Simulation of MEMS device undercut using KOH and Bosch process on Silicon substrate

Mohammad J. Bereyhi[1]

[1] *Swiss Federal Institute of Technology Lausanne (EPFL)*

Here I explain the KOH simulator software (ACES) from U of Chicago for a chain process of DRIE followed by KOH undercut. This software is very simple yet power to understand how Si etching works and design the mask to optimize the etch speed and crystal planes.

Keywords: KOH; Wet etching; Bosch process; MEMS

ACES is a program under JAVA that allows us to define isotropic and anisotropic etching of silicon or other crystalline materials (https://cleanroom.byu.edu/koh). There are several features available in this simple application: custom etch rates, loading of masks in GDS or BMP image format, cascade processing.

In order to start we choose the wafer crystal plane orientations: $\langle 100 \rangle$ face and $\langle 110 \rangle$ flat edge (this is the case for a standard Si wafer). Mask file is either sketched or loaded from a GDS file (or snap shot from GDS saved in BMP format - recommended since it is faster to import and lower chance of crashing the software since it is very old and not optimized for large files). Mask can be either positive or negative or even flipped in the software. Under the "Etchant" bar you can add the desired process. Here two are explained that are widely used for undercutting of long nanobeam structures. (1) DRIE: $3\mu m$/min in $\langle 100 \rangle$ direction and zero in other orientations to represent the DRIE Bosch process and (2) KOH 40% - 52 degrees: $12\mu m$/min in $\langle 100$ direction and 1/100 times slower in $\langle 111 \rangle$ direction. Etching can be performed now given the time used in the timing window. After the etching is finished we can look at the results and judge the etching time. In case addition in timing is needed, the "chain Process" should be used to add this extra step to the previous results and cascade the processes. For the chain process another mask can also be used also another recipe.

Here we give an example of a DRIE process followed by a KOH release wet etching step: (1) Selecting the DRIE mask (we first etch deep into Si using Bosch process and then use the top Si_3N_4 as a mask to do the KOH undercut). This step is shown in Fig. 1A panel (1). For DRIE we assume an ideal anisotropic etch into the Si wafer: DRIE for $21\mu m$ (7 min) - shows the DRIE etch profile which is ideally vertical. Now we perform the wet etching for the Si_3N_4 mask (nanobeams). We etch in the chain mode in steps to know how it proceeds: The pillars are etched but under the beams there is still Si (purple), and now is the time that it is going to finish fast since it is attacked from the corners that are formed underneath (Fig. 1A(2)). The structure is fully released after adding 5 more minutes of KOH etch (Fig. 1A(3)). Zooming to the clamping region shows that the clamps are intact and the beam is released.

Fig. 1B shows a SEM micrograph of a nanobeam device that is in step (2) of the simulation. The accuracy of the simulator is evident from the key points shown in the SEM: the left over Si under the nanobeam section and also the Si pyramids that are formed by corner attacks of the DRIE recess structure. Here it is clear how the etching proceeds in our suspension technique. First, the pedistles are etched from the side and the slow etching planes of Si meeting under the Si_3N_4 nanobeam and on the bottom substrate. Then the Si under the nanobeamgets attacked from underneath, where there are corners formed from the meeting point of the slow etching planes.

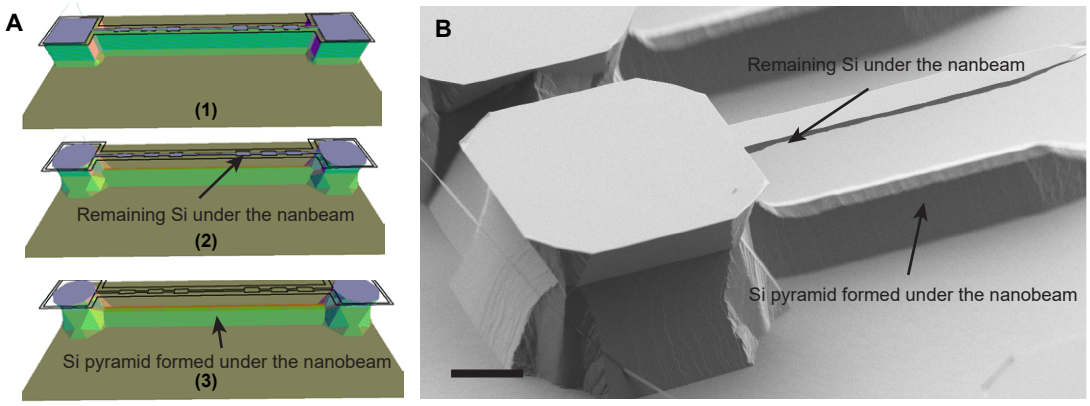

FIG. 1. **Simulation of undercut process using ACES software.** (A) From 1 to 3 shows the simulation result for DRIE recess, KOH undercut (mid process) and longer KOH etch when all the Si is etched. In step (2) we can see how the etch is proceesing in during the wet etch process and the Si under the nanobeam is the last part to be etched. The purple shade in the simulation results show the remaining Si and the mask is shown using black lines. (B) SEM image of a test sample before full undercut corresponding to step (2) on the simulation result in (A) showing the leftover Si unde the beam and also the pyramid formed under the nanobeams.