**Fabrication of a Micromachined Silicon Structure**

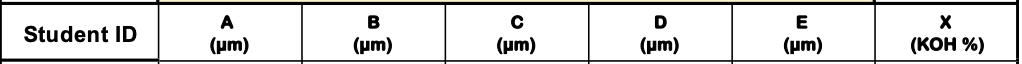
**PART A)**

The aim of the exercise is to predict the etching characteristics of a MEMS structure (shown in Figure 1) and to design a suitable fabrication process.

A diagram of a diagram

Description automatically generated

Figure 2 shows the design parameters to be used in this exercise:



features a heavily doped p+ region, indicated in grey, **the depth of this p+ layer is 1.2μm**

The substrate is oriented along the (100) crystal plane with pattern edges aligned in the [110] direction. The MEMS structure is to be etched using a KOH solution at 70 °C temperature.

**PART B)**

**The etch rate at 70 degrees Celsius and 42% KOH solution can be extrapolated from the graph:**

**A graph with a line

Description automatically generated**

**Extrapolating to the y-axis, we can see the etch rate of the silicon is roughly 33 microns per hour.**

**Now, we know that the Boron concentration in the heavily doped regions is 10^20 cm^-3, we can determine the relative etch rate of Boron from the below graph:**

**A graph with different colored lines

Description automatically generated**

**It can be seen that the relative etch rate is approximately 10^-1. This means the etch rate is 10 times slower in the Boron than it is in the Silicon. This implies then that the etch rate in the Boron layer is the etch rate of silicon, divided by 10:**

**We know that the etch rate in silicon for 42% KOH solution is 33 microns per hour, and thus the etch rate for Boron in 42% KOH solution is 3.3 microns per hour. Dividing this by 60 will give us the etch rate per minute, which means:**

**After 20 minutes of etching in the KOH solution, we can say that 1.1 micro-meters of Boron is etched, while 11 micro-meters of the Silicon is etched. The cross-section diagram would look as follows:**

1.1μm

P+

P+

P+

0.1μm

11μm

9.8μm

Lightly Doped Silicon

**The Etch rate of Boron per minute is 0.055 μm / min. Thus, the entire Boron layer is etched after :**

**This still leaves 158 minutes of etching in the lightly doped Silicon region, where the etch rate is 0.55 μm / min. This means 86.9 μm of Silicon will be etched after the Boron is depleted. The new cross-sectional diagram after 3 hours is:**

165 μm

520 μm

P+

P+

P+

54.7 °

54.7 °

54.7 °

54.7 °

86.9μm

300 μm

99μm

397 μm

23 μm

61.5 μm

61.5 μm

71 μm

71 μm

**The dimensions of the above figure were calculated from the values of A, B, C, D and E given and knowledge that anisotropic at the (111) to (110) plane occurs at 54.7 degrees. Thus the horizontal distance from the start of the Silicon Nitride to the corner were the etching has stopped is given by:**

**Adding in the values for the two etched regions we get:**

**And**

**Giving values of x to be 61.5 and 71 respectively. The distance then between corners can be derived from the original values given:**

**Giving values of 397 and 23 as seen in the cross-section diagram.**

**PART C)**

**1 – Substrate preparation**

**Before the process is started, it is crucial that the substrate is cleaned such that the subsequent fabrication steps are not affected. This step aims to remove any contaminants from the silicon wafer [1].**

**2- Boron Doping**

**To create heavily boron-doped regions, which are critical for defining the electrical and structural properties of the MEMs device, Boron implantation would be employed. This involves implanting Boron ions into the silicon substrate to achieve the desired doping concentration. After implantation, thermal annealing will be performed to activate the dopants and repair the lattice damage caused by the ion implantation process. [1]**

**3. Silicon Nitride Deposition**

**The silicon Nitride layer acts as a mask during KOH etching process and provides mechanical stability to the structure. Plasma-enhanced chemical vapour deposition (PECVD) can be used for depositing silicon nitride films due to its ability to deposit uniform films at relatively low temperatures, which is crucial for maintaining the integrity of the underlying silicon and doped layers.**

**4 – Patterning and etching**

**The next step involves patterning the silicon nitride layer to expose areas of the silicon substrate that will be etched away. This is achieved using photolithography, where a light sensitive chemical (photoresist) is applied to the surface, exposed to light through a mask defining the structure, and then developed to remove either the exposed or unexposed regions, depending on the type of photoresist used. Following patterning, reactive ion etching (RIE) or deep reactive ion etching (DRIE) can be used to etch the silicon where needed, based on the pattern defined by the silicon nitride mask.**

**5- Critical Analysis**

**Factors such as the uniformity of the boron doping and silicon nitride deposition, the resolution and accuracy of the photolithography step, and the etch rate consistency during the KOH etching process.**

**PART D)**

**KOH Etching Process Instruction Manual**

**Overview**

This manual provides a comprehensive guide to the KOH etching process, used to shape silicon-based MEMS structures. Potassium Hydroxide (KOH) etching is a popular anisotropic wet chemical etching method, offering precise control over the etch rate and directionality, critical for MEMS device fabrication.

**Required Apparatus and Materials**

- KOH pellets (potassium hydroxide)

- DI water (deionized water) for solution preparation

- Silicon wafer with patterned silicon nitride mask

- Etching tank (Teflon or polypropylene)

- Hotplate or water bath capable of maintaining 70°C

- Thermometer or thermocouple

- Protective equipment: gloves, goggles, lab coat

- Nitrogen gun or air gun for drying

- pH meter (optional, for concentration verification)

**Precautions**

- KOH is a strong base that can cause severe burns. Use appropriate personal protective equipment (PPE) including gloves and goggles.

- Work in a well-ventilated area or fume hood to avoid inhalation of fumes.

- Handle silicon wafers with care to prevent breakage or contamination.

**Procedure**

**1. Solution Preparation**

- Dissolve KOH pellets in DI water to achieve the desired concentration. Common concentrations range from 20% to 30% by weight.

- Heat the solution to 70°C on a hotplate or in a water bath, ensuring the temperature is stable before proceeding.

**2. Substrate Preparation**

- Clean the silicon wafer to remove any contaminants. A standard RCA clean can be used, followed by a rinse in DI water and drying with a nitrogen gun.

**3. Etching**

- Place the silicon wafer into the etching tank containing the preheated KOH solution.

- Maintain the solution at 70°C throughout the etching process. Monitor the etch progress periodically by removing the wafer, rinsing, and inspecting.

- Etching time will depend on the desired depth and the etch rate, which should be determined from preliminary experiments or literature.

**4. Post-Etching Processing**

- Upon reaching the desired etch depth, remove the wafer from the KOH solution and rinse thoroughly with DI water.

- Neutralize the wafer surface by dipping in a dilute HCl solution or a neutralizer specific to KOH.

- Dry the wafer using a nitrogen gun or air gun.

**5. Inspection and Analysis**

- Inspect the etched structures under a microscope for depth uniformity and pattern fidelity.

- Measure the etched features using profilometry or SEM (Scanning Electron Microscopy) for precise depth and dimension analysis.

**Tips and Troubleshooting**

- \*\*Etch Rate Control\*\*: The etch rate can be influenced by KOH concentration, temperature, and doping concentration. Adjust these parameters to fine-tune the etch depth and profile.

- \*\*Undercutting\*\*: Minimize undercutting beneath the mask by optimizing the etch time and monitoring the etch progress closely.

- \*\*Uniformity\*\*: Stirring the KOH solution can help achieve more uniform etching across the wafer.

**Disposal**

- Neutralize the used KOH solution with an acid (e.g., HCl) until the pH is neutral (pH 7) before disposal. Follow local regulations for disposal of chemical waste.

**Conclusion**

KOH etching is a critical step in the fabrication of MEMS devices, allowing for the precise sculpting of silicon substrates. By following these instructions, users can achieve consistent and accurate etching results, essential for the successful manufacture of MEMS structures.**References**

**[1]** Han, X., Huang, M., Wu, Z. *et al.* Advances in high-performance MEMS pressure sensors: design, fabrication, and packaging. *Microsyst Nanoeng* **9**, 156 (2023). <https://doi.org/10.1038/s41378-023-00620-1>

**Appendix**

**A graph with a line

Description automatically generated**

**A graph with different colored lines

Description automatically generated**