EE 147/247A Prof. Pister
Fall 2021

Homework Assignment #6 Rubric

[50 points total]

1. [6 points] In Go & Pohlman (reference [Go10]), they plot measured breakdown voltage vs. electrode gap for many different MEMS structures. The data are taken from many different research papers. As they write, "Fig. 3 highlights the complexity of breakdown at the microscale, where general trends are common but quantitative data are heavily dependent on the electrode geometry, material, and surface roughness."
   a. [2 points] In Figure 3, given all of the different data sets, what is the largest safe voltage (no breakdown in any data set) with a 5um gap? With a 1um gap?

      1 point for answer between 100 and 150V

      1 point for an answer between 5 and 30V

   b. [2 points] In Figure 4c, the data sets from references 19 and 24 are for silicon-silicon gaps, which generally have higher breakdown voltages than metal-metal or silicon-metal gaps. For those two data sets, what is the largest safe voltage with a 5um gap? With a 1um gap?

      The largest safe voltage with a 5µm gap is about 300V.

      1 point for approximately right answer

      The largest safe voltage with a 1µm gap is the point between 410V-630V, so about 500V. If you used the same answer for the 5um gap (you assumed there will be a 5um path somewhere), you can give yourself fullcredit.

      1 point for approximately right answer

   c. [2 points] From Figure 4c, make a table for the data from reference 19, with a column for the gap, the breakdown voltage, and an estimate the electric field at which the devices broke down.

Gap [m]	$V_{breakdown}$ [V]	E-field [V/m]
5.00E-07	640	1.28E+09
2.00E-06	410	2.05E+08
2.50E-06	390	1.56E+08
4.00E-06	340	8.50E+07
5.50E-06	310	5.64E+07
6.50E-06	340	5.23E+07
7.00E-06	330	4.71E+07

1 point for effort

1 point for approximately right answer

2. [5 points] In reference [Chu97],
   a. [2 points] What is the approximate average vertical etch rate in microns/minute of bulk silicon in XeF_2 (see Figure 5) in the first 15 seconds? In the first 360 seconds? You can use any size aperture you like.

      1 pt. for each etch rate (2 pts. total)

      First 15 seconds: 40um/min

      First 360 seconds for 3x3 aperture: 3.33um/min

b. [3 points] In figure 8, which structures etched fastest in the first two pulses, the 50um, 200um, or 800um square openings? What about after 12 pulses? What might account for the difference, and the shape of the etch front of the 800um aperture after 12 pulses?

1 pt. for each aperture, 1 pt. for any explanation attempt for the 800um aperture - we actually don't know.

After 2 pulses: 50um opening
After 12 pulses: 200um opening

3. [2 points] In reference [Hamzah12],
    a. From Figure 1, estimate the etch rate of a mixture of equal parts of 49% HF, 69% nitric, and acetic acids.

[1 point] A mixture of equal parts would be 33% of each acid. Drawing lines from the 33% mark of each acid's axis lands on the 51um/min etch rate contour line.

    b. In Figure 13, estimate the radius of curvature at the tip

[1 point] The radius of the tip looks to be about 200nm

4. [6 points] In reference [Brockmeier12],
    a. In figure 5, cross-sections AA and BB are on the wafer with the standard CMOS orientation and flat. Other than ~54 degrees, what other sidewall angles are possible, what combination of mask layout and processing is necessary to get them, and what crystal planes define them?

1 pt for each sidewall angle, 1 points forr naming each sidewall plane, and 1 for the conditions of each sidewall.

45 degree and 90 degree sidewalls are possible with a square mask oriented 45 degrees with respect to the wafer flat. The 45 degree sidewalls are formed between {100} planes and using high KOH concentration and the 90 degree sidewalls are formed between {100} and {110} and using low KOH concentration. Note that these etches will terminate on {111} planes if allowed to continue.

5. Coventor problem [31 points for completing the tutorial] It's ok if your simulation is slightly different.
    a. 5 points for picture of model
    b. 5 points for screenshot of resulting stress
    c. 5 points for Wheatstone bridge output voltage
    d. 6 points for voltage vs pressure plot
    e. 10 points for stressed plot for R1 and R2

[Go10] Go, Pohlman, "A mathematical model of the modified Paschen's curve for breakdown in microscale gaps", J. Applied Physics, 2010.

[Chu97] Chu et al., "Controlled Pulse Etching with Xenon Difluoride", Transducers 97, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=613739

[Hamzah12] Hamzah et al. "Optimization of HNA Etching Parameters to Produce High Aspect Ratio Solid Silicon Microneedles" J. Micromechanics and Microengineering, 2012 http://iopscience.iop.org/0960-1317/22/9/095017/pdf/0960-1317_22_9_095017.pdf

[Brockmeier12] Brockmeier et al. "Surface tension and its role for vertical wet etching of silicon", J. Micromechanics and Microengineering, 2012 http://iopscience.iop.org/0960-1317/22/12/125012/pdf/0960-1317_22_12_125012.pdf