**Fabrication of a Micromachined Silicon Structure**

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# **Introduction**

The advent of Microelectromechanical Systems (MEMS) has marked a significant milestone in the miniaturization and integration of mechanical and electrical components. At the heart of MEMS technology lies the intricate process of fabricating micromachined structures, which requires precise control over material properties and etching techniques. This report delves into the detailed methodologies employed in the creation of MEMS devices, with a particular focus on the use of Potassium Hydroxide (KOH) for silicon etching.

Silicon, owing to its excellent mechanical and electrical properties, has become the substrate of choice in the majority of MEMS applications. The fabrication process of a MEMS device is a complex, multi-step endeavour that involves layer deposition, patterning, and etching to create the desired microstructures. One of the critical steps in this process is the etching of silicon, which defines the three-dimensional aspects of the device. KOH etching, a widely used anisotropic wet etching technique, plays a pivotal role in shaping the silicon substrate into precise geometrical structures. This report meticulously analyses the calculation of the etching profile after KOH etching, providing insights into the factors that influence the final geometry of the silicon structures, such as etchant concentration, temperature, and etching time.

Prior to delving into the specifics of KOH etching, this report presents a comprehensive overview of the fabrication process for the MEMS device. This includes the selection of materials, deposition techniques, and the photolithographic process required to prepare the silicon substrate for etching. The sequence of these fabrication steps is crucial for achieving the desired quality and functionality of the final MEMS device.

Furthermore, recognizing the importance of knowledge dissemination in advancing MEMS technology, this report includes an instruction manual on the design of the MEMS device. This manual is intended to serve as a practical guide for researchers and engineers involved in MEMS fabrication, offering step-by-step instructions on design considerations, material selection, and process parameters.

# **Methodology**

## **Design Parameters**

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.

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

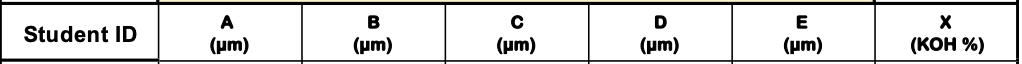


Table 1 Unique Design Parameters

The structure 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.

## **Etch Rate**

The etch rate at 70 degrees Celsius and 42% KOH solution can be extrapolated from the graph in **figure 2**:

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**Figure 2 Etch rate of silicon in KOH solution with temperature.**

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 , we can determine the relative etch rate of Boron from figure 3:

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Figure 3 Relative Etch rate of Boron with Boron concentration.

It can be seen that the relative etch rate is approximately . 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:

(1)

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 μm and 71μm respectively. The distance then between corners can be derived from the original values given:

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

## **Fabrication Process**

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].

1. **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]

1. **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.

1. **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.

1. **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.

## **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.

# **Conclusion**

The exploration and elaboration presented in this report underscore the pivotal role of KOH etching in the realm of Microelectromechanical Systems (MEMS) fabrication, shedding light on the meticulous procedures and considerations imperative for the creation of precise and functional micromachined silicon structures. Through a detailed examination of the etching profile after KOH etching and a comprehensive delineation of the fabrication steps preceding the etching process, this report has furnished critical insights into the nuanced interplay between material properties, etching parameters, and device design that dictates the successful realization of MEMS devices.

A cornerstone of this discourse has been the analytical prediction of etching characteristics of MEMS structures, underscored by a rigorous investigation into the influence of KOH concentration, temperature, and the presence of heavily doped regions on the etching dynamics. The findings illuminate the nuanced control required over etching conditions to achieve the desired geometric and material properties, a testament to the complexity and precision inherent in MEMS fabrication.

The procedural narrative of fabricating a MEMS device, from substrate preparation through to the final etching in a KOH solution, encapsulates the multifaceted and layered nature of MEMS manufacturing. This journey through the fabrication process not only highlights the critical role of each step in shaping the final device but also underscores the importance of meticulous planning and execution in achieving the desired device characteristics and functionality.

In conclusion, this report has traversed the intricate landscape of MEMS fabrication, with a special focus on the role of KOH etching in sculpting the microcosmic terrains of silicon that form the backbone of MEMS devices. It has illuminated the critical considerations, challenges, and methodologies that underpin this fascinating field, offering a comprehensive resource for those engaged in the pursuit of advancing MEMS technology. As we stand on the precipice of new discoveries and innovations in MEMS fabrication, this report not only chronicles current knowledge and practices but also invites continued exploration and refinement in the fabrication of micromachined silicon structures, promising to propel the field into new realms of possibility and application.

# **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**

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