Advanced MEMS and MST

Questions list for the Oral Exam

(June-July 2025)

1. Describe the design (supported with some basic equations), operation and read-out of a surface micromachined capacitive and 1-axis MEMS accelerometer. What is changing in the design for a low and high sensitivity accelerometer ? How would you package such an accelerometer and what is the influence of the pressure inside on the frequency bandwidth of the accelerometer ? Provide the design for a 3-axis accelerometer. Explain how self-testing can be performed.

2. How does a MEMS capacitive accelerometer work ? What is the advantage of using the capacitive principle instead of the piezoresistive principle for an accelerometer? Describe the accelerometer implementation by SAFRAN-Colibrys, architecture, cross-section view with materials, signal read-out, advantages and drawbacks in comparison to a surface micromachined accelerometer.

3. Provide the relationships between the resistance variation and the materials properties of a silicon piezoresistive strain gauge used in a pressure sensor. Describe the design of a pressure sensor with the placement and orientation of the strain gauges. Give the electrical circuit used and relationship voltage vs variation of pressure. Give the difference between absolute and differential pressure sensors in terms of operation and packaging implementation. How important is the membrane thickness in a pressure sensor and how can one control this during microfabrication?

4. Explain the operating principle of a piezoresistor made of silicon with some equations to relate the change of resistance with the materials properties of silicon: gauge factor, strain applied, coefficient of piezoresistance, etc. Explain the difference in placement and signal in a longitudinal and transverse piezoresistor. Provide an example of implementation to realize a gas sensor array unit and its application: design, materials involved, placement of piezoresistors, read-out circuitry. What is the advantage to use such a configuration in comparison of using a standard silicone membrane from a pressure sensor ?

5. How does a MEMS gyroscope work ? Provide equation and schematic design of the MEMS device.
   How can you optimize the sensitivity ? How can be avoided the influence of the acceleration?
   How is it implemented in a 3-axis configuration ?
   What is the vacuum level required, how would you encapsulate it?
   Give some applications.

6. Compare the energy density vs scaling and operating characteristics of the following actuating principles: electrostatic and electromagnetic.
   Explain the operating principle supported by equations of a parallel plate electrostatic actuator.
   Describe the implementation and operation of such an actuator in a Digital light projection system. Explain how the actuator is driven and how the image is obtained.

7. Compare the characteristics of the following actuating principles: electrostatic, electromagnetic, piezoelectric, thermal.
   List the domains of application of Optical MEMS in relation to the optical spectral domain concerned.
   Describe one example and application of an Optical MEMS device working using the electrostatic principle.

8. Explain the operation principal of a parallel plate and comb drive electrostatic actuator with equations.
   How does a Zipping-actuator work ? Provide an example, design and operation, advantage of using such an actuator win an Optical MEMS system.

9. How does an electromagnetic actuator work? Provide an example, design and operation principle, of such and actuator implemented in a projector, using a single mirror and two mirrors. Explain how the actuator is driven and describe how to image is formed.

10. How does a MEMS-based microphone work? How is it fabricated? What is the typical transduction mechanism? How do you encapsulate a MEMS Microphone?) Does it change depending on the transduction chosen?

11. What is the difference between a microphone and a pressure sensor? Why? Which transduction mechanisms work for each type? (microphone and pressure sensor) Why do you need a scape valve in a microphone?

12. PMUTS: What is a PMUT? Design rules. Comparison between pmut and cmut. What is the interest of arraying? Give an application for PMUT array.

13. Resonators: What is the Quality factor of a resonator? Is it good to have it high or low? What causes that you have a high or low Q? Elaborate on the loss mechanisms.

14. Resonators: Can you enumerate the different types of MEMS resonators we discussed in class? Pick one type, formula for the resonance frequency, typical frequency range, typical applications, advantages and disadvantages.

15. Resonators: Why are RF-MEMS interesting as filters? Describe the receiver port of a phone and then describe how it would be different if we had an RF-filter. What is the FoM that is important for filters?

16. Resonators: Difference between resonator and oscillator. Oscillator applications. What is different between different applications? What is the FoM important for oscillators? Temperature stability in oscillators. Why is it important? How to compensate for this? (3 ways) – Compare. Why is phase noise important? Communications – receiver case. Leeson's formula – what about extra terms?

17. NEMS Case study 1 – DNA detection via surface stress – Describe the system, the experiment, the importance of a reference beam.

18. Design and fabrication of silicon micro-hotplates, materials, cross-section view, specific aspects to consider.
    What are the heat losses involved and how can they be minimized ?
    What factors can influence temperature distribution on heating area ? Which physical parameters are important to know for simulation ? What are the failure mechanisms ?
    Describe how to realize an IR emitter in terms of hotplate implementation and packaging.

19. Design of micro-hotplates for application as 1) Thermal flow sensor & 2) Accelerometer
    Specific hotplate design rules, thermal losses involved, materials & cross-section view.
    Describe the operation of these 2 devices: thermal flow sensor (with equations) and thermal accelerometer
    How would you package these sensing devices ?

20. Design of micro-hotplates for application as thermal conductivity and catalytic gas sensor.
    Specific hotplate design rules, thermal losses involved, materials & cross-section view.
    Describe the operation of a thermal conductivity gas sensor and of a catalytic gas sensor.
    Explain also how they are implemented and list the gases detected with this type of sensors.

21. Design of micro-hotplates for application as chemo-resistive (metal-oxide) gas sensor.
    Specific hotplate design rules, thermal losses involved, materials & cross-section view.
    Describe the operation of a metal-oxide gas sensors and draw a typical response curve and gases detected with this type of sensors. How can the sensitivity be improved ?
    How would you package such sensors ?

22. Give the advantage of optical gas sensors. Describe the non-dispersive optical gas sensor and photoacoustic gas sensor for CO_2 detection: operating principle and implementation, with architecture and components involved. Describe the design and operating principle of the MEMS components involved.

23. Describe the advantages to produce sensors using CMOS technology.
    Provide the design and operating principle of sensors produced using CMOS technology by Sensirion: 1) for the detection of humidity and 2) for the detection of volatile organic compounds.

24. List the roles of MEMS packaging and its differences in comparison with MEMS IC packaging. Die vs wafer level packaging and give their architectures. Provide some wafer bonding techniques to package MEMS with advantages and disadvantages. Vacuum requirements for different MEMS with an order of magnitude of pressure involved.
    How would you hermitically package a MEMS, materials and processes used. Gas sources and main contamination sources in hermetic packaging ? How can you measure the hermeticity of MEMS packages ?

25. Describe few wafer bonding techniques and their application in MEMS packaging.
    Comment on reliability and thermal issues in MEMS packaging ?
    Describe the characterization methods used to determine leakage rate in hermetic packaging. Describe the pressure evolution as a function of time and of the leak rate for a sealed cavity, and draw the curve ?
    How can you pass electrical feedthrough from inside to outside the MEMS packaged cavity ?
    Why 3D integration and advantages of using Through Silicon Vias (TSVs) and Through Glass Vias (TGVs), Explain the difference between 2.5D & 3D integration

26. Describe the design and operating principle of micromachined thermoelectric generators with some drawings. Provide information on the basic principle, efficiency, materials involved, configuration and optimization in relation to the figure of merit, challenges and advantages of miniaturization. Provide an electrical model and circuit for such generator and explain how to optimize the power output. Output power level generated. What is important to consider when packaging them ?

27. List and explain the different transducing principles to convert mechanical energy to electrical energy, with their advantages and drawbacks when implemented at the micro-scale. Rank them in terms of power density. What is the difference between a strain and inertial based mechanical energy harvesters ?
    What is the principle of operation of resonant type vibration energy harvester and how to optimize the power generation linked to the different parameters involved: mass, frequency, damping, etc ?
    Discuss the wideband vs. the narrow band operation, in relation to damping, the quality factor, and its packaging
    Show its implementation on silicon with a cross-section view including the different materials/layers involved.