BEE026- Micro Electro Mechanical Systems

EEE- Final year

Compiled by K.Dwarakesh

# Micro-Electro-Mechanical Systems (MEMS)

Introduction

MEMS technology consists of microelectronic elements, actuators, sensors, and mechanical structures built onto a substrate, which is usually silicon. They are developed using microfabrication techniques: deposition, patterning, and etching. The most common forms of production for MEMS are bulk micromachining, surface micromachining, and HAR fabrication. The benefits on this small scale integration brings the technology to a vast number and variety of devices.

Introduction/Outline

- **What Are MEMS?**

- **Components of MEMS**

- **Fabrication**

- **MEMS Operation**

- **Applications**

- **Summary**

- **5 Key Concepts**

- **?Questions?**

What are MEMS?

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.
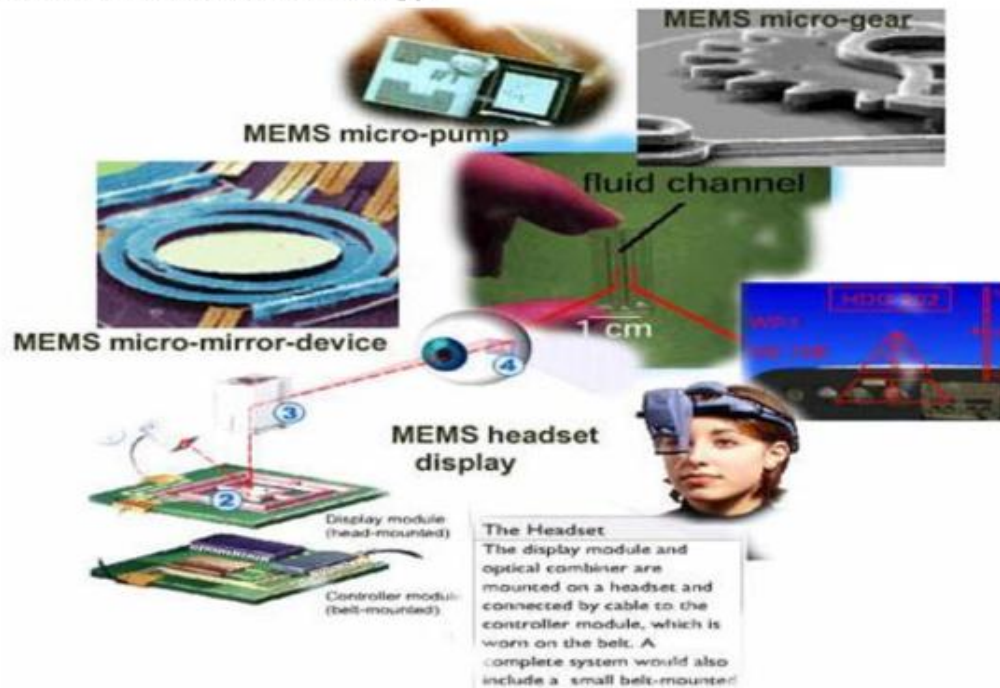
What are MEMS?

- **Made up of components between 1-100 micrometers in size**

- **Devices vary from below one micron up to several mm**

- **Functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics**

- **One main criterion of MEMS is that there are at least some elements that have mechanical functionality, whether or not they can move**

Components

Microelectronics:

- "brain" that receives, processes, and makes decisions
- data comes from microsensors

Microsensors:

- constantly gather data from environment
- pass data to microelectronics for processing
- can monitor mechanical, thermal, biological, chemical readings

Microactuator:

- acts as trigger to activate external device
- microelectronics will tell microactuator to activate device

Microstructures:

- extremely small structures built onto surface of chip
- built right into silicon of MEMS

https://www.mems-exchange.org/MEMS/what-is.html
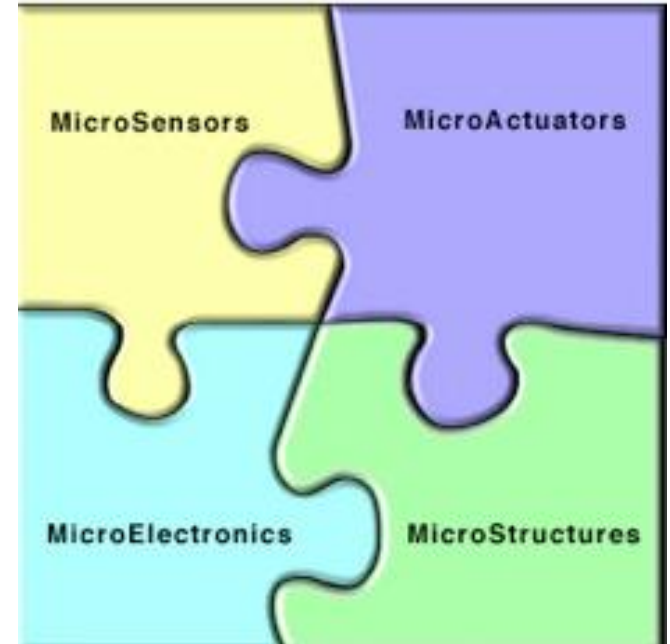
Fabrication Processes

Deposition:

- deposit thin film of material (mask) anywhere between a few nm to 100 micrometers onto substrate

- **physical:** material placed onto substrate, techniques include sputtering and evaporation

- **chemical:** stream of source gas reacts on substrate to grow product, techniques include chemical vapor deposition and atomic layer deposition

- **substrates:** silicon, glass, quartz

- **thin films:**polysilicon, silicon dioxide, silicon nitride, metals, polymers
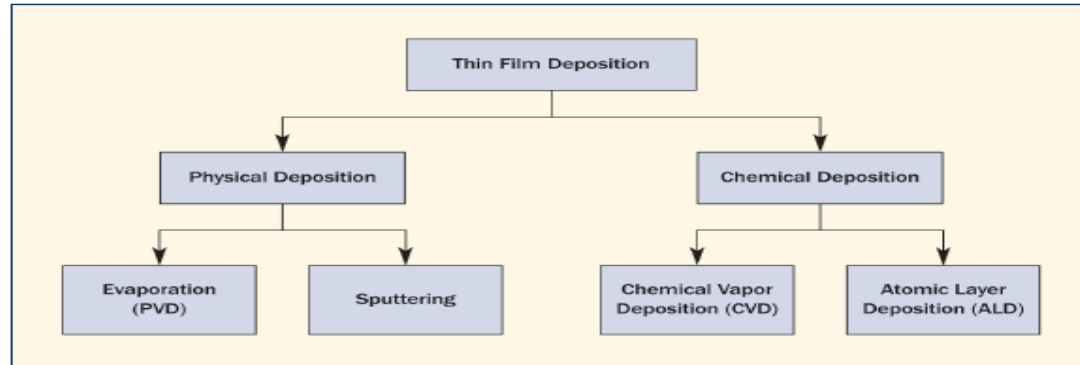
Patterning:

- transfer of a pattern into a material after deposition in order to prepare for etching

- techniques include some type of lithography, photolithography is common

Etching:

- **wet etching:** dipping substrate into chemical solution that selectively removes material

- process provides good selectivity, etching rate of target material higher that mask material

- **dry etching:** material sputtered or dissolved from substrate with plasma or gas variations

- choosing a method: desired shapes, etch depth and uniformity, surface roughness, process compatibility, safety, cost, availability, environmental impact

Fabrication Methods

Bulk Micromachining:

- oldest micromachining technology

- technique involves selective removal of substrate to produce mechanical components

- accomplished by physical or chemical process with chemical being used more for MEMS production

- chemical wet etching is popular because of high etch rate and selectivity

- isotropic wet etching: etch rate not dependent on crystallographic orientation of substrate and etching moves at equal rates in all directions

- anisotropic wet etching: etch rate is dependent on crystallographic orientation of substrate

Surface Micromachining:

- process starts with deposition of thin-film that acts as a temporary mechanical layer (sacrificial layer)
- device layers are constructed on top
- deposition and patterning of structural layer
- removal of temporary layer to allow movement of structural layer

- benefits: variety of structure, sacrificial and etchant combinations, uses single-sided wafer processing
- allows higher integration density and lower resultant per die cost compared to bulk micromachining
- disadvantages: mechanical properties of most thin-films are usually unknown and reproducibility of their mechanical properties

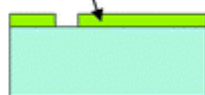a. bulk micromachining

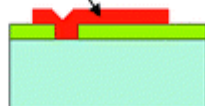isotropic etching

anisotropic etching
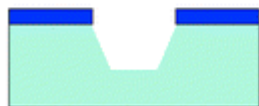
b. surface micromachining

substrate (Si)   sacrificial layer

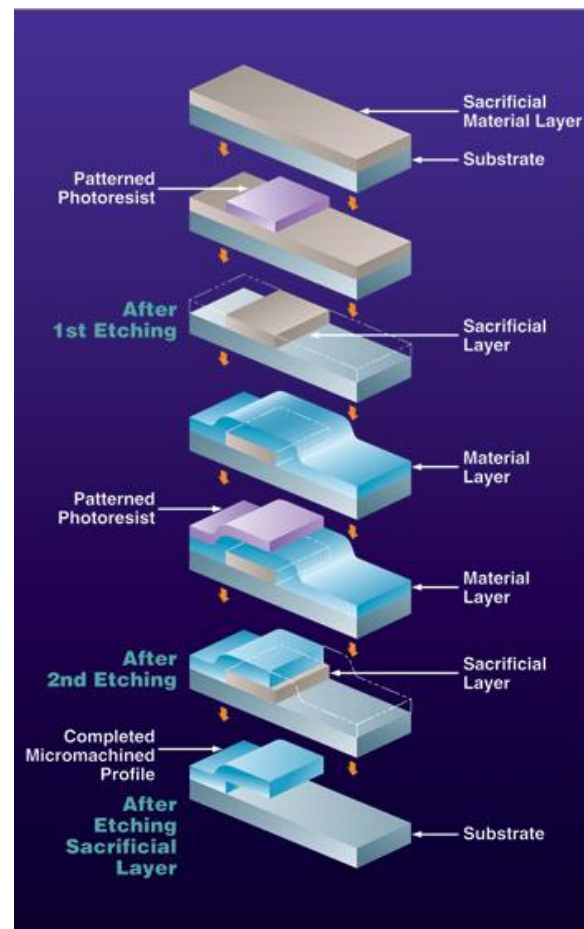structural layer   microstructure

http://pubs.rsc.org/en/content/articlehtml/2003/AN/B208563C#sect274

http://www.photonics.com/images/Web/Articles/2008/11/1/thumbnail_35519.jpg

Sacrificial Material Layer
Substrate
Patterned Photoresist
After 1st Etching
Sacrificial Layer
Material Layer
Patterned Photoresist
Material Layer
After 2nd Etching
Sacrificial Layer
Completed Micromachined Profile
After Etching Sacrificial Layer
Substrate

Wafer Bonding:

- Method that involves joining two or more wafers together to create a wafer stack
- Three types of wafer bonding: direct bonding, anodic bonding, and intermediate layer bonding
- All require substrates that are flat, smooth, and clean in order to be efficient and successful

cross section of a silicon wafer demonstrating trenches that can be fabricated using DRIE tech
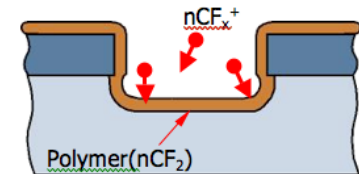
https://www.memsnet.org/mems/fabrication.html

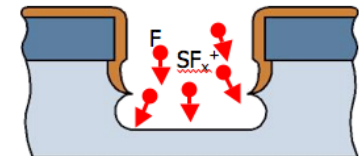# High Aspect Ratio Fabrication (Silicon):

- Deep reactive ion etching (DRIE)
- Enables very high aspect ratio etches to be performed into silicon substrates
- Sidewalls of the etched holes are nearly vertical
- Depth of the etch can be hundreds or even thousands of microns into the silicon substrate.
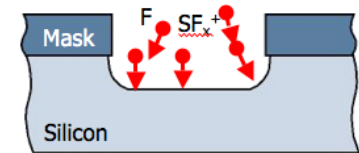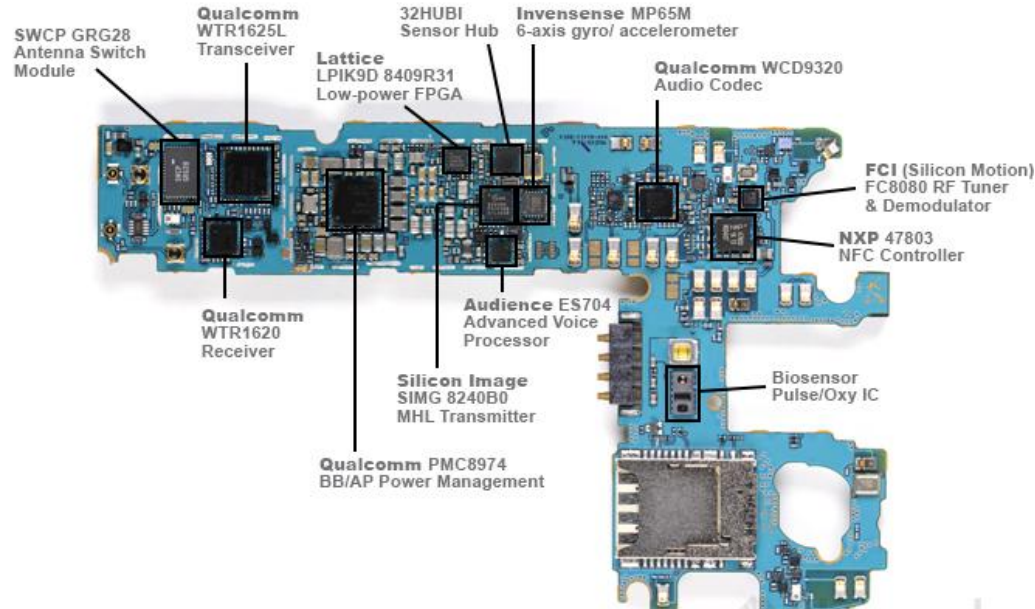

Etch

Deposit Polymer

Etch

Figure 7: Illustration of how deep reactive ion etching works.

Benefits/Tradeoffs

- Much smaller area
- Cheaper than alternatives
    - In medical market, that means disposable
- Can be integrated with electronics (system on one chip)
- Speed:
    - Lower thermal time constant
    - Rapid response times(high frequency)
- Power consumption:
    - low actuation energy
    - low heating power

- Imperfect fabrication techniques
- Difficult to design on micro scales

Where Are MEMS?

Smartphones, tablets, cameras, gaming devices, and many other electronics have MEMS technology inside of them

SWCP GRG28 Antenna Switch Module

Qualcomm WTR1625L Transceiver

32HUBI Sensor Hub

Invensense MP65M 6-axis gyro/ accelerometer

Lattice LPIK9D 8409R31 Low-power FPGA

Qualcomm WCD9320 Audio Codec

FCI (Silicon Motion) FC8080 RF Tuner & Demodulator

NXP 47803 NFC Controller

Qualcomm WTR1620 Receiver

Audience ES704 Advanced Voice Processor

Biosensor Pulse/Oxy IC

Silicon Image SIMG 8240B0 MHL Transmitter

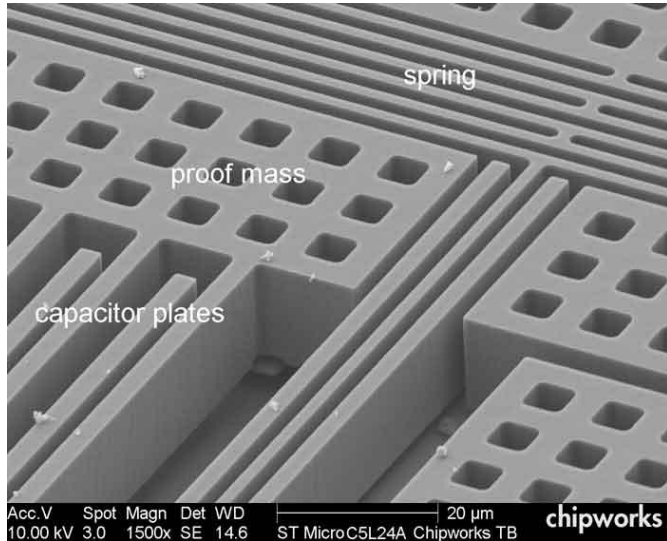Qualcomm PMC8974 BB/AP Power Management

chipworks

MEMS Operation

- Sensors & Actuators
- 3 main types of transducers:
  - Capacitive
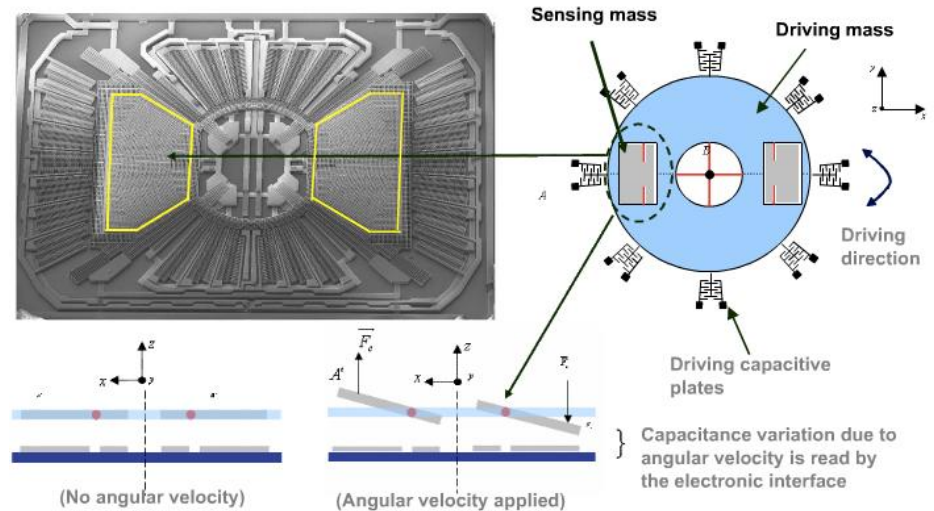 - Piezoelectric
  - Thermal
- Additionally: Microfluidic
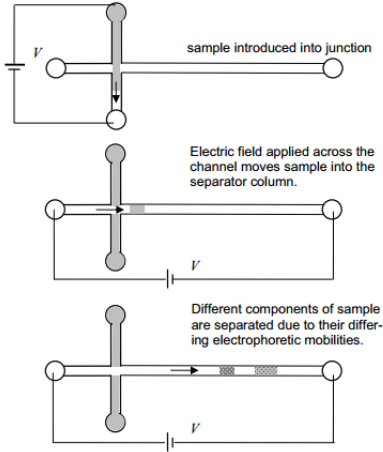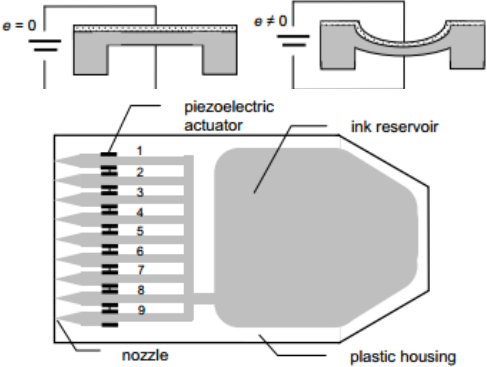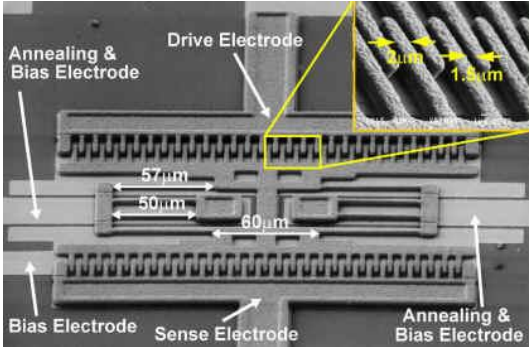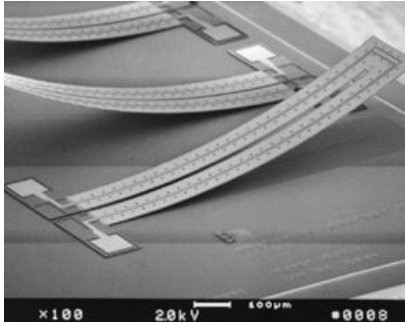
Inertial Sensors

## MEMS Accelerometer

MEMS Gyroscope

Biomedical Applications

- Usually in the form of pressure sensors
  - Intracranial pressure sensors
  - Pacemaker applications
  - Implanted coronary pressure measurements
  - Intraocular pressure monitors
  - Cerebrospinal fluid pressure sensors
  - Endoscope pressure sensors
  - Infusion pump sensors
- Retinal prosthesis
- Glucose monitoring & insulin delivery
- MEMS tweezers & surgical tools
- Cell, antibody, DNA, RNA enzyme measurement devices
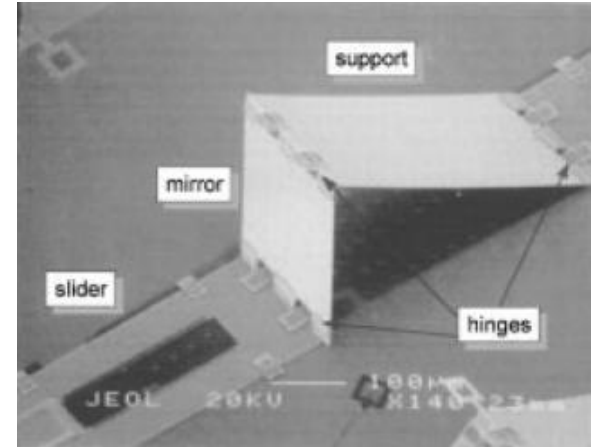

Blood Pressure sensor
on the head of a pin

In the Car
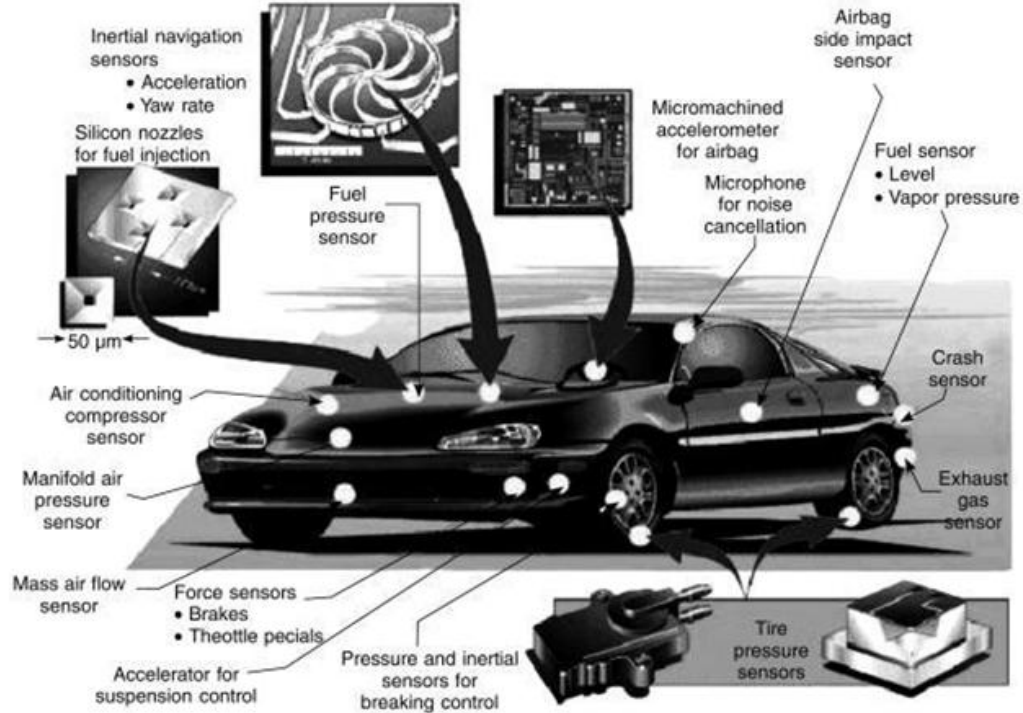
Additional Applications

- ## Optical MEMS

  - o Ex: optical switches, digital micromirror devices (DMD), bistable mirrors, laser scanners, optical shutters, and dynamic micromirror displays

- ## RF MEMS

  - o Smaller, cheaper, better way to manipulate RF signals

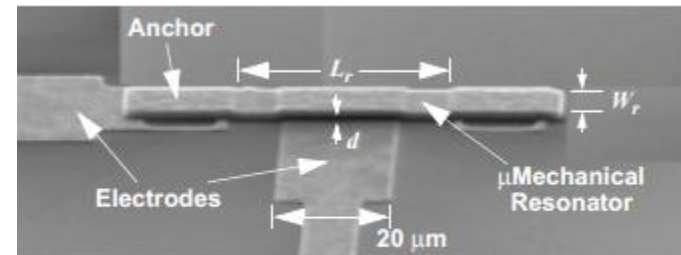 - o Reliability is issue, but getting there

Fig. 6. SEM of an 8.5MHz clamped-clamped beam μmechanical resonator.

Summary/Conclusion

Micro-Electro-Mechanical Systems are 1-100 micrometer devices that convert electrical energy to mechanical energy and vice-versa. The three basic steps to MEMS fabrication are deposition, patterning, and etching. Due to their small size, they can exhibit certain characteristics that their macro equivalents can't. MEMS produce benefits in speed, complexity, power consumption, device area, and system integration. These benefits make MEMS a great choice for devices in numerous fields.

5 Key Concepts

1. MEMS are made up of microelectronics, microactuators, microsensors, and microstructures.

2. The three basic steps to MEMS fabrication are: deposition, patterning, and etching.

3. Chemical wet etching is popular because of high etch rate and selectivity.

4. 3 types of MEMS transducers are: capacitive, thermal, and piezoelectric.

5. The benefits of using MEMS: speed, power consumption, size, system integration(all on one chip).