Student Name: ID No.:

Birla Institute of Technology and Science (BITS) Pilani, Hyderabad Campus
Comprehensive Exam || Semester I, 2022-2023
Course: BITS F415 - Introduction to MEMS
Date of examination: December 31, 2022

Total marks:120 *Total Time: 3 Hours*

- Part A: Objective – 10 Marks (Max. time: 30 Minutes) **(Collected Separately)**
- Part B1: Subjective – 40 Marks and Research Article – 30 Marks **(Collected Separately)**
- Part B2: Subjective – 40 Marks **(Collected Separately)**
- Read the instructions carefully and answer all parts of a question together.
- Allowed: Only hand-written notes, textbooks, and reference books are allowed.
- Not Allowed: Printouts (including printouts of lecture ppts), loose sheets, hand-written notes on printouts (lecture ppts), photocopies of hand-written notes, electronic devices
- Be brief and to the point. Being an open-book exam, no marks will be awarded for vague and copied answers.

Part A: Objective - 10 Marks (Max. Time: 30 minutes)

1. Laser-Induced Graphene fabricated under different environments via CO_2 laser affects the surface wetting properties. (True/False)
2. Thyristors and Transistors belong to passive components of electronic devices (True/False)
3. TEM sample preparation requires 1 mm thick samples for analysis (True / False)
4. Conventional Photolithography is limited by _____ of Light.
5. SLA printing works with Thermoplastic materials, and FDM printing works with Thermosetting plastics – True/False)
6. Capillary rise according to lumped model
    a. Proportional to the square root of time for a small time scale
    b. Proportional to the square of time for a small time scale
    c. Inversely proportional to time for a small time scale
    d. None of the above
7. If centrifugal force scales to L^4, what is the scale of time
    a. Scales to L
    b. Independent of length scale
    c. Scales to L^3
    d. Scales to L^3
8. _____ process can produce silicon wafers with more purity than other processes?
9. _____ equipment is used to study the depth or surface profile of the resist layer.
10. Choose the correct statement about pressure-driven flow in the microchannel
    a. Flow can be considered fully developed
    b. Fully developed flow is non-accelerating, or core velocity does not change
    c. Piezometric head varies linearly
    d. All the above

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Part B 1: Subjective – 70 Marks

1. (a) MMNE lab has developed a new dry film photoresist, MMNE-US-8. Each layer of dry film photoresist is 20 μm thick. The energy density required for photoresist curing is 100 mJ / (cm^2.μm). A 405 nm UV exposure unit with a power density of 1000 W/m^2 is used to cure MEMS-US-8. For complete development, calculate the exposure time that will be required for 3 layered photoresists. (5 Marks)
   (b) Describe schematically the construction of the Direct Laser Writing System (DLW)? Explain the importance of "Focus Offset" on the channel line width. (5 Marks)

2. (a) Explain the advantages of paper-based wax-coated MEMS/Microfluidics devices compared to photoresist-based devices. (2 Marks)
   (b) Explain the working principle involved in Additive Manufacturing with its advantages over conventional manufacturing. Is SLA printing prominent over FDM printing in fabricating Microfluidic chips? If Yes or No, explain the reason with schematics. (5 Marks)
   (c) Explain the pros vs. limitations of paper-based, 3D printed, and PDMS MEMS devices, respectively. (3 Marks)

3. (a) State the working principle of UV Visible Spectroscopy (UV-Vis) and its basic components. Justify whether UV-Vis is used as a qualitative or quantitative tool with valid reason and a real-time example. (5 Marks)
   (b) Why does vacuum conditions needed during SEM analysis and explain the different types of scatterings? Explain the sample preparations in the case of SEM, UV-Vis, and XRD techniques (5 Marks).

4. (a) To characterize the surface topography by contact, which technique will be leveraged. Explain the technique in detail, along with the working principle. Also, explain the drawbacks of the contact-based characterization technique. (5 Marks)
   (b) Differentiate between scanning tunnelling electron microscopy and optical microscopy regarding working principles and applications. Provide proper schematics (5 Marks)

5. Please answer the following questions via your observations and inferences based on the work "Wafer-Level Patterning of SnO_2 Nanosheets for MEMS Gas Sensors". No marks will be awarded for copying the contents of the paper verbatim. Please write your inferences with suitable illustrations. (5 * 6 = 30 Marks)
   a. Brief the complete fabrication procedure with dimensional information's provided in the paper.
   b. Explain the importance of nanomaterials in gas sensing and what are the possible ways to make a stable suspension of nanomaterials.
   c. Explain the procedure of Hydrothermal synthesis and the role of spin coating.
   d. Interpret the results and provide crisp scientific details. What do you observe from the SEM image at different resolutions?
   e. What do you understand by selectivity, sensitivity, and repeatability? Interpret the gas sensing results and provide your comments.

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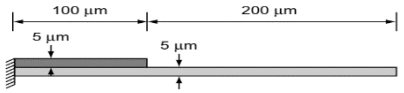
Part B 2: Subjective – 40 Marks

1. (a) What is Bimorph Effect? Discuss the applications and drawbacks of this effect in the MEMS perspectives. (5 Marks)
   (b) Figure shows a spring steel cantilever beam (Young's modulus = 210 GPa) over which there is a piezo patch (Young's modulus = 300 GPa). The lengths of the beam and the piezo patch are shown in the figure. The in-plane width (25 μm) and out-of-plane thickness (5 μm) of the beam and piezo patch are the same. If the piezo patch contracts axially by 1%, compute the deflection of the free tip of the spring steel beam in the axial and transverse directions. (5 Marks)



2. (a) To a cantilever beamed MEMS structure, derive an expression for stiffness F (in y direction) load at free end pointed downwards. (3 Marks)
   (b) A research lab tried to make a 314 μm long cantilever beam with diamond-like-carbon (DLC) thin-film technology. The beam had a rectangular cross-section with 15 μm in-plane width and 5 μm out-of-plane thickness. In its released condition, it was noticed that it had curled into a semi-circular form. The Young's modulus and Poisson's ratio of DLC were measured to be 100 GPa and 0.3, respectively. (a) What is the residual stress gradient that caused this curling? (b) What is the anticlastic curvature along the in-plane width direction? Draw that shape. (7 Marks)

3. (a) Differentiate between Electrophoresis and Electro osmosis through suitable examples and applications. (4 Marks)
   (b) Consider a 3 mm thick and 3 mm radius glass frit disc of 1 μm pore size having tortuosity and porosity of 1.4 and 0.3, respectively, is used to develop a multichannel water EOS pump. The permittivity of water is 80 times the ε_0 (ε_0 = 8.8541×10-12 Fm-1) considering the zeta potential of 90 mV for glass and water combination. For an applied voltage of -10 V, calculate the maximum flow rate and maximum pressure drop. (6 Marks)

4. (a) Start with the general transport equation and write the momentum and mass conservation equation. (5 Marks)
   (b) Consider following Poisson–Boltzmann equation and boundary conditions. Apply Debye Huckel Linearization and derive an expression to find EDL thickness (λ) and voltage distribution ϕ (5 Marks)
   Boundary conditions:

$$\frac{d^2\phi}{dz^2} = \frac{2C_0ZF}{\varepsilon}\sinh\left(\frac{Ze\phi}{k_BT}\right) \qquad y = 0; \phi = \zeta$$
$$z \to \infty; \phi = 0$$