Packaging for MEMS

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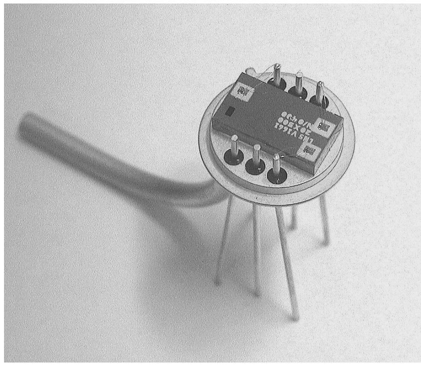
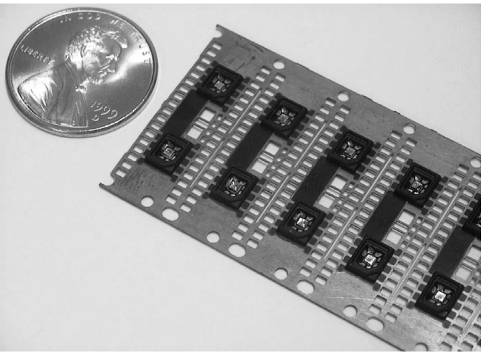

K. Williams / NovaSensor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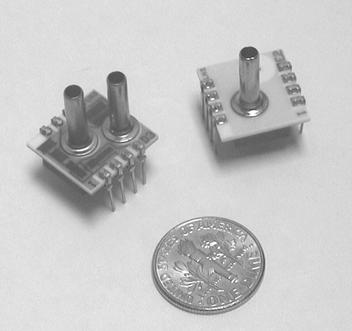
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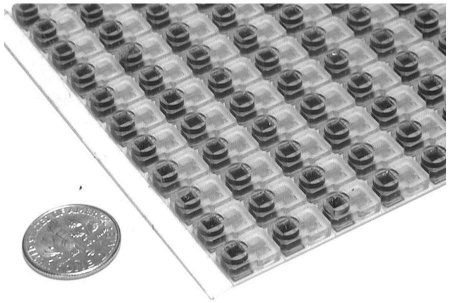
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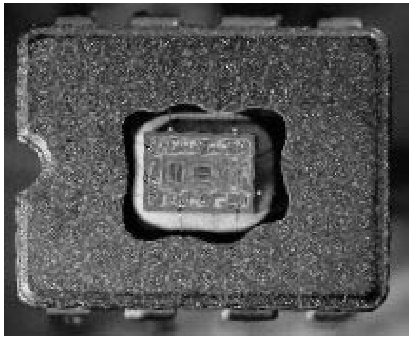
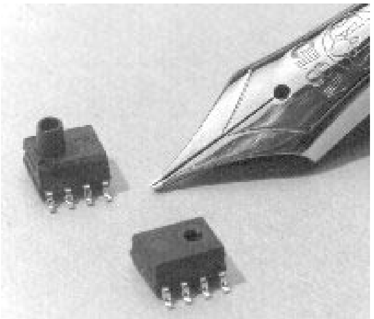
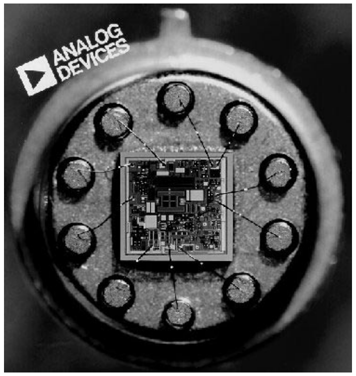

courtesy M. Judy/Analog Devices


NovaSensor


NovaSensor



courtesy M. Judy/Analog Devices

Packaging for MEMS Outline

- Packaging goals
- Materials properties:
  Thermal stress, heat transfer,
  and hermetic sealing
- Types of packaging
  - On-chip
  - Metal
  - Glass
  - Ceramic
  - Plastic
  - Comparison
- Packaging costs
- Summary

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Packaging Goals

Goals of Packaging for ICs

- Electrical power in
- Signal input/output
- Remove heat
- Protect chip during product manufacturing and in use
  - Breakage
  - Corrosion

Goals of Packaging for MEMS

- **Microelectromechanical devices/systems usually have both electrical and non-electrical input or output signals**

- **They must interact with the outside world**

- **Each has its own unique *additional* requirements**

  Examples:
  - **Contact with outside gas or liquid**
  - **Cannot allow packaging stress to affect signal**
  - **Hermetic seal**
  - **Lifetime (may be long or short--disposable)**

- ***And for a product, packaging must be done at a sellable cost***

  Application and market determine sales price

Packaging Goals

Packaging Requirements for Specific MEM Devices

- Pressure sensors
  - Electrical contact
  - Part of chip contacts pressure to be measured
  - Another part of chip may contact a different pressure (e.g., atmospheric pressure)

- Accelerometers/gyros
  - Electrical contact
  - Inertial force transferred without filtering
  - Known mounting angle
  - Maintain atmosphere (e.g., vacuum, overpressure, no humidity)

Packaging Goals

Packaging Requirements for Specific MEM Devices (cont.)

- Projection display
  - Electrical contact
  - Light enters and exits without distortion
  - May need to conduct heat out

- Micromachined infrared imager
  - Electrical contact
  - IR light enters
  - Maintain vacuum for thermal isolation

- Optical switch
  - Electrical contact
  - Light enters and exits
  - Fibers accurately held in place
  - May need hermetic seal with high voltages

Packaging Requirements for Specific MEM Devices (cont.)

- Ink-jet head
  - Electrical contact
  - Ink exits
  - Smooth, low-wear, low-friction surface
  - Low cost

- Flow sensor
  - Electrical contact
  - Flow passes chip in controlled manner

- Valves
  - Electrical contact
  - Flow enters and exits
  - Need particle filtering

Packaging Goals

Packaging Requirements for Specific MEM Devices (cont.)

- Microfluidics (e.g., electrophoresis)
  - Electrical contact or electric field
  - Flow enters
  - Displaced air is removed

- Wet chemical, *p*H, and gas sensors
  - Electrical contact
  - Contact chemical or gas

- RF devices: filters, mixers, etc.
  - Signals in and out without attenuation or reflection (good transmission lines)
  - Good signal isolation/low coupling

Packaging Goals

Points to Consider

- Each application has its own unique requirements
  → Many different custom-made packages
  - Some standardization for well-commercialized devices
    - Pressure sensors
      Same engineers and founders at several co.'s
    - Accelerometers
      Off-the-shelf packages

- Must develop package in conjunction with chip design
  Not afterwards!

- Lose some of MEMS size and cost advantage with packaging
  - Packaging is usually dominant part of MEMS cost
    - Including more in a single package can save cost
      (e.g., sensor and IC; sensor and actuator)

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Thermal Stress

Thermal Expansion

Unconstrained thermal strain ε is proportional to thermal coefficient of expansion (TCE or α) and temperature rise

$\varepsilon = \alpha\ \Delta T$

TCE often given in ppm/K (= 10^{-6} strain per °C)

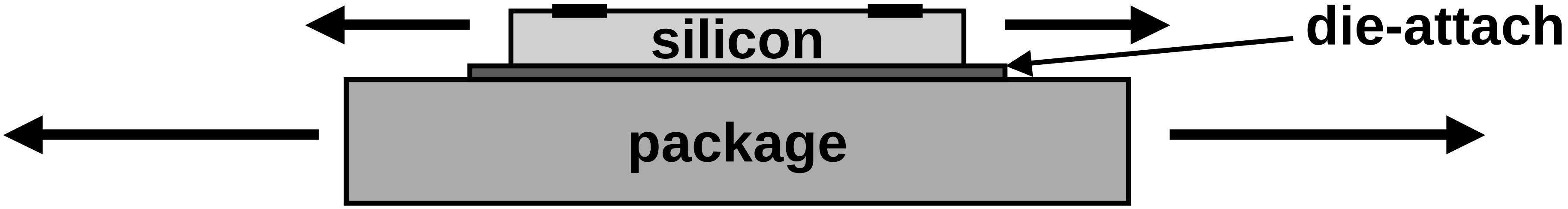
Silicon has a very low TCE (compared to other materials) of

ε **= 2.6e-6 K^{-1} at room temperature**

TCE of Si rises with temperature, but linear approximation is usually used

Thermal Stress

Different expansion rates of silicon chip
and packaging result in stress on chip
that varies with temperature



Stress at top of silicon (where sensitive part usually located)
depends on

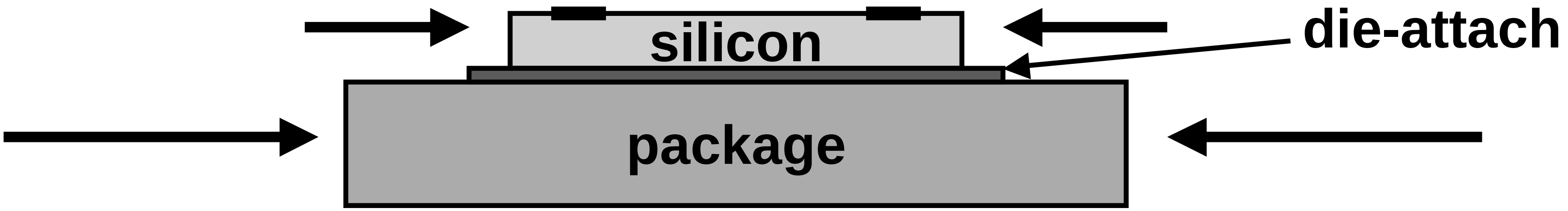
- TCE difference
- Thicknesses
- Young’s modulus
- ...and interface (die-attach)

Thermal Stress (cont.)

If a hard die-attach material is used
and high temperature is needed
(e.g., to melt solder),
stress will be “frozen in” when
die-attach material hardens

Example:

63% tin / 37% lead solder melts/freezes at 183°C
Package will shrink more than silicon
down to room temperature,
resulting in permanent compressive stress in chip
Can bend beams, cause offsets, etc.



Thermal Stress

Temperature Cycling

- With a hard die-attach material (e.g. solder) stress is transferred from package to chip
- Large temperature swings can fracture chip or package or cause plastic deformation of the die-attach material
- Temperature cycling can cause fatigue of chip, package, or die-attach material, leading to fracture

Reducing Thermal Stress

Question:

How can thermal stress at chip surface be reduced?

- Soft die-attach material
- TCE-matched package
- Make silicon chip thicker
    - Or thicken with material with same TCE
- Make silicon wider (for certain geometries)
- Reduce contact area
    - Only part of chip can be adhered to package

Thermal Stress

Packaging Material Properties

Material	TCE α (ppm/K)	Y's Modulus E (GPa)	Therm. Cond. κ (W/m-K)
silicon	2.6 (rises w/T)	180	156
Pyrex 7740	3.2	~80	?
window glass	9	~80	0.78
low-C steel	12.1	210	97
typ. stainless steel	17.3	210	16
Kovar (54Fe 29Ni 17Co)	5.1	~210	17
Alloy 42 (58Fe 42Ni)	4.1	~210	15
copper alloys	17	120	260
alumina (Al_2O_3)	6.0	275	~20
AlN	4.3	340	160
beryllia (BeO)	8.5	345	218
eutectic 96 Au 4 Si (~300C)	12	83	27
solder 63Sn 37Pb (~350C)	23	31	50
epoxy Hysol 9394	56	4.2	0.33
silver epoxy	53	3.5	0.8
RTV silicone	370	0.0012	~0.2

Thermal Stress

On-Chip TCE-Matched Packaging

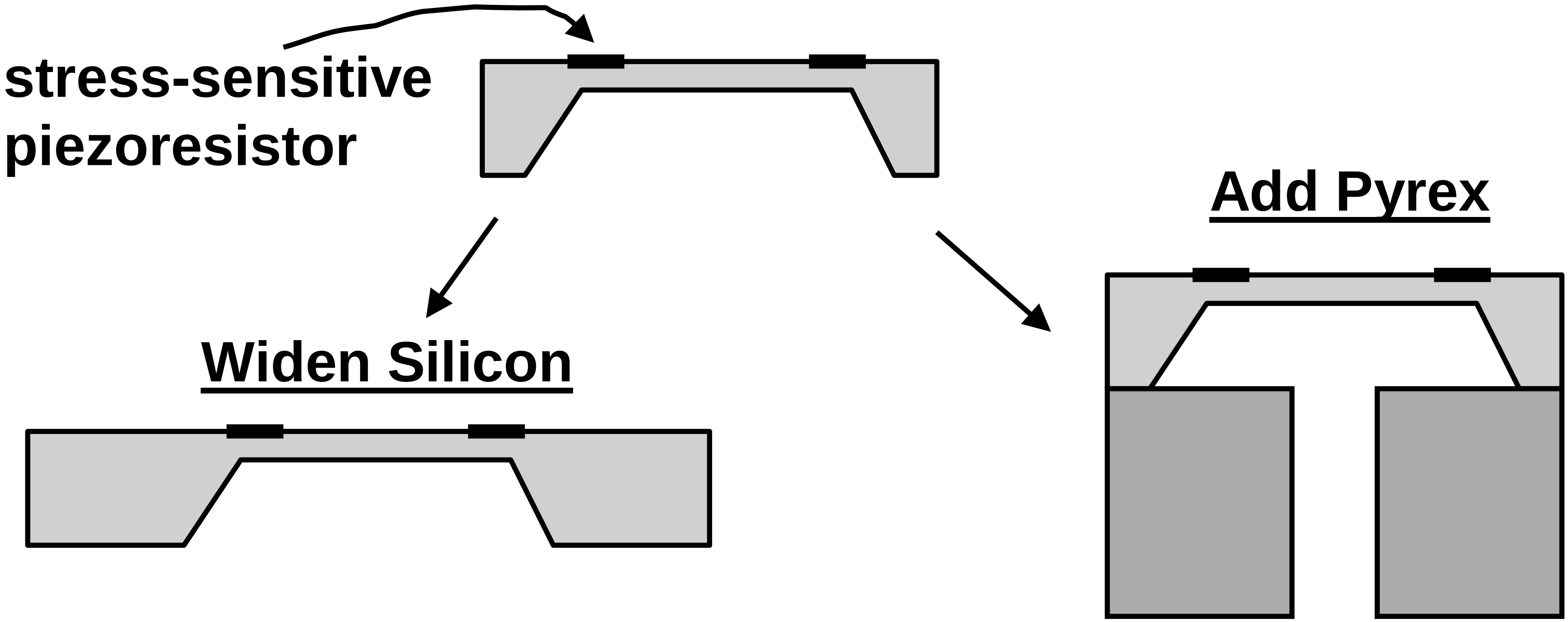
- Silicon has a *perfect* match to silicon chip
- Pyrex 7740 has an excellent match to silicon chip

→ Use these for isolation from the main packaging

Thermal Stress

On-Chip TCE-Matched Packaging (cont.)

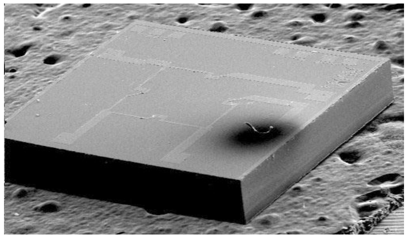
Example: Piezoresistive pressure sensor

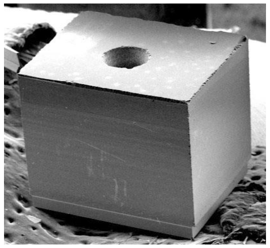


stress-sensitive
piezoresistor

Add Pyrex

Widen Silicon

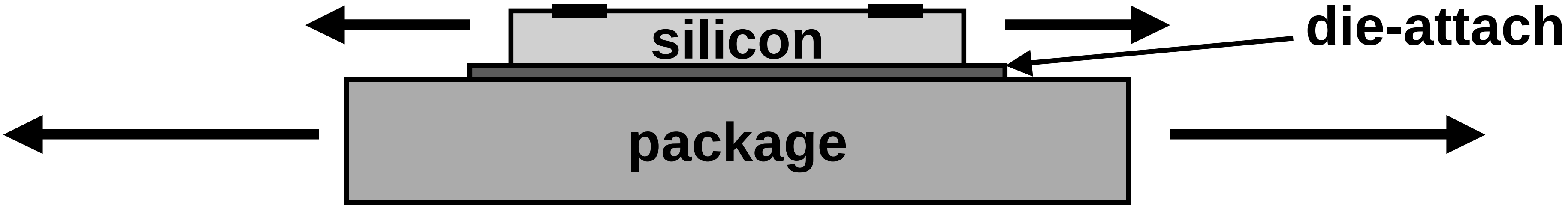




Choose cheapest solution that works

Thermal Stress

Stress-Isolation with Die-Attach Material



- Use soft (low-modulus) material
  → Allows chip and package to expand at different rates

- RTVs (room-temperature-vulcanizing silicones)
  are most common for pressure sensors

Thermal Stress and Heat Transfer

TCE-Matched Packaging and Heat Transfer: Materials Comparison

- Most metals have a high TCE
  - Special iron alloys have lower TCEs
    - Alloy 42 used for leadframes
    - Kovar used for headers (cans)
- Surprisingly, most metals have lower thermal conductivities than packaging ceramics
    - Cold-rolled steel has higher TCE but also higher κ
      Also used in headers

- Oxides and nitrides used for ceramic substrates
  - Alumina (Al_2O_3) has low TCE,
    Also cheap, good κ
    Very common
  - Beryllia (BeO) has very high κ, but is expensive
  - Aluminum nitride has very low TCE, but is expensive

Die Attach for High Heat Transfer

- Metal die-attach materials have thermal conductivities ~ two orders of magnitude higher than polymers
  - But metals are much less compliant → Lead to greater stress
- Fortunately, most MEM devices do not require low thermal resistance
- Note: die-attach material must wet both chip and package for good thermal contact
  - Thermal conduction from one rough surface to another is via gas conduction or radiation

Die Attach Thermal Resistance Calculations

- Thermal resistance θ found with in analogy to electrical resistance,

  $\theta = t / A \kappa$ (in K/W)

  where

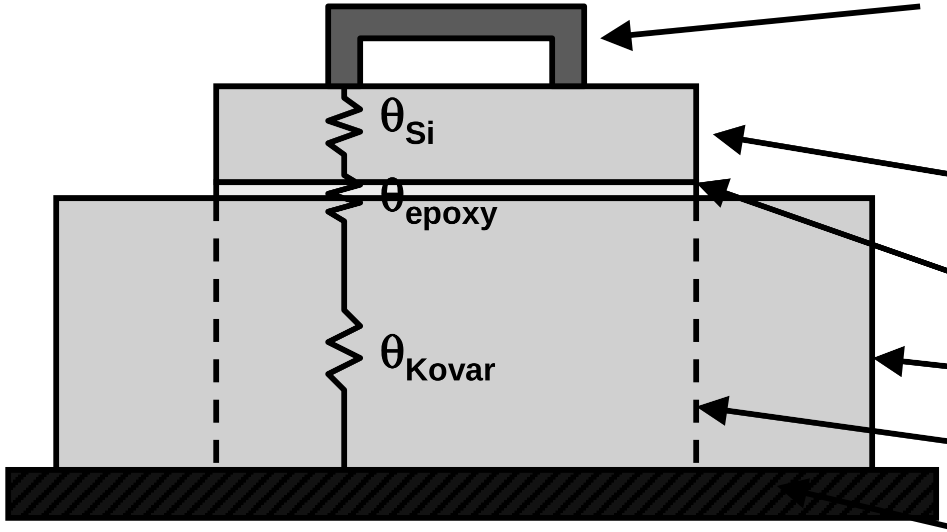
  t = thickness

  A = area

  κ = thermal conductivity

- Thermal resistance of die-attach layer can dominate
  - Keep thin for low thermal resistance

Thermal Resistance Example



hot structure at top of chip (assume at constant T)

500 μm Si, 5 x 5 mm area

4 mil = 100 μm silver epoxy

1.5 mm Kovar header

main heat-flow area=5x5mm

good thermal heat sink *(more typically to air)*

θ_{Si} = 500e-6 m / [(5e-3 m)^2 × 156 W/m-K] = 0.13 K/W

θ_{epoxy} = 5.2 K/W

θ_{Kovar} = 3.5 K/W

- Total thermal resistance θ_{total} = 8.2 K/W
- If 1 W is generated in hot structure, top of silicon heats by

  $\Delta T = P \times \theta_{total} = 1\ W \times 8.8\ K/W = 8.8\ K$

Heat Transfer

Package Thermal Resistance

Thermal resistance of package depends on

- **Materials**
- **Dimensions**

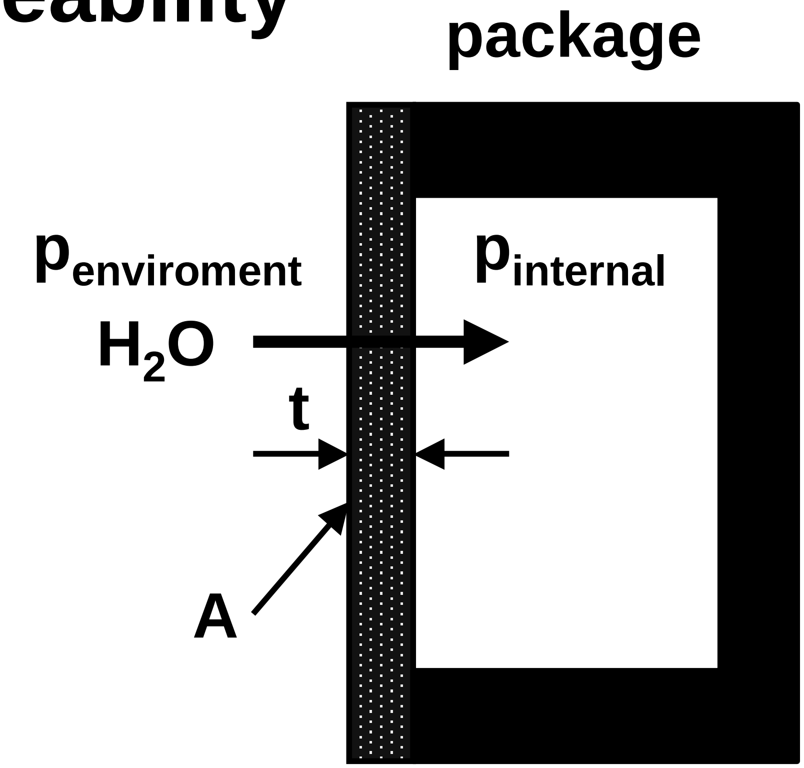
Comparison of 64- to 68-Pin Packages

Type	Material	$\theta_{\text{junction-pin}}$ (K/W)
DIP	ceramic	32
DIP	plastic	35
PGA	ceramic	20
Leadless chip carrier	ceramic	13
Leadless chip carrier	plastic	28

data from C. Steidel in *VLSI Technology*, S. Sze, ed., Ch. 13, McGraw-Hill, 1983.

Hermetic Sealing

Materials Permeability



mass flow rate

= permeability x $\Delta p_{gas} \times A / t$

Permeability of packaging materials to gas diffusion varies by orders of magnitude

Permeability to moisture (g/atm-m-s)

• silicones	$\sim 10^{-2}$
• epoxies	$\sim 10^{-5}$
• fluorocarbons	$\sim 10^{-5}$
• glasses	$\sim 10^{-7}$
• metals	$\sim 10^{-11}$

$\}$ **considered suitable for hermetic sealing** (glasses, metals)

data from R. Traeger, quoted in C. Steidel, *VLSI Technology*, S. Sze, ed., Ch. 13, Mc-Graw Hill, 1988.

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On-Chip Packaging

Some of device “packaging” may be on the chip itself

Reasons: May be

- **Cheaper**
- **More reliable**
- **More effective**

Examples:

- **Stress isolation (already discussed)**
- **Surface protection**
- **Vacuum packaging**

On-Chip Packaging

Surface Protection

Coating the surface at wafer level is common with ICs

- Chemical-vapor-deposited silicon dioxide
- CVD silicon nitride

Can be used with some sensor and actuators

Results in stress problems with pressure sensors

→ Not used much

Coating the chip surface and package with a polymer after wire bonding can be done

- Parylene results in hysteresis with pressure sensors

  → Not used much

- Silicone gel used in pressure sensors

  Moisture can penetrate

Q: What can be done to prevent corrosion to Al lines?

Q: Why is it not done on most pressure sensors?

On-Chip Packaging

On-Chip Hermetic Sealing

Some parts of MEM devices must operate in vacuum or controlled environment

- **High-Q resonators**
    - **Some accelerometers and gyros**
    - **Mechanical filters**
- **Thermally isolated devices**
    - **Infrared sensors**
- **Hot devices than can be oxidized**
    - **Incandescent lamps, electron sources**
- **Absolute pressure sensors**
- **High-voltage devices**
    - **Some optical switches**

- **Resonators and pressure sensors can be vacuum-sealed packaged on-chip**

Do not need optical connections to outside-- opaque seal is suitable

On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

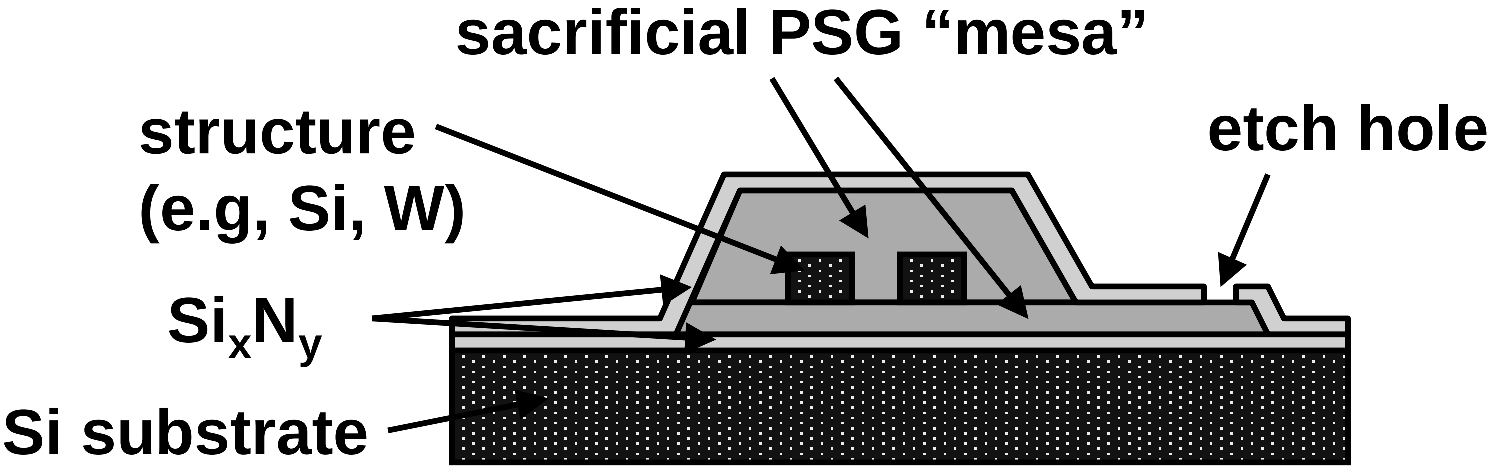
Some on-chip vacuum packaging methods

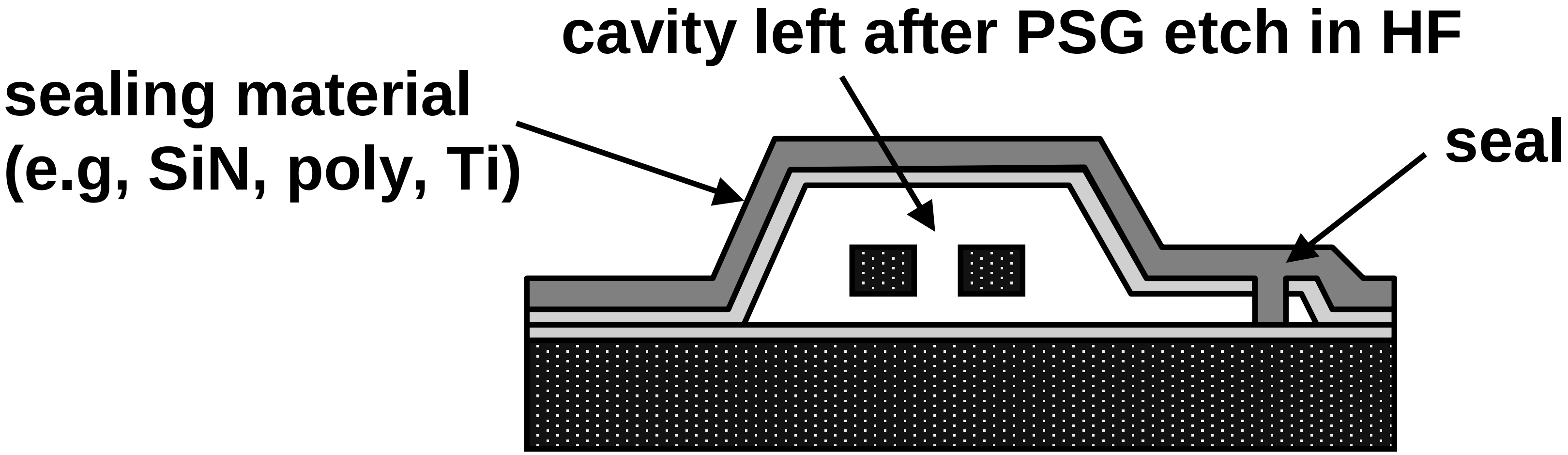
- Shell of low-pressure CVD silicon nitride
- Silicon-fusion bonding in vacuum
- Anodic bonding in vacuum
- Eutectic bonding in vacuum

On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

On-Chip Silicon Nitride Shell--Fabrication





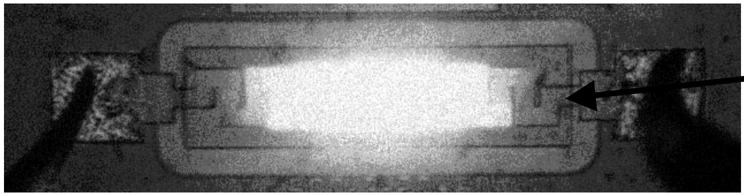
On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

On-Chip Silicon Nitride Shell--Examples

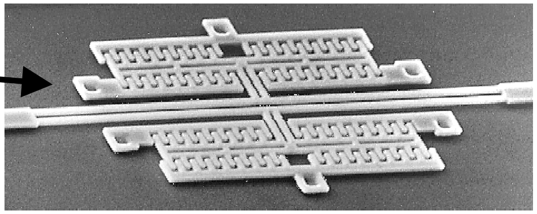
Hot tungsten filament

Polysilicon resonator

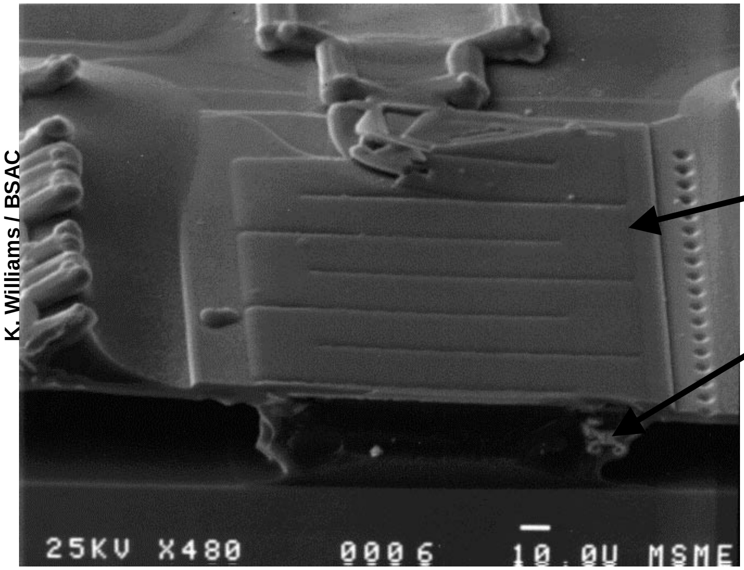


K. Williams / BSAC

devices
without covers



courtesy
B. Clark / BSAC



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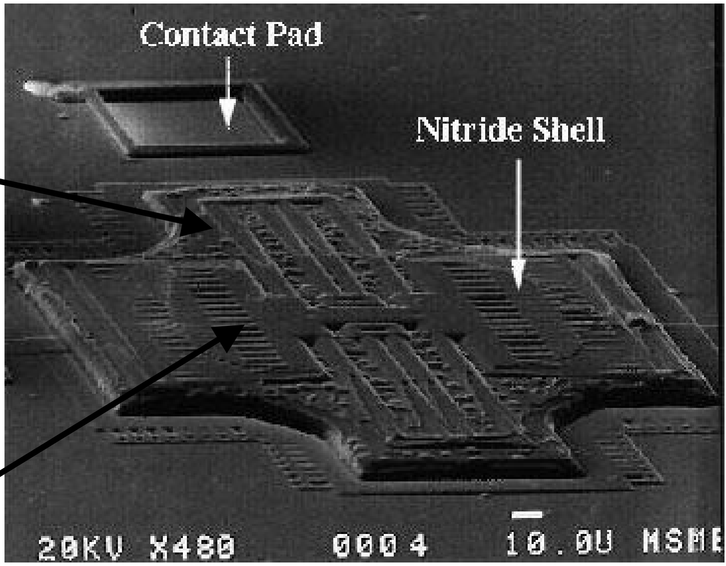
low-stress
silicon nitride
shell

tungsten
filament

polysilicon
resonator



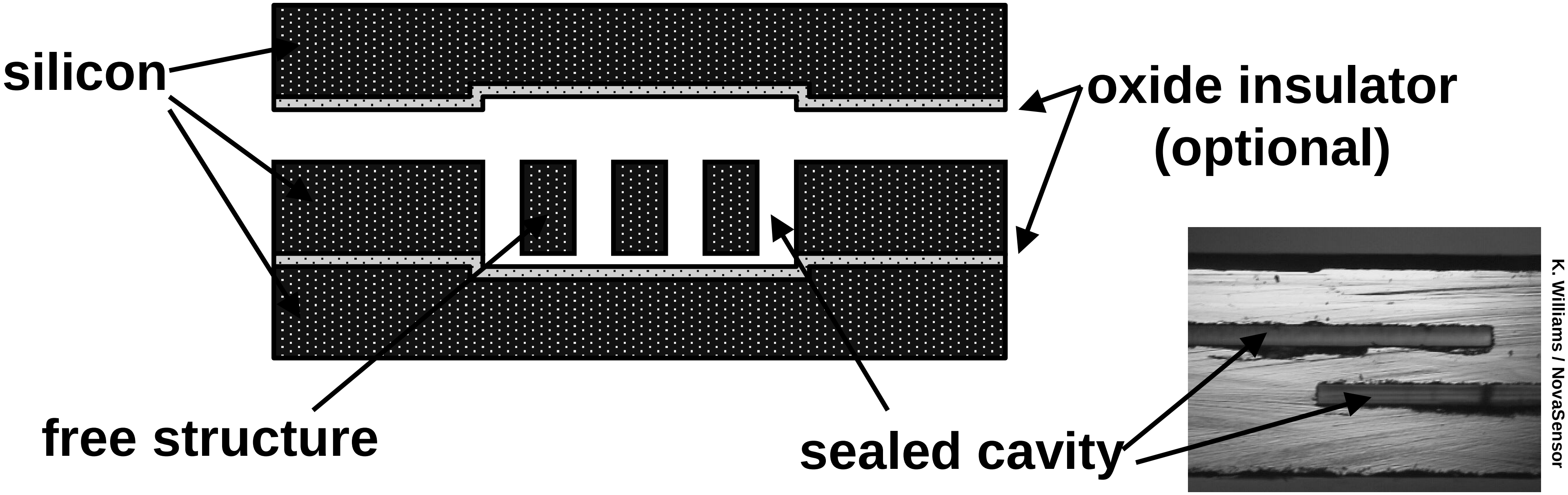
courtesy of L.W. Lin/BSAC

Research Only

On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

Silicon Fusion Bonding



silicon

oxide insulator (optional)

free structure

sealed cavity

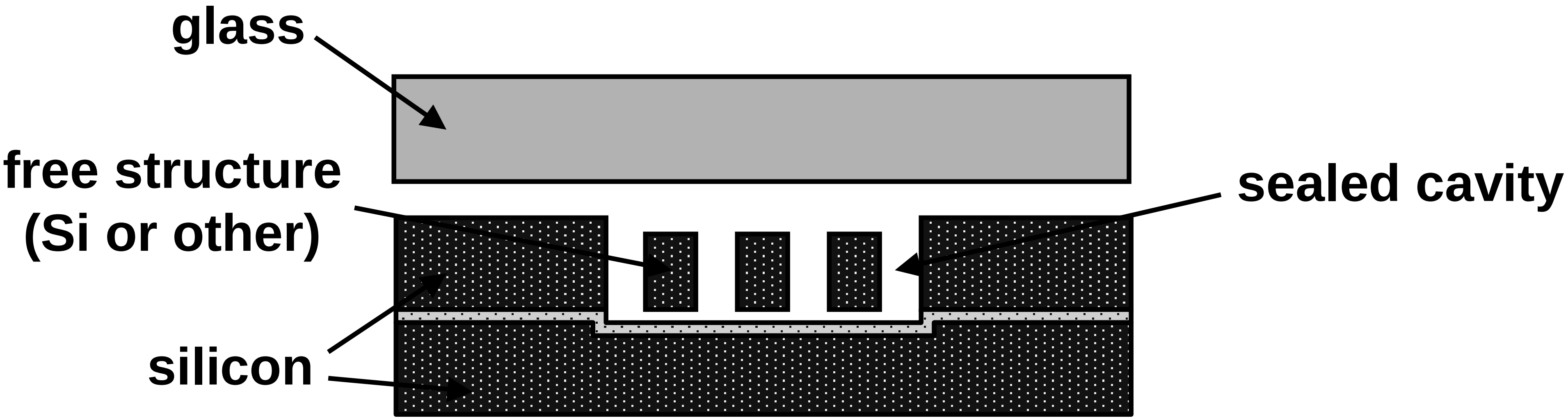
K. Williams / NovaSensor

- SFB in commercial use for absolute pressure sensors
- Development for other devices (e.g., accelerometers)
- Problems: need very smooth, clean surfaces
  - Multiple electrical contacts to outside/isolation
  - Very high temperature for bonding

On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

Anodic Bonding



- Anodic bonding in commercial use for pressure sensors
- Research (?) for other devices
- Problem: movable structures can also get bonded
    - Solution: locally eliminate electric field

On-Chip Packaging

On-Chip Hermetic Sealing (cont.)

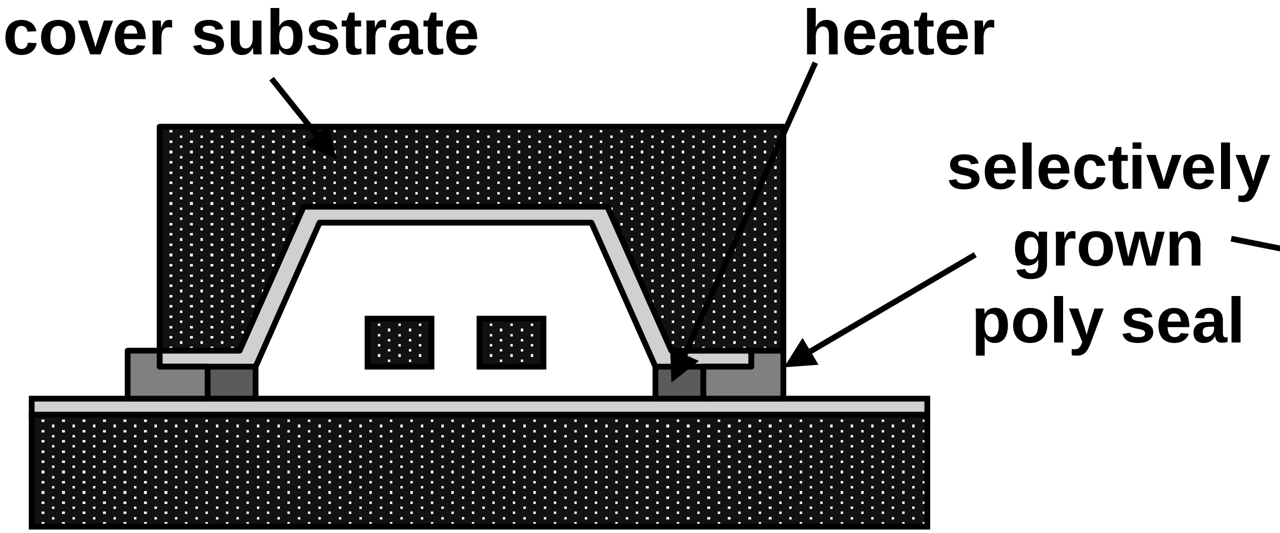
Local CVD Polysilicon Bonding

Flow current through existing line on chip

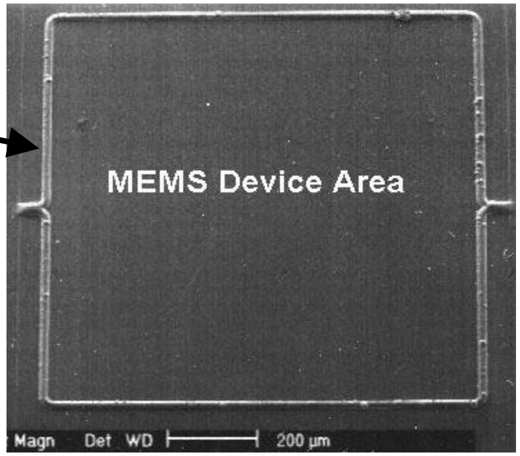
→ Only local heating

Selective chemical-vapor deposition of polysilicon

- Avoids problem of SFB of whole wafer
- Requires electrical connections



SEM with Cover Removed

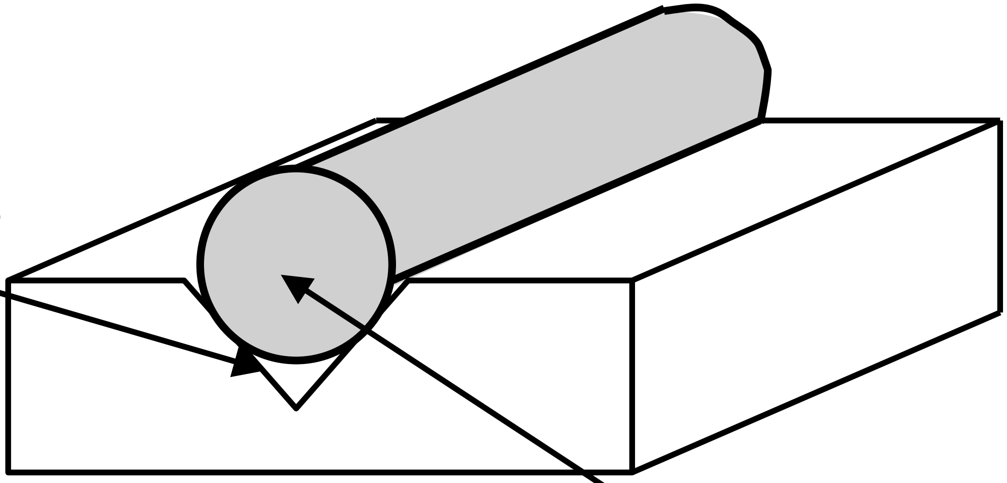


courtesy of L.W. Lin/BSAC

On-Chip Packaging

Use a Chip as Part of Packaging

Example: Aligner for Optical Fibers



KOH-etched groove in silicon

fiber (glued in place)

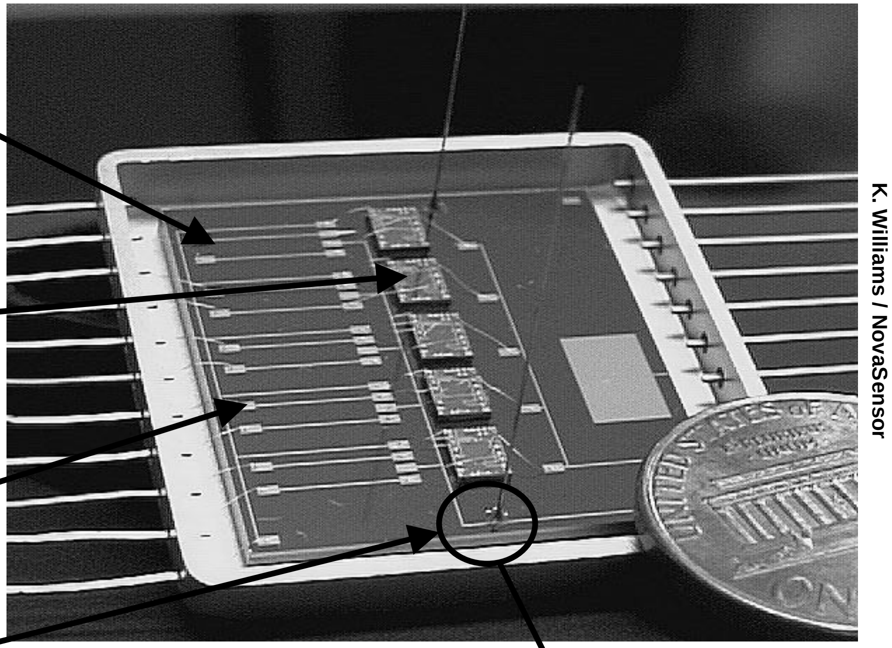
Either on optical-switch chip or on another chip in same package

On-Chip Packaging

Use a Chip as Part of Packaging (cont.)

Example: Microfluidics “PC Board”

NovaSensor DARPA project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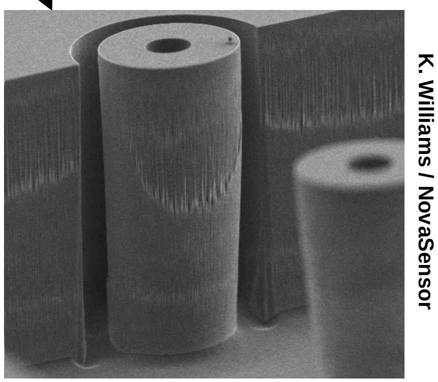
multi-layer chip
with buried channels

pressure sensors
adhered with RTV

electrical connections

fluidic connections:
capillary tubes over sleeves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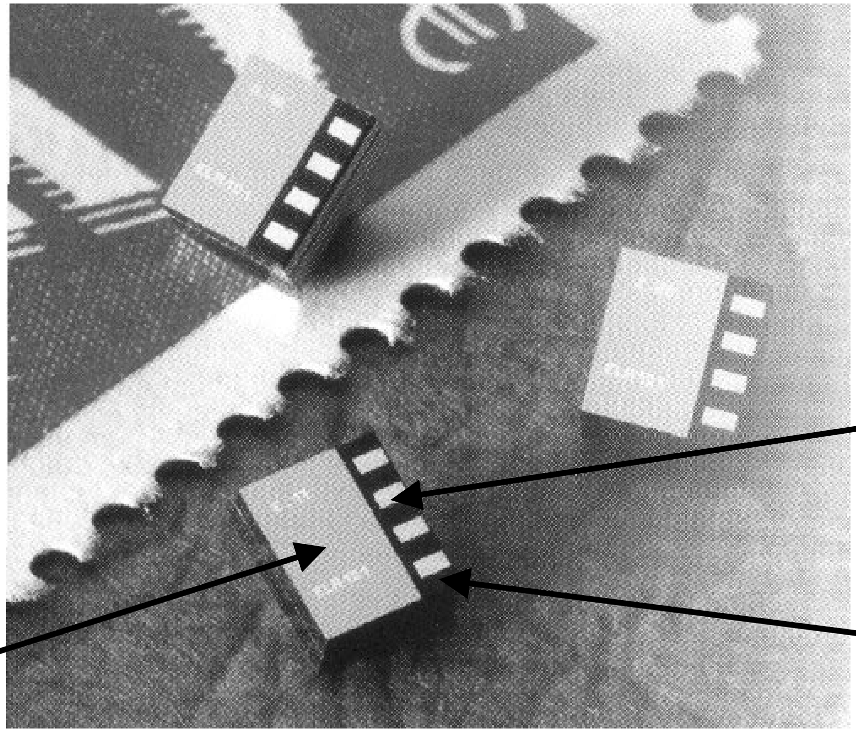
On-Chip Packaging

Chip-Size Packaging

Package outline is the same as chip outline

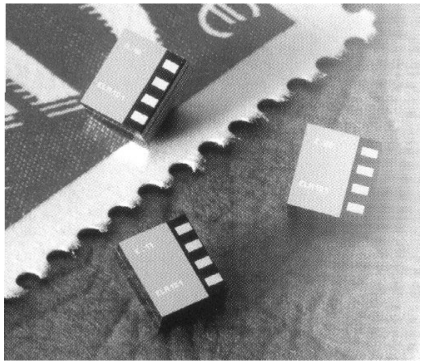


TRONIC'S Microsystems literature

TRONIC'S Microsystems Accelerometer

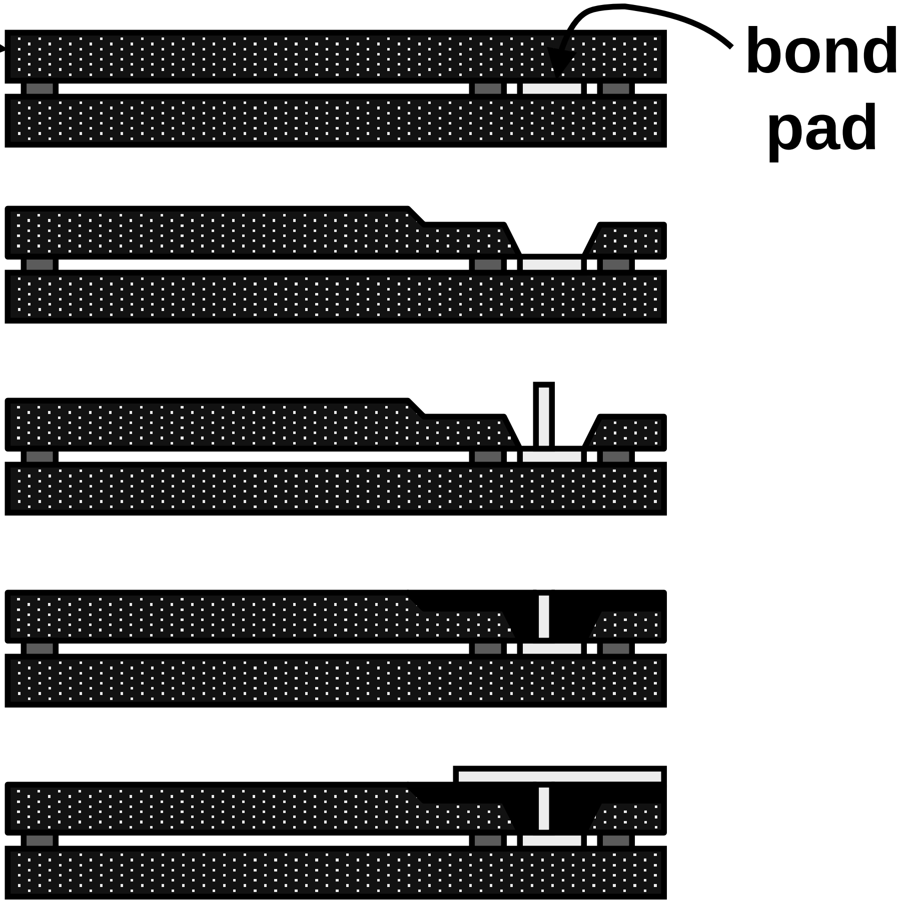
On-Chip Packaging

Chip-Size Packaging (cont.)



TRONIC'S literature

TRONIC'S CSP Process



Bond silicon cap wafer onto sensor wafer

Etch contact hole in cap

Wire bond (free end)

Epoxy fill, polish

Deposit pad metal. Dice

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Metal Packaging

- Metal packaging is the most durable

- Often the easiest to prototype using off-the-shelf packages

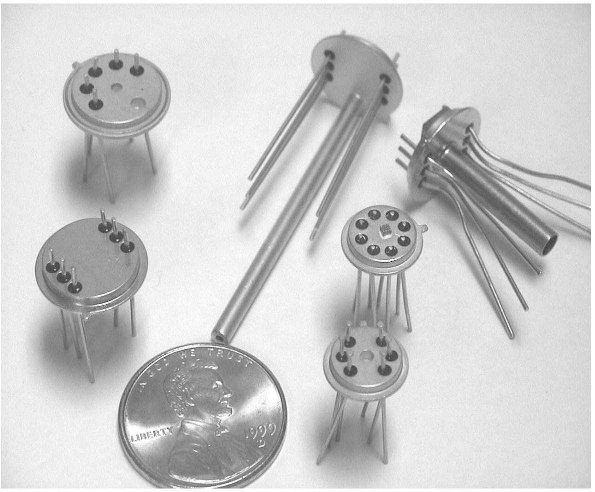
- Can be hermetic

- Can have the lowest setup cost
  (non-recurring engineering cost)
  - But can have the highest unit cost

- Discuss
  - Fabrication
  - Use
  - Off-the shelf packages (e.g., headers)
  - Custom stainless-steel pressure-sensor package

Metal Packaging

Header Fabrication



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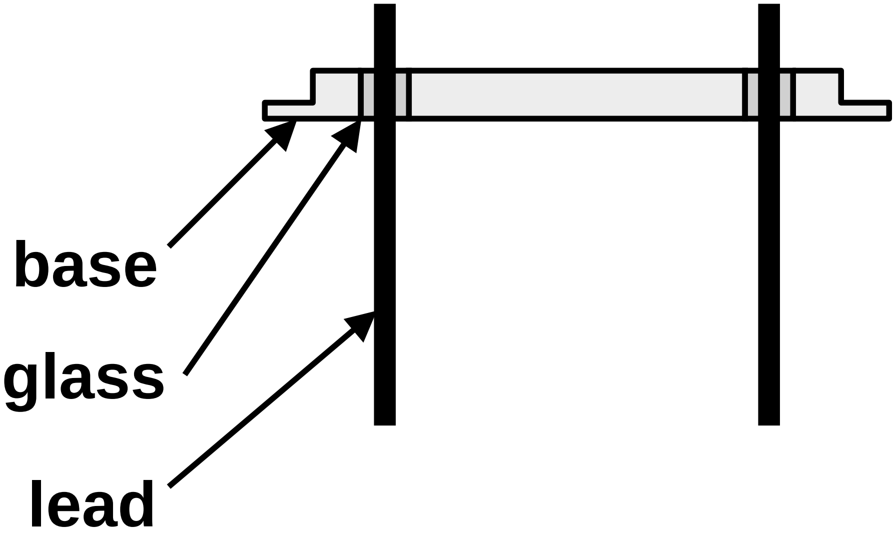
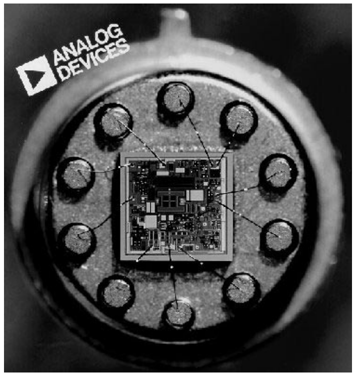
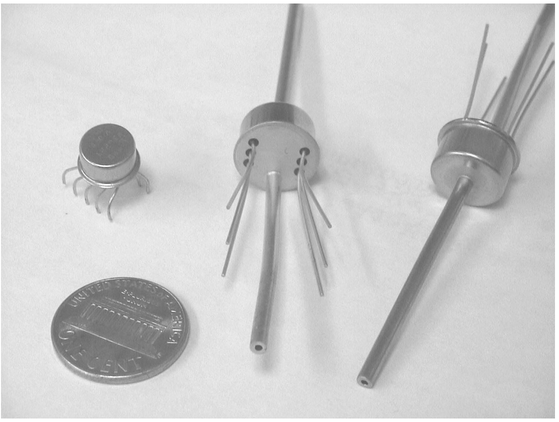
- Stamp base and punch holes
- Oxidize base and wires
- Place glass beads
- Place wire leads
- Fuse glass to base and wires
- Clean off oxide
- Nickel plate
- Gold plate



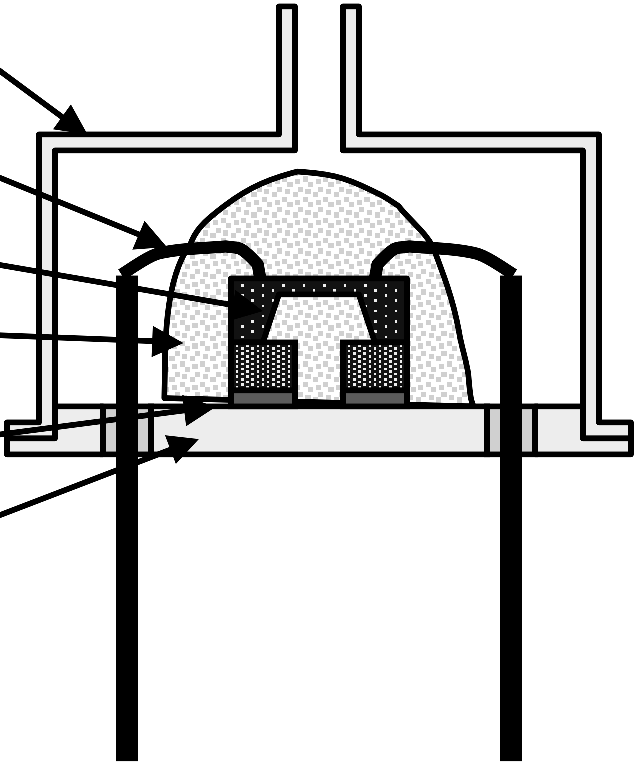
Metal Packaging

Header Use


courtesy M. Judy/Analog Devices


K. Williams / NovaSensor

- Select header
- Trace adhesive
- Place chip
- Cure
- Wire bond
- Place blob of gel
  (pressure sensors)
- Resistance-weld lid
  (option: header
  and/or lid may have tubes)



lid

bond wire

chip

gel

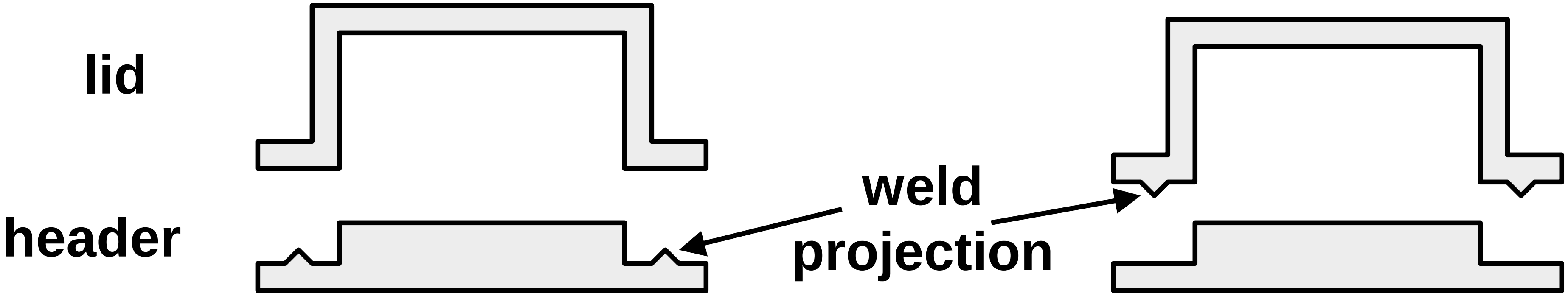
adhesive

header

Metal Packaging

Header Notes

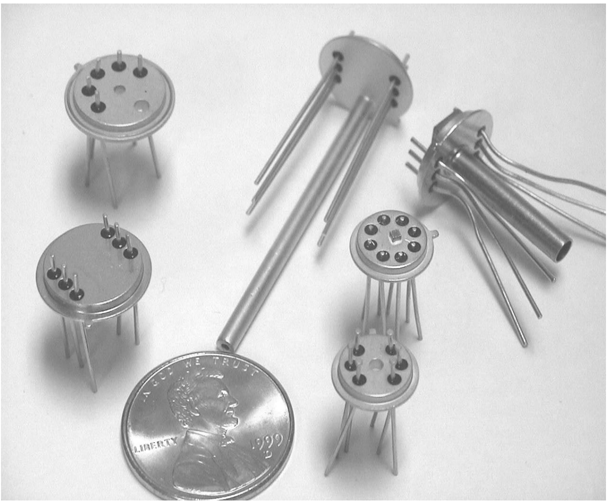
- Gold plating is needed for wire bonding
  - Gold is expensive
  - Can mask it off where not needed, but masking costs money
- Weld projection usually added to header or lid
  - Gives local high current during resistance welding
  - Ensures good seal around entire perimeter
  - Less heating of chip



Metal Packaging

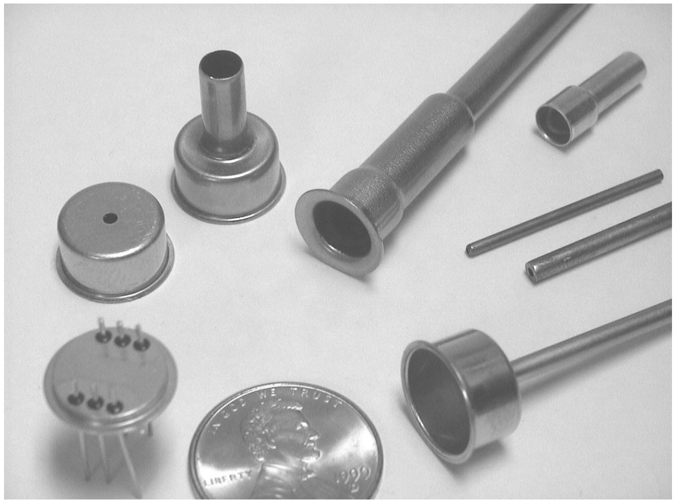
Metal Headers

TO-8, TO-5 Headers



K. Williams / NovaSensor

Lids



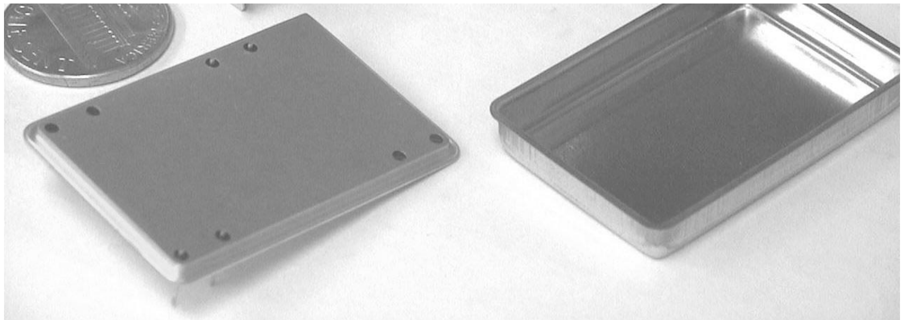
K. Williams/NovaSensor

- Large variety of headers available off the shelf
- Can custom build
- Large variety of lids available
  - Can extrude, braze on, or resistance weld tubes
  - Can include windows, but fired-in windows difficult to make with good optical quality

Metal Packaging

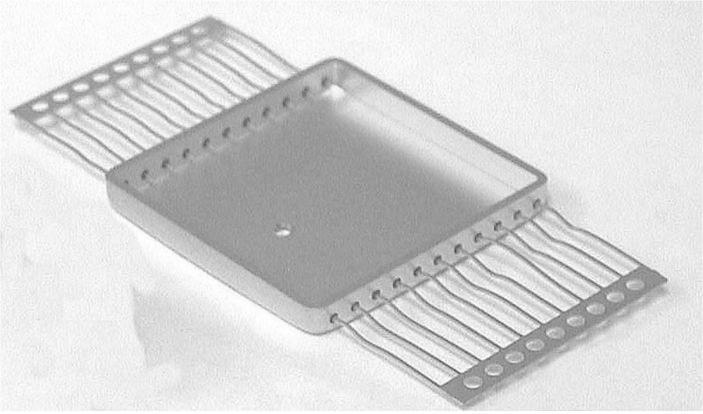
Large Metal Packages

Large-Format Header

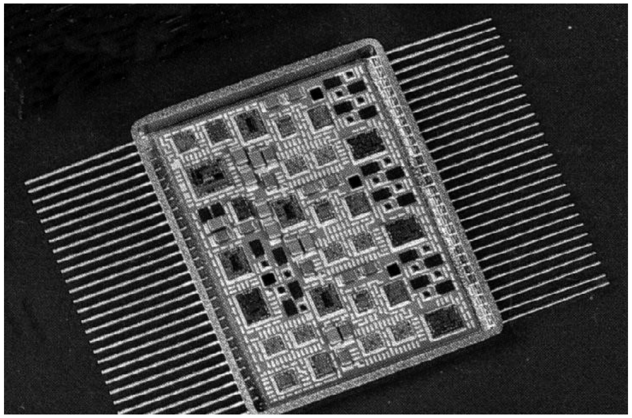


K. Williams / NovaSensor

Hybrid/MCM



K. Williams / NovaSensor



Advanced Packaging Technology of America literature

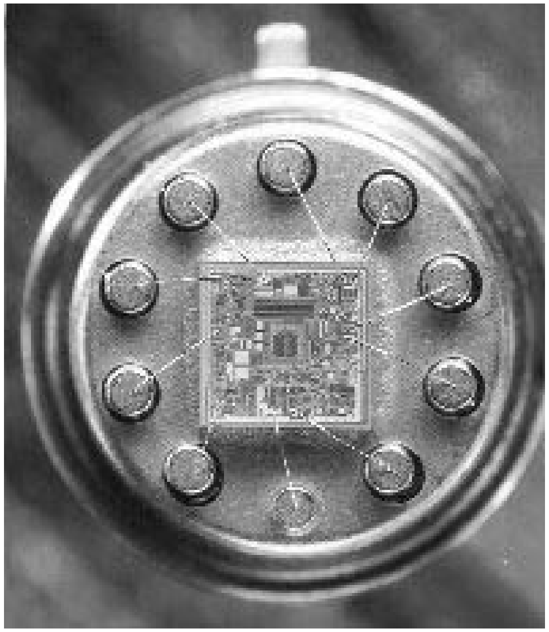
- Available off the shelf
- Can be custom-made to specs

- Hybrid is more difficult to bond wires to due to lead bending

Metal Packaging

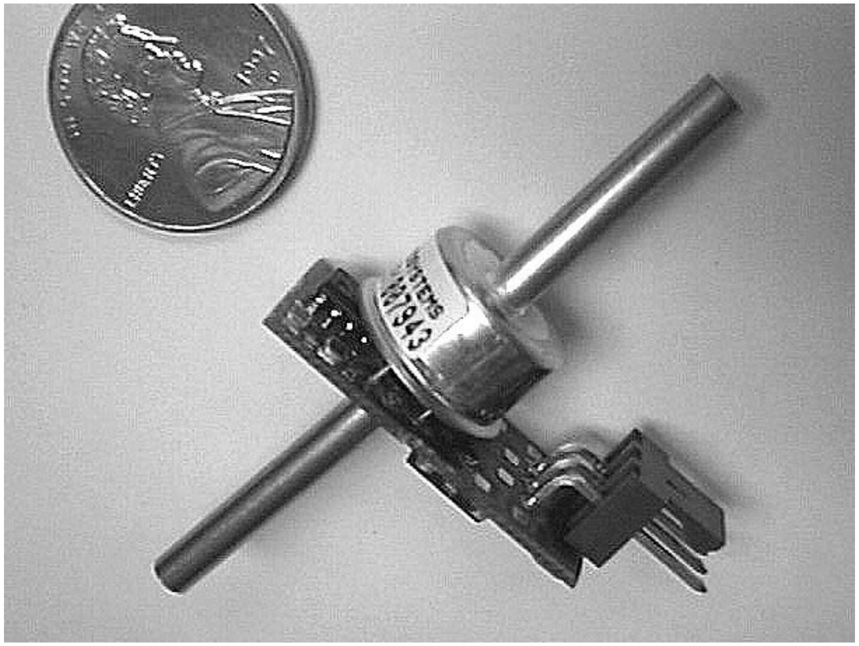
Commercial MEMS Metal Packaging Examples

Headers are most common
These examples have hermetic seals



courtesy M. Judy/Analog Devices

Analog Device ADXL05 surface-micromachined accelerometer



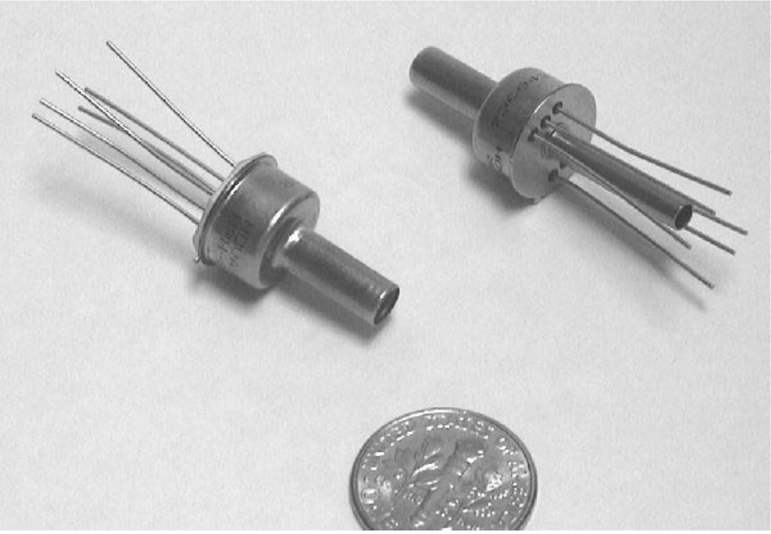
K. Williams / NovaSensor

Redwood Microsystems NC-1500 Fluistor^{TM} valve

Metal Packaging

Commercial MEMS Metal Packaging Examples (cont.)

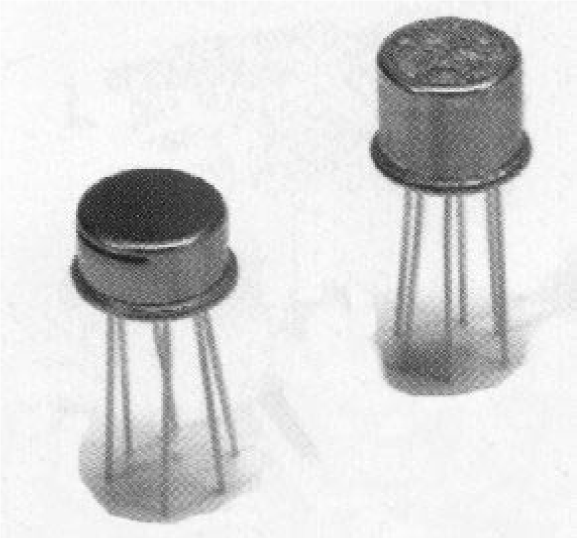
More MEM devices in headers



K. Williams / NovaSensor

NovaSensor
bulk-micromachined
NPH pressure sensors

Tubes in top only or top and bottom for absolute and differential pressure



Honeywell literature

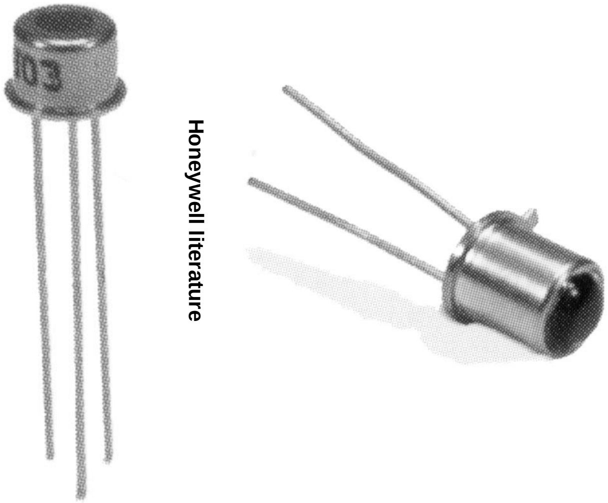
Honeywell
humidity sensors

Slot or mesh on lid for air access

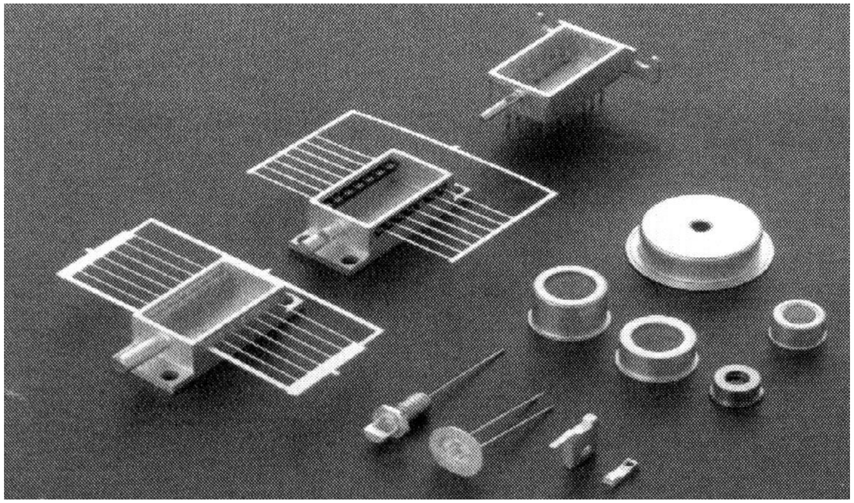
Metal Packaging

Commercial MEMS Metal Packaging Examples (cont.)

Windowed for Optoelectronics



Honeywell literature



Prolyx literature

Honeywell VCSELs

Flat or domed window

Prolyx Packages

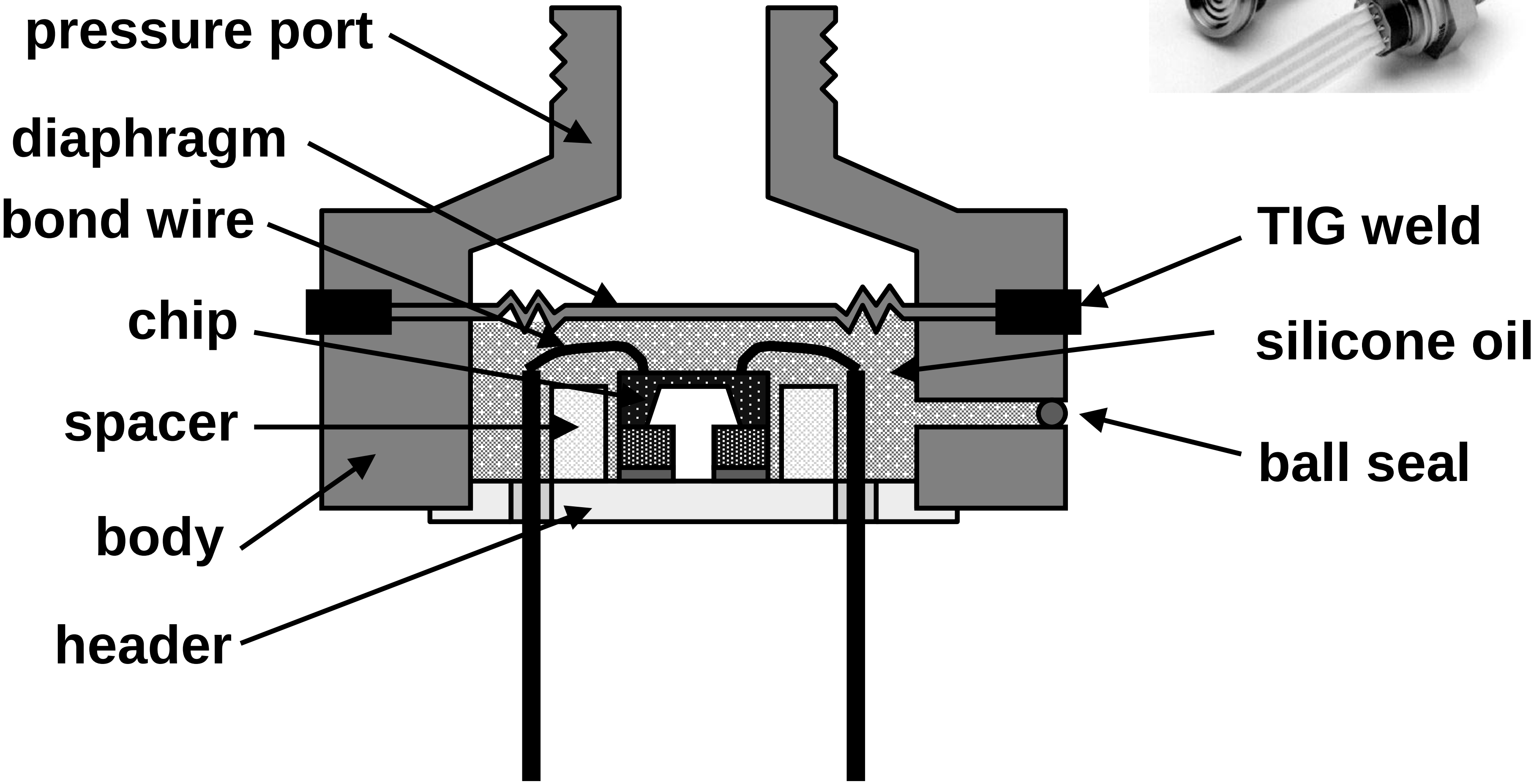
Header and other styles

Metal Packaging

Media-Isolated Metal Pressure-Sensor Package

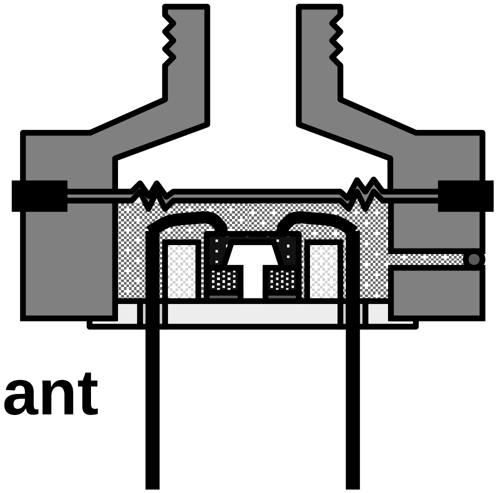
Construction


NovaSensor



Metal Packaging

Media-Isolated Metal Pressure-Sensor Package (cont.)



Some Requirements

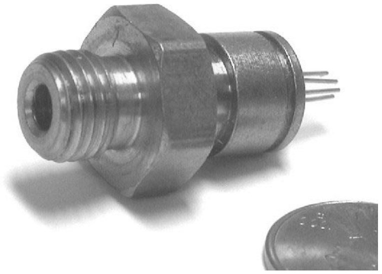
- Metal diaphragm must be > 100 X more compliant than silicon diaphragm:
  - For complete transfer of pressure (iso sensors only go down to ~15 psi full-scale)
  - To allow for thermal expansion of oil (~1000 ppm/K)

  → Make it thin, corrugated
- The insert reduces oil volume and thermal expansion effect
- Must eliminate gas inside sealed volume
  - Oil must be free of dissolved gases
  - Oil fill and ball seal must not allow gas inside

Metal Packaging

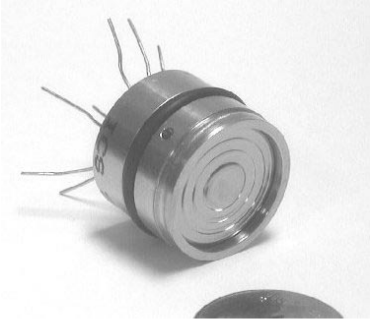
Media-Isolated Metal Pressure-Sensor Package (cont.)

Package Variations



K. Williams/NovaSensor

Pelagic



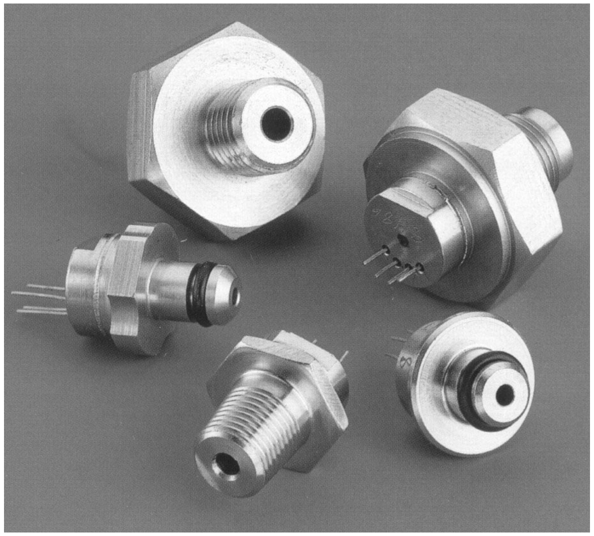
K. Williams/NovaSensor

IC Sensors

NovaSensor

NovaSensor

- Various stainless-steel and other alloys for different applications and costs
- Different pressure ports
  - Various diameters
  - Threaded or not
  - Exposed or recessed diaphragm (flat is easier to clean but less protected)



SSI literature

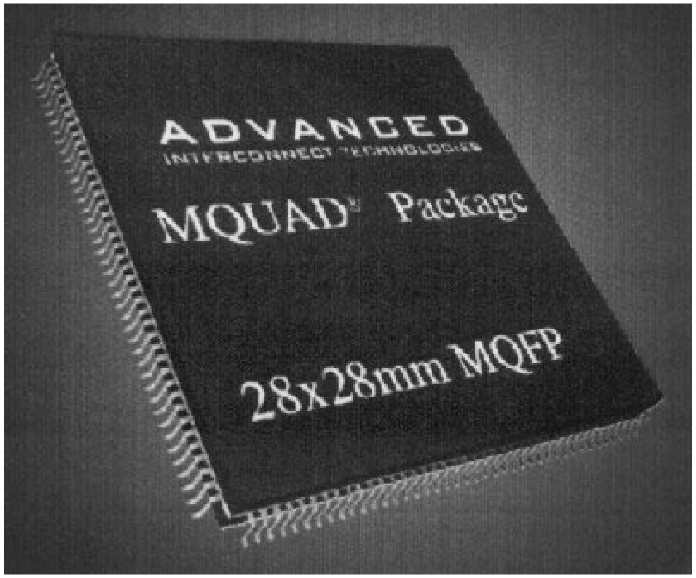
SSI

Metal Packaging

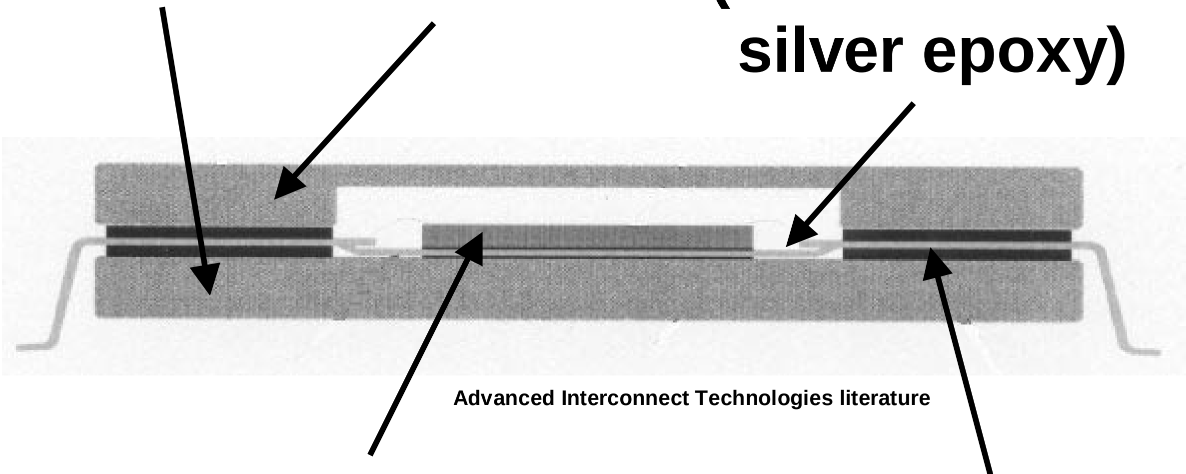
Metal Quad Flat Pack

Advanced Interconnect Technologies

Like a ceramic or plastic QFP, but made of anodized aluminum



Advanced Interconnect Technologies literature



anodized aluminum
base and lid

lead frame
(attached with
silver epoxy)

Advanced Interconnect Technologies literature

chip

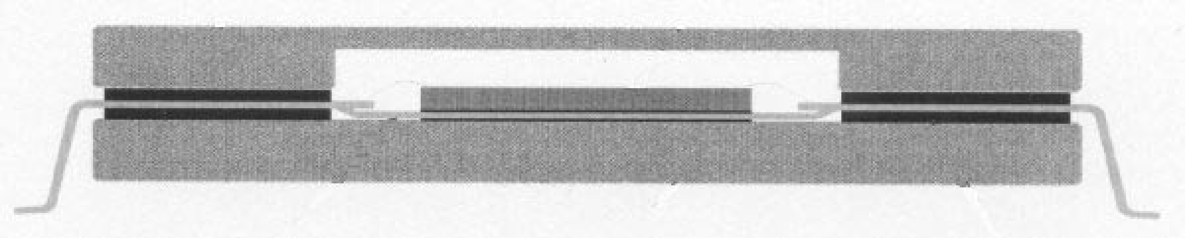
adhesive seal

Metal Packaging

Metal Quad Flat Pack (cont.)

- Advantages of MQFP
  - Low thermal resistance (~17 K/W)
  - Ground planes below, above, and around chip
  - Hermetic seal

- Potential disadvantages
  - High thermal expansion rate of aluminum (buffered by silver epoxy and lead frame)
  - Cost

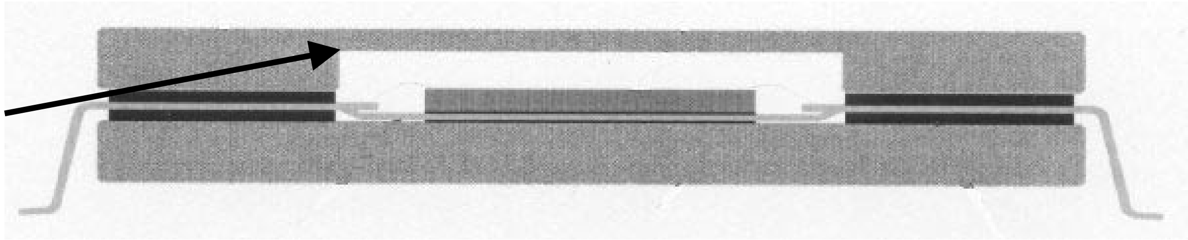


Advanced Interconnect Technology literature

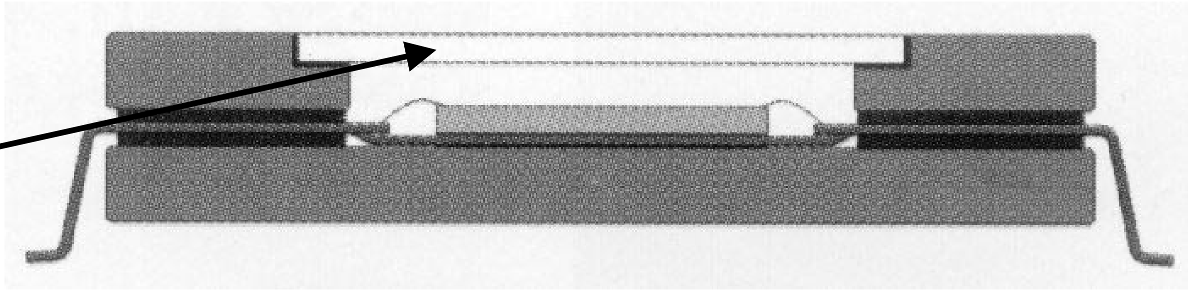
Metal Packaging

Metal Quad Flat Pack (cont.)

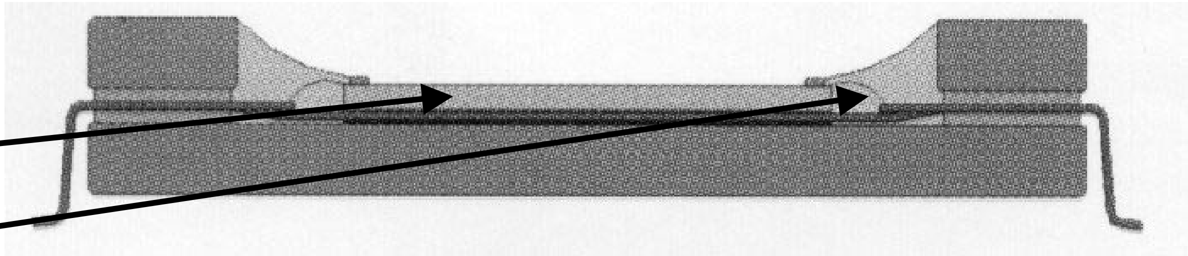
MQFP Packaging for MEMS



Standard IC hermetic package with metal lid



CCD imager package with glass lid



Fingerprint sensor package with exposed die and sealed leads

Advanced Interconnect Technology literature

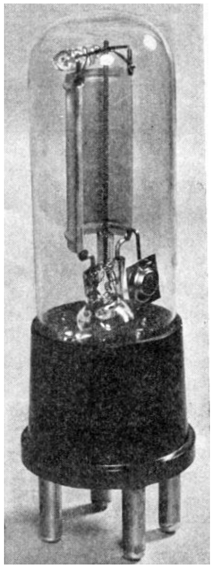
Packaging for MEMS Outline

- Packaging goals
- Materials properties:
  Thermal stress, heat transfer,
  and hermetic sealing
- Types of packaging
  - On-chip
  - Metal
  - Glass
  - Ceramic
  - Plastic
  - Comparison
- Packaging costs
- Summary

Glass Packaging

Glass packaging has been in use for a *long* time

**RCA
vacuum tube**

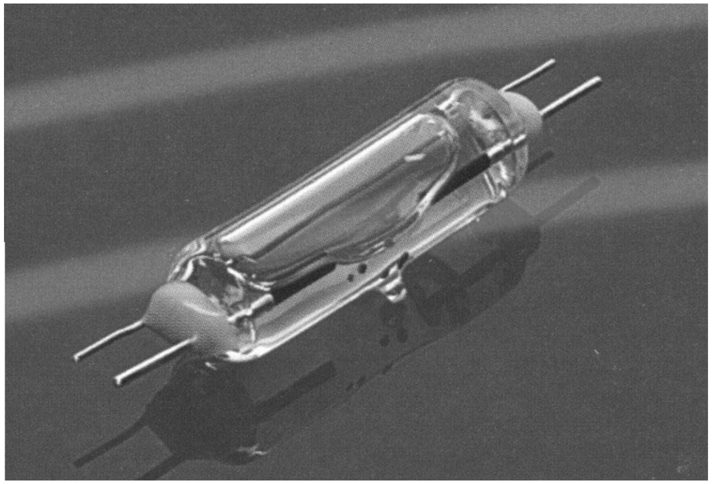


**Westinghouse
photodetector tube**

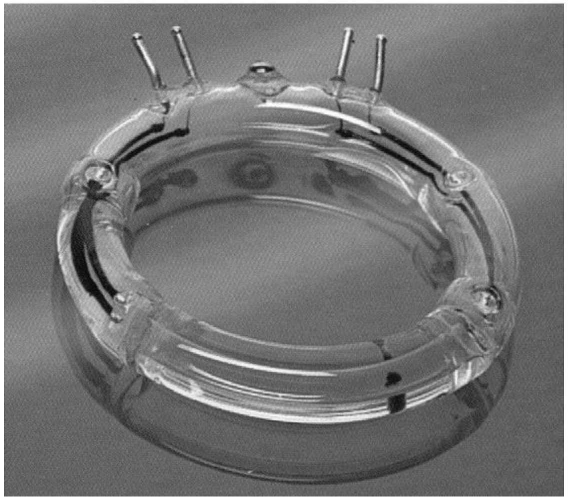
- Glass envelope
- Metal leads fired in (similar to fabrication of headers)
- Can pump to high vacuum before sealing
- Can hold at high vacuum for years
  with getter (e.g., Ba, Mg, Al, Ti)

Glass Packaging

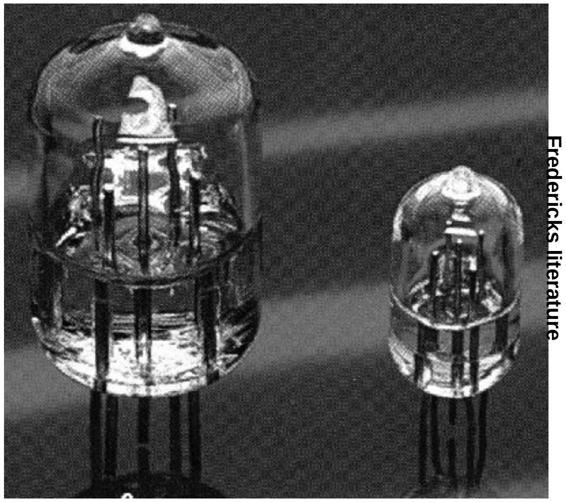
Glass Packaged Sensors



Fredericks literature



Fredericks literature



Fredericks literature

Fredericks Electrolytic Tilt Sensors

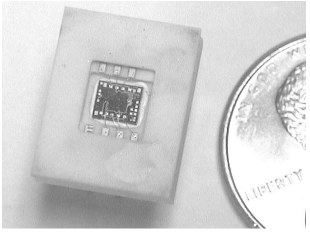
- These are not MEM devices
- Give an idea of the variety of glass packages that can be made
- Glass tubes can be made very small--down to capillary size
- May be difficult to form a flat face--
  probably not suitable for optical imaging

Packaging for MEMS Outline

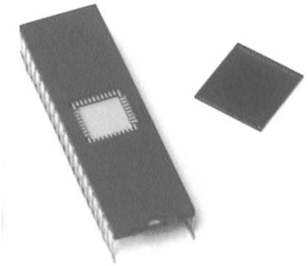
- Packaging goals
- Materials properties:
  Thermal stress, heat transfer,
  and hermetic sealing
- Types of packaging
  - On-chip
  - Metal
  - Glass
  - Ceramic
  - Plastic
  - Comparison
- Packaging costs
- Summary

Ceramic Packaging

Ceramic Packaging



K. Williams



K. Williams

- Ceramic packaging can be very durable
- Can be hermetic
- Can have low thermal resistance
- Low thermal expansion rate (especially AlN)
- Cover can have clear window
- Can have high setup costs if not off-the-shelf (non-recurring engineering cost)
  - Low to high unit cost, depending on size and complexity

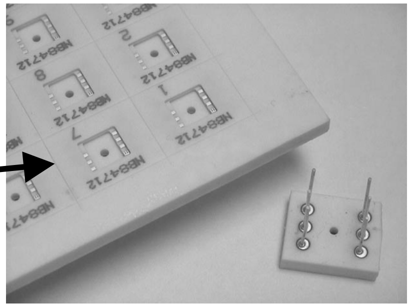
Discuss

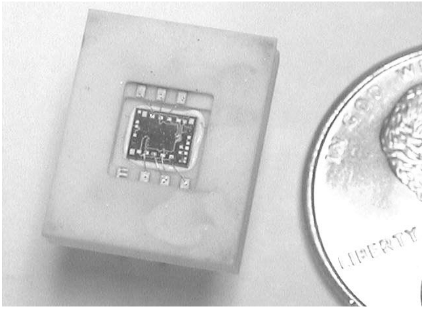
- Fabrication
- Use
- Off-the shelf packages
- Custom packages

Ceramic Packaging

Ceramic Package Fabrication

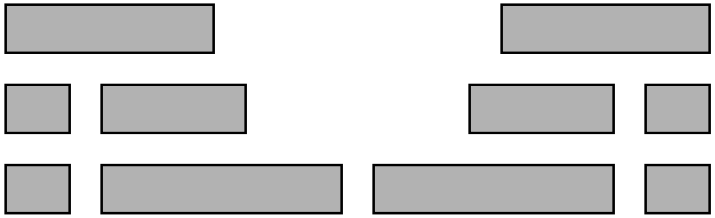
Many packages are made together on the same plate


K. Williams

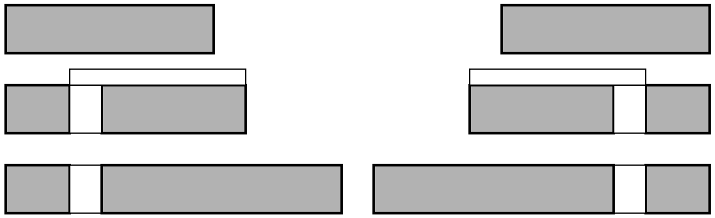

K. Williams

- Mix fine ceramic powder with organic binders and solvents to form uniform “tape”

- Punch holes in tape



- Fill vias, screen print metal (typically tungsten or W+Mo powder paste onto tape

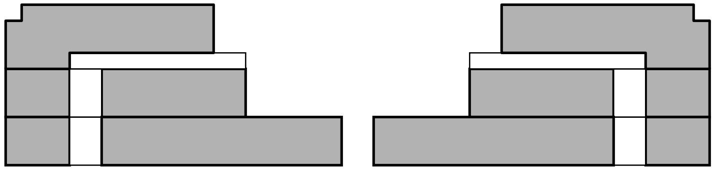


see Coors Ceramics literature

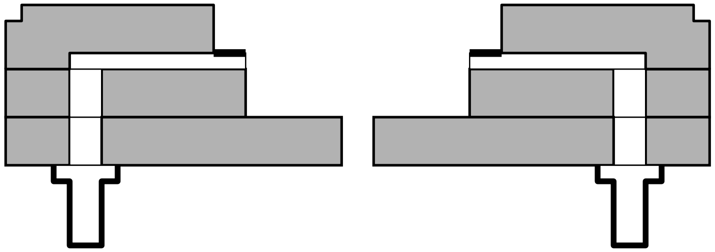
Ceramic Packaging

Ceramic Package Fabrication (cont.)

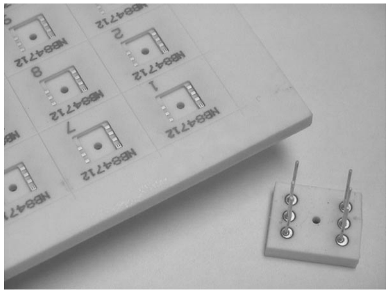
- **Stack layers, score at edges for later separation**
- **Sinter (at up to 1600°C)**
  - **Get ~20% shrinkage in all dimensions**
- **Plate exposed metal with nickel**



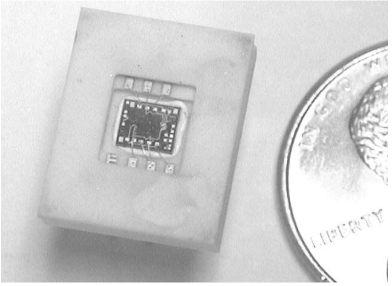
- **Braze on leads (Kovar or Alloy 42) with silver or Ag/Cu alloy**
- **Plate with gold or nickel**



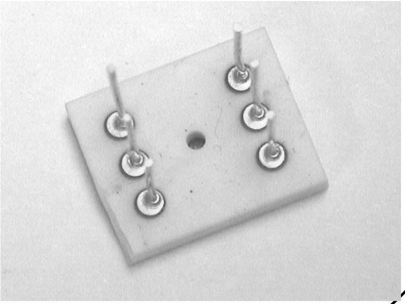
- **Whole plate shipped to customer for handling ease**



K. Williams



K. Williams



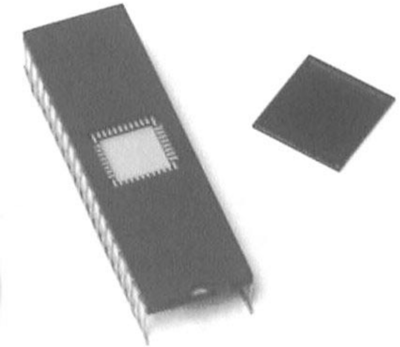
K. Williams

see Coors Ceramics literature

Ceramic Packaging

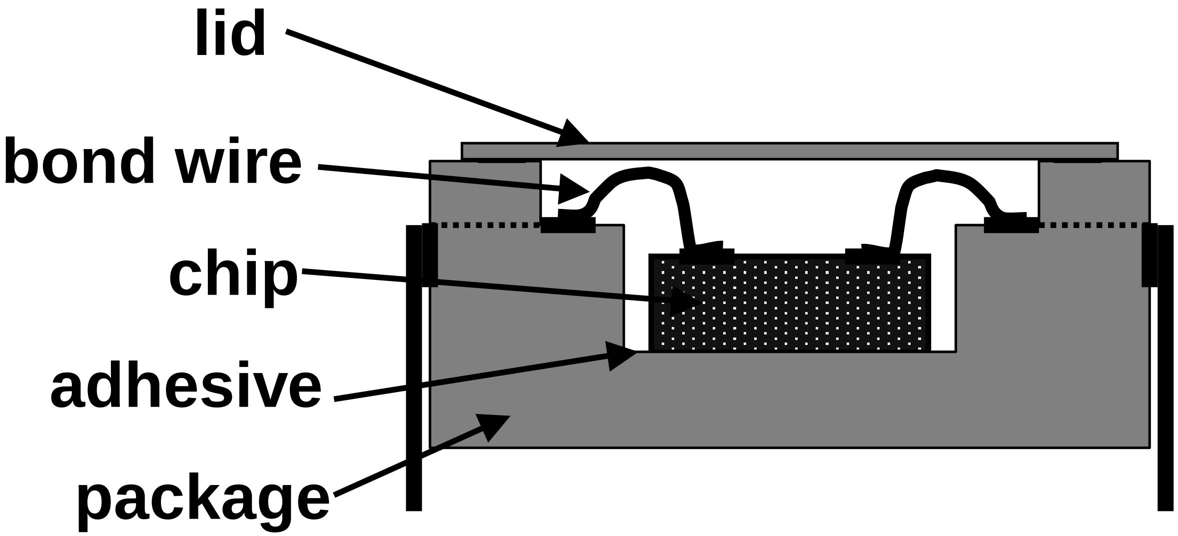
Ceramic Package Use

Typical DIP



K. Williams / NovaSensor

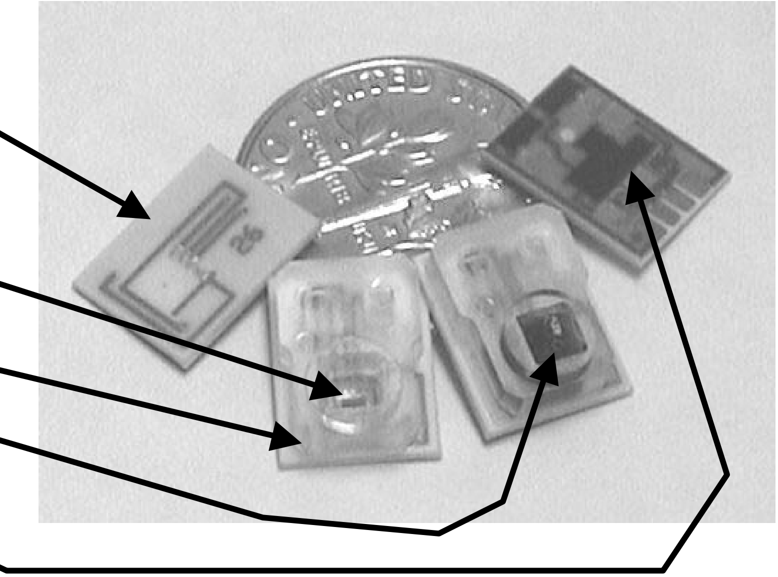
- Select package
- Apply adhesive
- Place chip
- Cure
- Wire bond
- For pressure sensors:
  Place blob of gel
- Seal lid



Ceramic Package Use (cont.)

Blood-Pressure Sensor on Custom-Made Ceramic Plate with Thick-Film Trim Resistors

- Custom-made plate
- Trace RTV
- Place chip
- Trace adhesive
- Place plastic cover
- Protect with black gel
- Trim thick-film resistor

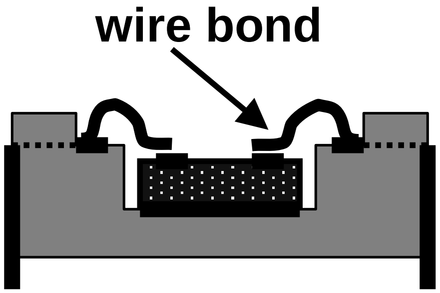


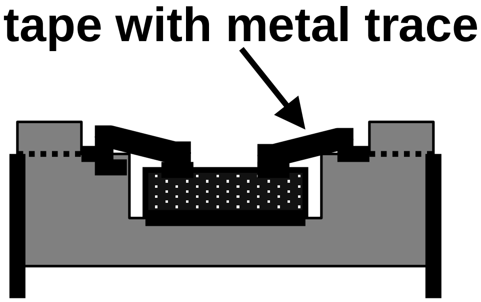
K. Williams / NovaSensor

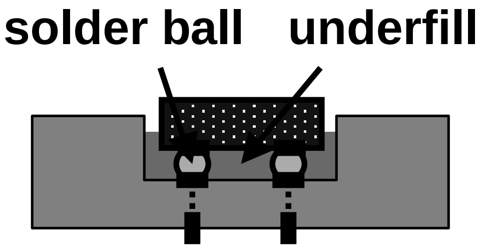
Ceramic Packaging

Ceramic Package Options

Connecting Wires:
- Wire bond
- Tape-automated bond
- Flip-chip solder to metal bumps





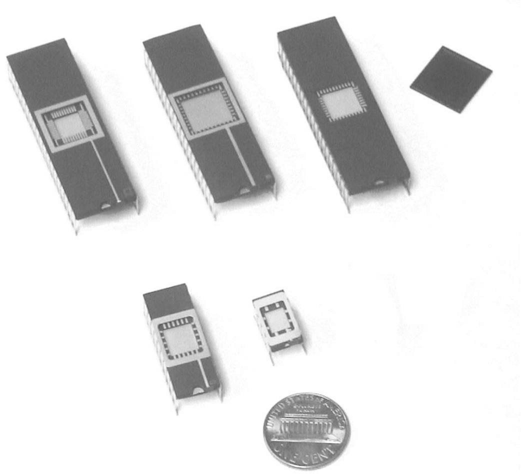


Die Attach:
- Epoxy (can be silver-filled)
- RTV
- Solder
- Flip-chip solder with underfill

Lid Sealing:
- Metal lid: braze, solder, or epoxy
- Ceramic lid: solder, epoxy, or glass

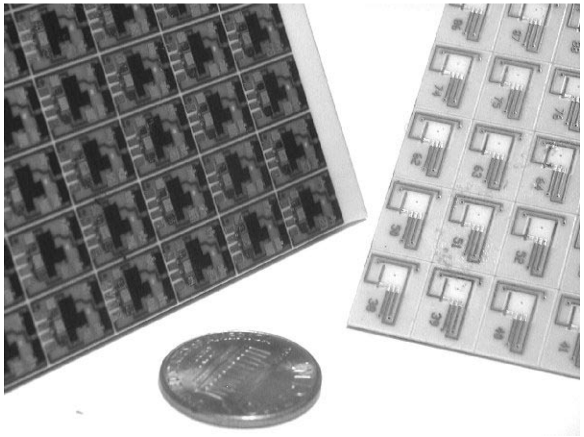
Ceramic Package Examples

DIPs



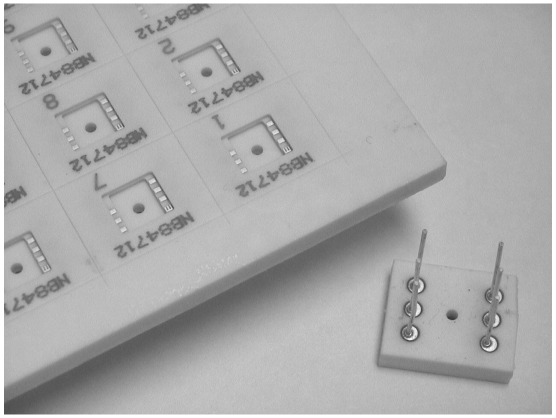
K. Williams / NovaSensor

Custom Plate with Thick-Film Resistor



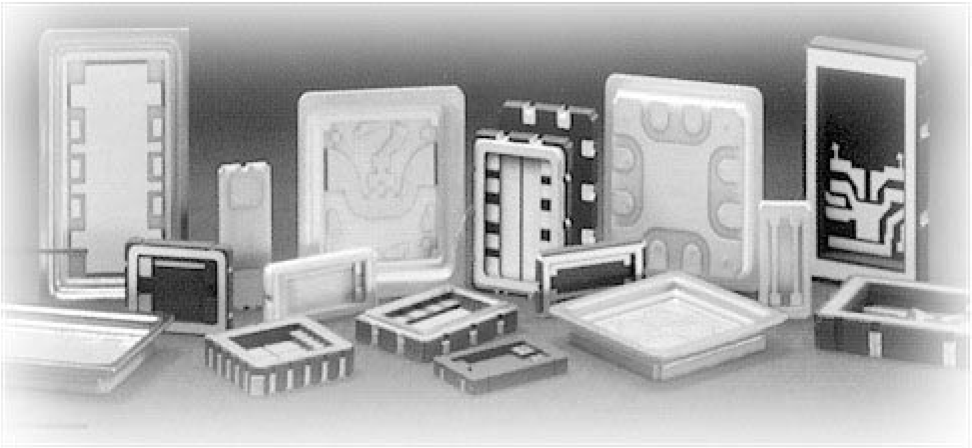
K. Williams / NovaSensor

Custom 3-Layer with Hole



K. Williams / NovaSensor

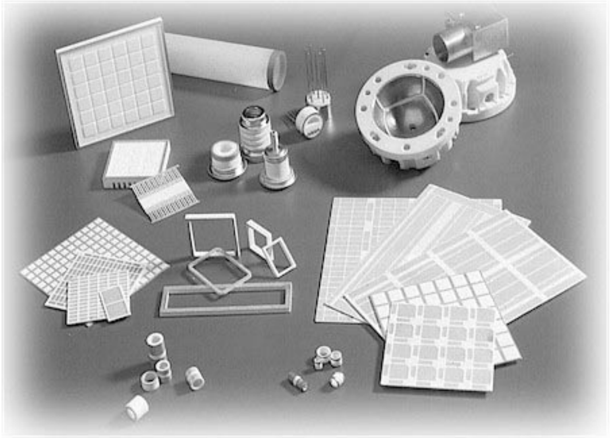
Variety of IC Packages



Coors Ceramics literature

Coors

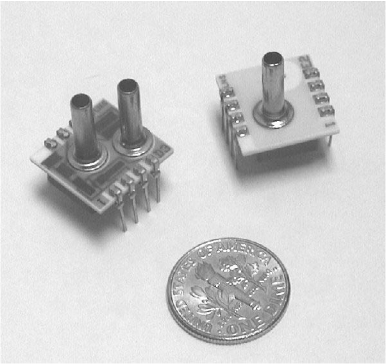
Variety of Plates+



Coors Ceramics literature

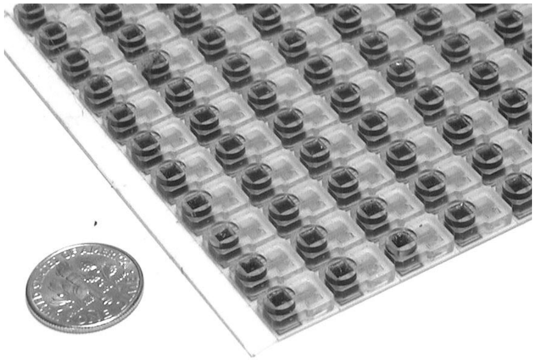
Ceramic Packaging

Commercial MEMS Ceramic Package Examples



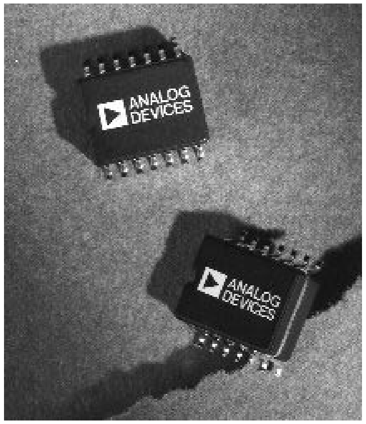
K. Williams / NovaSensor

NovaSensor bulk-micromachined NPC pressure sensors (absolute and differential)

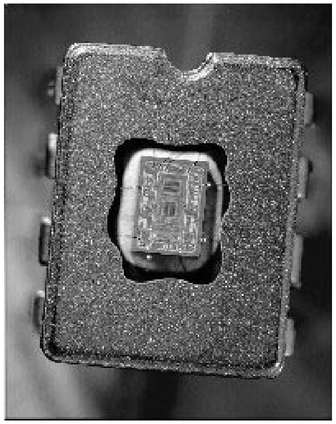


K. Williams / NovaSensor

NovaSensor disposable bulk-micromachined blood-pressure sensors



courtesy M. Judy/Analog Devices



courtesy M. Judy/Analog Devices

Analog Devices surface-micromachined accelerometers

Ceramic Packaging

Ceramic Package Notes

- Materials notes
    - Ceramic:
        - 90+% alumina most common
            - Cheapest
        - Aluminum nitride, beryllia also used
            - Certain better thermal properties
  - Metals:
      - Tungsten or W+Mo traces (to withstand sintering)
      - Kovar or Alloy 42 for leads for TCE match
      - Nickel plating for soldering (Ni doesn’t corrode easily)
      - Gold plating for corrosion prot., wire bonding, wetting
- Many packages on single ceramic plate
    - Parallel processing saves time, handling cost
        - Both for ceramic producer and user
    - “Singulation” shock can damage MEM parts

Packaging for MEMS Outline

- Packaging goals
- Materials properties:
  Thermal stress, heat transfer,
  and hermetic sealing
- Types of packaging
  - On-chip
  - Metal
  - Glass
  - Ceramic
  - **Plastic**
  - Comparison
- Packaging costs
- Summary

Plastic Packaging

- Plastic packaging typically is not as good as metal or ceramic:
  - Higher thermal expansion
  - Higher thermal resistance
  - Higher moisture permeability

- But cheapest for high volume
  - Most common for ICs
  - Good choice for some MEM parts
  - Parallel processing

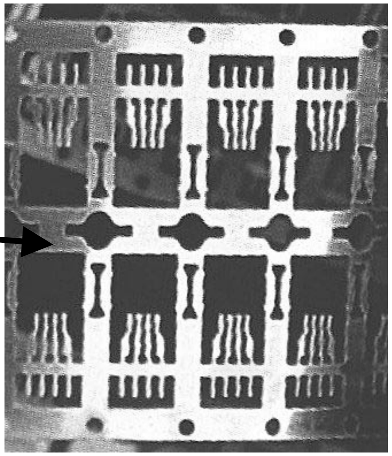
- Setup costs can be high (non-recurring engineering cost)
  - Unit cost can be lowest

- Discuss
  - Fabrication and use
  - Various packages

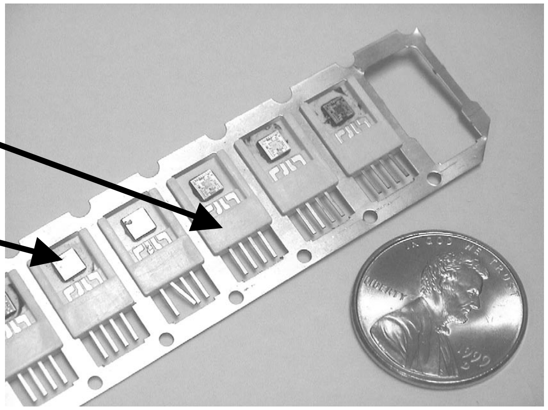
Plastic Package Fabrication

Typical IC Packaging Sequence

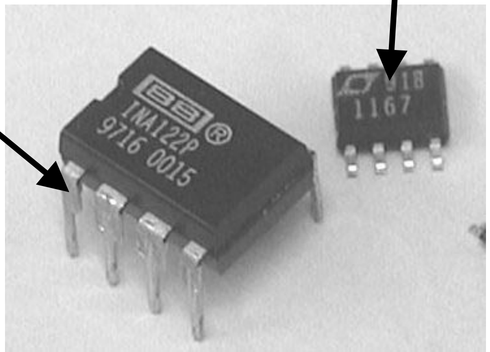
- Form metal leadframe
  - Etched (lo-vol) or stamped (hi-vol)
  - Many made together
  - Plate gold in wire-bond area
- Injection-mold plastic base
- Adhere silicon chip
- Transfer mold plastic top
- Cut packages from leadframe
- Bend leads



Handy&Harmon/ELE literature



K. Williams/NovaSensor



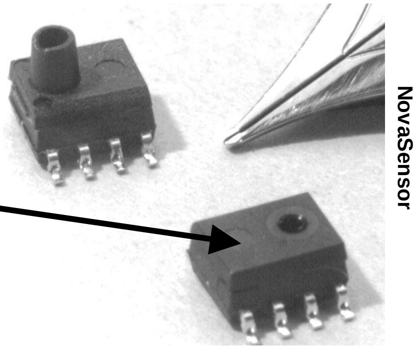
K. Williams/NovaSensor

Plastic Packaging

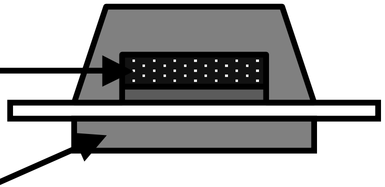
Plastic Package Fabrication (cont.)

Some Variations

- Instead of transfer-molded top, adhere hollow top on
  - Epoxy or plastic welding
  - Suitable for pressure sensors



- Instead of injection molding base first, add chip to paddle on lead frame, then transfer mold top and bottom plastic

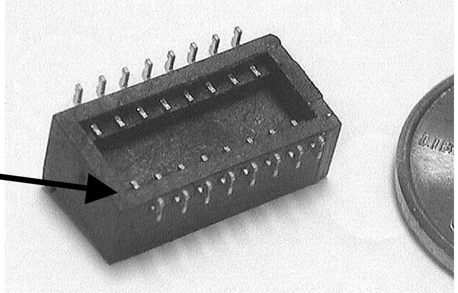


Plastic Packaging

Plastic Package Fabrication (cont.)

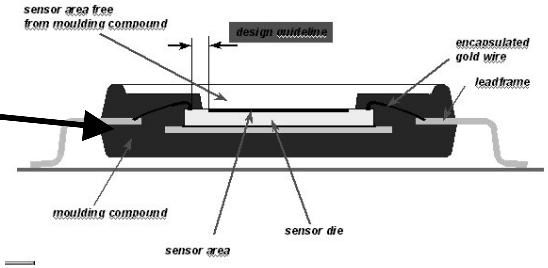
More Variations

- Instead of molding over leadframe, leave holes for pins, insert pins later



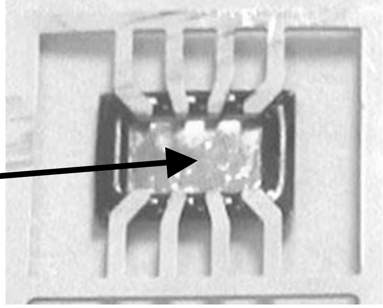
K. Williams/NovaSensor

- Overmold only at edge of chip over bond wires (Eurasem, AIT)
  - Useful for exposed sensors



Eurasem lit.

- Instead of plastic under chip at bottom, add metal that protrudes to back of package (R-Pak, AIT) for lower thermal resistance



K. Williams/NovaSensor

Plastic Packaging

Molding Comparison

Injection molding process:

- Melt polymer (thermoplastic)
- Inject at high temperature (~280 °C) and pressure
  - Cannot injection mold over part
- Hardens when cool
- Cheaper tooling (~$40k)

Transfer molding process (most common):

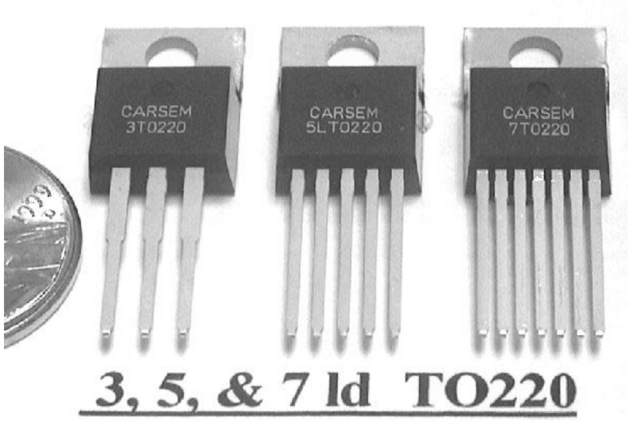
- Mix epoxy (thermoset) and fillers
  - ~70% filler (e.g., silica, alumina)
  - Determines thermal conductivity and expansion
- Inject at moderate T (~175 °C) and pressure
- Hardens by crosslinking
- More expensive tooling (~$100k+)
- Cheapest in high volume

Molding is typically done at the vendor

Plastic Packaging

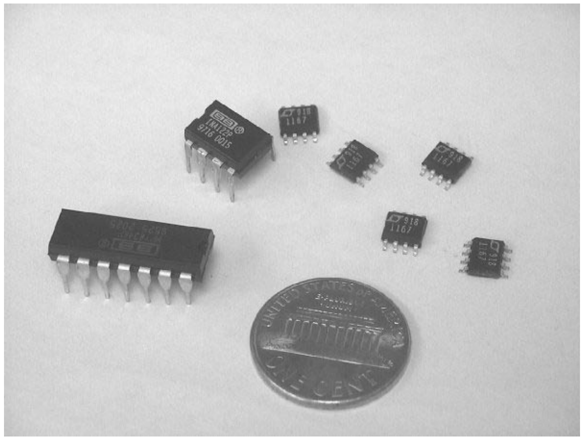
“Standard” Plastic Packaging Examples

TO-220--high-power



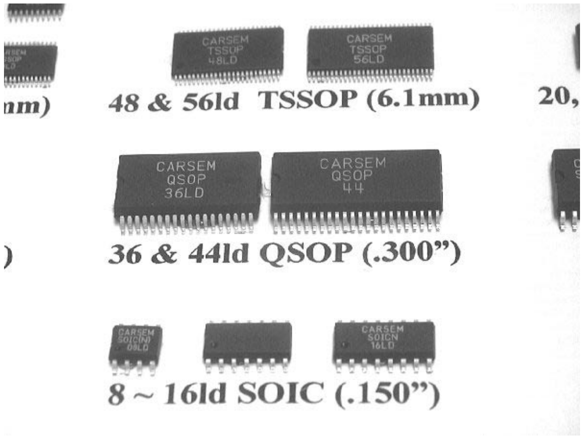
K. Williams/NovaSensor

DIP and SOIC--“standard”



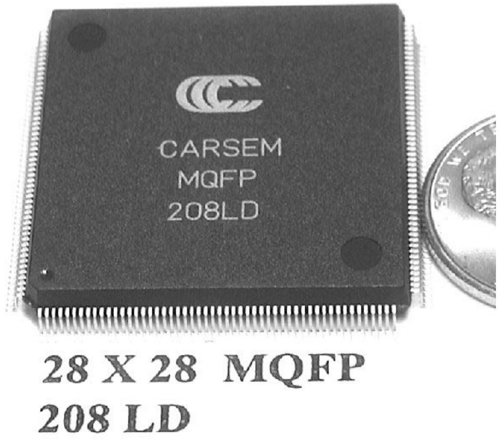
K. Williams/NovaSensor

SOIC, QSOP--more pins



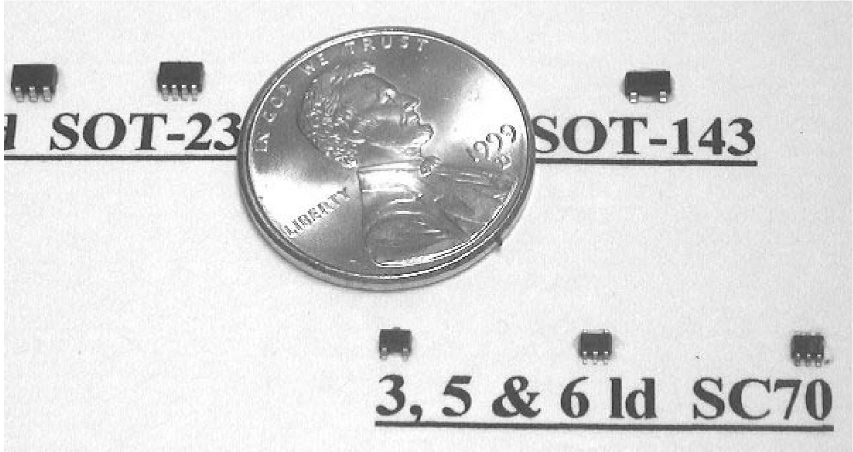
K. Williams/NovaSensor

MQFP--high pin count



K. Williams/NovaSensor

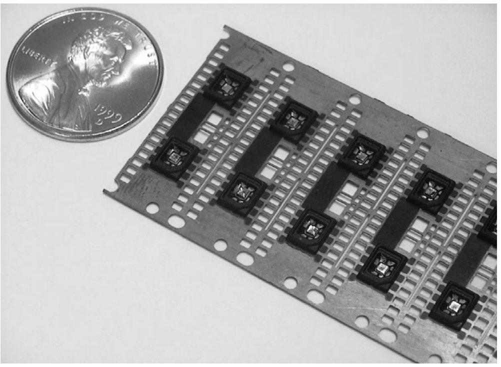
SOT--very small, low pin count



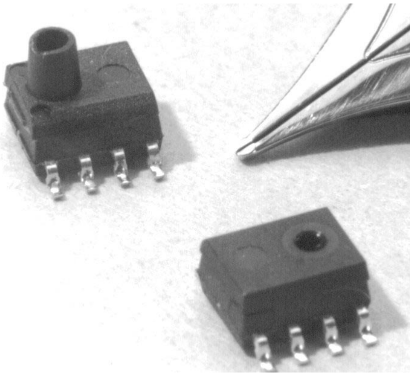
K. Williams/NovaSensor

Plastic Packaging

MEMS Plastic Packaging Examples

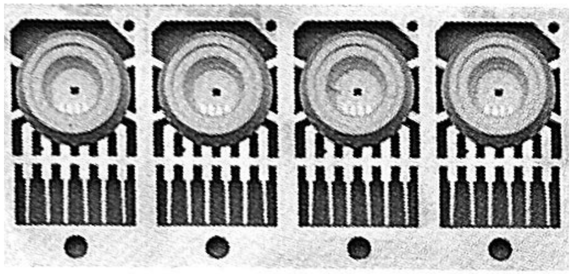


K. Williams/NovaSensor

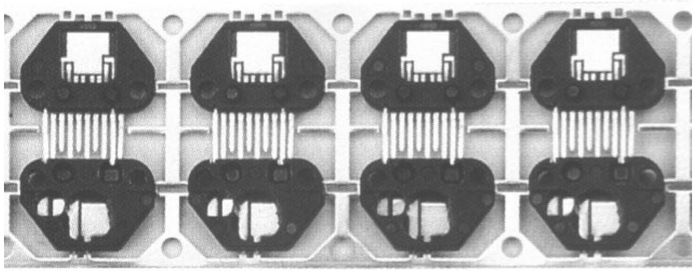


NovaSensor

NovaSensor package with hole for pressure sensor



Handy&Harmon/ELE literature

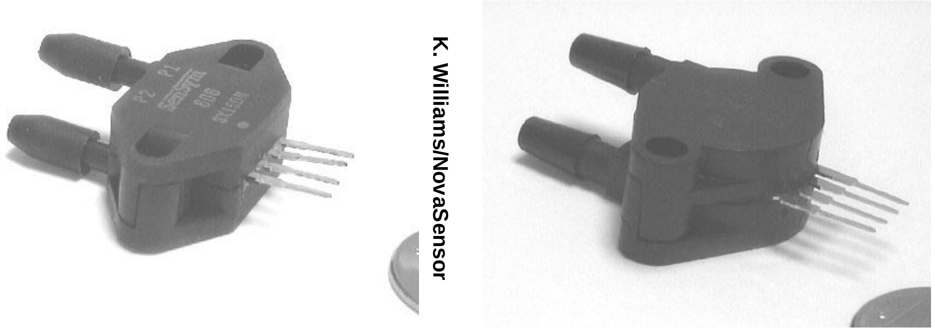


Handy&Harmon/ELE literature

Handy & Harmon/ELE pressure sensor packages (open tooling-- available off the shelf)

Plastic Packaging

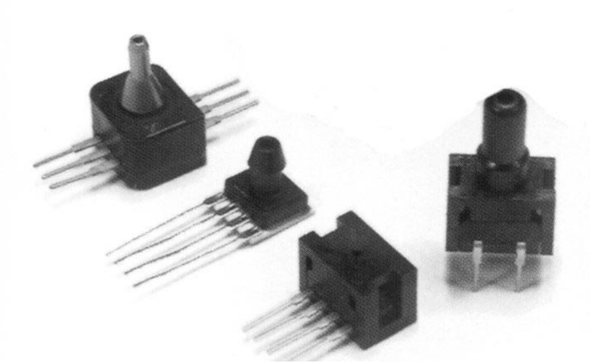
MEMS Plastic Packaging Examples (cont.)



K. Williams/NovaSensor

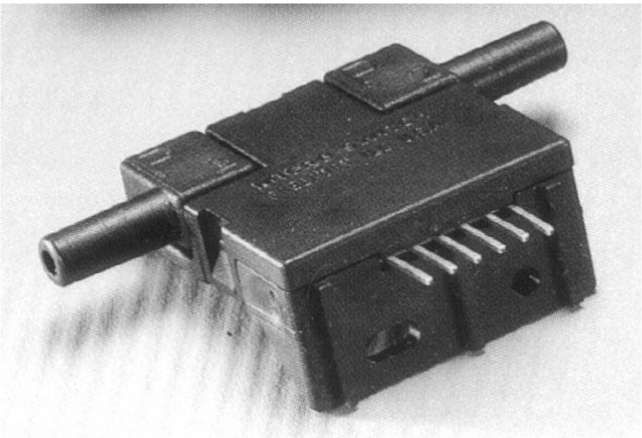
K. Williams/NovaSensor

SenSym and Motorola differential pressure sensor modules



Honeywell literature

Honeywell pressure sensors

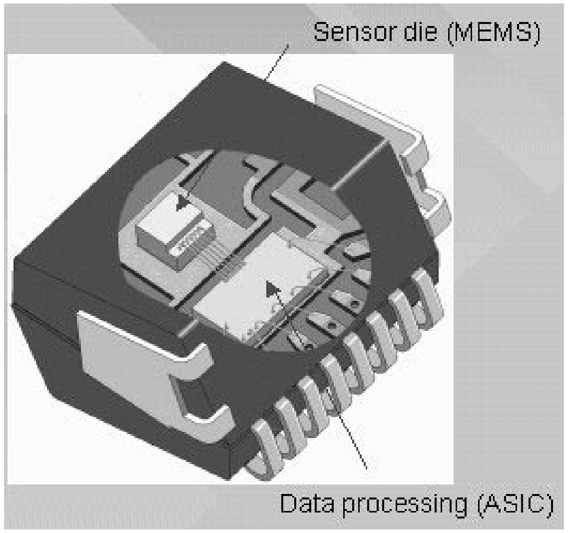


Honeywell literature

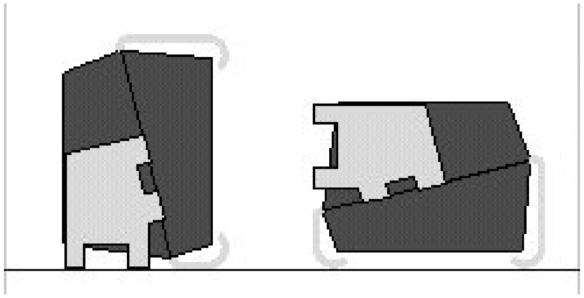
Honeywell microbridge mass air-flow sensor

Plastic Packaging

MEMS Plastic Packaging Examples (cont.)

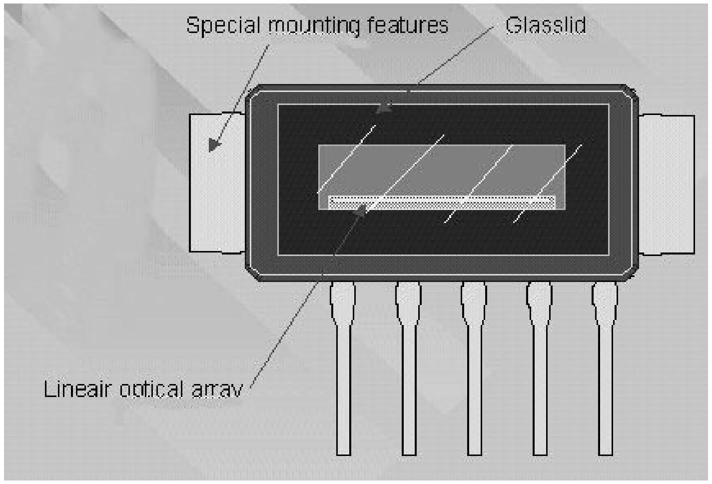


Eurasem literature



Eurasem literature

Eurasem custom package for airbag accelerometer+ASIC (two overmolding steps). Mounted at specified angle



Eurasem literature

Eurasem custom package with glass lid for linear optical array

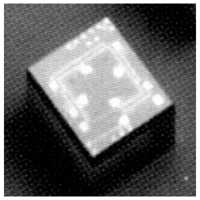
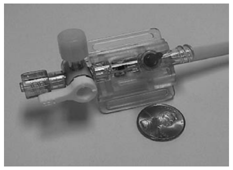
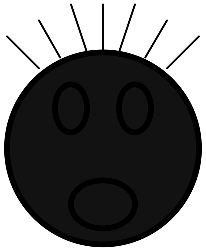
Packaging for MEMS Outline

- **Packaging goals**
- **Materials properties:**
  Thermal stress, heat transfer,
  and hermetic sealing
- **Types of packaging**
  - **On-chip**
  - **Metal**
  - **Glass**
  - **Ceramic**
  - **Plastic**
  - **Comparison**
- **Packaging costs**
- **Summary**

Packaging Costs

Pressure-Sensor Cost at Increasing Levels of Packaging (and Testing)

Data from J. Bryzek (1998) for disposable blood-pressure sensors:

Die	**$ 0.45**	 NovaSensor
Ceramic board with trimmed chip	**$ 1.10**	 K. Williams
Board in plastic arterial line	**$ 10.00**	 K. Williams
Billed to patient	**$300.00**	

data from J. Bryzek, talk at Sensors Expo West, 1998

Packaging Costs

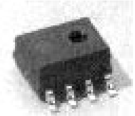
Cost Comparison of Pressure Sensors in Different Packages

- Same or similar dice in each package
- Dice cost $0.50 or less
- Cost also a function of volume, trimming

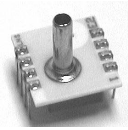
- Ceramic board
  - High-volume, fully automated, trimmed ~$1


K. Williams

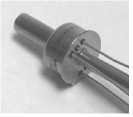
- Plastic DIP
  - High-volume, fully automated, untrimmed $5-10


NovaSensor

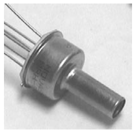
- Ceramic board with tubes
  - Lower-volume, untrimmed ~$20


K. Williams

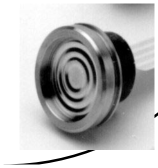
- Header
  - Lower-volume, untrimmed ~$30


K. Williams

- Header
  - Lower-volume, trimmed ~$35


K. Williams

- Media-isolated stainless steel
  - Lower-volume, trimmed $60-80


K. Williams

Packaging Costs

Cost Comparison of Pressure Sensors in Different Packages (cont.)

So what percentage of packaged part cost is from the chip?

You do the math!

Chip is typically less than half of the manufacturer's cost

Package Cost Comparison

Two components to package purchase price:

- Non-recurring engineering (NRE)
    - Packaging design
    - Building tooling
    - Process development

- Per-unit incremental manufacturing cost
    - Raw materials
    - Labor

Varies widely with packaging type

Packaging Costs

Package Cost Comparison (cont.)

Typical NRE and Incremental-Unit, and Total Unit Costs ($)

Vary with Quantity (and Complexity)--
Show for hundreds and millions of units

	NRE Off-Shelf	NRE Custom	Incr.-Unit (100s)	Incr.-Unit (M's)	Total Unit (100)	Total Unit (M)
Metal Headers	0	2k	5-10	1-3	5-10	1-3
Ceramic	0	?	10-20	?	5-?	0.3-6
Injct.-Mold Plas.	?	40-80k	~20¢	~20¢	?	~20¢
Trnsf.-Mold Pla.	?	100-200k	~4¢	~4¢	?	~5¢

Packaging for MEMS Outline

- Packaging goals
- Materials properties:
  Thermal stress, heat transfer,
  and hermetic sealing
- Types of packaging
  - On-chip
  - Metal
  - Glass
  - Ceramic
  - Plastic
  - Comparison
- Packaging costs
- Summary

Summary

Some Packaging Terms

BGA = Ball Grid Array
C prefix = Ceramic
M prefix = Molded
TO = Transistor Outline
DIP = Dual Inline Package
LCC = Leaded Chip Carrier
P prefix = Plastic
PGA = Pin Grid Array
PLCC = Plastic Leaded Chip Carrier

Q prefix = Quad
QFP = Quad Flatpak
SMT = Surface Mount Technology
SOIC = Small Outline IC
SOT = Small Outline Transistor
SOP = Small Outline Package
SSOP = Shrink Small Outline Package
TSOP = Thin Small Outline Package
TSSOP = Thin Shrink SOP

see list and drawings of packages at http://www.national.com/packaging

Summary   Packaging Comparison

Key:
+ = agree
0 = neutral
or variable
- = disagree

	off-the-shelf part	low cost for prototyping	low cost in high volume	easily modified by user	variations from vendor	CTE match to silicon	low thermal resistance	hermetic seal	chemical protection	compact size	high pin count	
metal header	+	+	-	+	+	0	0	+	0	-	-	
stainless can	-	-	--	0	+	+	0	+	+	--		
ceramic DIP	+	+	-	0	0	0	0	+	0	0	0	
ceramic SMT	+	+	-	-	0	0	0	+	0	+	+	
alumina board	-	-	+	-	+	+	0	0	0	0	-	
beryllia board	-	-	-	-	+	+	++	0	0	0	-	
AlN board	-	-	-	-	+	++	+	0	0	0	-	
custom ceramic	-	-	0	-	++	+	0	+	0	0	0	
plastic SOT	0	-	++	-	+	-	-	-	-	++	-	
plastic DIP	0	-	++	-	+	-	-	-	-	++	0	
plastic SMT	0	-	++	-	+	-	-	-	-	+	+	
custom plastic	-	-	+	-	++	-	-	-	-	0	0	

Summary

Class Discussion:
Choose a package for each MEMS application

- Pressure sensor
- Accelerometer
- Vapor sensor
- *p*H sensor
- Infrared sensor
- Micro projection display
- Valve

Packaging for MEMS Summary

- Several materials available

- Some of packaging can be done on chip at wafer level

- Many off-the-shelf packages available--good starting point
- Even more custom packages possible

- Usually must contact and be compatible with environment

- Pay attention to thermal expansion and heat flow

- Cost is a major factor in selection

- Most MEMS applications require custom-made packages

- Develop package in conjunction with chip

Summary

Contacts for references noted in this talk

Chip-size: TRONIC'S Microsystems	Grenoble, France; +33 (0)4 76 88 91 39; www.tronics-mst.com
Ceramic, metal pack. sales: Spectrum Semiconductor	San Jose, CA; (408) 435-5555; www.spectrum-semi.com
Header manuf: Glasseal Products	Lakewood, NJ; (732) 370-9100; www.glasseal.com
Metal QFP manuf: Advanced Interconnect Technl.	Manteca, CA; (209) 824-1166
Ceramic manuf: Coors Electronic Package Co	Chattanooga, TN; (423) 755-5408; www.chattanooga.net/cepc
Plastic open tooling: Handy & Harmon/ELE	Fontana, CA; (909) 355-4299; elecorp@aol.com
Custom plastic: Eurasem	www.eurasem.com.com
Standard plastic: Carsem	Malaysia, Scotts Valley, CA; (831) 438 6861; www.carsem.com
Low-therm-res plastic: RJR Polymers (R-Pak)	Oakland, CA; (510) 638-5901