquid**



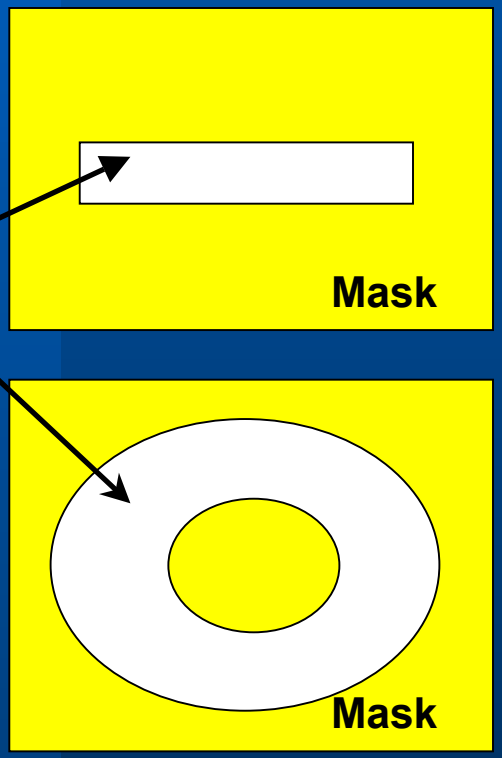


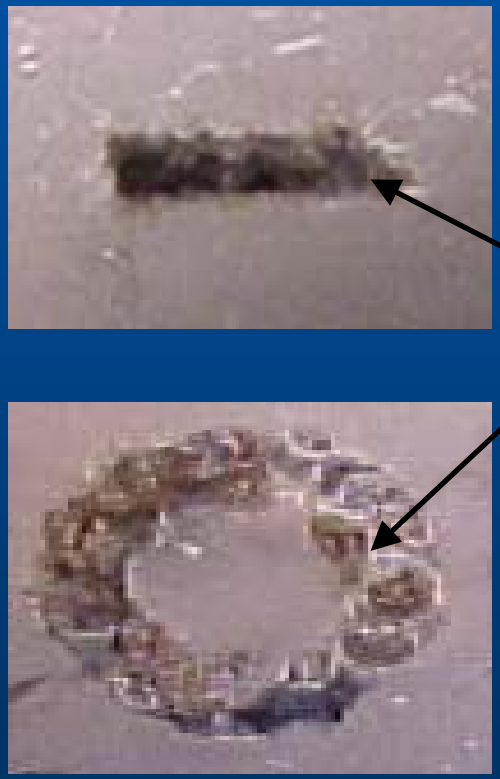
Surface +

Nanosecond Laser Welding

- **Ultrafast bonding, Restricted heating zone, Parallel packaging**

Patterns which pre-define Bonding areas

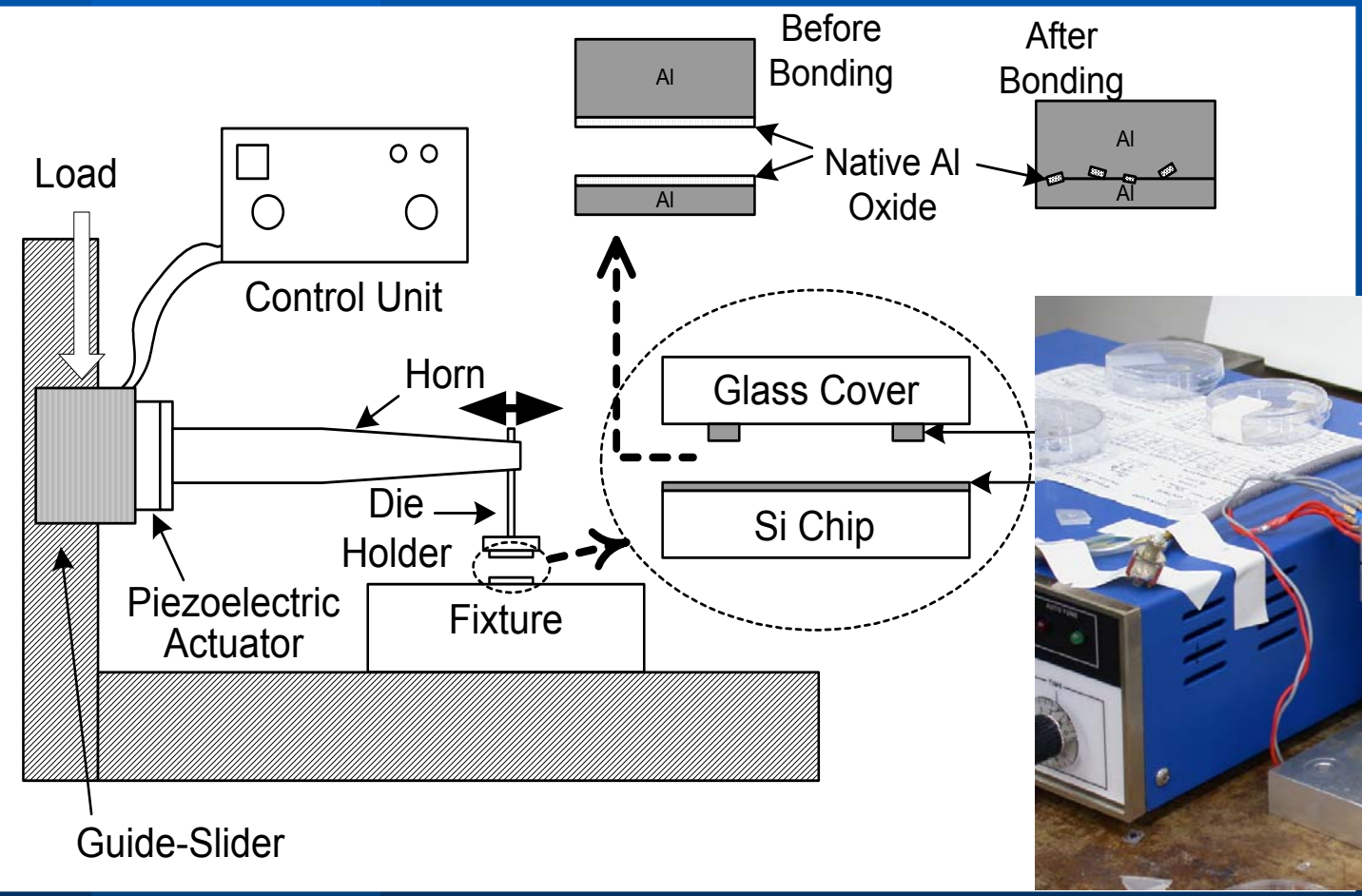


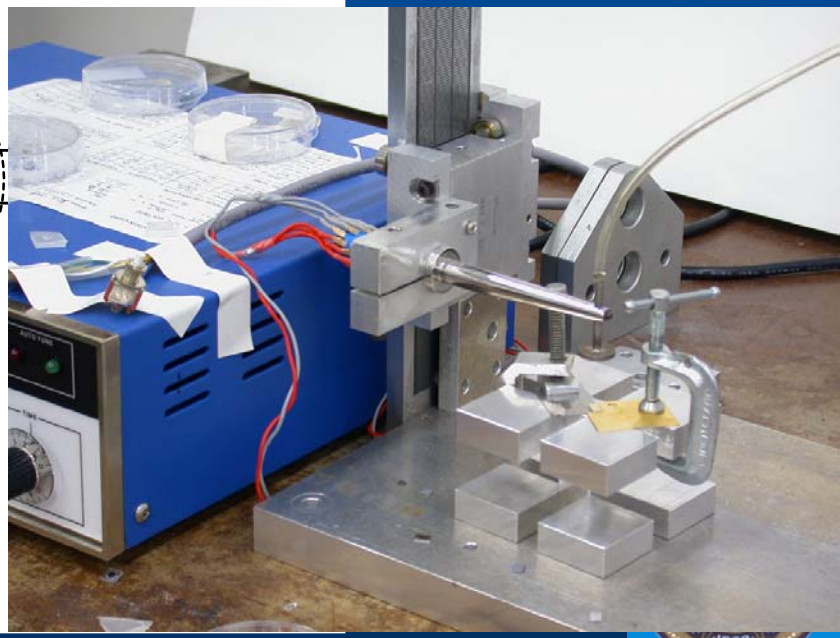


Bonding results

Ultrasonic Bonding and Sealing

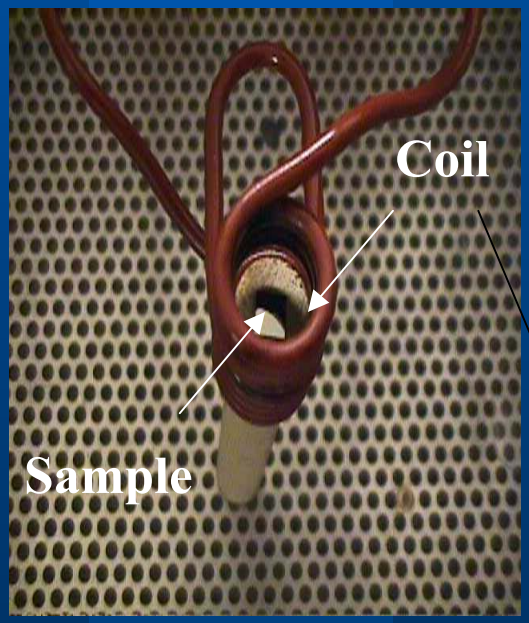
- **Lateral vibration setup for ultrasonic bonding**

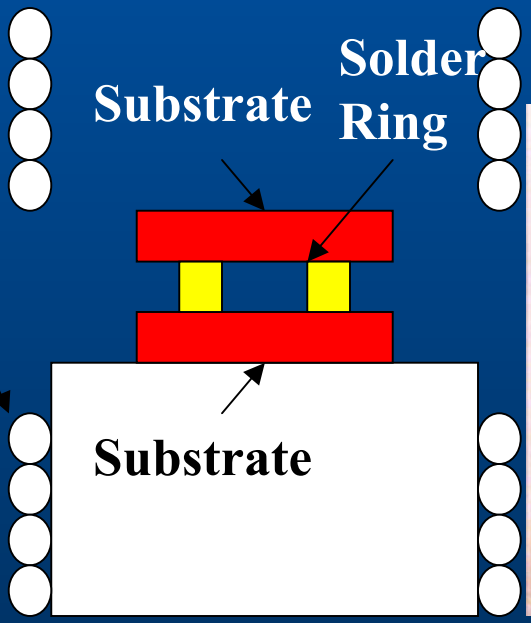


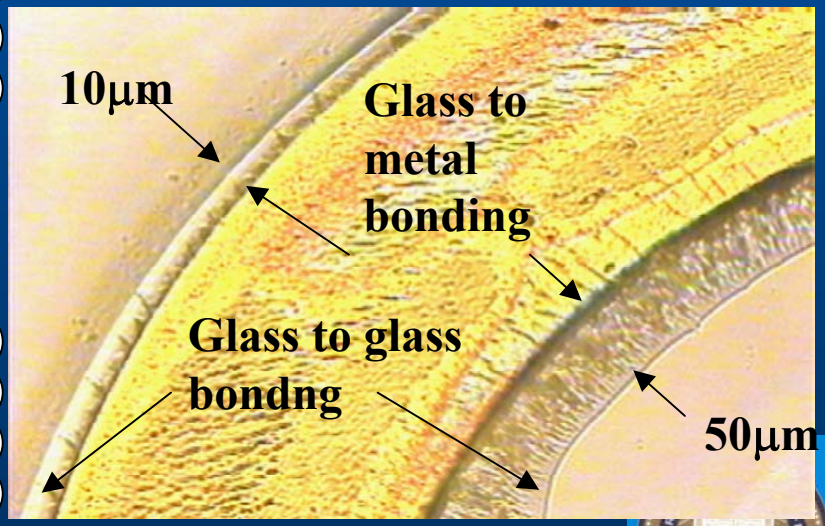


Selective Induction Bonding

- This method has great potential for wafer-level selective packaging processes
- The bonding time can be very fast and the heating zone can be well confined by remote heating source



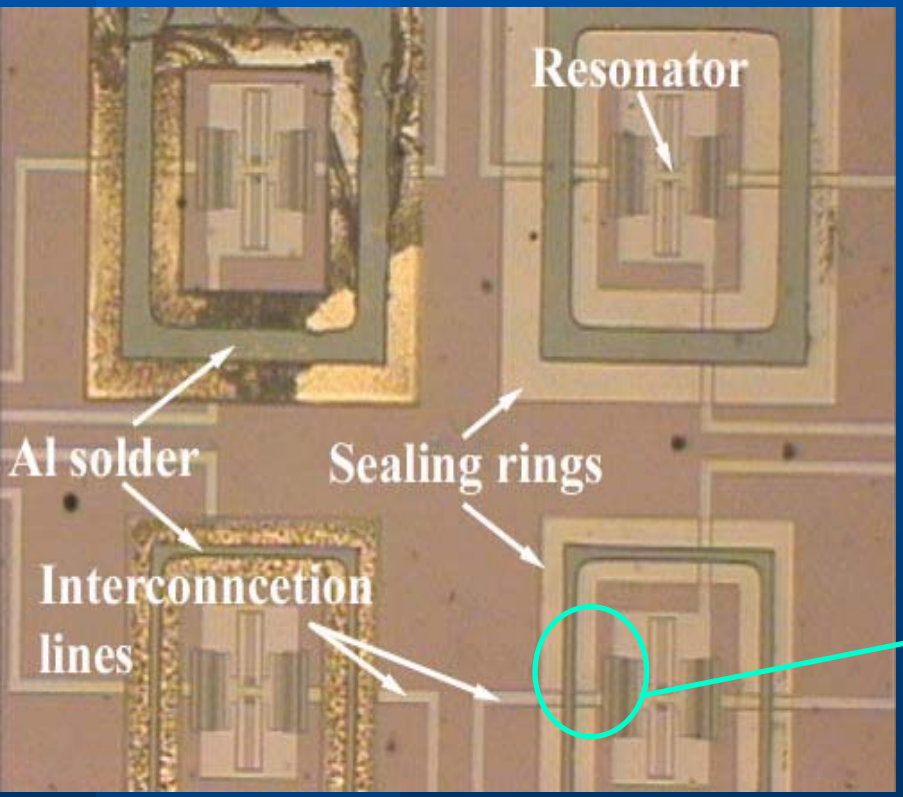


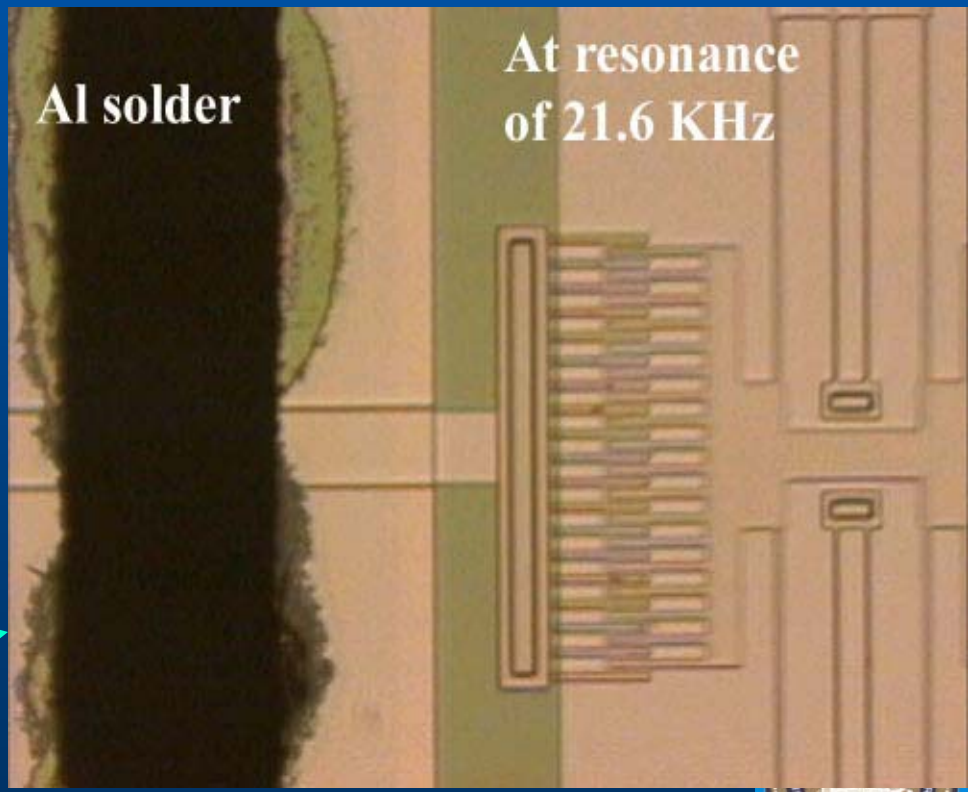


Surface +

RTP Bonding (Al to Glass or Nitride)

- RTP (Rapid Thermal Processing) for device encapsulations (750°C for 10 seconds)

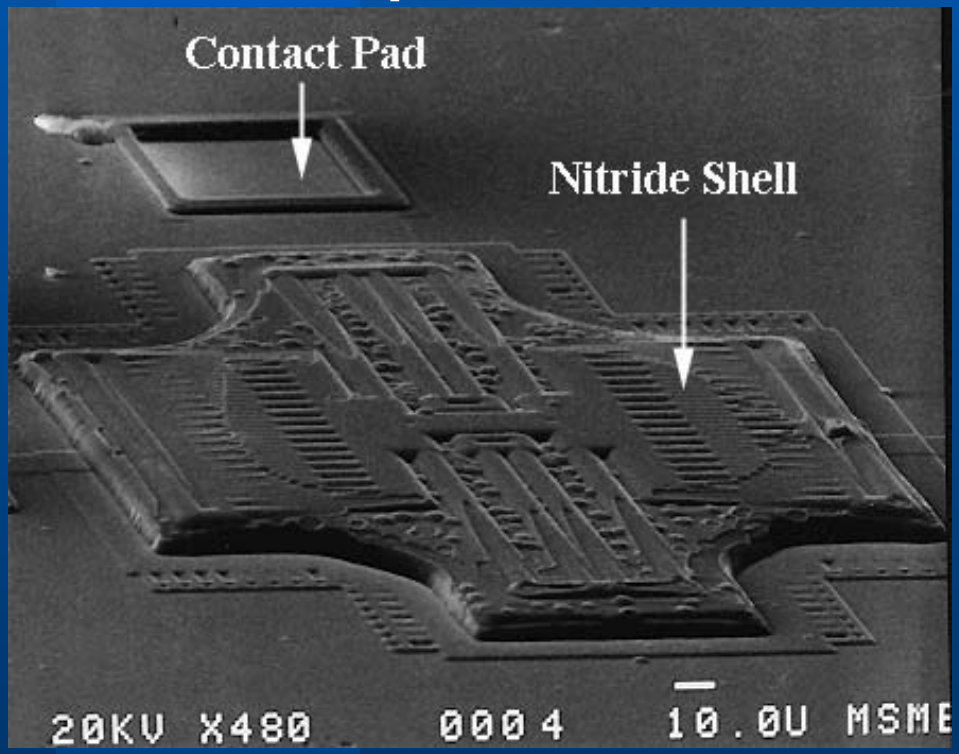




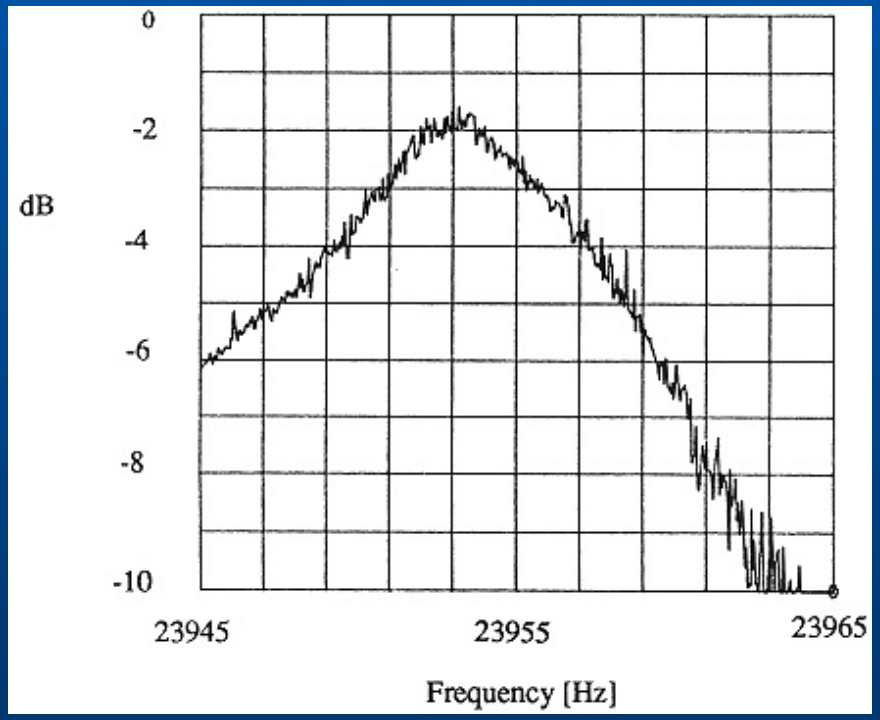
Lin et. al., "Microelectromechanical Filters for Signal Processing,"
IEEE/ASME J. of Microelectromechanical Systems, Vol. 7, pp.286-294, 1998

LPCVD Selective Encapsulation

SEM Microphoto



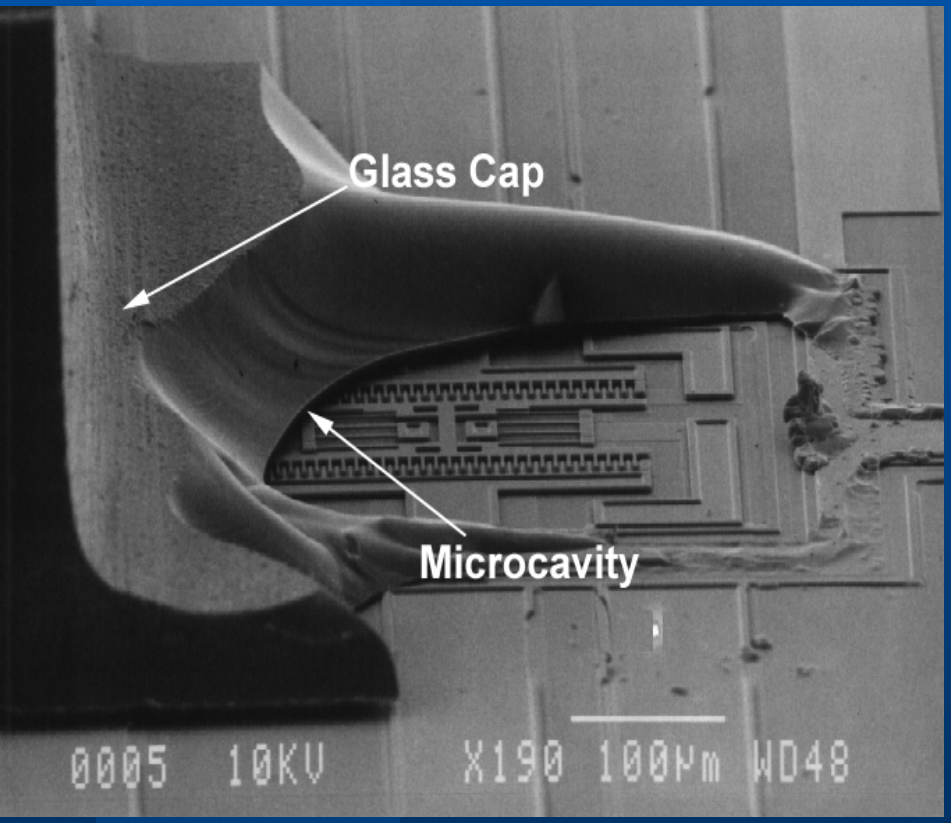
Measured Spectrum, Q = 2200



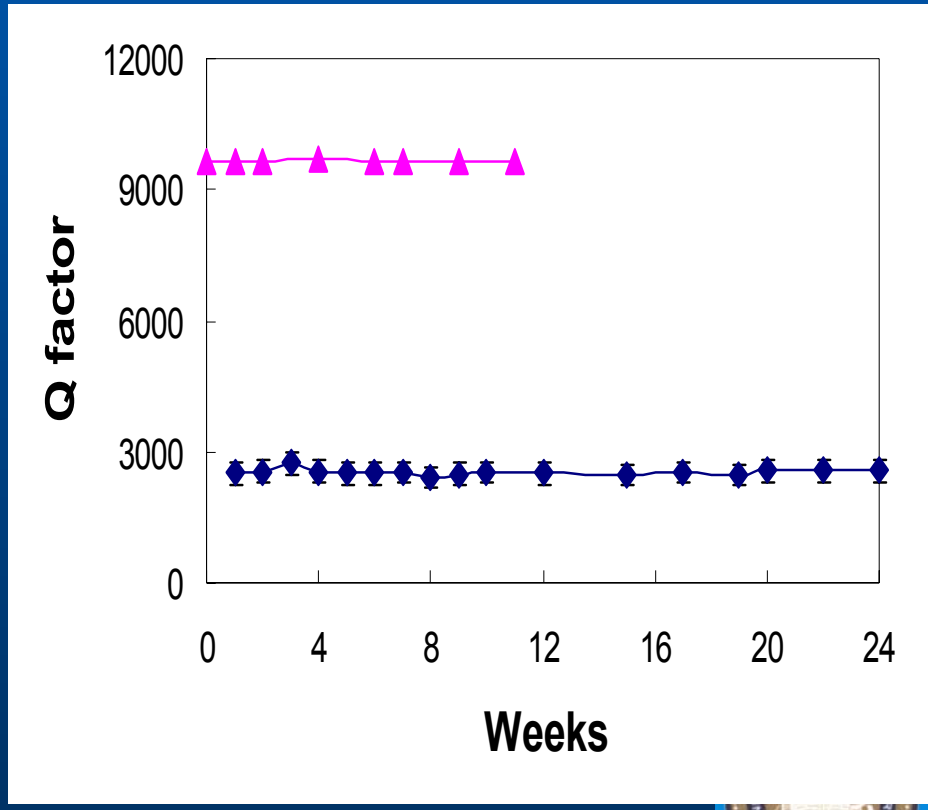
Surface +

Localized Vacuum Encapsulation

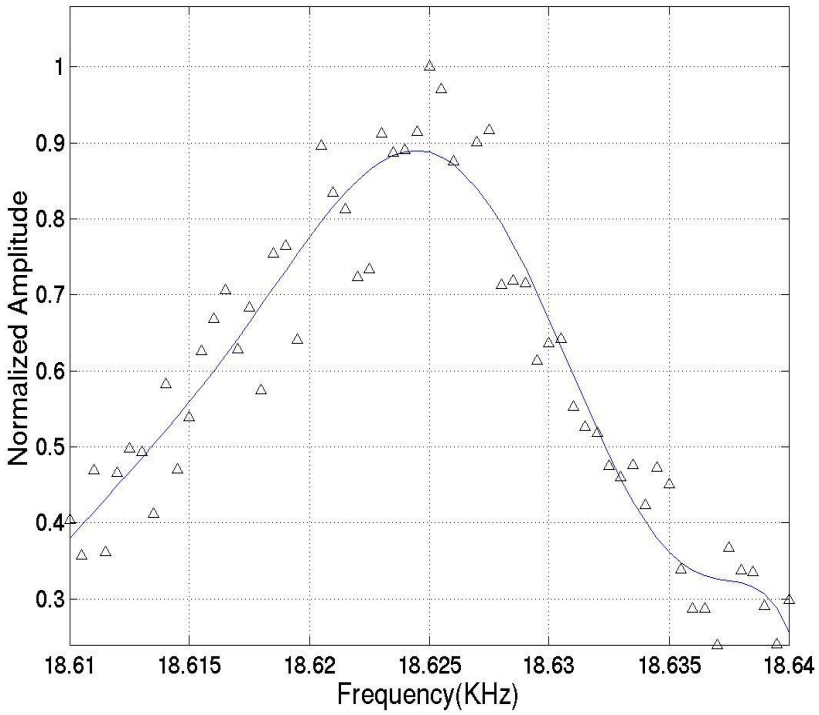
- **Vacuum encapsulated** comb resonator under a glass cap

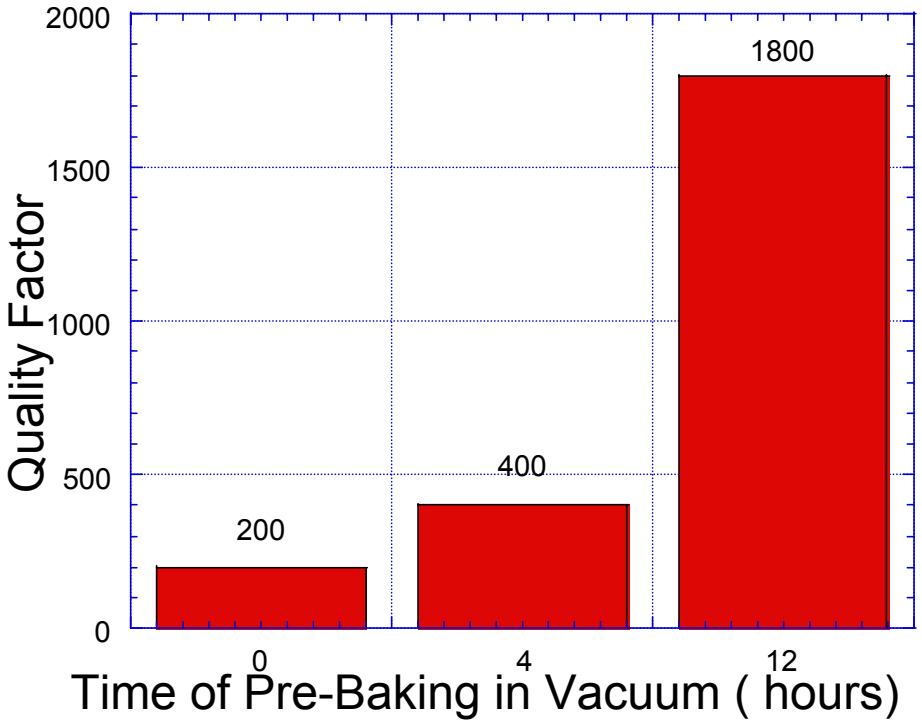


- **Long-term** testing under the vacuum packaged cavity



RTP Vacuum Packaging Results





- Quality Factor~ 1800?200
- Pressure inside the package ~ 200mTorr

- Quality factor increases with the pre-baking time

MEMS Packaging Summary

- **Localized thermal bonding processes**
  - **Eutectic, fusion, solder, laser welding, ultrasonic, plastic bonding processes**
- **RTP bonding**
  - **Aluminum-to-glass, aluminum-to-nitride**
- **Vacuum packaging processes**
  - **Integrated LPCVD nitride sealing**
  - **Localized aluminum-glass bonding**
  - **RTP aluminum-nitride bonding**

Acknowledgements

- **Researchers**
  - **Dr. Y.T. Cheng – Localized resistive heating & bonding**
  - **Dr. M. Chiao – RTP bonding**
  - **Dr. C. Luo – Nanosecond laser welding**
  - **Mr. Y.C. Su – Plastic bonding**
  - **Mr. J.B. Kim – Ultrasonic bonding**
  - **Mr. A. Cao – Inductive heating and bonding**
- **Funding sources**
  - **NSF CAREER AWARD, DMII grant**
  - **DARPA/MTO/MEMS Program, DARPA/DSO/BioFlips program**