CSCI 4974 / 6974
Hardware Reverse Engineering

Lecture 2: Packaging

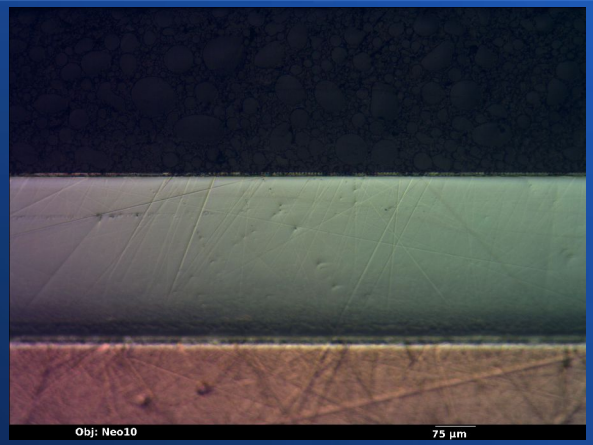
Packaging

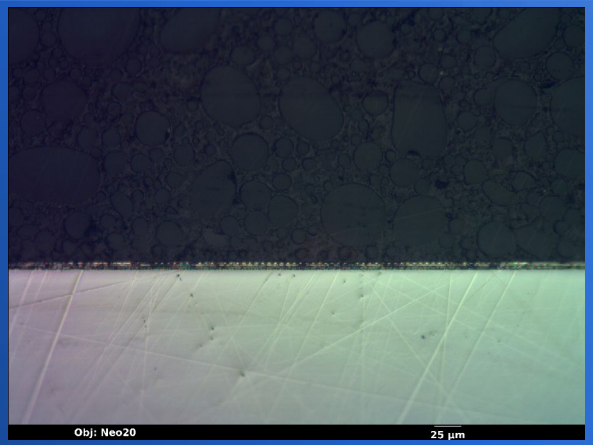
- Bare silicon devices are useless if you can't talk to them
- Something has to connect them to the board
- To get to the silicon, we have to know what's in the way

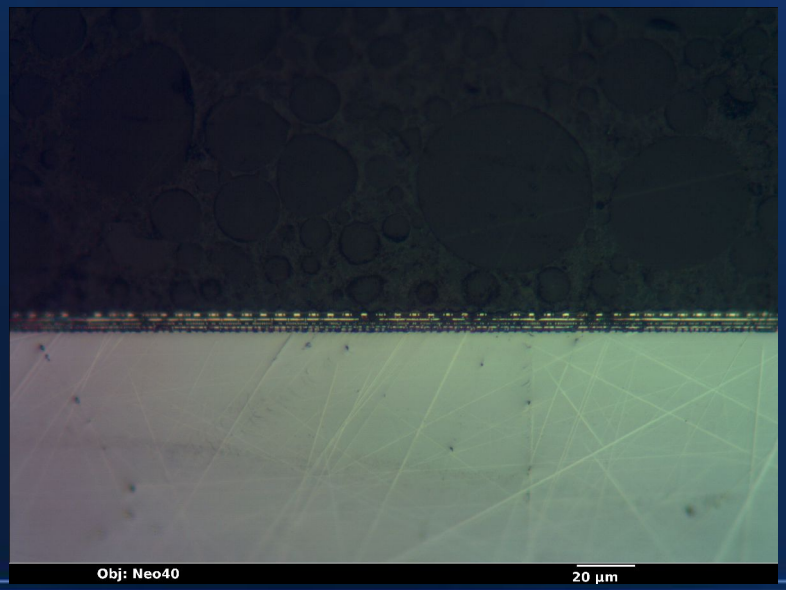
Parts of an IC

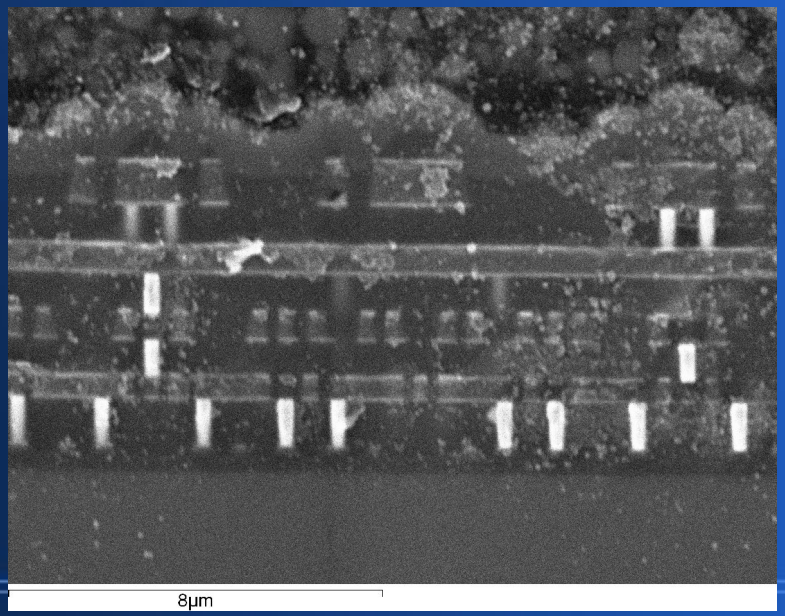
- **Die**
  The actual silicon “chip”
- **Leadframe**
  Pins that are soldered to the board
- **Molding compound**
  Protects die and wires
- **Wires or bumps**
  Electrically connects die to leadframe
- **Die attach**
  Mechanically connects die to leadframe

Die vs circuit thickness







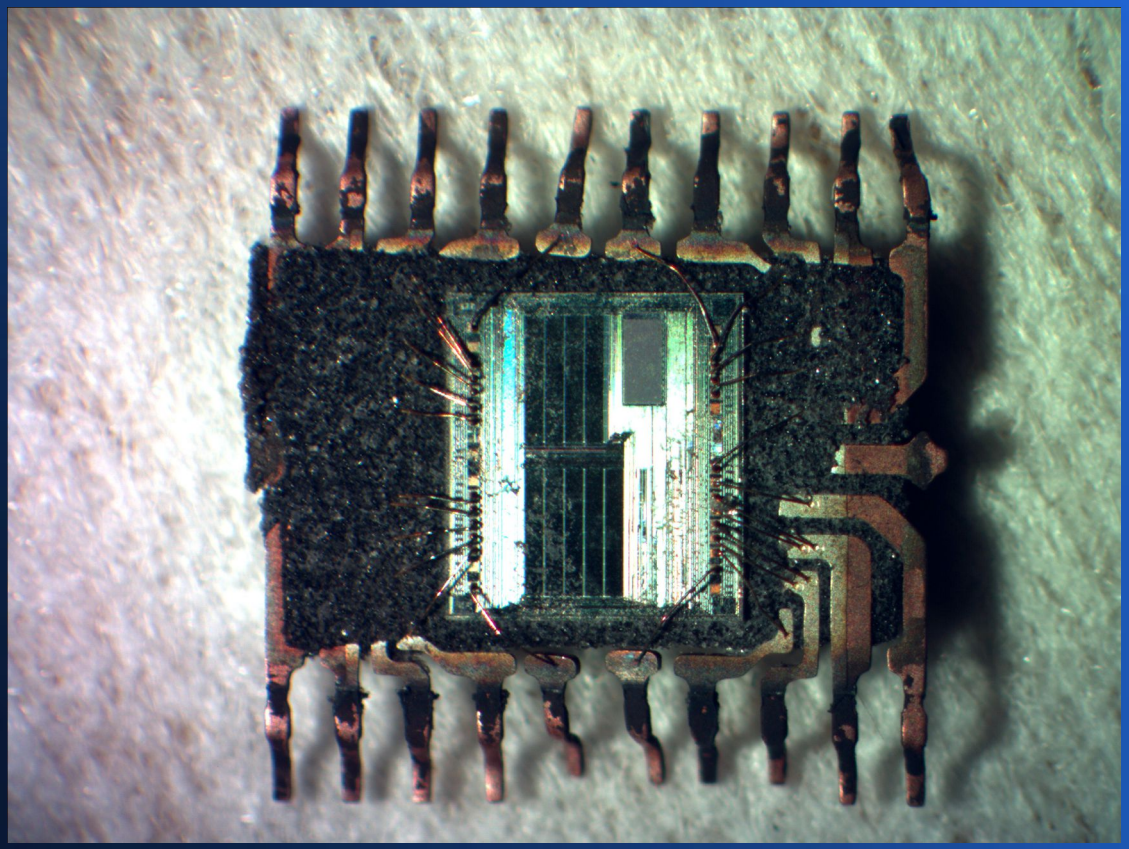


Multi-die packages

- Several dies in one package
- FPGA + flash
  - We may see one of these next Friday's lab
- MEMS + ASIC
- High-density NAND/DRAM

Leadframe

- The actual pins which get soldered to the board



Package classification

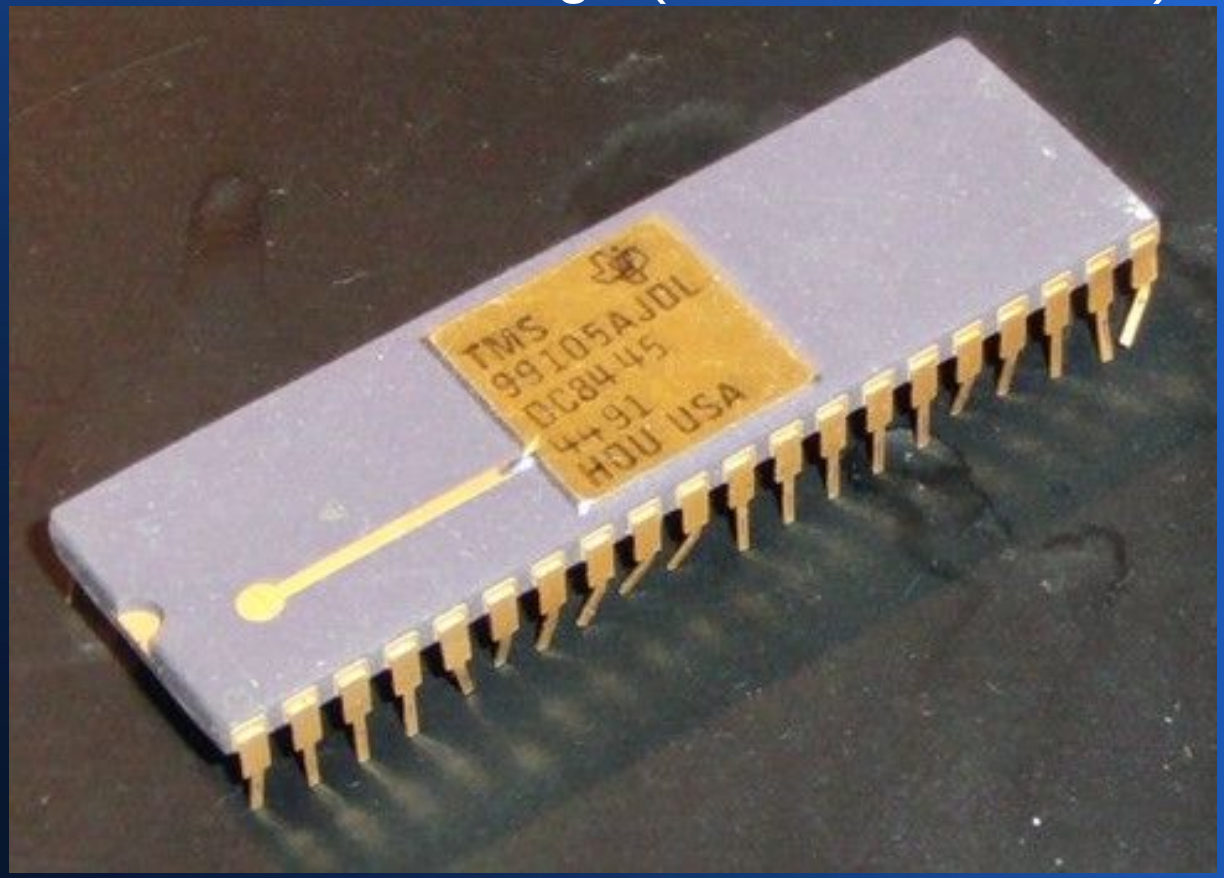
- Material - ceramic, plastic, etc
- Mounting type - through hole or surface mount
- Cavity direction - up/down
- Wire bond vs flip chip
- Through hole vs SMT
- Topology - linear vs area array

Packaging evolution

- Large, fragile devices, low logic density
- Not many pins
- Hermetically sealed packages required
- EPROM needs UV exposure

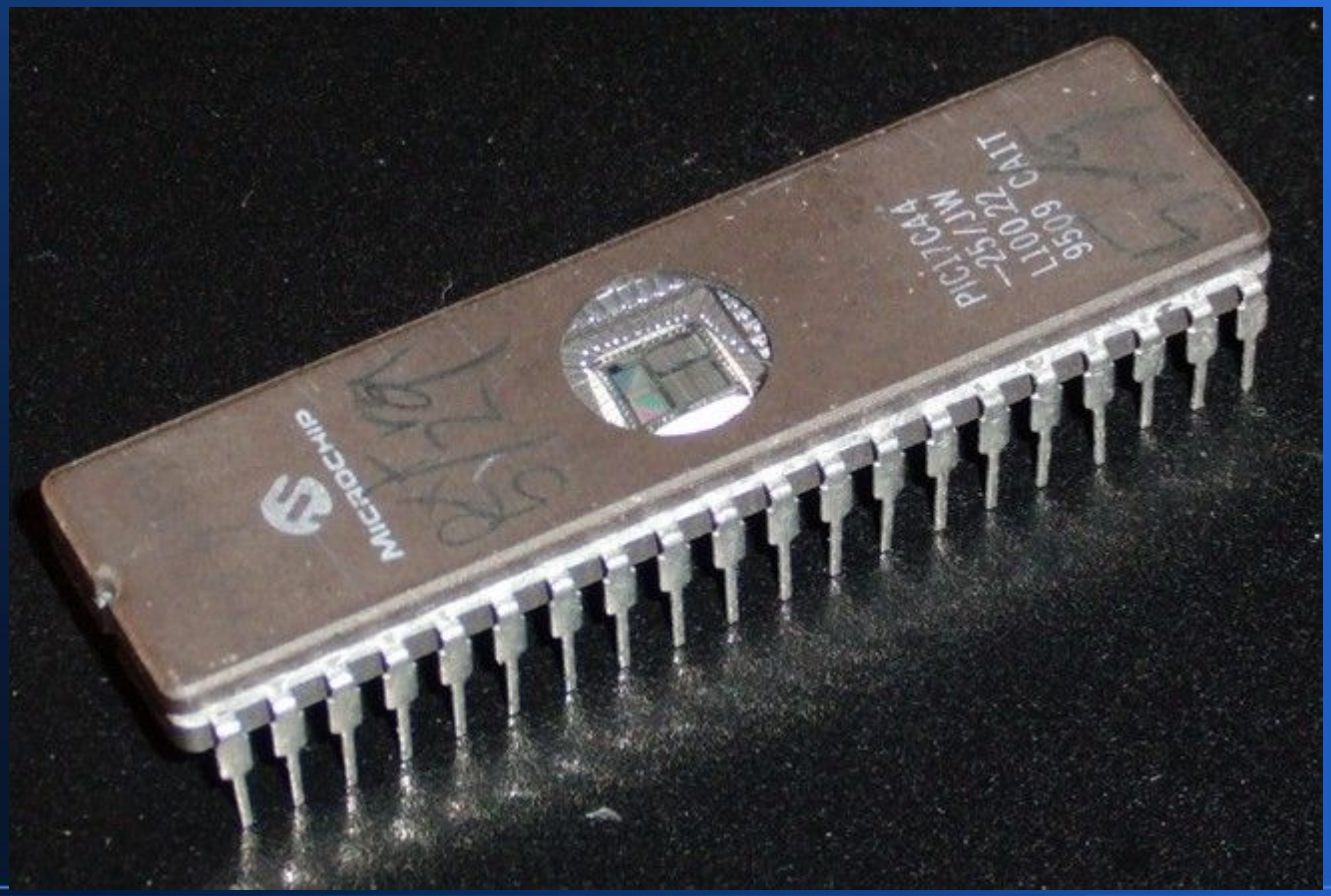
Package types

- Ceramic Dual Inline Package (CDIP or CERDIP) w/ soldered lid



Package types

- CDIP with window

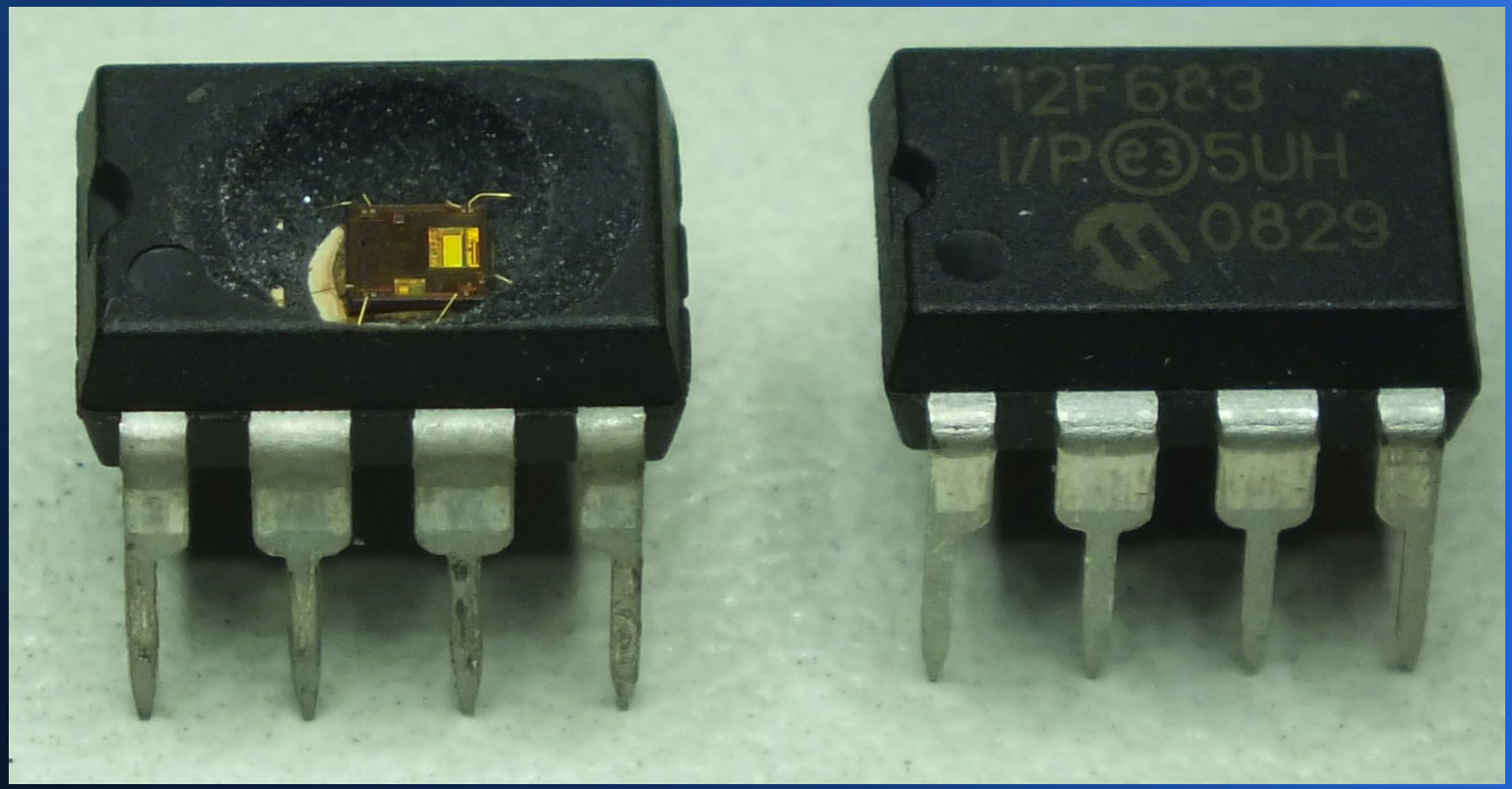


Packaging evolution

- Ceramic is expensive, can we do something cheaper?
- Plastic costs a lot less
- Ceramic is still used in rare cases (some mil-spec etc) but nearly unheard of in modern consumer devices

Package types

- Plastic Dual Inline Package (PDIP)

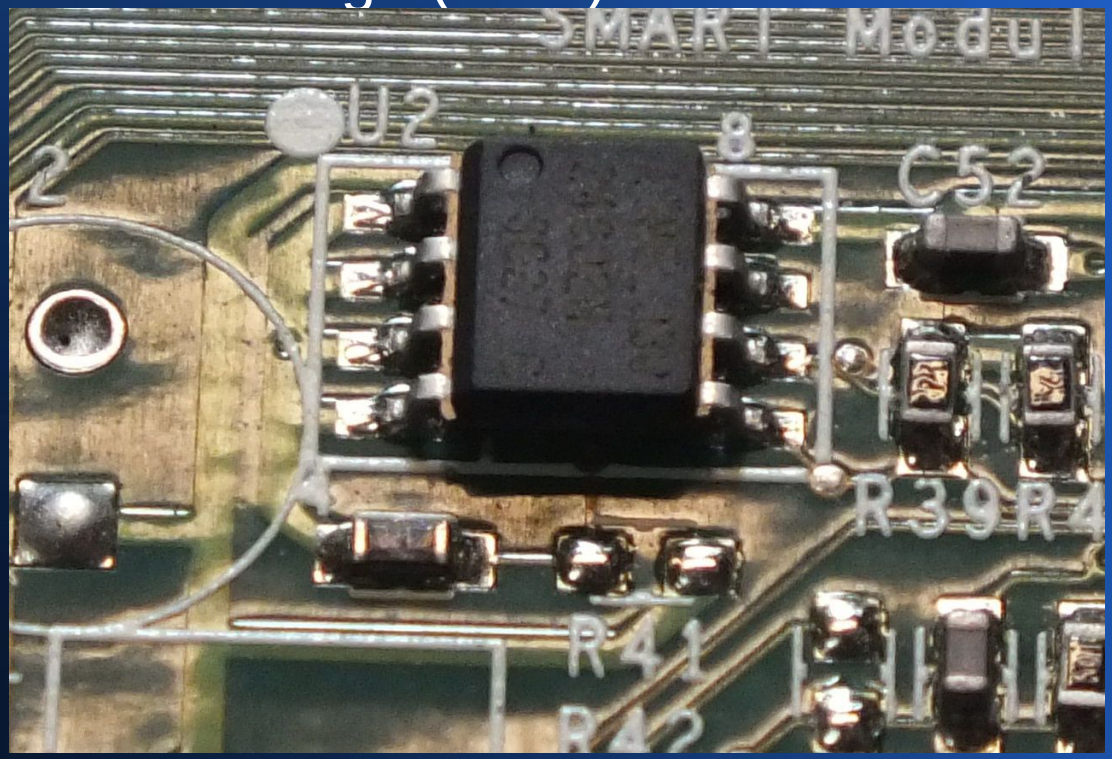


Packaging evolution

- DIPs waste a lot of space for high-density devices
- Drilling holes requires more manufacturing time
  - Surface mount technology!

Package types

- Small Outline IC (SOIC)
- Small Outline Package (SOP)



Packaging evolution

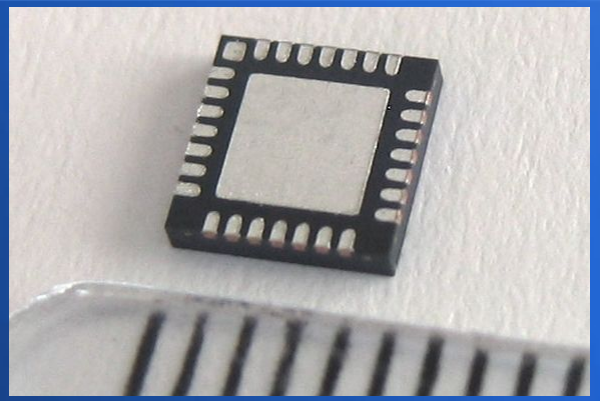
- Having pins on only two sides makes for long, skinny, awkwardly shaped packages
- What if we used all four?

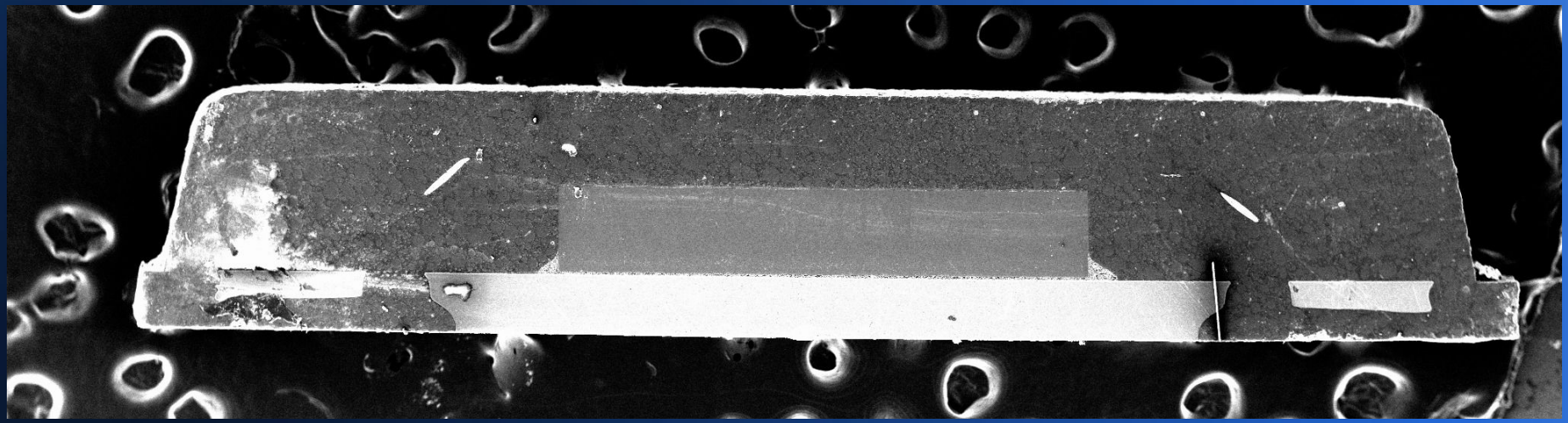
Package types

- Quad Flat Pack (QFP)

Package types

- Quad Flat No-Leads (QFN)



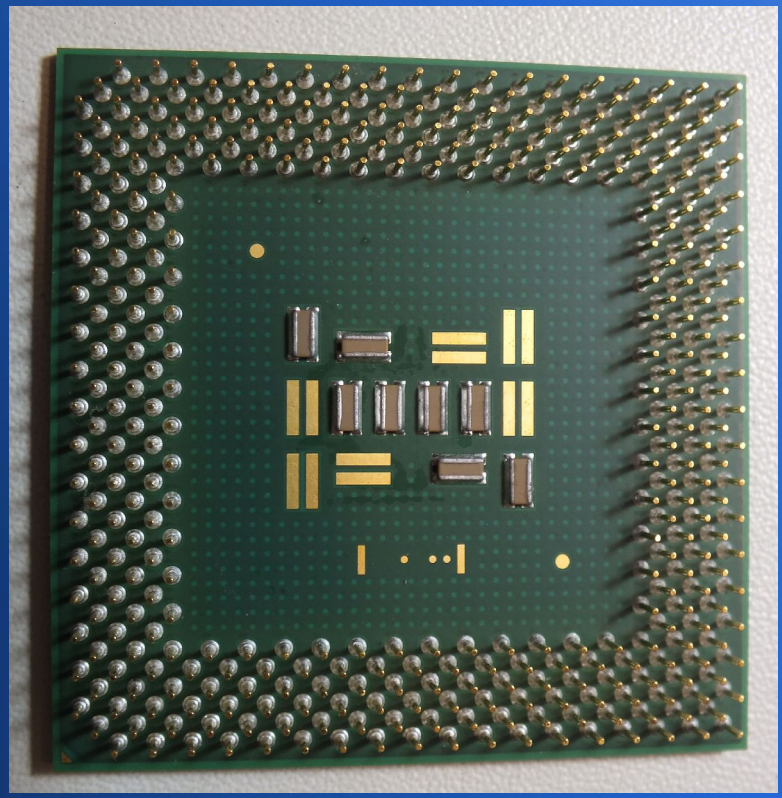


Packaging evolution

- Even higher density is required for modern electronics
- Why only use the perimeter of the package?

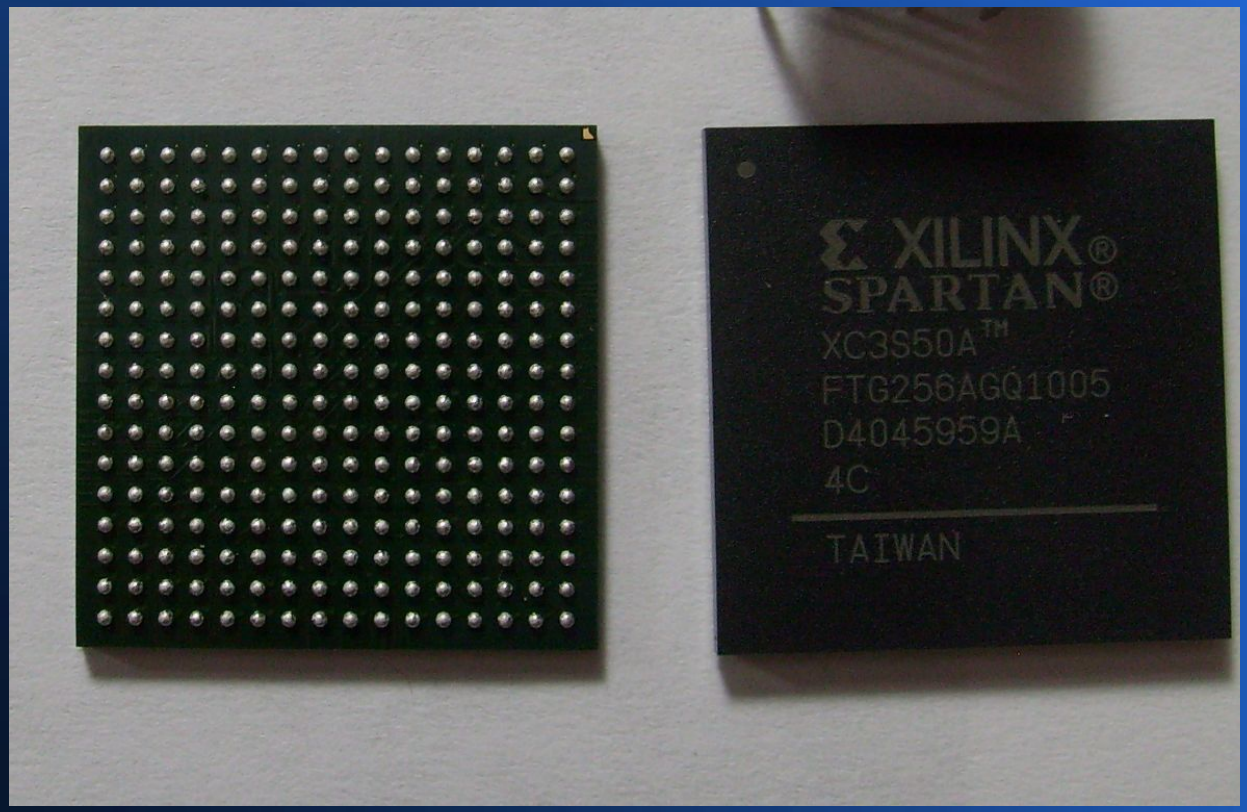
Package types

- Pin-grid array (PGA)



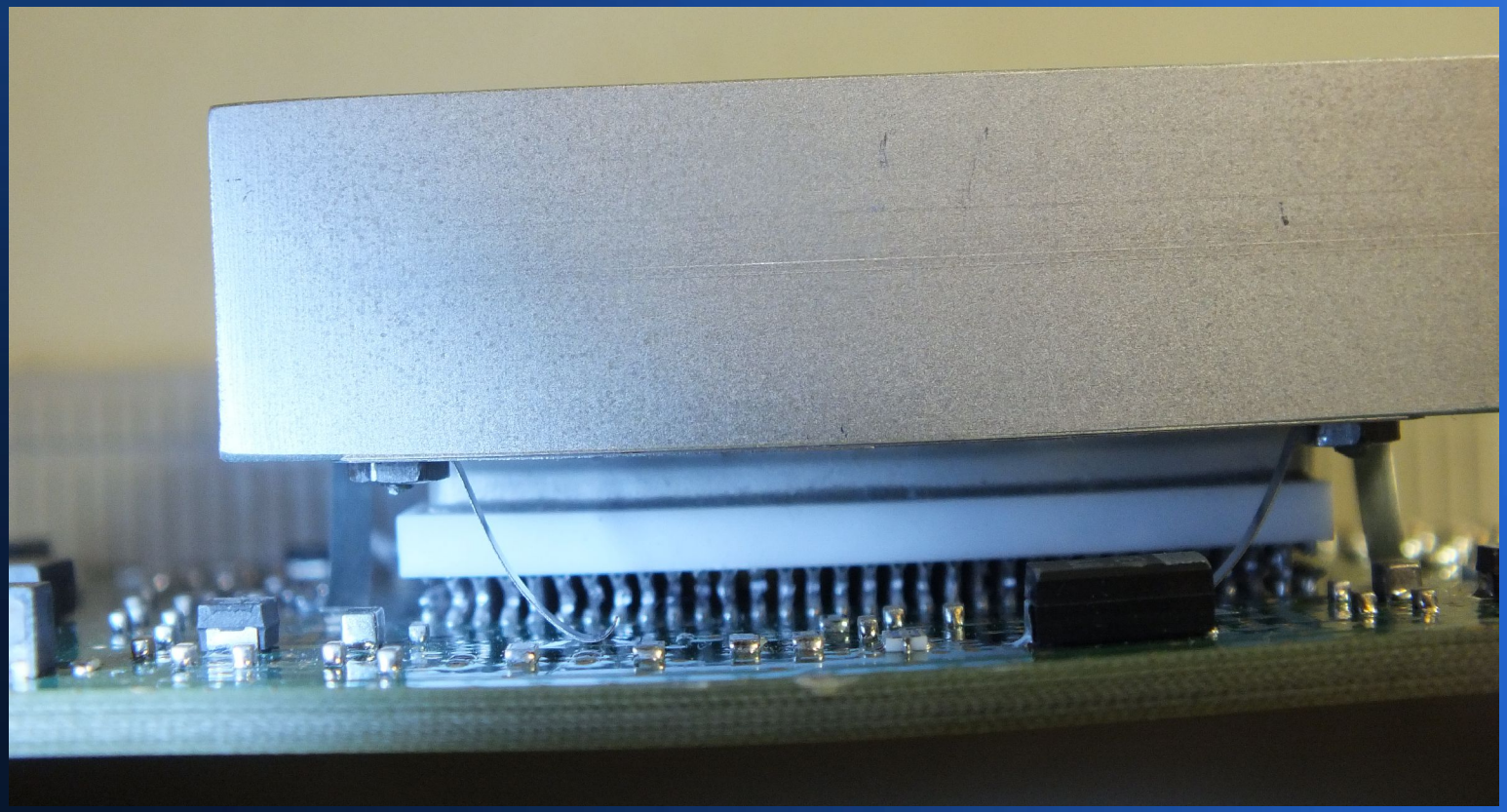
Package types

- Ball-grid array (BGA)



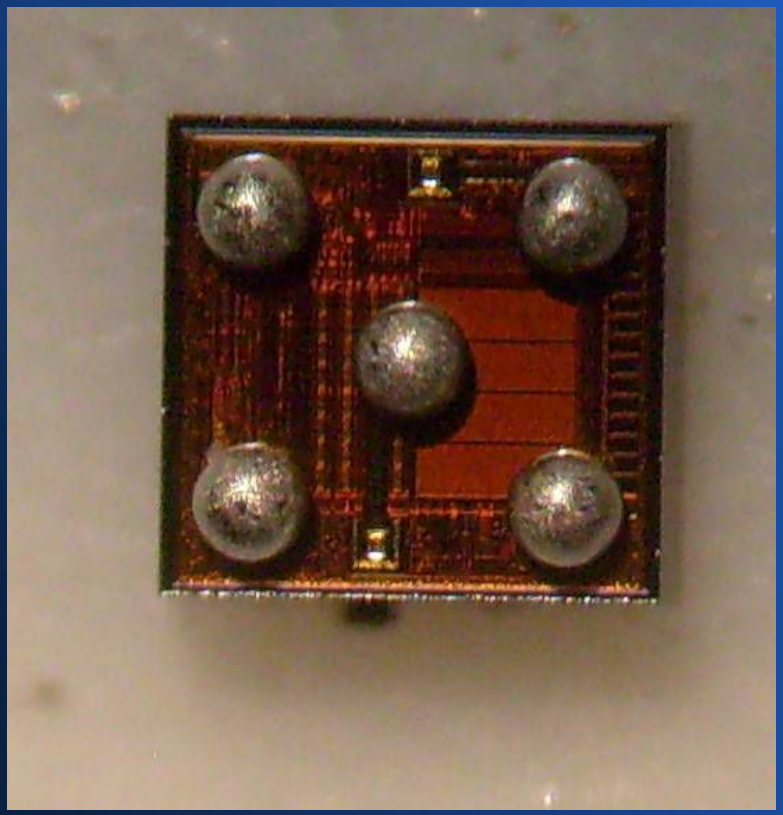
Package types

- Column Grid Array (CGA)



Package types

- Chip-scale BGA (CSBGA)



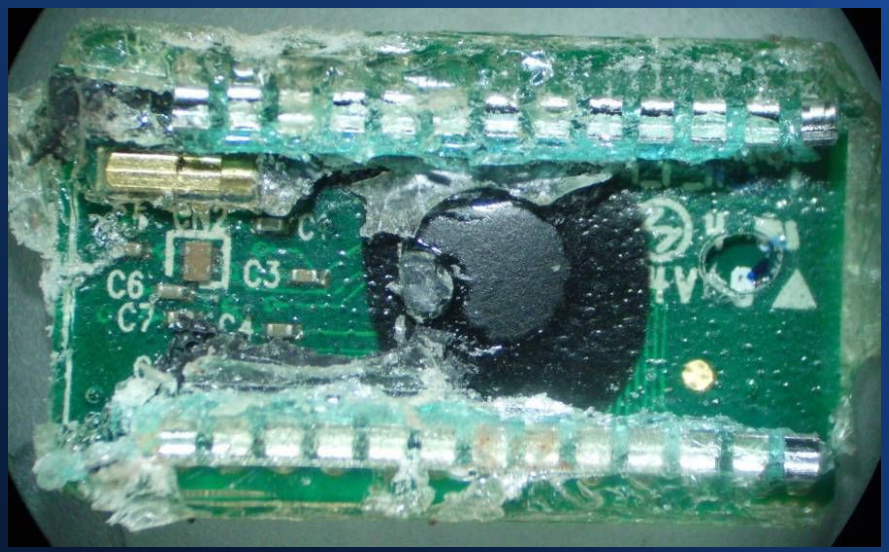
Packaging evolution

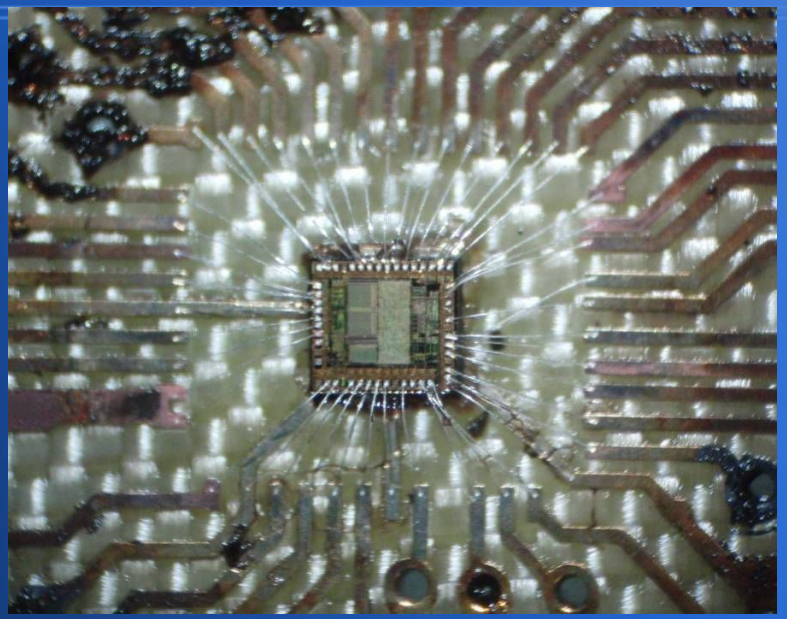
- Special needs call for special device packages

Package types

Package types

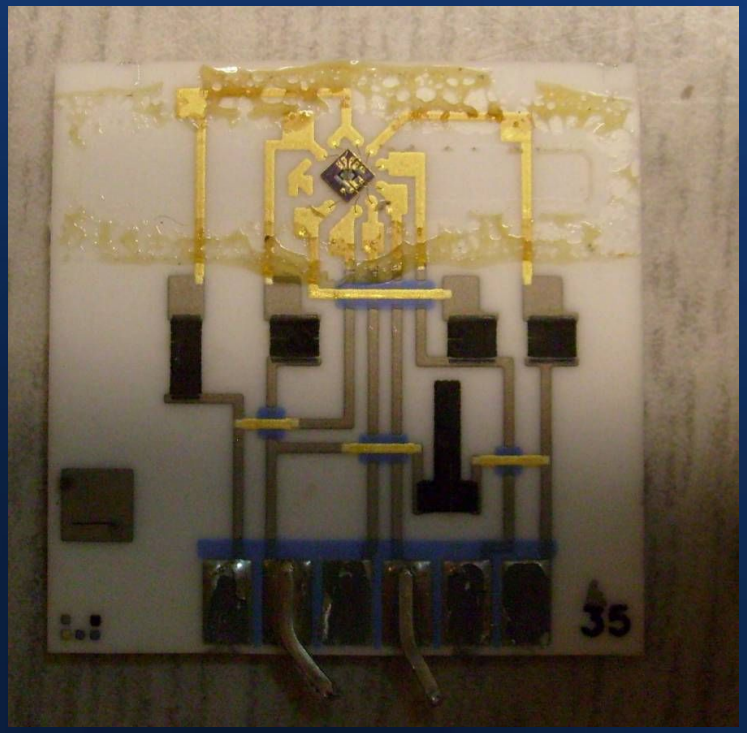
- Chip on Board (COB)

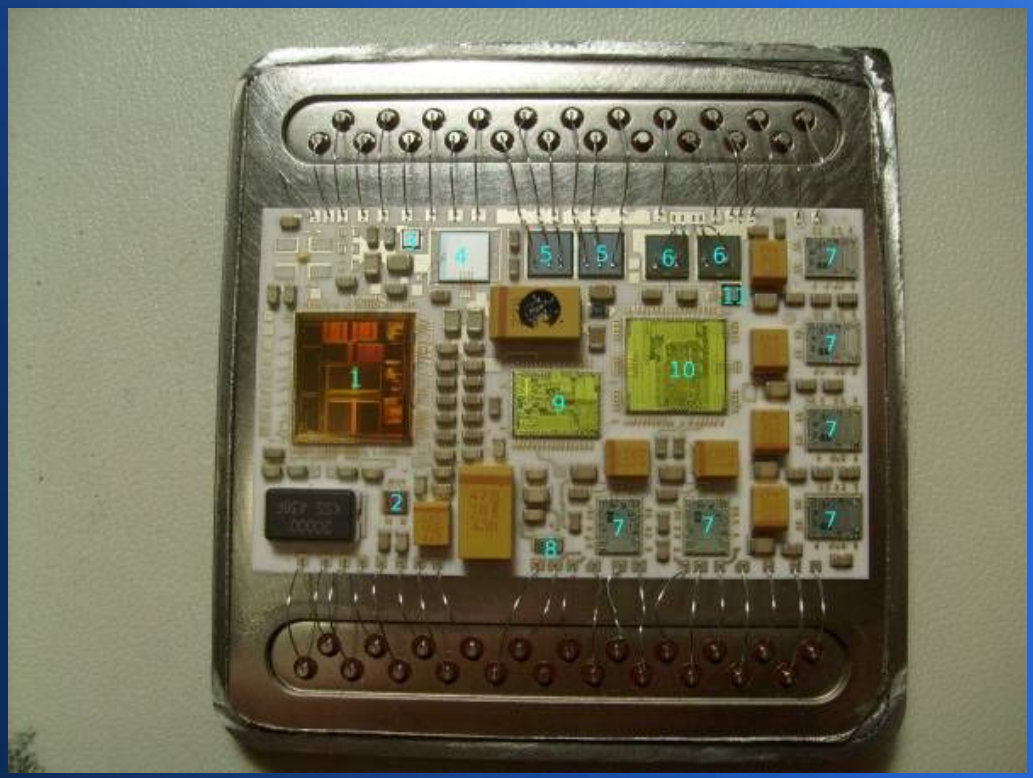




Hybrid circuits

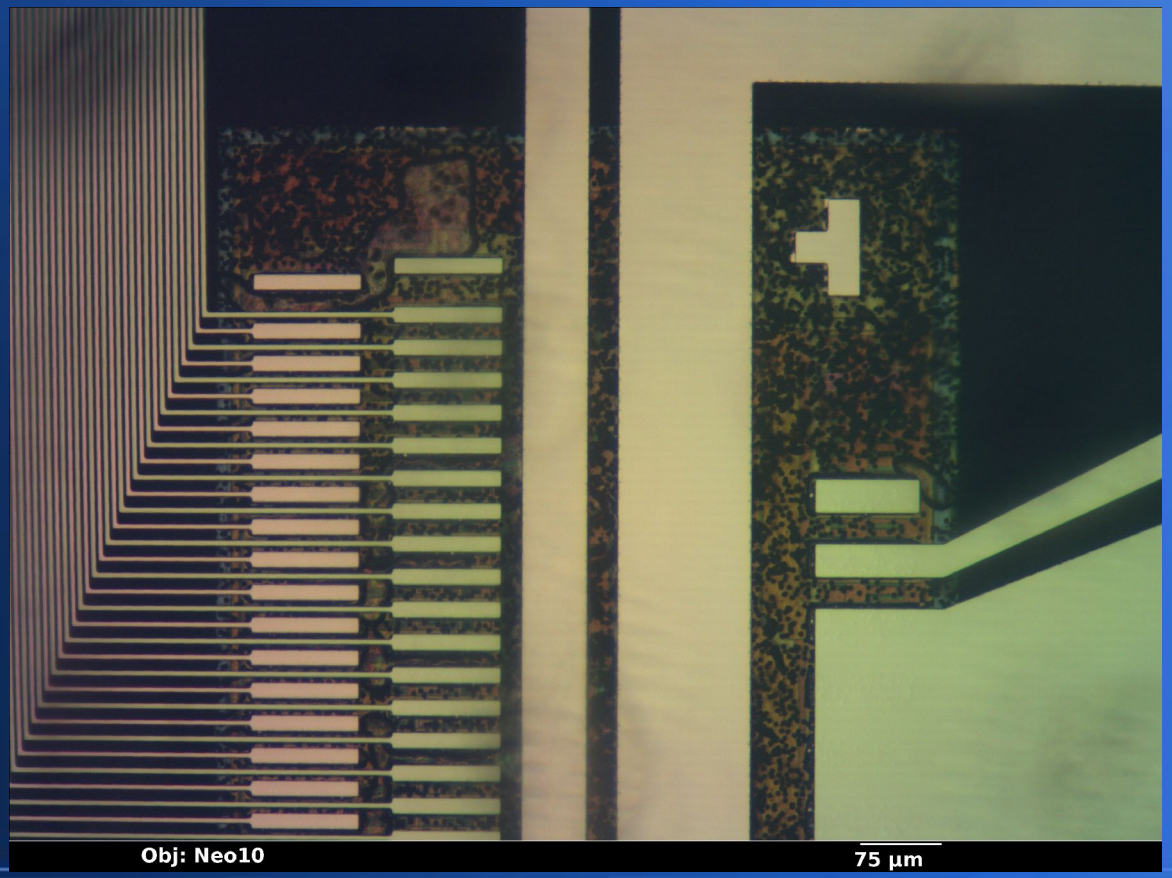
- One or more dies bonded to a ceramic (usually) substrate
- Film passives printed directly on substrate, optional laser trim





Chip on Glass (CoG)

- Die is attached directly to glass substrate
- Mostly used for LCDs



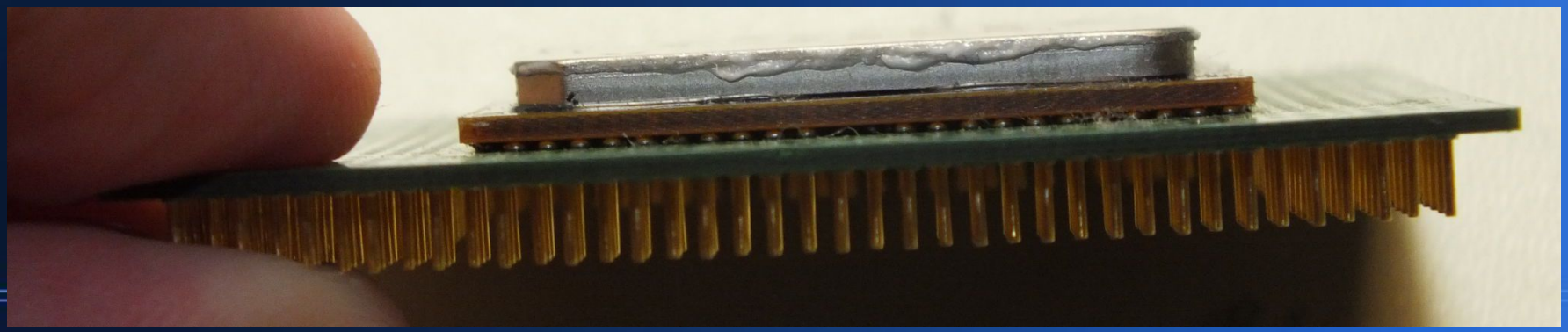
Multichip module (MCM)

Thermally enhanced packages

- Generally meant to be used with a heatsink
- Always flip-chip packaging
- Very difficult to microprobe
  - Chip will fry if not cooled
- Extra care required to decap

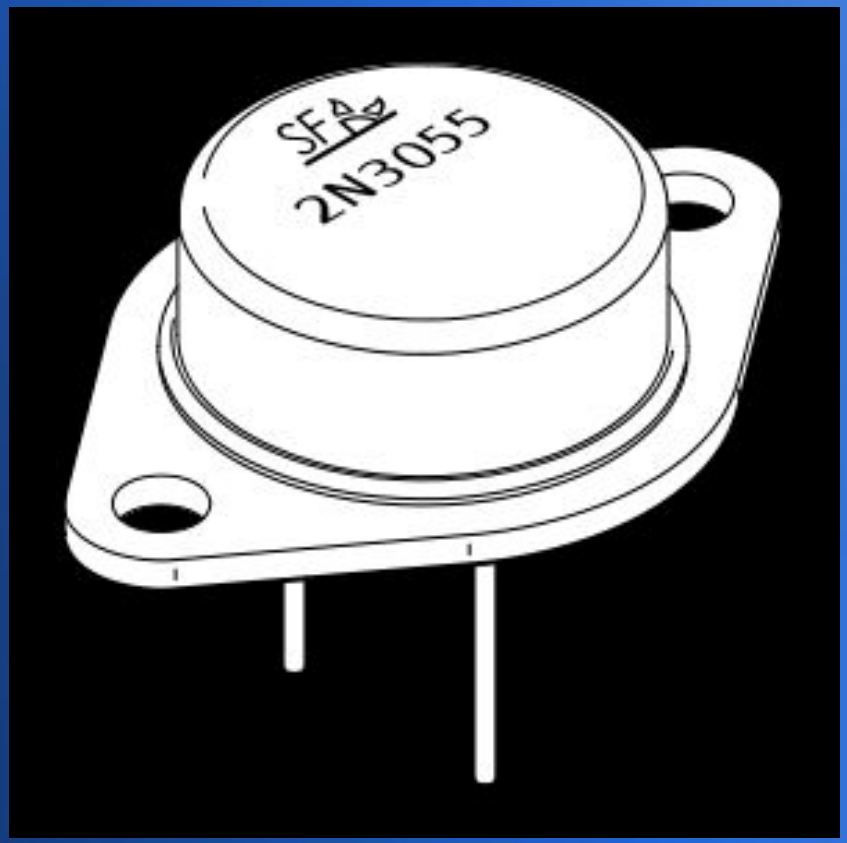
Double interposers

- Die in a BGA package soldered to a larger BGA or PGA
- Very rare, I've only seen this once



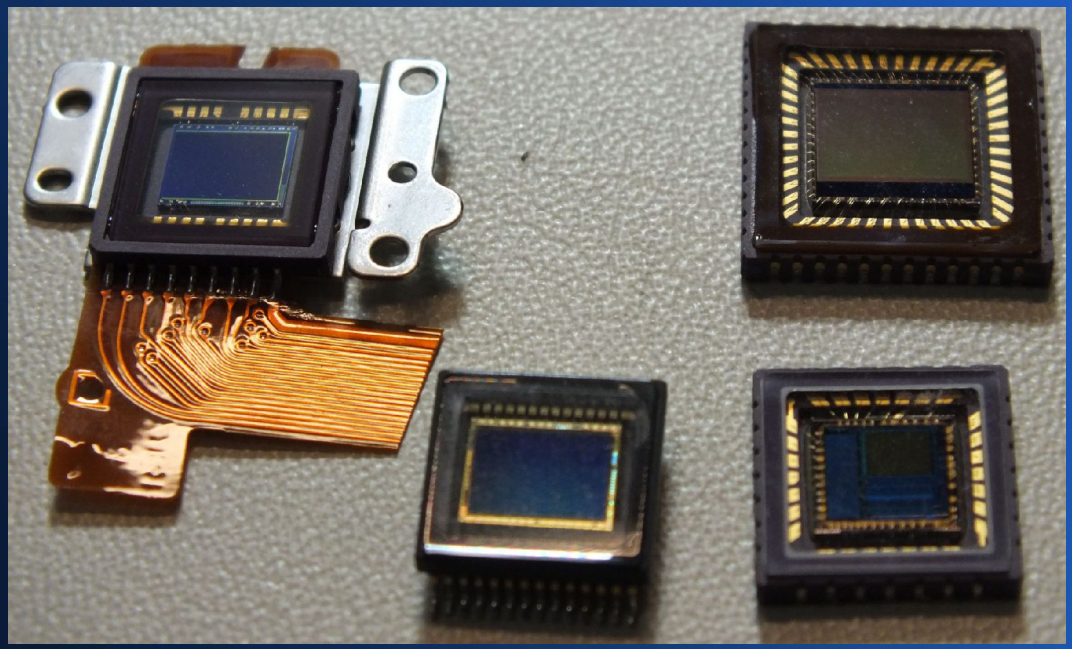
Metal cans (TO-x)

- Often used for old discrete transistors, laser diodes
- Some military / automotive ICs
- Good thermal properties
- Glass/metal hermetic seal
- Low pin count



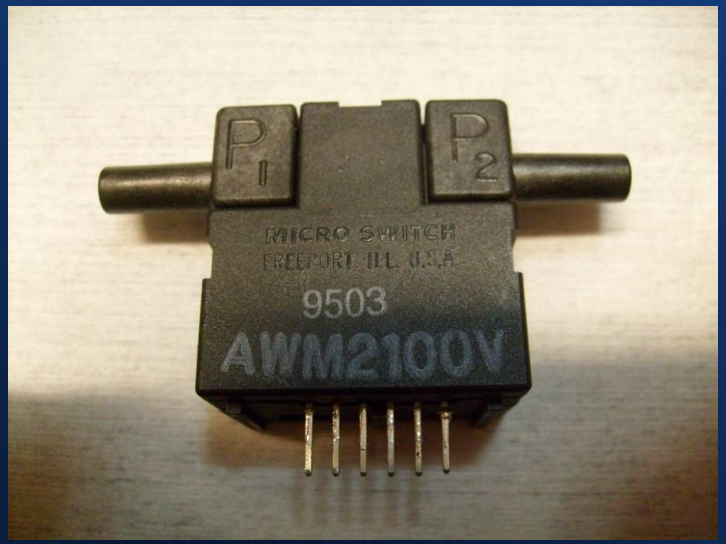
Camera sensors

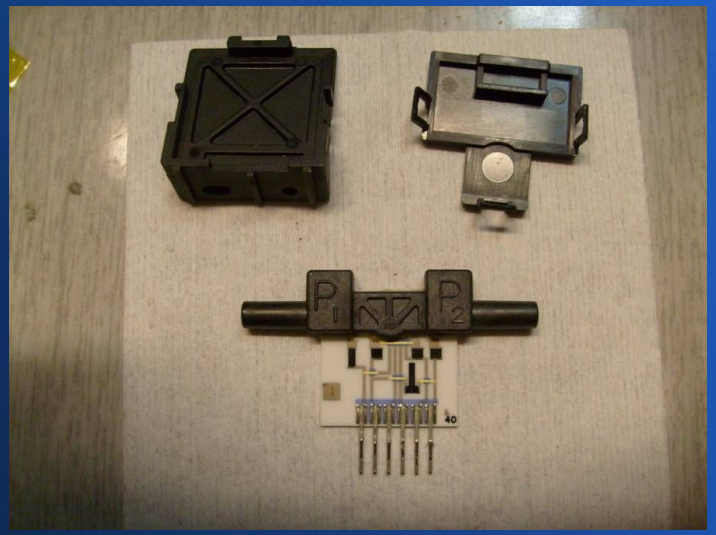
- Package is optically transparent
- May not need to decap at all - just image through window
- Typically ceramic with glass lid

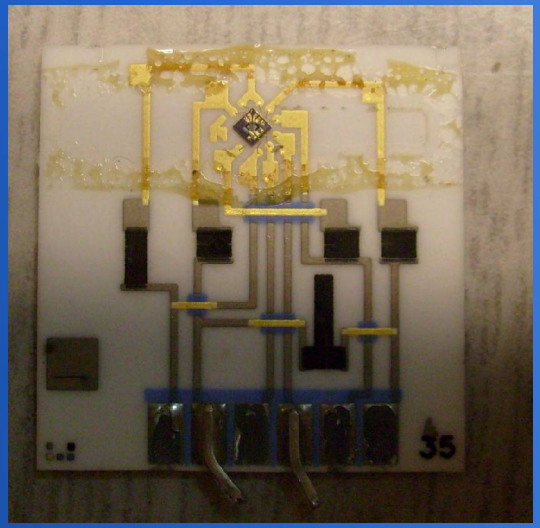


Other sensors

- Packaging varies widely depending on what's measured
- Example: MEMS mass airflow sensor

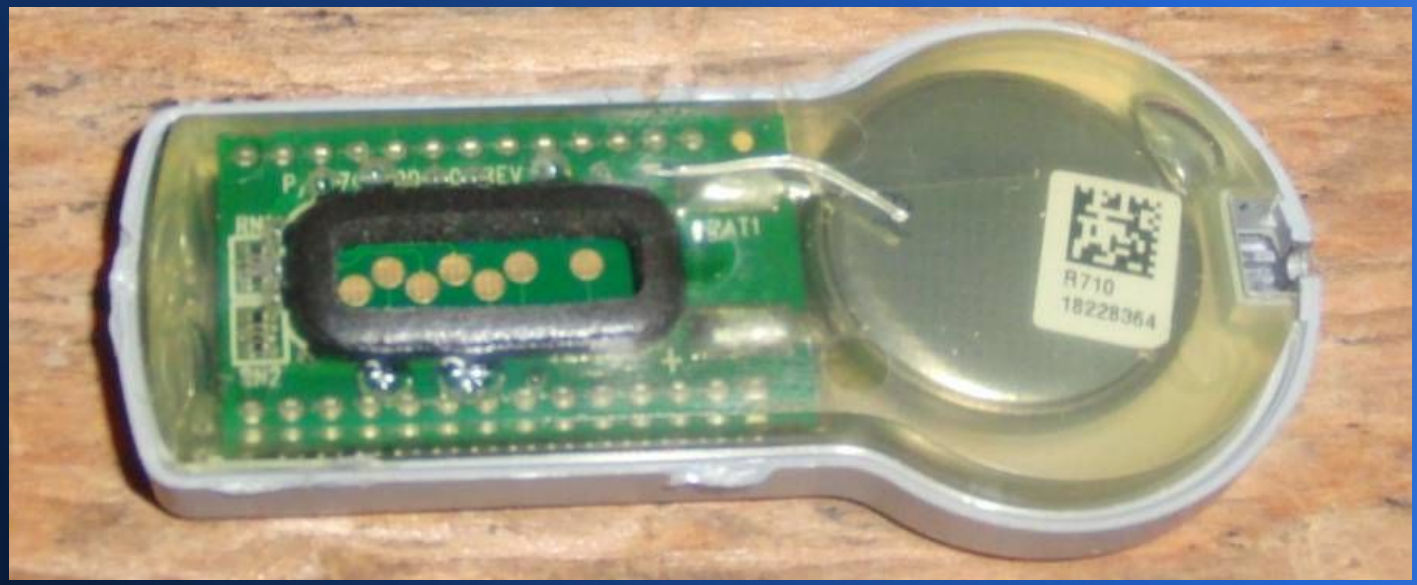






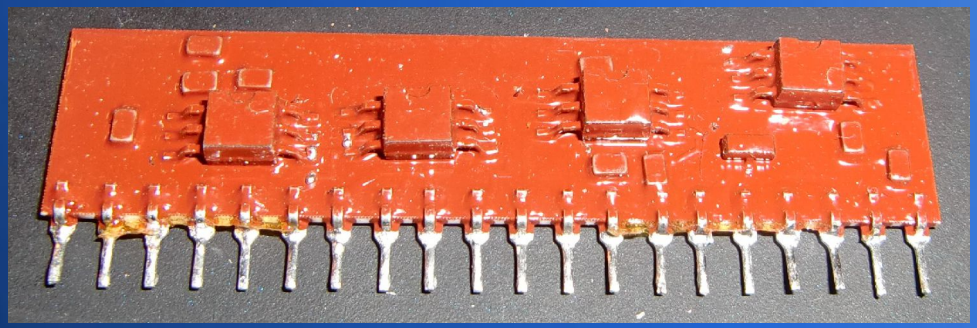
Potting

- Protects board from water, dirt, etc
- May also make tampering harder
- Needs to be removed to get to chips or probe board



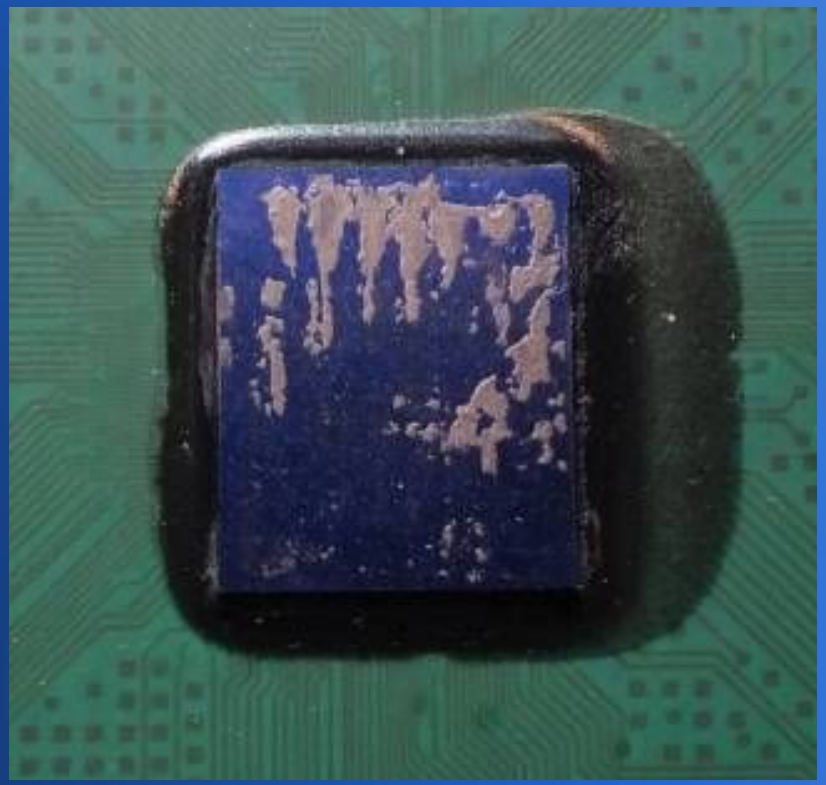
Conformal coating

- Like potting, but a thin layer that doesn't fill the enclosure
- May be clear or opaque



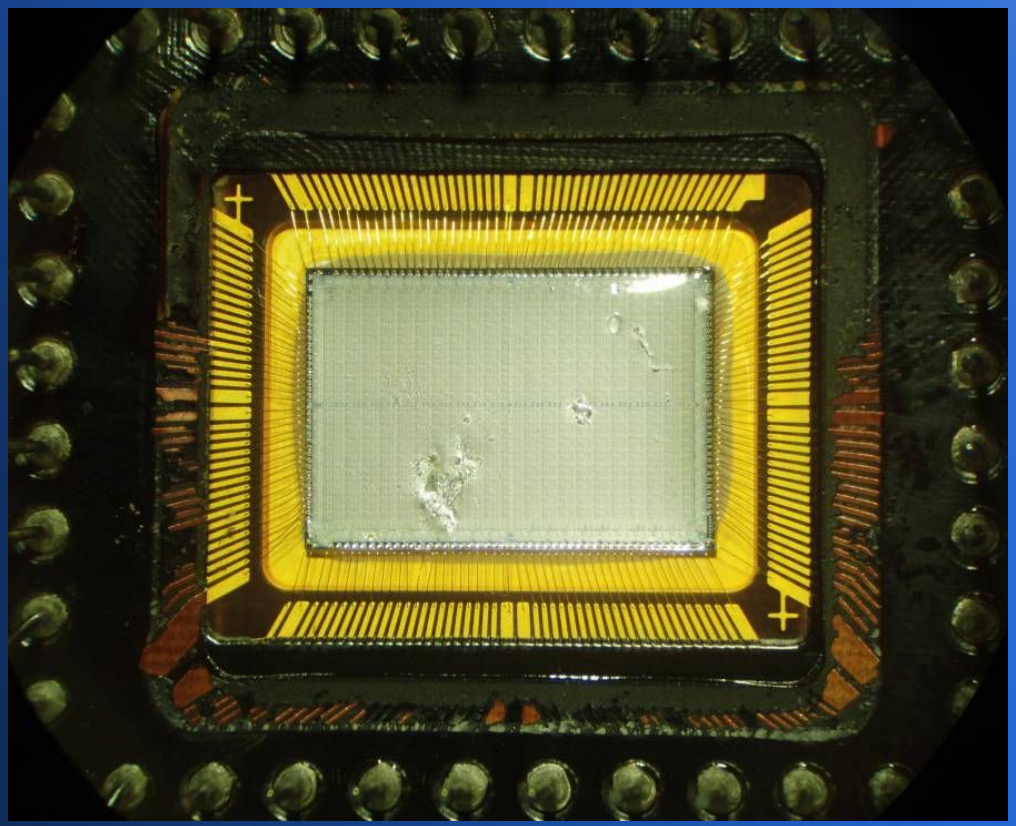
BGA underfill

- Provides mechanical stability to balls
- Improves resistance to cracking
- Makes desoldering difficult



Die coats

- Protection against particulates and (?) liquid ingress
- Polyimide film
- Silicone goo

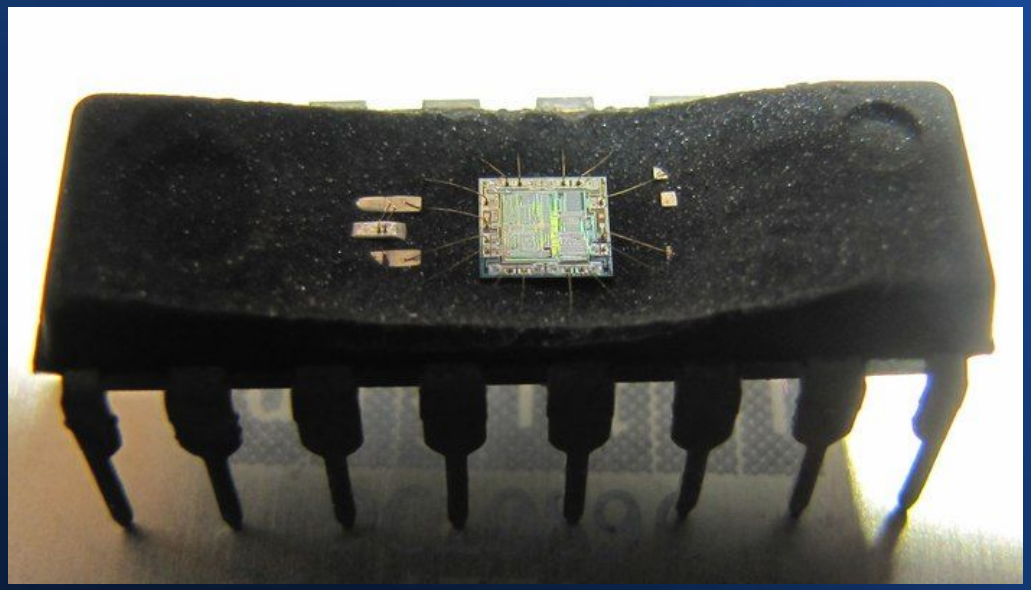


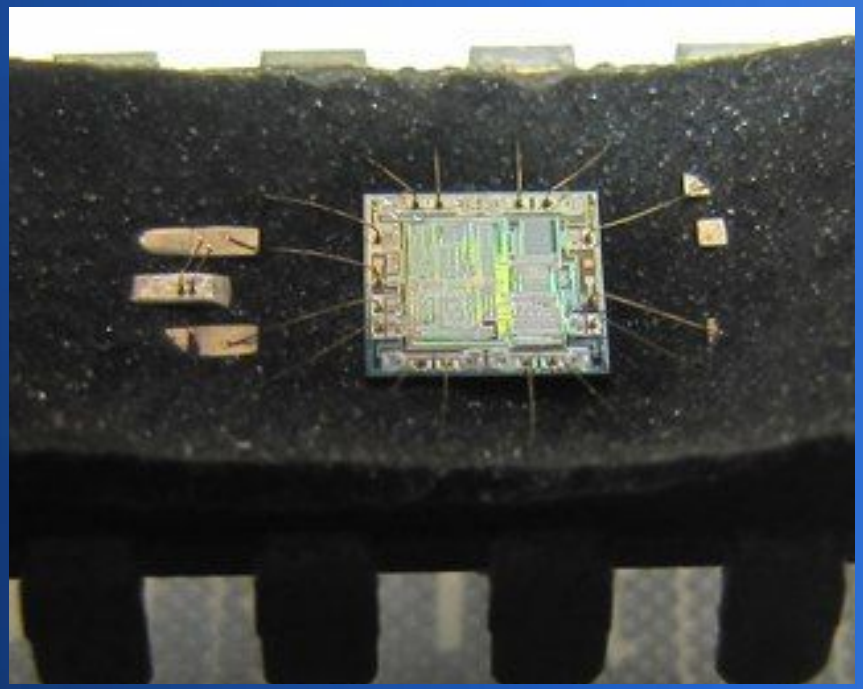
Package construction

- How is the chip connected to the leadframe?

Wire bonding

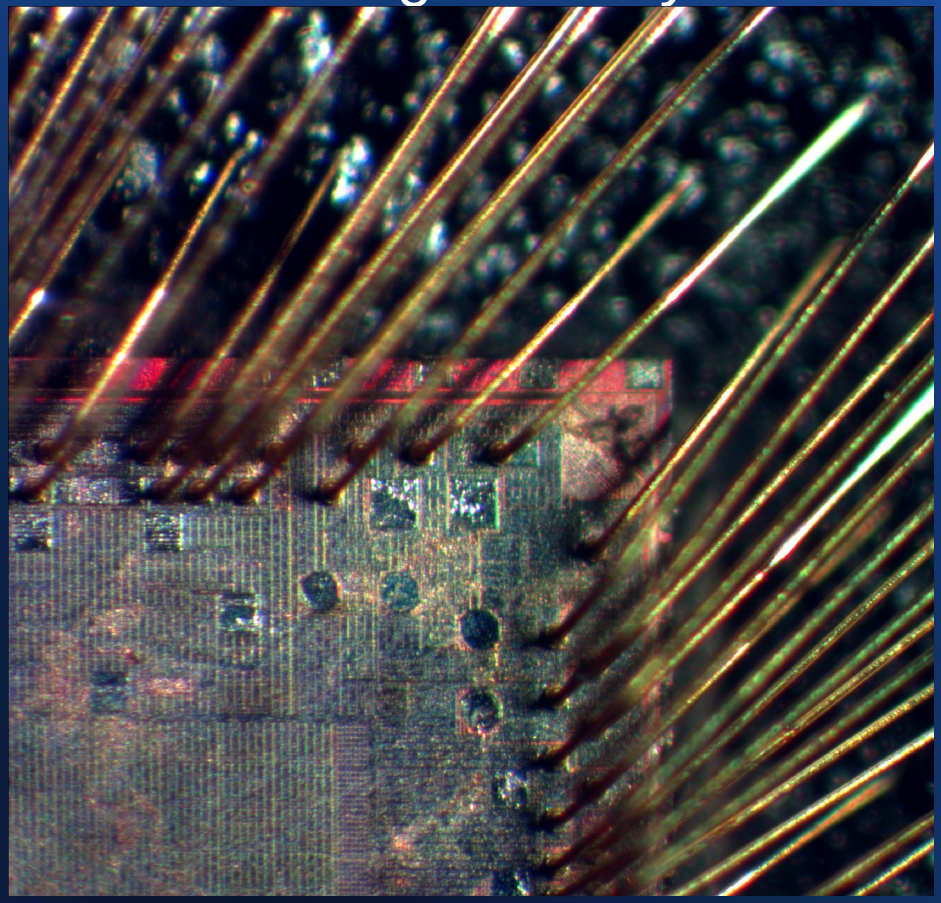
- Usually Au, but Al and Cu are used in special applications
- Cheapest way of connecting to leadframe

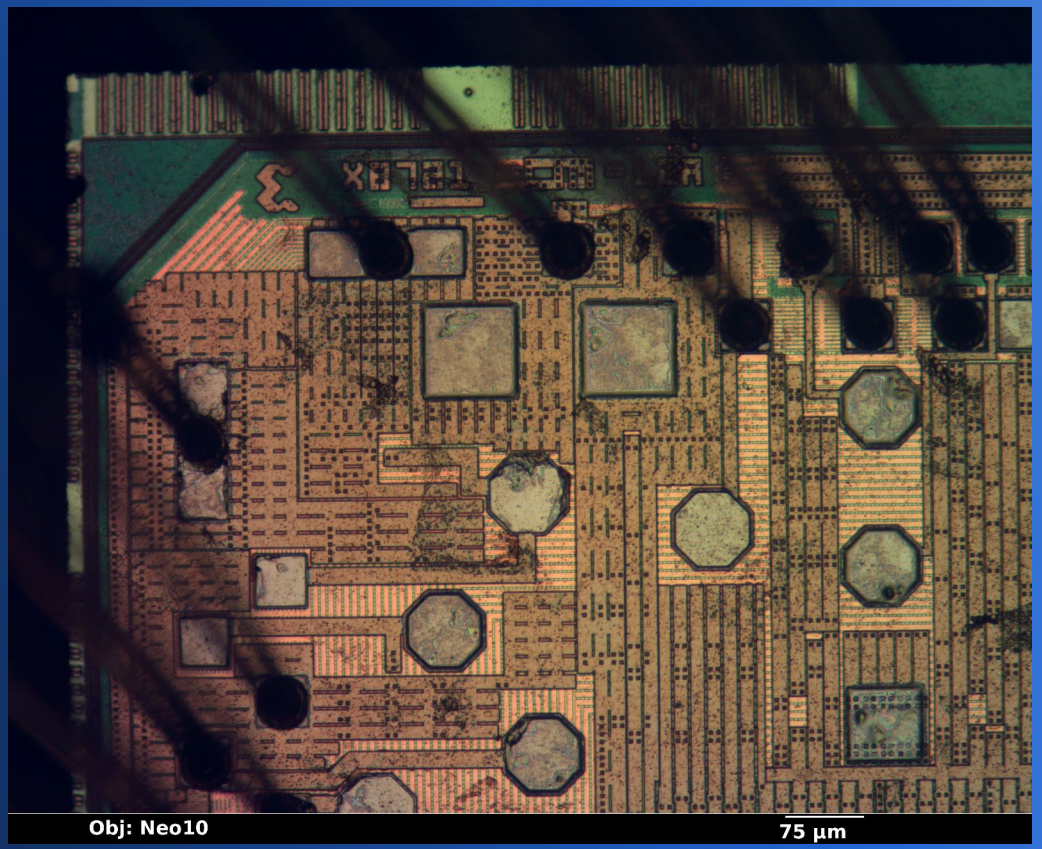




Concentric bond rings

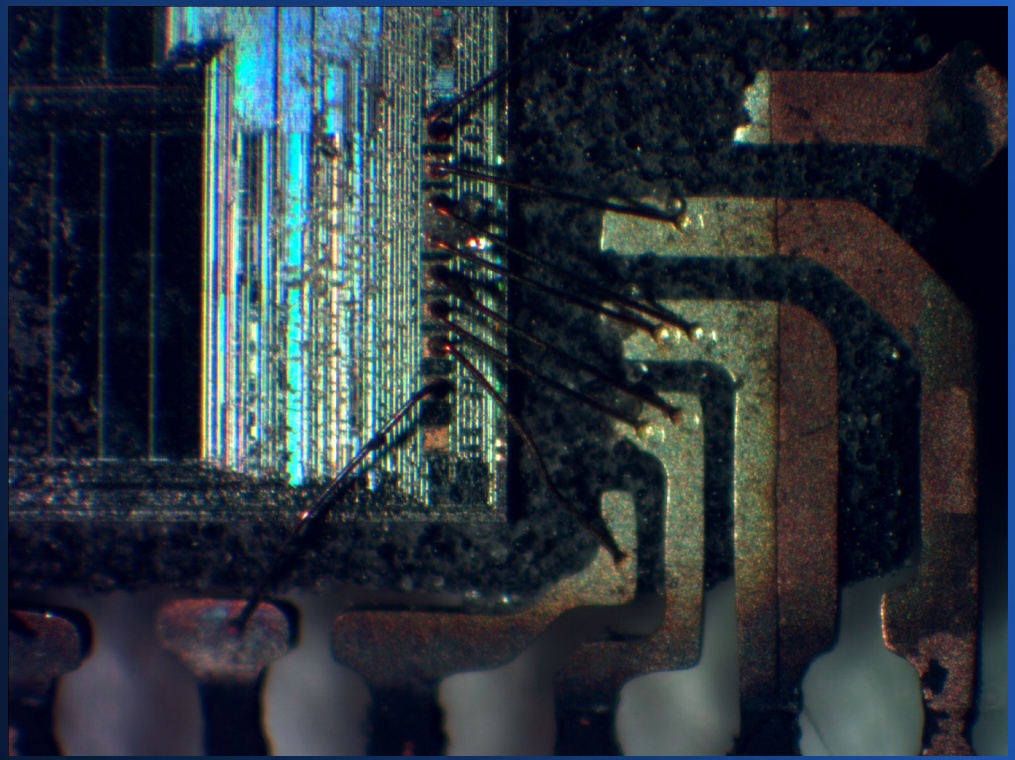
- Seen in high-density devices





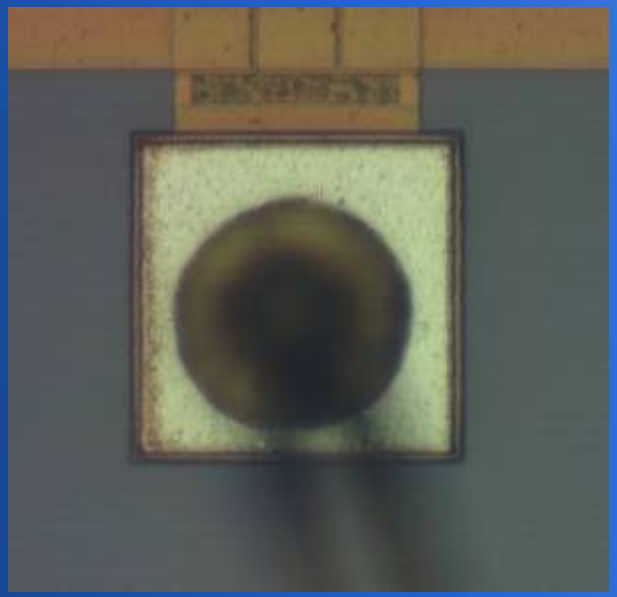
Double bonds

- Two wires from die to the same package pin
- Indicates a high-current line (often power)



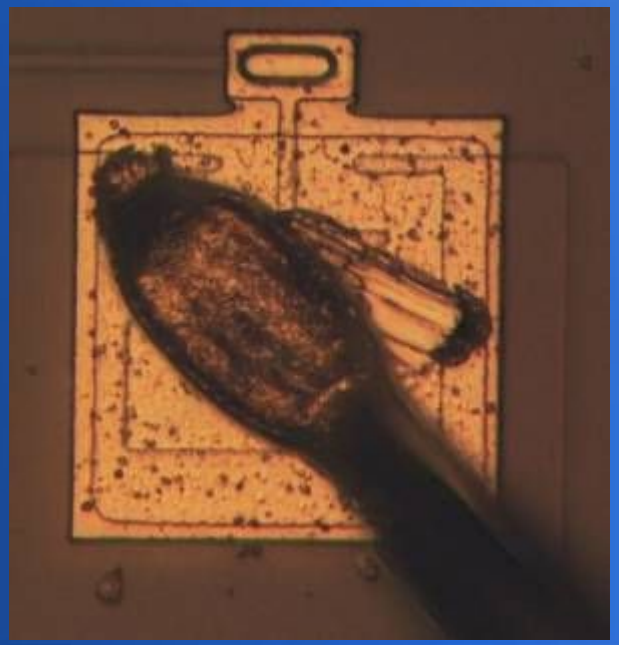
Ball bonding

- Wire feeds through needle
- Electrically melt tip into a ball
- Press onto bond pad with needle
- Apply heat and ultrasound to weld

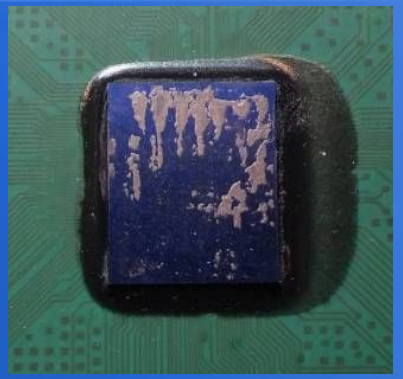


Wedge bonding

- Wire feeds through wedge-shaped nozzle
- Press onto pad
- Apply heat and ultrasound to weld
- Note probe scrub from wafer test



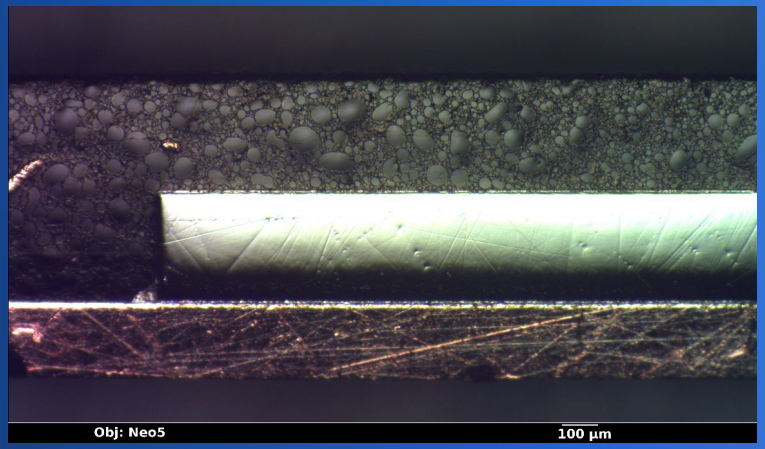
Flip chip



- Large, high-performance devices with lots of pins
- Active side of die goes down
- Solder bumps from top metal layer to interposer
- Interposer is basically a fine-pitch PCB with lots of layers
- Breaks super-fine solder bumps out to saner pitch
- Front-side attacks very hard
- Back-side attacks easier, top of die is already exposed :D

Carrier island / paddle

- Surface that the die rests on
- Typically connected to die substrate and electrically grounded
- Plastic packages: Cu with Sn plating
- Ceramic packages: Au plating over cofired leadframe metal
- Often fully covered by molding compound
- Exposed in QFNs for thermal reasons



Die attach

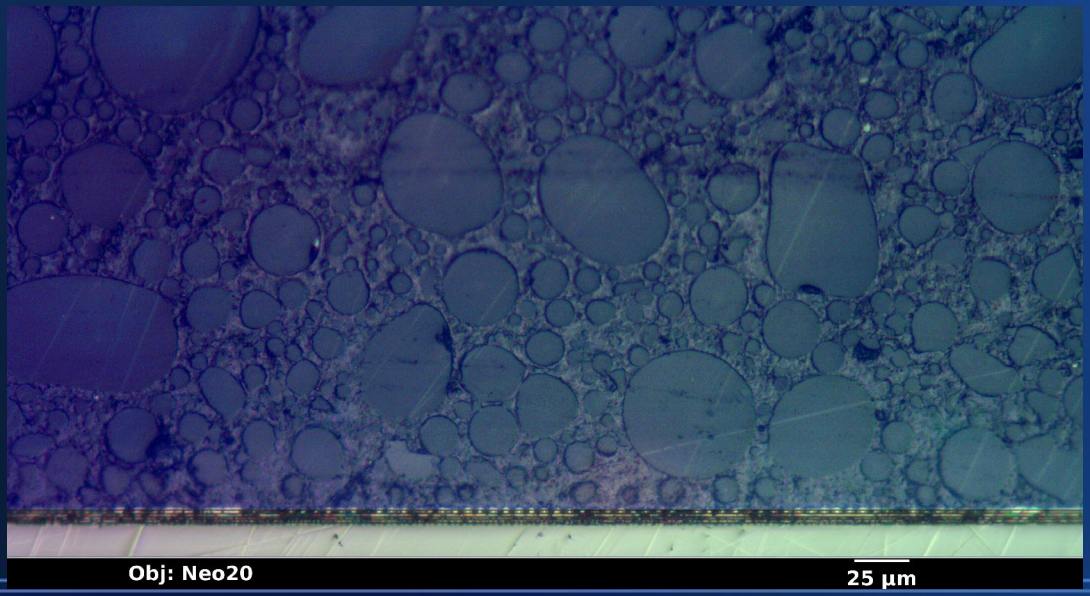
- Connects die to island
- Common materials:
  - Silver epoxy
  - Solder
  - Au-Si eutectic alloy
  - NanoFoil (Al-Ni + solder)

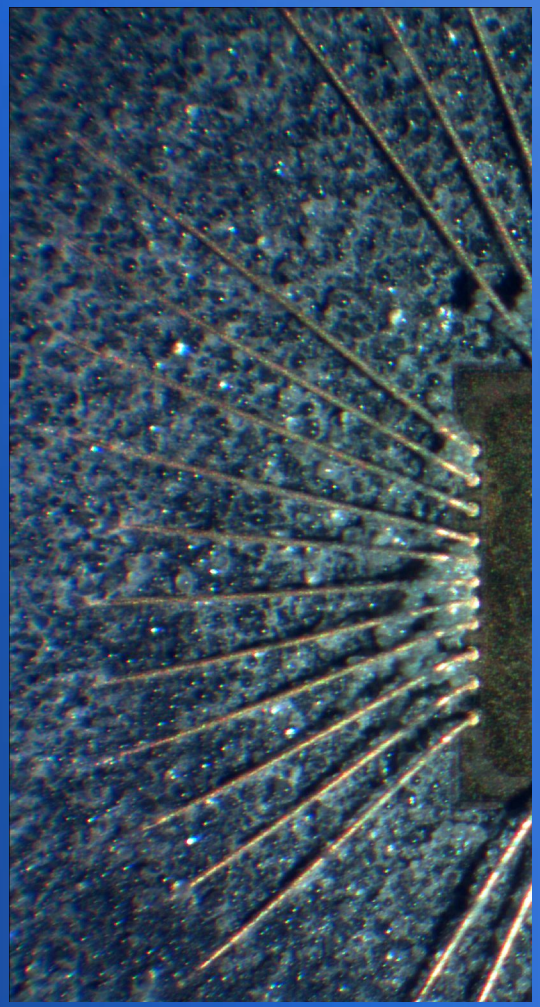
Package materials

- To reverse the device, we have to get the package off
- Knowing exactly what it's made of helps

Plastic package materials

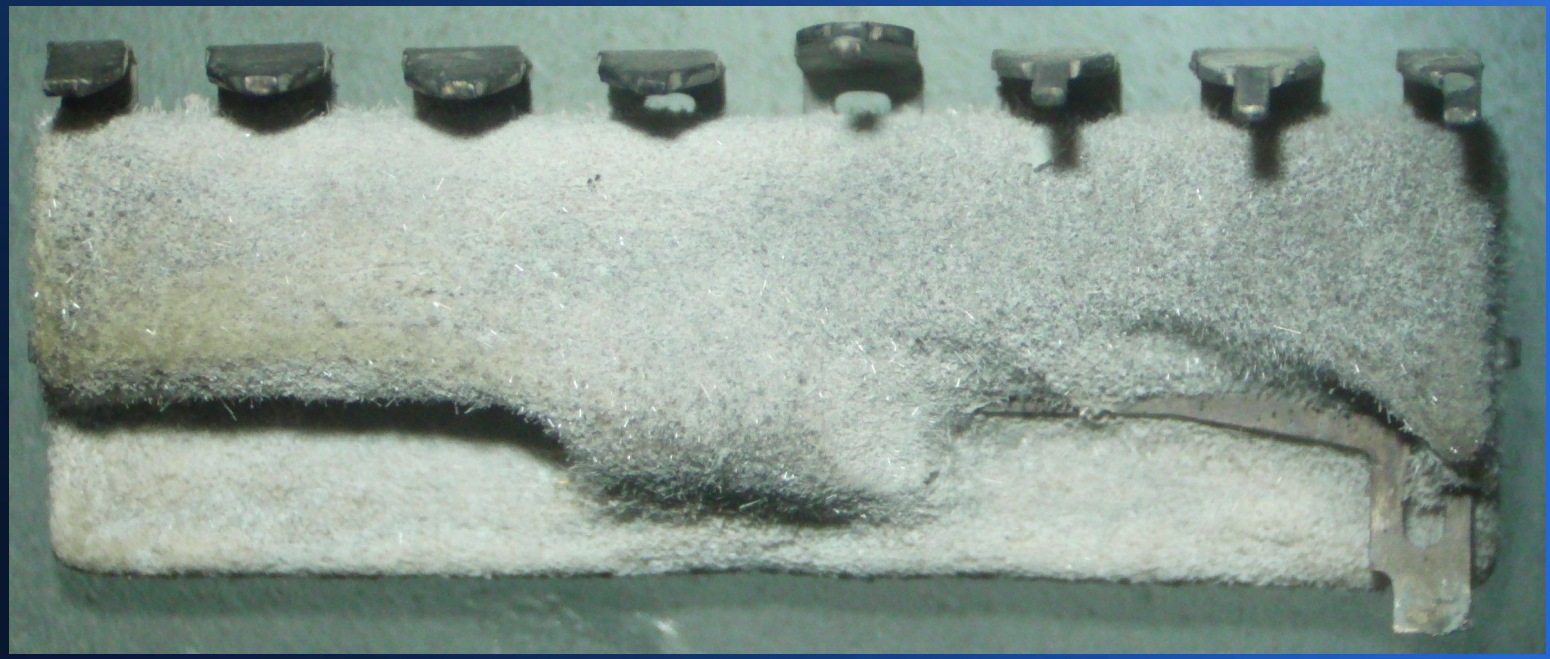
- “Plastic” chips are not actually plastic!
- Normally a composite, glass beads in epoxy
- Wire bonds are Au / Cu
- Leadframes Sn, Cu





Plastic package materials

- Epoxy is a thermoset (won't melt, just burns or decomposes)
- Glass content varies greatly, but is usually fairly high (>> 50%)
  - Sometimes a lot higher!



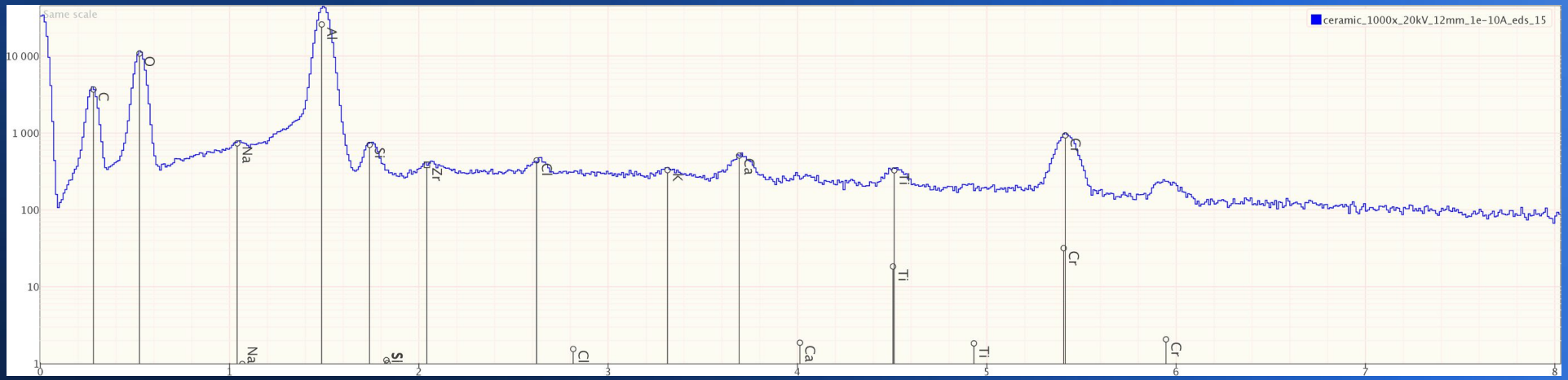
Ceramic package materials

- Fired ceramic clays
- Pieces often held together with glass
- Cofired packages use Mo or W interconnect
- Lids may be held on with solder or glass
- Extremely chemical resistant, very little will etch it
- Very good seals, used for high-reliability applications
- Brittle, can crack

Ceramic package materials

- Can be white, brown, or purple
- Al_2O_3 is by far the most common ceramic
- Often mixed with SiO_2
- AlN and BeO are used in some special cases, rare
- All are colorless
- Brown color comes from a few percent of MnO

Purple ceramic analysis



Questions?

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