Quiz - Solutions

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Generalities

Q1.1: Provide the name of 4 families of MEMS devices

- BioMEMS
- MEMS
- Optical MEMS / MOEMS
- PowerMEMS
- RF-NEMS
- NEMS

Q1.2: True or False: A MEMS is not always a Microsystem, but a Microsystem is always a MEMS

Answer: FALSE

Q1.3: List 5 advantages of using MEMS technology

- Performance benefits from scaling: sensitivity, faster response…
- Cost advantage under mass production
- Low power
- Arrays formation
- Reproducibility
- High volume
- Higher integration / signal processing integrated
- Compact, portable

Q1.4: Place these MEMS devices in their chronological order of commercialisation, oldest to most recent

1. Inkjet print head
2. Accelerometer
3. Digital light projector
4. Microphone
5. Finger print sensor

Q1.5: What is the largest diameter (in mm) for a silicon wafer ?

Are MEMS mainly produced using this size of wafer (Yes/No)?

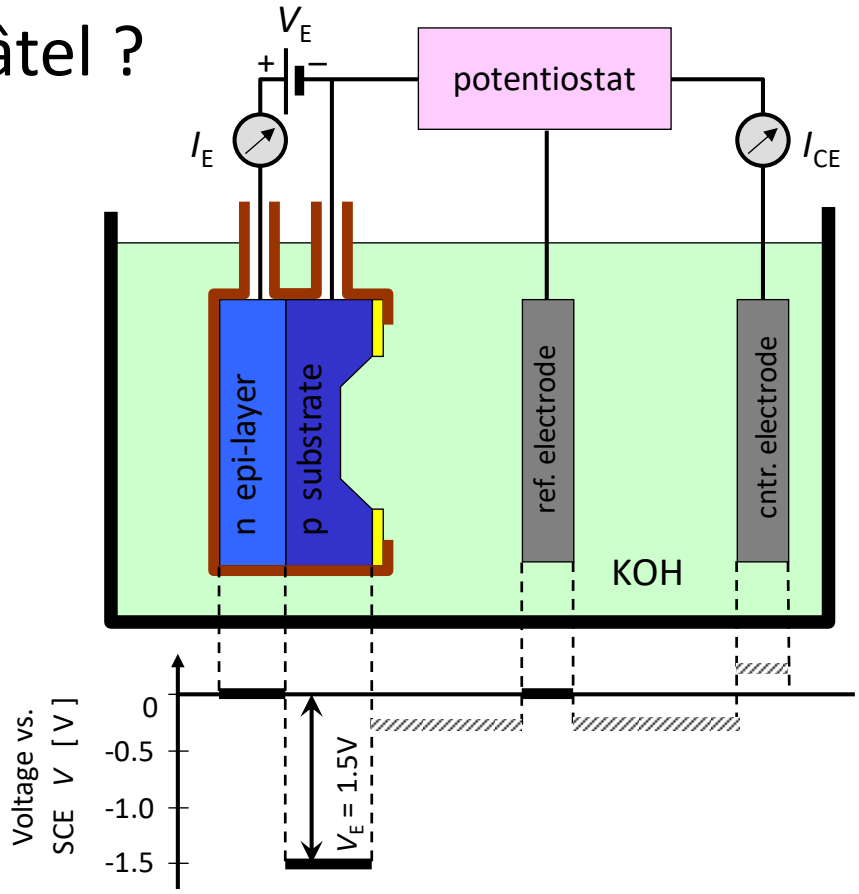
- 300 mm
- No, mainly produced using 150 and 200 mm wafers

Q1.6: What are the two main techniques to micromachine silicon wafers to release mechanical microfabricated silicon structures (membranes, beams, comb drives…)

- Bulk micromachining
- Surface micromachining

Q1.7: Which etch-stop technique to control the thickness of silicon membranes during silicon micromaching in KOH has been invented in Neuchâtel ?

- Electrochemical etch-stop



Q1.8: I am Franz Lämmer, inventor at Bosch of a process used to etch silicon, named also the Bosch process. What is the technical name of this process ?

Answer: Deep Reactive Ion Etching (DRIE)

Q1.9: Is increasing or decreasing at lower scale:

- The surface to volume ratio ? Increasing

- The resonance frequency ? Increasing

Q1.10: What is this «MEMS» ?

Answer: Capacitive humidity sensor

MEMS Players

Q2.1: Who is the largest MEMS producer in revenue ?

Which product do they produce for which market ?

- Broadcom Inc (USA)
- Bulk acoustic wave (BAW) resonators for telecommunication / smart phones

Q2.2: Name 3 MEMS producers in Switzerland ?

- Colibrys (inertial sensors)
- CSEM (Small production)
- Sensirion (Humidity, flow, gas,…)
- Sercalo (MOEMS)
- Axetris (IR sources
- Nanoworld / Nanosurf (AFM)
- TE Connectivity (pressure sensors)

Q2.3: Name the top 2 major MEMS European producers

- Bosch GmBH (DE)
- ST Microelectronics (FR/CH)

Q2.4: Name a major MEMS/Microelectronics producer in Taiwan ?

- TSMC: Taiwan Semiconductor Manufacturing Company

Q2.5: Who is the leader in the optical MEMS field ?

- Texas Instruments – TI (USA)

Q2.6: What product is producing Knowles ?

- Microphones

Q2.7: Name three «MEMS» devices produced by Sensirion

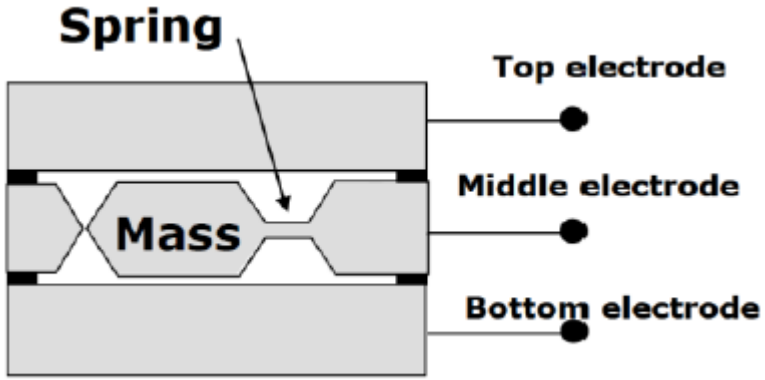
- Humidity
- Flow
- Gas
- Temperature
- Particles

Q2.8: What is the specificity of Sensirion in comparison to other MEMS company ?

- CMOSens^{TM}: CMOS electronics integrated with digital interface

Q2.9: What is the transducing principle of Colybris MEMS accelerometers ? Sketch their device

- Capacitive



Q2.10: Tilting MEMS at SAFRAN-Colibrys operating at 175°C, provide the application ?

- For drilling

Q2.11: In the next 5 years, which market segment will represent 50% of the total MEMS market value ?

- Consumer market

Q2.12: What is this MEMS ?

- Liquid flow sensor

by Sensirion

Transducers and MEMS Sensors

Q3.1: Name 3 types of MEMS devices using comb drives

- Accelerometers
- Gyroscopes
- Actuators: Optical MEMS mirrors
- Resonators

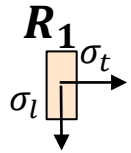
Q3.2: What is the transducing principle used for accelerometers in airbags ?

- Capacitive

Q3.3: Provide the formulae relating $\Delta R/R$ of a narrow and long piezoresistor to the stresses on the membrane of a pressure sensor

$$\frac{\mathrm{d}R}{R} = \pi_l \sigma_l + \pi_t \sigma_t$$

(any crystal direction)



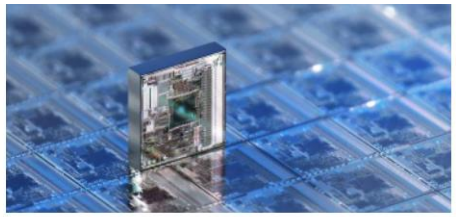
Q3.4: How can you play with the dimensions of the membrane to increase the sensitivity of a pressure sensor ? Which one would you favor and why ?

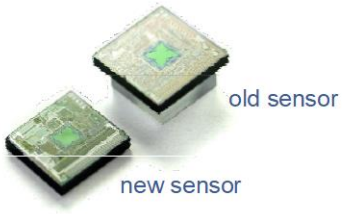
- Larger membrane
- Thinner membrane

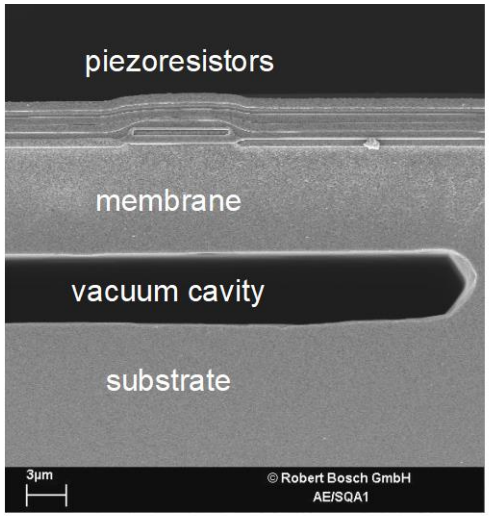
Thinner since large membranes = larger area and then cost

But control on thickness is important

Q3.5: Bosch has developped a pressure sensor on silicon integrating a sealed cavity. What is the specific material used in their process ?







Automotive Electronics

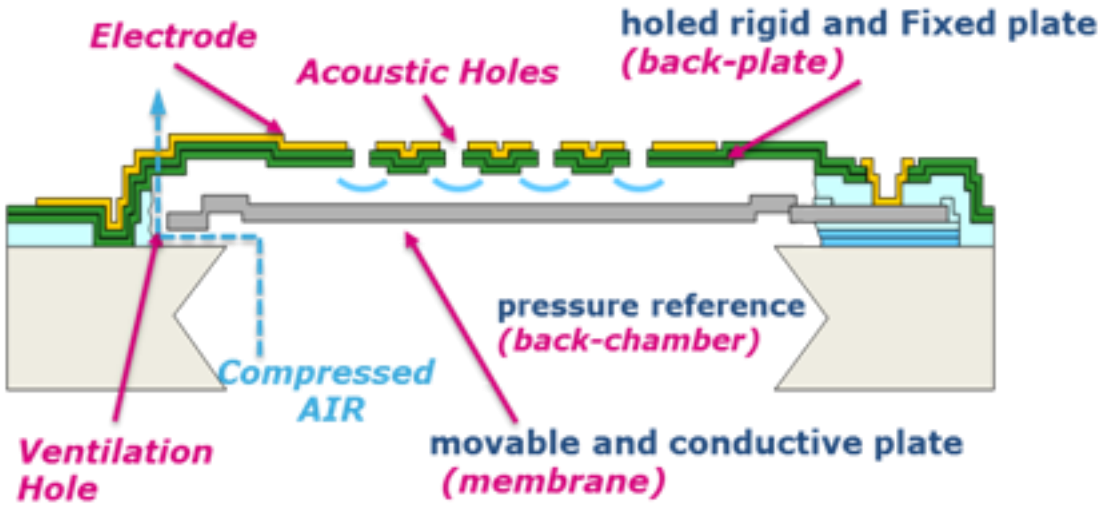
BOSCH

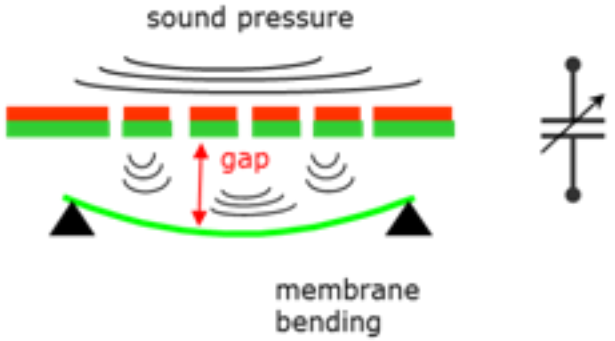
Answer: Porous silicon

Q3.6: Name the main transducing principle used in MEMS microphone and the one that is now emerging

- Now capacitive
- Coming piezoelectric

Q3.7: Draw the cross-section of a microphone





Q3.8: Which force is involved in the operating principle of a MEMS gyroscope ?

- Coriolis force

Q3.9: What are the 9 axis that can be found in a Inertial Measurement Unit (IMU) ?

- 3 axis accelerometer
- 3 axis gyroscope
- 3 axis magnetometer

Q3.10: How do we call the fact of combining different sensors to extrat specific information ?

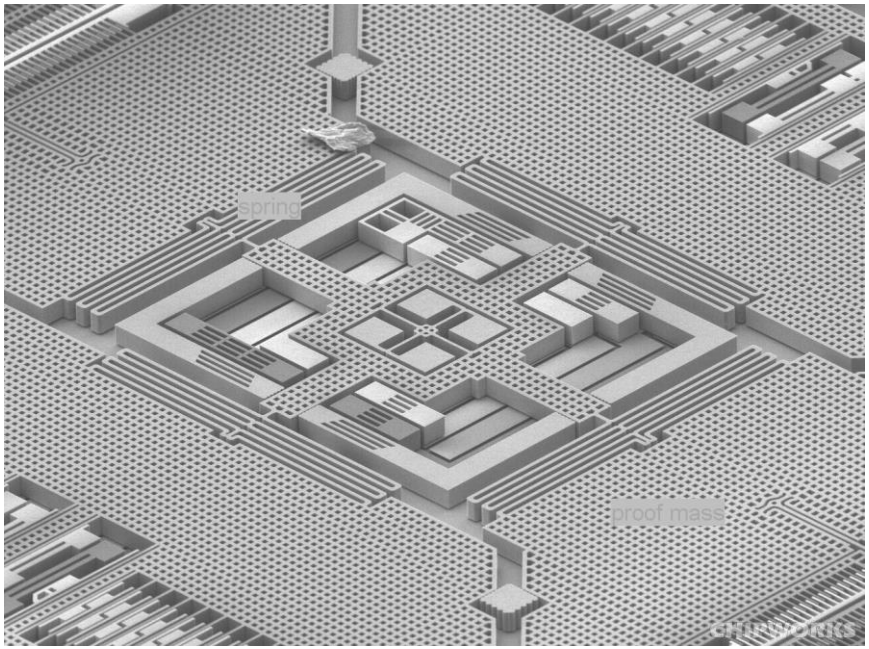
- Sensors fusion

Q3.11: What does mean ASIC ?

- Application-Specific Integrated Circuit

Q3.12: What is this MEMS ?

- Gyroscope from Apple iPhone 5



Optical MEMS

Q4.1: Name 3 MOEMS applications and their associated domains in the optical spectrum

- Display
- Telecom
- Spectroscopy

Domain	λ [µm]	ν [THz]	E [eV]	MOEMS Applications
Visible	0.4 – 0.7	400 – 750	1.65 – 3.10	Displays
Near-Infrared	0.7 – 3	100 – 400	0.41 – 1.65	Telecom (0.85, 1.3, 1.55)
Mid-Infrared	3 – 8	37 – 100	0.16 – 0.41	Spectroscopy
Long-Infrared	8 – 15	20 – 37	0.08 – 0.16	(Thermal Imaging)

Q4.2: Name the 2 main actuating principles used in Optical MEMS.

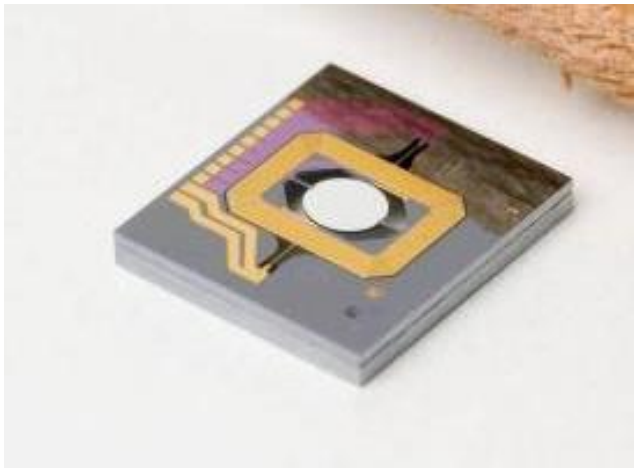
List one advantage and one drawback for each of them

- Electrostatic: low-power, high precision, but low-force

- Magnetic: High force, low voltage, but high power

Q4.3: What is this device used for ? And what is the actuation principle implemented ?

- 2D scanning MEMS mirror as bar code reader

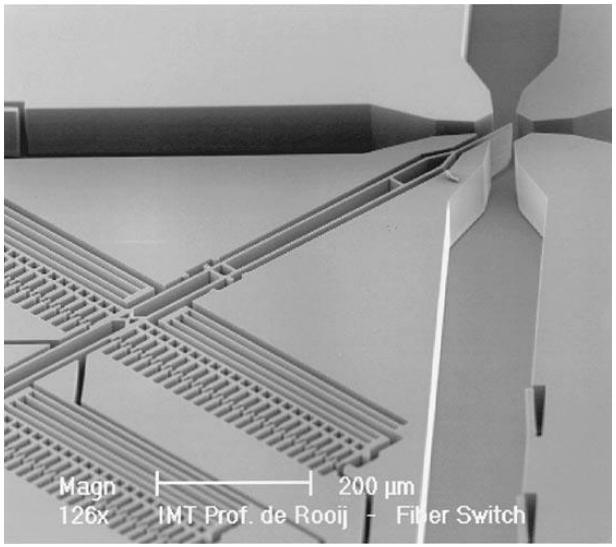


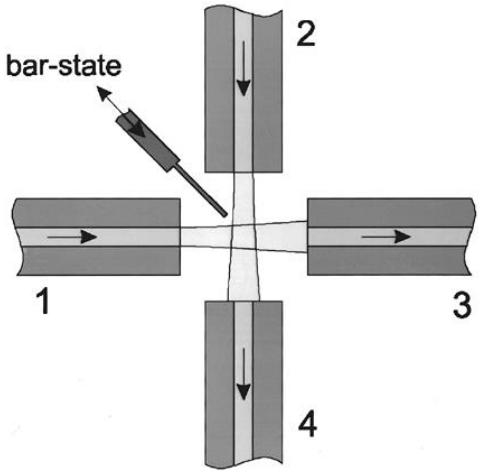
- Magnetic actuation, coil with current and bulk magnet

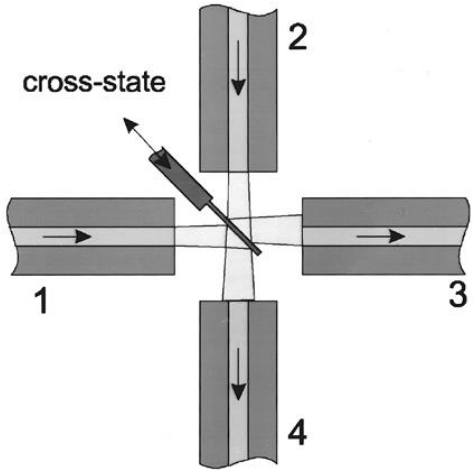
Q4.4: What is a LIDAR, what does it mean, what is the working principle, for which application ?

- Light Detection and Ranging
- Is a remote sensing method that uses light in the form of a pulsed laser to measure ranges between objects by looking at the reflected pulses with a sensor
- Controlling distance between vehicules

Q4.5: Draw the top view of a 2 x 2 Optical switch







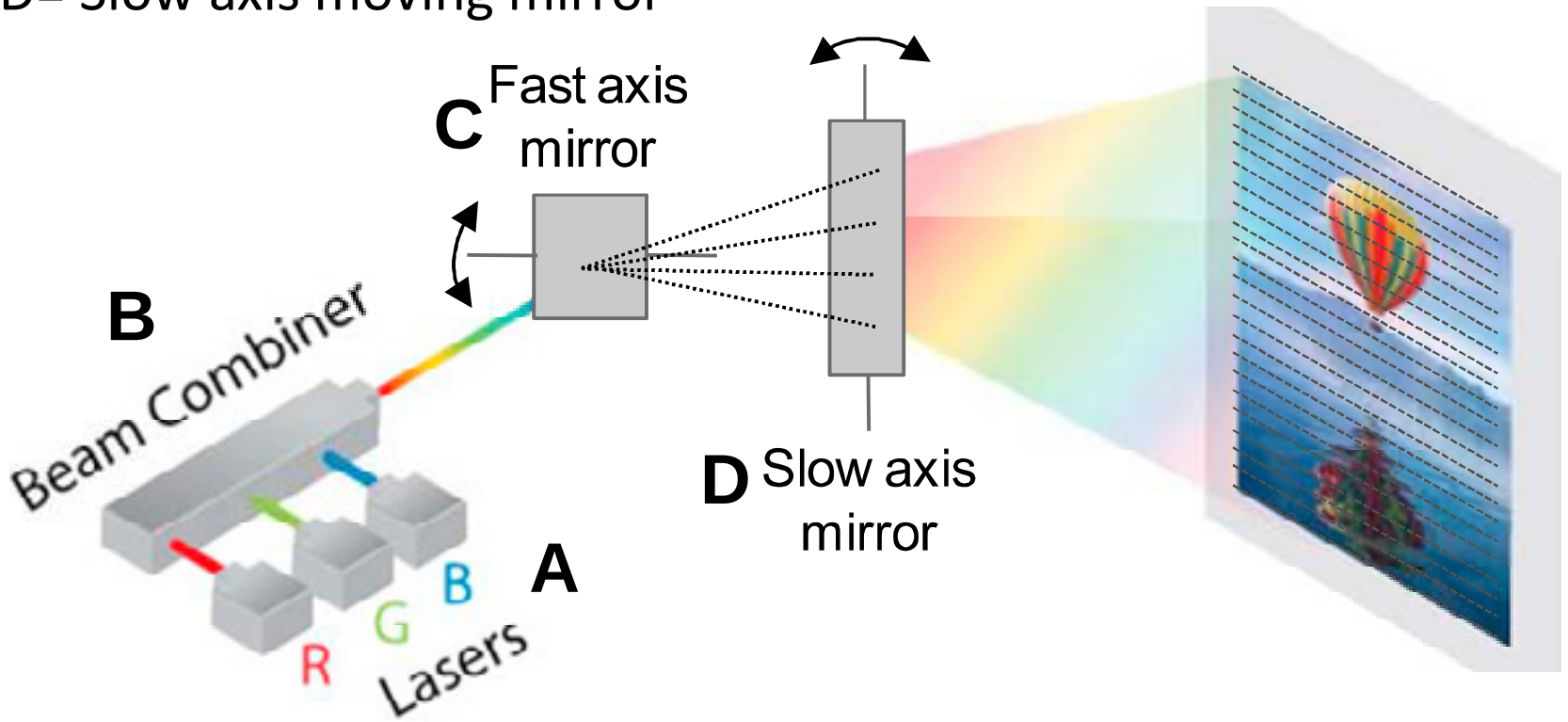
Q4.6: Complete with the name of the components missing

A= Laser red, green, blue

B= Beam combiner

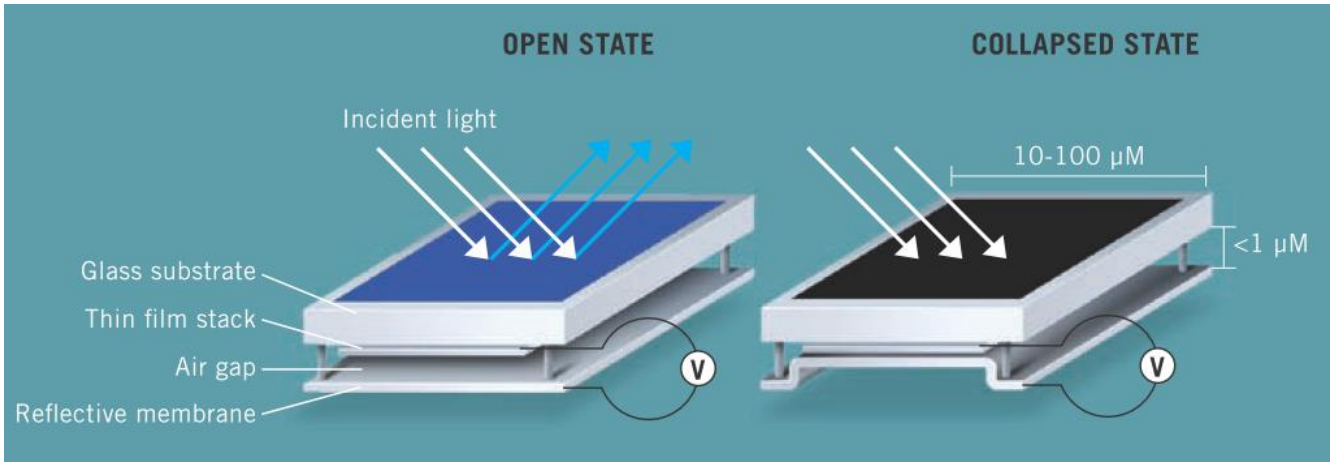
C= Fast axis moving mirror

D= Slow axis moving mirror



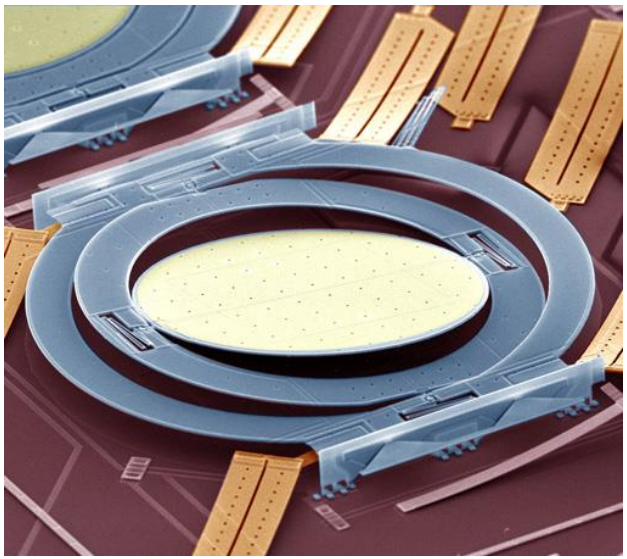
Q4.7: For what is used this Optical MEMS ?

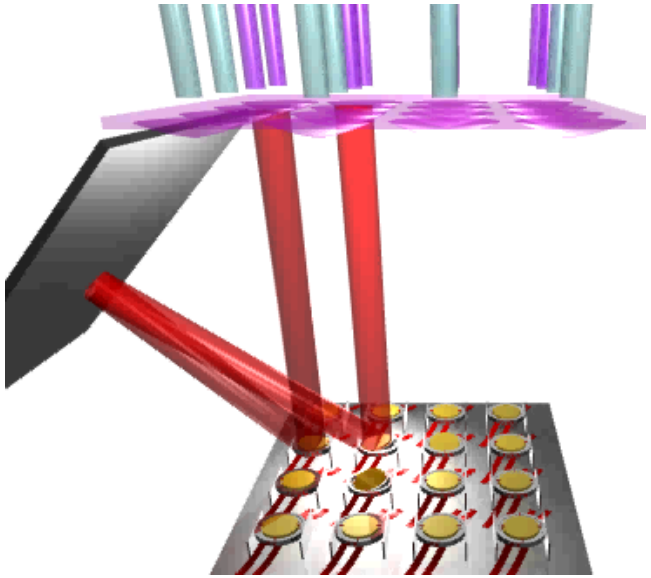
- As reflective display



Q4.8: For what is used this Optical MEMS ?

- As optical crossconnect





Beam scanning during connection setup.

substrate **lift arms** **mirror** **Frame, hinges, locks**

Gas sensors, PowerMEMS and Packaging

Q5.1: In a micro-hotplate structure, list two:

A. Materials used to make the membrane
B. Materials used to make the heater
C. Failure modes

A. Silicon nitride and silicon oxide

B. Pt, W, Mb, Poly-Si

C. Membrane breakdown, electro-migration

Q5.2: Name 3 types of sensing devices using heat generation in their sensing principle.

- Accelerometer
- Gas sensors (Infrared emitters)
- Flow sensors

Q5.3: What is the different between a thermal conductivity and a catalytic gas sensor ?

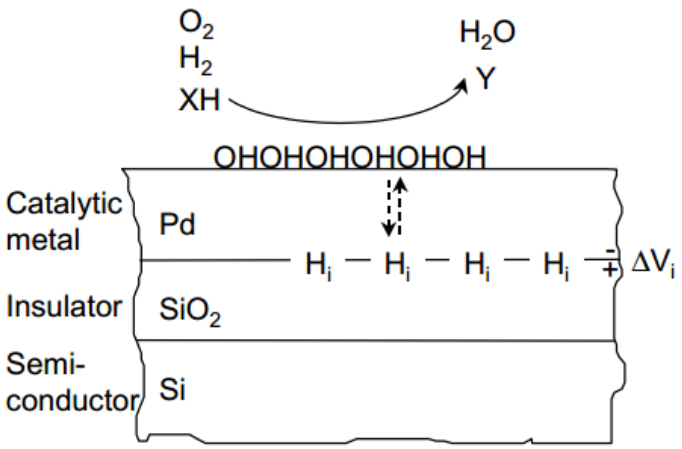
Thermal conductivity detector (TCD)

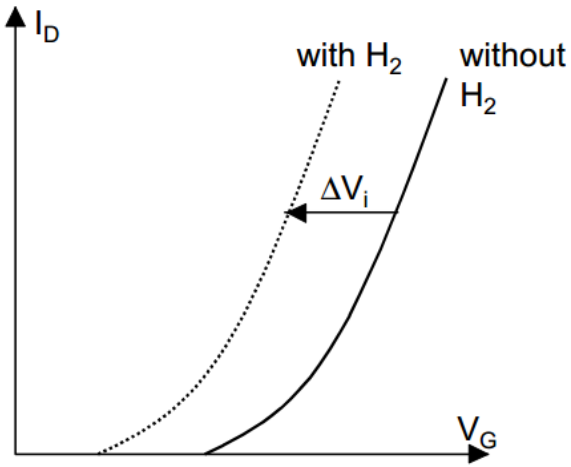
- This detector senses changes in the thermal conductivity of surrounding atmosphere. Operating principle is based on thermal flow transfer which is directly depending on the gas conductivity.

Catalytic sensor

- Measure heat involved/exchange during the chemical reaction / combustion of gases

Q5.4: Draw the Id-Vg curve for a gas sensitive field-effect transistor (GasFET) without and in presence of hydrogen.





Q5.5: Name the 3 converting principle used to harvest energy from mechanical vibrations.

Rank them from highest to lowest power density at the micro-scale.

1. Piezoelectric
2. Capacitive
3. Electromagnetic

Q5.6: For vibrations energy harvester, list 4 parameters influencing the amount of power harvested.

1. Acceleration amplitude
2. Frequency
3. Mass
4. Damping

$$\dot{W}_e(\omega_n) = \frac{m\zeta_e A^2}{4\omega_n \zeta_T^{\,2}}$$

Q5.7: Name 3 materials properties important to optimize the performance of thermoelectric generators.

- Seebeck coefficient
- Electrical conductivity
- Thermal conductivity

See figure of merit ZT

Q5.8: Which material is mainly used for thermoelectric generator working from ambient to ~ 100°C

Name two techniques used to deposit it.

- Bismuth Telluride
- Sputtering and electroplating

Q5.9: Name 4 bonding techniques suitable for hermetic packaging.

- Anodic bonding
- Thermocompression
- Eutectic bonding
- Soldering
- Glass frit

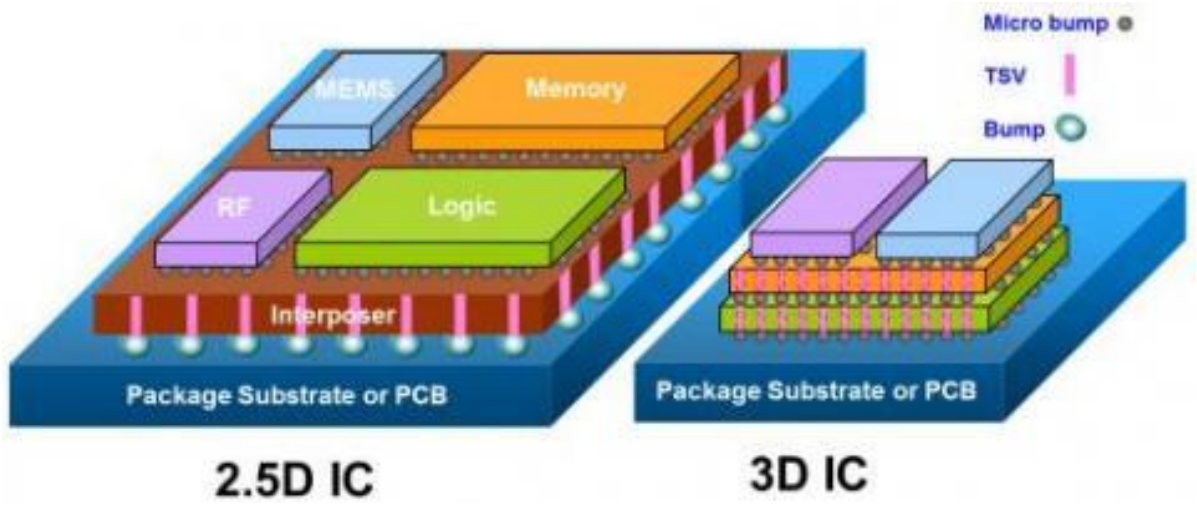
Q5.10: What is the typical range of working pressure for 1- accelerometer / 2- gyroscope

Accelerometer: 300-700 mbar

Gyroscope: 10^{-1} to 10^{-4} mbar

Q5.11: What is the different between 2.5D and 3D integration ?

2.5D: Interposer substrate with Through Silicon Vias which function is to make the electrical link between different functional components and/or PCB-package



3D: Through Silicon Vias (TSVs) made directly in the functional substrate(s)

Q5.12: Name 3 methods/materials used to make TSVs.

- Copper filling
- Poly-silicon filling
- Highly conductive silicon substrate