

EE 245 Introduction to MEMS Fabrication and Design

Homework 1 Solutions

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2. Information on important MEMS conferences:

- International Conference on Solid State Sensors and Actuators (Transducers)
 - Held every 2 years, last one in Boston, MA, next one in Seoul, Korea
- Solid State Sensor and Actuator Workshop (Hilton Head)
 - Held every 2 years, always in Hilton Head, SC.
- MicroElectroMechanical Systems Workshop (MEMS)
 - Held every year, last one in Kyoto, Japan, next one in Maastricht, Netherlands
- MicroTotalAnalysis Systems (microTAS)
 - Held every year, last one in Nara, Japan, next one in Squaw Valley, CA.

3. The angles between the {110} and {111} families of planes can be found using the following formula, where **a** and **b** are the Miller indices of the planes:

$$|\mathbf{a}| |\mathbf{b}| \cos \theta = \mathbf{a} \cdot \mathbf{b}$$

$$\{110\} = (110), (101), (011), (-110), (1-10), (-101), (10-1), (0-11), (01-1), (-1-10), -10-1), (0-1-1)$$

$$\{111\} = (111), (-111), (1-11), (11-1), (-1-11), (-11-1), (1-1-1), (-1-1-1)$$

For all of the combinations of these planes, you get:

$$\begin{aligned} \cos \theta &= 2/\sqrt{6} = 0.8165 \\ &= -2/\sqrt{6} = -0.8165, \text{ or} \\ &= 0. \end{aligned}$$

Using \cos^{-1} , the angles between the planes are 35.26, 144.74, and 90°.

4. For a given etch time, the KOH etch rate for {100} planes is 400 times faster than for {111} planes. Therefore, from the top of the mask opening (which is exposed for the full time to the etchant), {100} etching proceeds down to a depth d , while etching of the (111) plane proceeds a distance of $d/400$ perpendicular to the (111) plane.

Using trigonometry, the length of the perfect (111) side, s , can be derived from:

$$\begin{aligned} \sin 54.74 &= d/s \\ s &= 1.225 d \end{aligned}$$

Then, β can be determined:

$$\begin{aligned} \tan \beta &= (d/400)/s \\ \tan \beta &= (d/400)/1.225d \end{aligned}$$

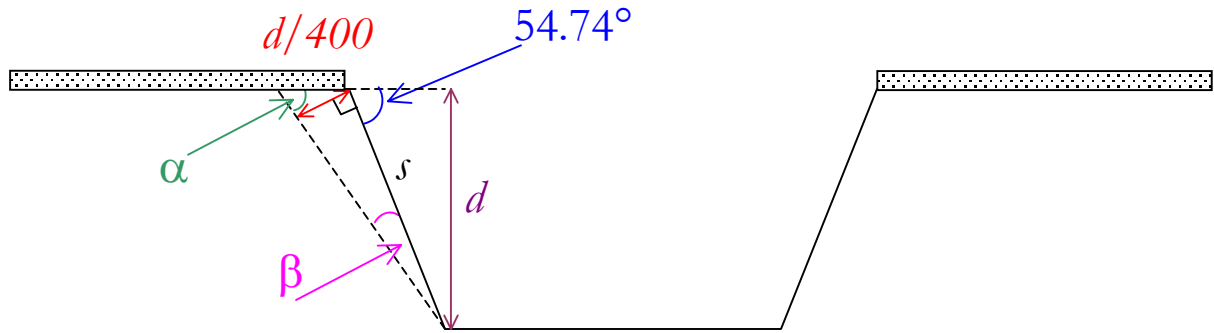
$$\beta = 0.1170^\circ$$

Finding α by adding up the angles of the triangle:

$$\alpha + \beta + (180 - 54.74) = 180^\circ$$

$$\alpha = 54.62^\circ$$

(Therefore you can figure out how much the masking layer will be undercut.)



b. To find the etch ratio, $x : 1$, needed to make 45° sidewalls, replace $d/400$ by d/x , and set $\alpha = 45$. Find β :

$$\beta + \alpha + (180 - 54.74) = 180$$

$$\beta + 45 + (180 - 54.74) = 180$$

$$\beta = 9.74^\circ$$

Then, to find x :

$$\tan \beta = (d/x)/s$$

$$\tan \beta = (d/x)/1.225 d$$

$$x = 4.756$$

Therefore the etch ratio is $4.756 : 1$, or $1 : 0.2103$.

5. a) The scalloped topography of the DRIE etched sidewalls is due to the alternating etching and deposition cycles of the Bosch process. During the etch step, reactive ions etch the trench in a vertical fashion, with some neutral species etching the trench isotropically. In the deposition step, the walls are uniformly coated with a protective Teflon-like layer. During the next etch step, this coating is removed at the bottom of the trench due to the directionality of the etching ions. The bottom of the trench is then etched, and the cycle continues.

b) The nonuniformity of the etch depths is a result of their different widths. The etch rate of the DRIE process is diffusion-limited, so that transport of the etchant into (as well as etch products out of) the narrow trenches is slower. Therefore, the etch rate slows down for smaller trench widths.