MEMS Packaging

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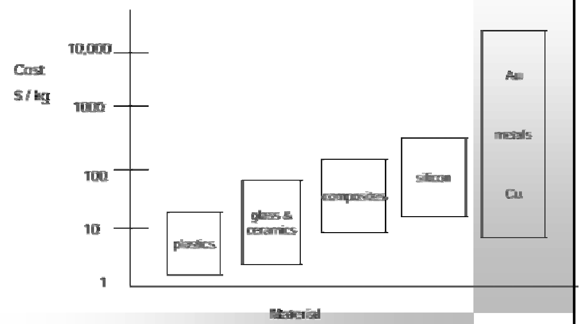
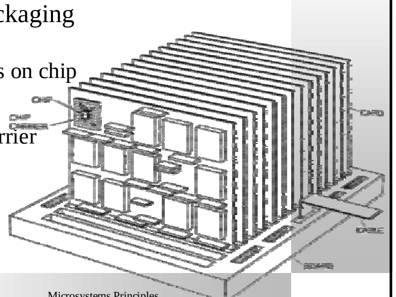
with assistance from Robert Giasolli
Microsystems Principles
ENGR 494C and 594C

Material Costs



What Does "Packaging" Mean

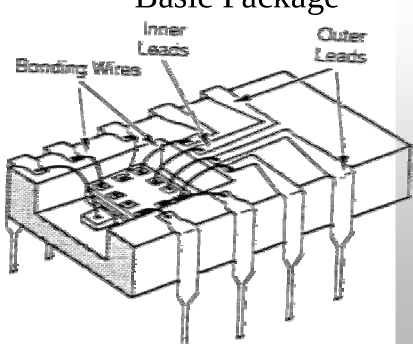
- Connections from chip to outside world
- Levels of packaging
  - L0: Features on chip
  - L1: Chip
  - L2: Chip carrier
  - L3: Card
  - L4: Board
  - L5: Cables



General Packaging

- Packaging serves two main functions:
  - Protection of device from working environment
  - Protection of environment from device material and operation
- Protection from environment
  - Electrical isolation or passivation from electrolytes and moisture
  - Mechanical protection to ensure structural integrity
  - Optical and thermal protection to prevent undesired effects on performance
  - Chemical isolation from harsh chemical environment
- Protection from device
  - Material selection to eliminate or reduce host response
  - Device operation to avoid toxic products
  - Device sterilization

Basic Package



Packaging

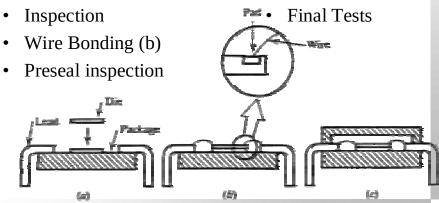
- One of least explored MEMS components
- No unique and generally applicable packaging method for MEMS
- Each device works in a special environment
- Each device has unique operational specs
- Electrical protection
  - Electrostatic shielding
  - Moisture penetration (major failure mechanism for biosensors)
  - Interface adhesion
  - Interface stress
  - Corrosion of substrate materials
- Mechanical protection
  - Rigidity; must be mechanically stable throughout device life
  - Weight, size, and shape for convenience in handling and operation

Major Issues in MEMS Packaging

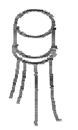
- Literature is scarce
  - Proprietary processes
- Up to and exceeding 75% of total cost
- MEMS must often be in direct contact with environment
- Often package must be designed specifically for device
- Reliability
- Media compatibility
- Modularity
- Small quantities
- Release and stiction
- Die handling and dicing
- Stress
- Outgassing
- Testing
- Encapsulation/ hermetic seals
- Integration

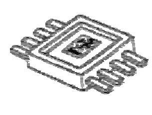
Basic Packaging Operations

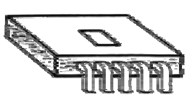
- Backside preparation
- Die separation
- Die pick
- Die attach (a)
- Inspection
- Wire Bonding (b)
- Preseal inspection
- Packaging and Sealing (c)
- Plating
- Lead trim
- Marking
- Final Tests

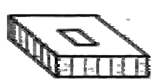


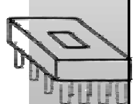
Basic Package Types





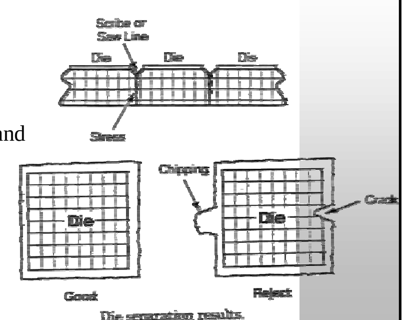

Dual inline package (DIP)


Chip Carrier


Pin Array

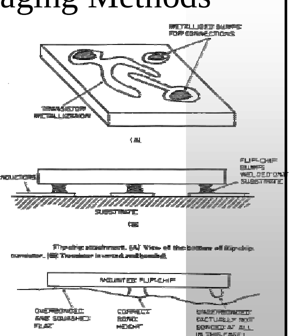
Die Separation

- Dies
  - Batch fabrication and parallel processing
  - Chop up device



Basic Packaging Methods

- Wire bonding used to connect microstructures to macro world
  - Uses variety of metals, Au/Al combination popular
- Flip chips
  - Solder bumps used to attach flipped chip
  - Quick universal connection
  - Allows individual chip optimization
  - Connect dissimilar materials



Package Sealing Methods

- Hermetic
  - Welding
  - Soldered lid
  - Glass-sealed lid or top
- Nonhermetic
  - Epoxy molding
  - Blob top

MEMS Packaging Introduction

- While MEMS devices are becoming a mainstream technology, packaging them for manufacture and ease of use is not matching development of MEMS proper.
- If MEMS are to become available as COTS components, many steps must be taken by industry to bring the many varied kinds of MEMS devices to a 'Packaged' state of commercial viability.

MEMS Packaging

- Black hole for cost models
- Modular packaging needed to span large application areas
- Incorporate methods for testing into design
- No standards exist.
- Just as in the IC and Discrete Electronics world, packaging for MEMS should be standardized for the sake of price and availability wherever possible.

MEMS Packaging

- MEMS will likely follow IC and discrete electronic package forms and types.
- As MEMS become more and more mainstream, Semiconductor manufacturers will likely use existing packages and adapt MEMS manufacturing to these well-established commercial form factors wherever the application of MEMS may be accommodated by IC packages which may open an 'Undiscovered Country' of applications.
- Not all MEMS devices are electronic in nature and may present challenges in packaging that are not solvable with PWB form factors.

MEMS Packaging

- MEMS will likely be electronically coupled with other devices in MCMs. COTS Semiconductor manufacturers are involved.
- For MEMS to provide optimal functional sensitivity and bandwidth, they may be mounted in MCM–D-C-Ls.
- This matching of multiple technologies in a single package is paramount to MEMS technology applications.
- This brings about the need for advanced packaging schemes.
- If a single package houses multiple MEMS, Discretes, and ICs, there stems the dilemma of interfacing the MEMS with the environment (gas, fluids, light, RF, inertia, sound, vibration, biomass, etc.) and still protect the Electronics from the environment.
- The common notion is that most MEMS will be PWB or MCM mounted but this will not always be the case.

MEMS Packaging

- MEMS packaging may vary widely by special function as opposed to electronic packaging for board mounting.
- As MEMS packaging evolves, packaging may specialize to accommodate the special function of the MEMS proper
  - Creates new form factors
- This evolution happens rapidly.
- E-COTS has a rollover of 12 to 18 months often with different packaging.
- As MEMS become more widely available, the need for special packaging will settle down to an accepted array of 'Package Form Factors.'
- All MEMS are not electronics-based, but are indeed small mechanical devices

MEMS Packaging

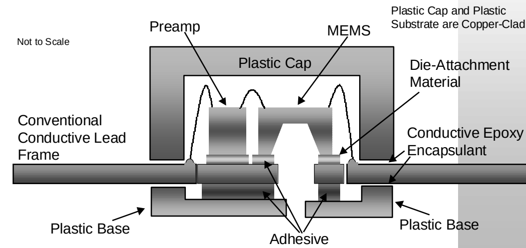
- Recent data gathering indicates a burgeoning effort to package MEMS for E-COTS.
- MEMS technology promises to integrate many electronic circuits 'On Board' and use popular E-COTS packaging technologies.
- Even though MEMS have been a laboratory curiosity for 25 years, they are only now becoming mainstream discrete-packaged products.

MEMS Packaging

- MEMS technology lends itself to Flip-Chip & Un-Flip-Chip, back-etched thinned silicon with through-hole vias, and Direct-Chip-Attach application.
- Whether attaching ICs to a MEMS substrate, attaching MEMS to an IC, or mounting MEMS, ICs and Discretes in an MCM, the possibilities of converging technologies for integrating MEMS and Electronics deserves great attention.

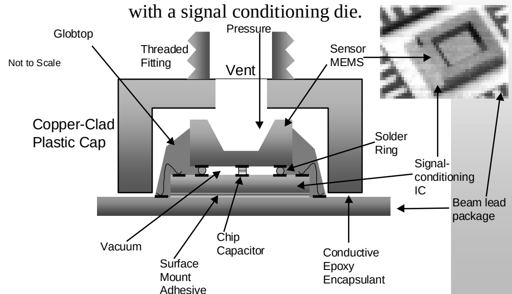
MEMS Packaging Lead Frame

Cross-Section of MEMS Acoustic Sensor packaged with a preamp die.



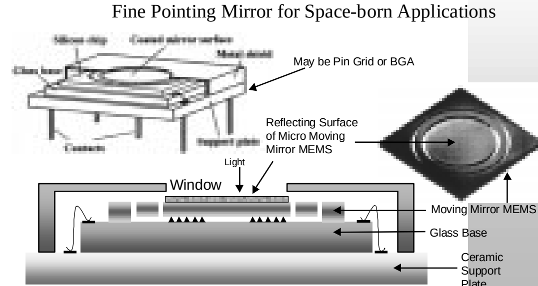
MEMS Packaging Surface Mount

Cross-Section of MEMS Pressure Sensor packaged with a signal conditioning die.



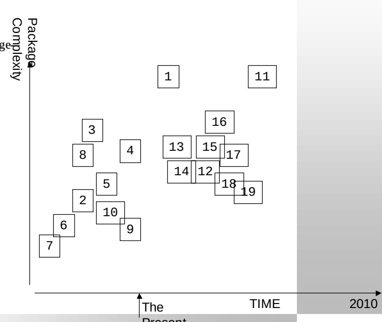
MEMS Packaging Ceramic

Fine Pointing Mirror for Space-born Applications



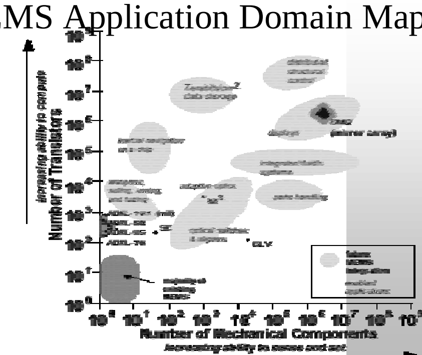
MEMS Packaging Roadmap

1. Product Specific Unique Package
2. 28 Pin CERDIP
3. Hermetic Firewall
4. Flip Chip
5. BGA
6. Air Bag Sensor
7. InkJet Print Cartridge
8. Photo and Voltaic
9. Pressure Sensor
10. Oxygen Sensor
11. Ultra-Thin Chip Stack
12. Microphone w Hybrid Amp
13. Plastic Cap
14. Metal Cap
15. Cavity
16. Chip on Chip
17. Chip in Cavity
18. MEMS on Chip
19. Chip on (in) MEMS

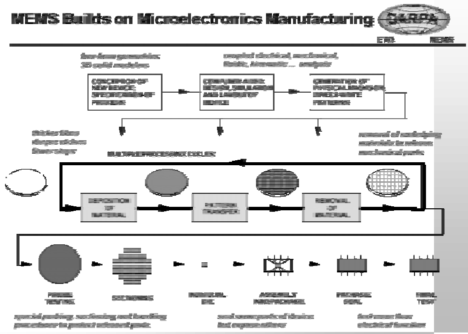


MEMS Application Domain Map

Chart of Number of Transistors Versus Number of Mechanical Components

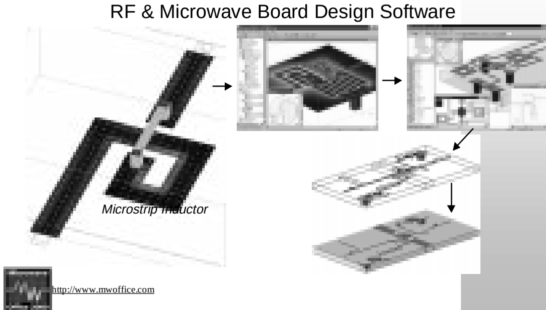


Typical MEMS-Electronics Manufacturing



MEMS Packaging – MEMS Software Design

RF & Microwave Board Design Software

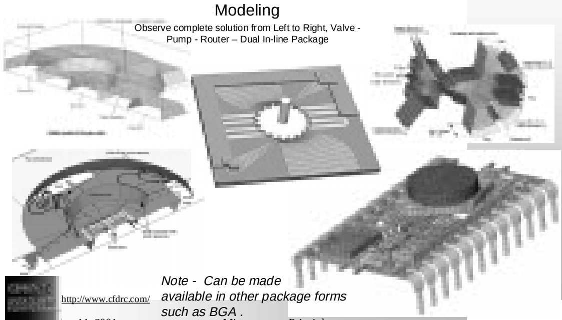


http://www.mwoffice.com

MEMS Packaging – MEMS Design Software

Gas, Fluid, Mechanical, 3D Geometry, & Package Modeling

Observe complete solution from Left to Right, Valve - Pump - Router – Dual In-line Package



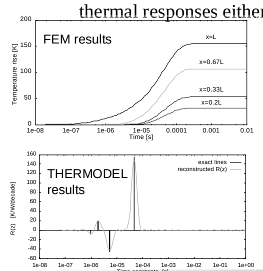
http://www.cfdrc.com/

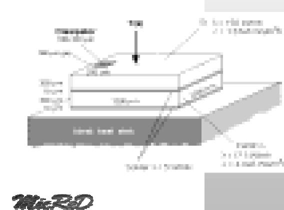
Note - Can be made available in other package forms such as BGA .

MEMS Packaging – Thermal Modeling

THERMODEL

Fast and accurate model generation, based on dynamic thermal responses either measured or simulated.

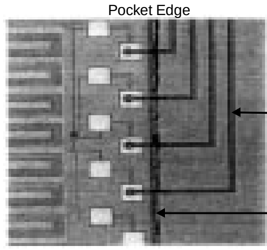




http://www.micred.com/

MEMS Packaging – Embedded Interconnection

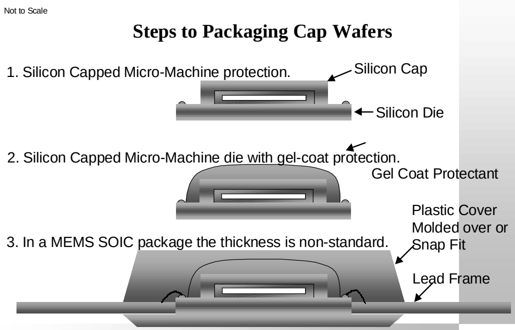
3D integration of embedded back-side-thinned IC into multi-layer interconnection substrate structure onto which may be mounted a MEMS for interconnect.



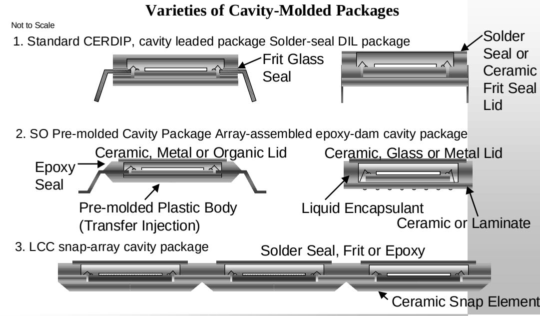
MEMS Packaging Issues

- Primary packaging types – Caps & Cavities
- Secondary packaging types – IC type packages & Custom
- **Barrier to Commercialization is Packaging**
- Barriers are falling
- 900 Packaging Patents filed this year (2000)
- Package must be inexpensive, capable of being handled by existing automated board assembly machinery, and capable of protecting the MEMS against contamination
- Each of the many package technologies has its own performance characteristics and associated price
- Defining package performance requirements is the key to selecting the correct package for a given application
- The package design must protect the MEMS at the wafer level and may involve an extra step or more in the fabrication process

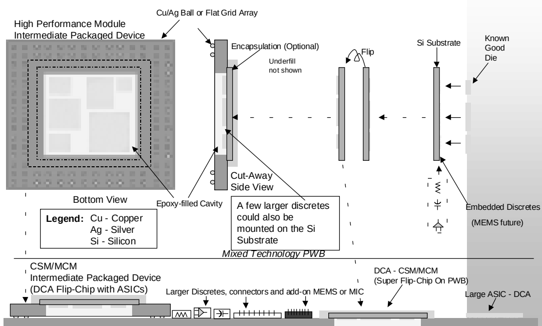
MEMS Packaging Issues - Cap Wafers



MEMS Packaging Issues – Cavity Packs



MEMS Packaging Issues – PWB and MCM



MEMS Packaging Issues – Summary

- If the MEMS devices is truly robust, the lowest-cost package may be from standard IC package types.
- The the MEMS is not quite robust enough to withstand injection molding, the gel coat method or some lower stress method may be employed.
- To Package MEMS, there will be tradeoffs in terms of cost versus environmental resistance.
- There will still be a requirement for custom form factors such as may be used to package non-electronic MEMS.

Packaging Materials

- Silicone
  - Excellent for short-term encapsulation
  - Medical-grade silicon is biocompatible
  - Easy to apply and sterilize
  - Excellent adhesion characteristics; flexible
  - Swells in most aqueous solutions
  - Air bubble entrapment is a problem
- Polyurethane
  - Good humidity and chemical resistance
  - High dielectric strength
  - Good mechanical properties, flexible
  - Attacked, swollen, or dissolved by many solvents

Packaging Materials

- Epoxy
  - Good mechanical properties
  - Poor ion and moisture barriers
  - Shrink when cured, changing mechanical, electrical, thermal properties
- Fluorocarbon
  - Most well known (polytetrafluoroethylene)
  - Desirable electrical characteristics
  - Poor adhesion and mechanical characteristics
- Acrylic
  - Good electrical properties
  - Hard, rigid, and tough
  - Little shrinkage during cure
  - Poor solvent resistance

Packaging Materials

- Parylene
  - Can use CVD to deposit thin, uniform pinhole-free films
  - Good electrical properties
  - Low permeability to moisture and gases
  - Poor adhesion
- Polyimide
  - Good mechanical and electrical properties
  - Stable over wide range of temperatures
  - Commonly used in microelectronics
- Glass
  - Thermal expansion coefficients must be matched
  - High strength, especially in compression
  - Good electrical properties
  - Localized stress concentrations due to surface imperfections

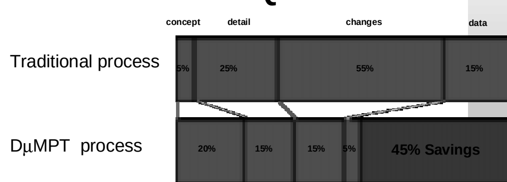
Packaging Materials

- Ceramic
  - Chemically inert
  - Brittle, low fracture toughness
  - Good electrical properties
  - Excellent moisture barrier
  - Require nigh temperature for sealing
  - Typically biocompatible
- Metal
  - Light weight
  - Some metals (e.g., titanium) have excellent corrosion resistance
  - Good mechanical properties

Die Attach Materials

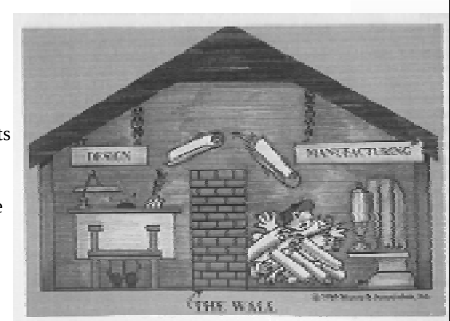
- Conducting
  - Gold / silicon eutectic
  - Metal filled epoxy
  - Conducting polyimide
- Non-conducting
  - Epoxy adhesive
  - Insulating polyimide

Designs that Consider Manufacturing, Packaging and Testing will get to Market Quicker



DμMPT Breaks Down the Wall

Designers are traditionally under great pressure to produce results as quickly as possible and often perceive DFMA as yet another time delay



Avoid Challenging the Designer

No one wants to be told that their design does not consider manufacturing.

MEMS Packaging - Bibliography

- MicReD – THERMODEL, Microelectronics Research & Development Ltd. http://www.micred.com
- Home of the IEEE Computer Society http://www.computer.org/
- CFD Research Corp. Home Page http://www.cfdrc.com
- Applied Wave Research http://www.mwoffice.com
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