Bulk Silicon Carbide Etching in PT-MTL

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0. ABSTRACT

The Plasmatherm Metal (PT-MTL) tool was used for bulk etching of Silicon Carbide. Our recipe involves an SF_6 & O_2 chemistry and a hard nickel mask. Various dry etch parameters were varied to characterize etch rates and selectivity. Potential applications include creation of microchannels for cooling of high power devices and enabling platforms for MEMS in extreme environments.

1. PROBLEM SUMMARY

Silicon carbide has been widely used in power electronics and harsh environment sensor applications due to its wide bandgap and good thermal conductivity properties. The thermal conductivity is nearly five times that of silicon that makes it an excellent material platform for high performance heat exchangers. In order to leverage the cooling properties of the Silicon Carbide, a fin structure design (figure 1) is used.

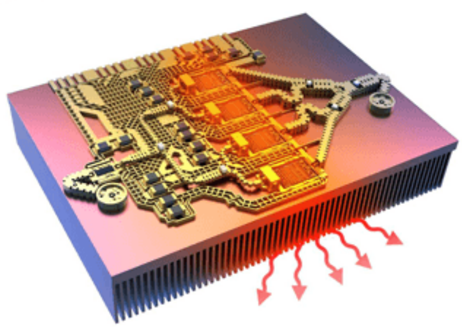


Figure 1 HEMT Heat Exchanger

The fin design requires deep anisotropic etching into the bulk silicon carbide. Traditionally, at the Stanford Nanofabrication facility, only thin film Silicon Carbide etching has been characterized. These thin films used SF_6/O_2 in and ICP tool with an oxide mask to etch the thin film Silicon Carbide. This project explores etching of bulk silicon carbide using the Plasmatherm ICP tool and a metal mask. Metal masks have better higher selectivity with the plasma that is imperative for the deep etch of bulk Silicon Carbide.

2. DEVICE FABRICATION

In order to characterize the etch rate of the SiC , 4” 4H- SiC wafers were obtained from Cree inc. The 4H-SiC wafer was diced into 1cm x 1cm pieces. 1.6 µm of SPR-3612 photoresist was spun on the 1cm x 1cm piece and was patterned using the Karlsuss. 20 nm of an adhesion Titanium layer and 200 nm of Ni was evaporated on the piece. Liftoff was performed to obtain the etch pattern on the piece.

For etch characterization, the following patterns were laid out on a photolithography mask. Squares on the four corners and the center will be used in order to determine etch depth on the profilometer.

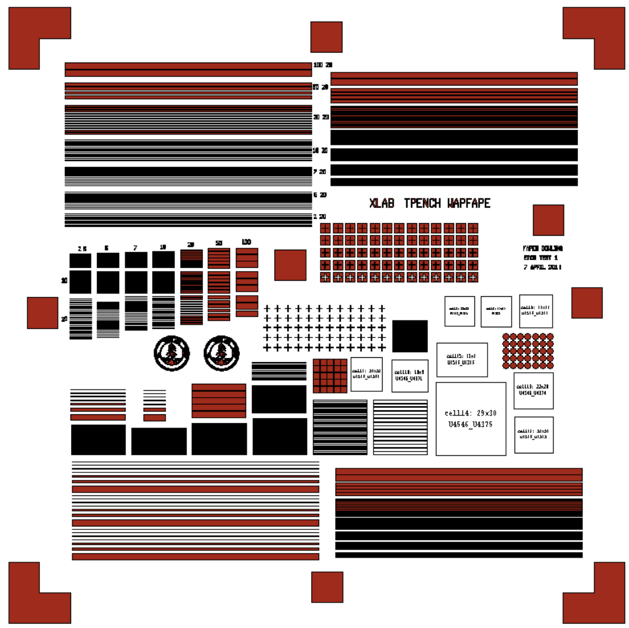


Figure 2 Etch Mask Pattern

The pieces were stuck on a 4” Sapphire carrier (hi-solar co., ltd.) wafer using PMMA (see SNF website for PMMA adhesion). PMMA has reasonable thermal conductivity properties that aid in the etch process. The use of diffusion pump oil and pocket wafers to hold the pieces is under examination. The pieces are now ready for the PT-MTL tool.

3. RECIPE DEVELOPMENT

Past work was referenced in order to find an optimal etch rate recipe. This recipe was then altered for deep etches of the bulk Silicon Carbide.

3.1 Mask Type

Deep etching required a highly selective process and thick mask to avoid early erosion. Many mask types have been used in the literature, but Nickel appears to be the best studied. It can be evaporated in innotec, sputters less than other metals (small amounts of sputtering still exists) and is allowed in the PT-MTL tool.

3.2 Pressure

Past work in plasma etching tools has shown low pressure yielding higher etch rates. Lower pressure increases the mean free path of particles in the chamber. Thus the by-products of etching come off easily. We chose to sweep pressure from 4 mTorr to 10 mTorr, to look for an optimal point.

3.3 O_2 concentration

Literature is ambiguous on O_2 concentration. While some papers show O_2 to improve etch rate and aid deep etches, others show the contrary. We chose to try 0%, 10%, and 20% for this study to try to find an optimal configuration.

3.4 ICP Power

High ICP power intuitively leads to a higher etch rate as a greater concentration of plasma is generated. However, sputtering of the mask also increases. Most papers keep this constant and change other parameters due to limitations. We decided to try 800 W, 1000W, and 1200W to observe the trends.

3.5 RF Bias Power

The bias voltage (controlled by rf bias power non linearly) is a crucial parameter for etch rate and sputter yield. We chose to try 200W, 100W, and 50W and observe its effect on etch rate, polymer deposition, and sputtering.

Starting Baseline Recipe

Thus, our baseline recipe is Power = 1000W, O2 conc = 10 % at 60 sccm flow rate, RF power = 100 W, and pressure at 7 mTorr.

The following table summarizes the recipes tested in PT-MTL:

Recipe #	ICP Power (W)	RF Bias Power (W)	Pressure (mTorr)	Flow Rate (sccm)	O_2 conc (%)
1	1000	200	7	55	0
2	1000	100	7	55	0
3	1000	100	7	60	20
4	1000	100	4	55	0
5	1000	100	7	60	10
6	1000	50	7	60	10
7	1000	100	4.61	60	10
8	800	100	7	60	10
9	1200	100	7	60	10
10	1000	200	7	60	10
11	1000	100	10	60	10

4. PROCESS CHARACTERIZATION

Inductive Coupled Plasma (ICP) Etching is a form of dry etching where the power used to create the plasma is decoupled from the power used to bombard ions on the sample. As shown in the figure below, the ICP power is used to generate plasma whereas the table (or RF Bias) power is used to energize the plasma ions for bombardment of the sample.

The PT-MTL chamber was first cleaned with a chlorine clean (Recipe : Cl_2 clean) followed by seasoning with the etch parameters for 10 minutes. A dummy silicon wafer was used during the clean and seasoning process. The recipe tables show parameters that were then varied on the PT-MTL tool. Etch rates were examined by measuring the depth of the trench using a profilometer.

The following legend summarizes the possible discrepancies from sample carrier and adhesion techniques, and the presence and absence of oxygen.

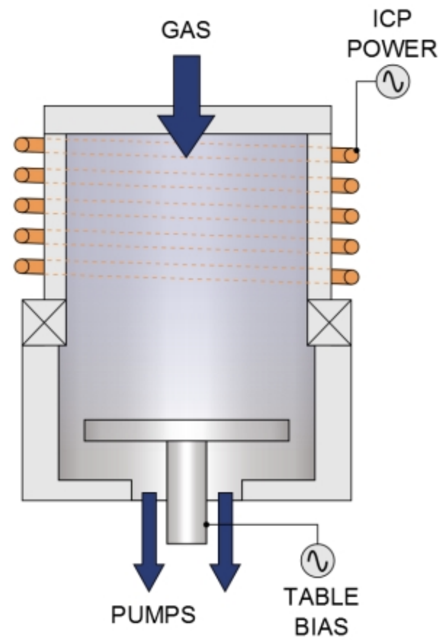
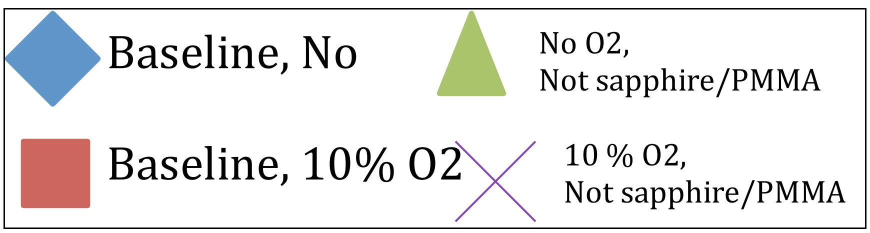


Figure 3 ICP etching tool



4.1 ICP Power

ICP power was varied between 800 W, 1000 W and 1200 W. The following graph shows the etch rate as a function of ICP power.

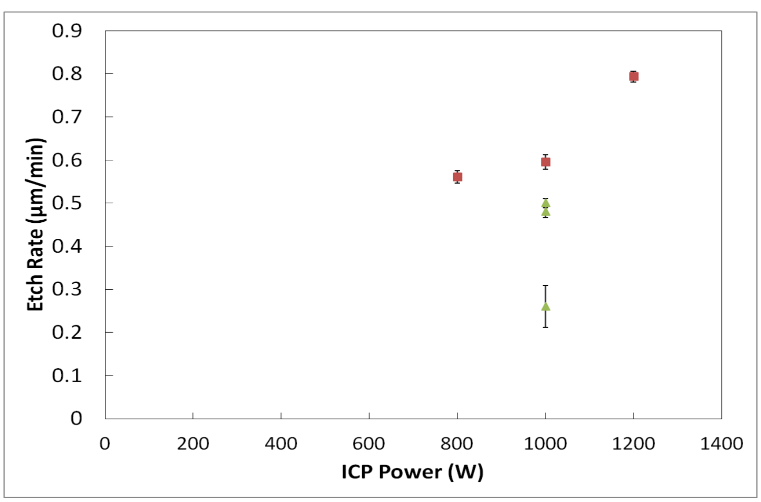


Figure 4.1 Etch Rate as a function of ICP Power

4.2 RF Bias Power

RF Bias or table power is varied between 50W, 100W and 200 W. Literature reports the energy of bombarding ions both in terms of RF power and RF Voltage. There is no direct relationship between RF power and RF voltage. The etch rates for the three cases are shown below.

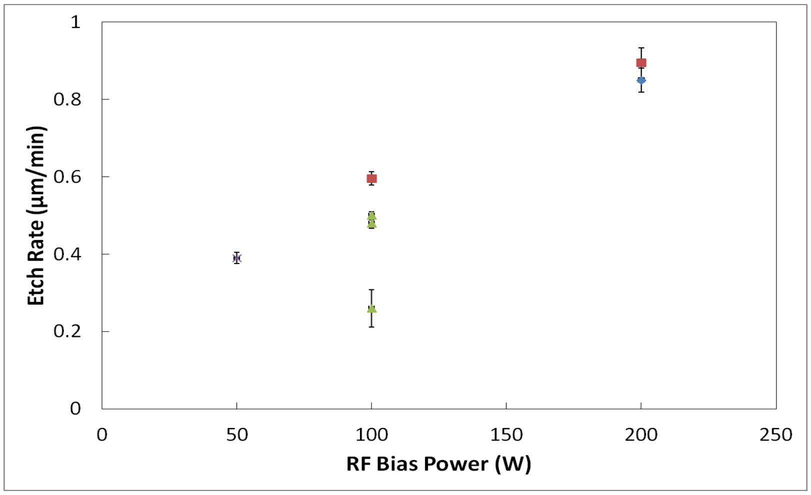


Figure 4.2 Etch Rate as a function of RF Bias Voltage

4.3 Pressure

Pressure was varied between 4mTorr, 7mTorr, and 10 mTorr. The lower pressures must be achieved by allowing the proper gas flow rate. When the PT-MTL throttle position is at 100%, the chamber cannot pump the gases fast enough to maintain low pressures. These experiments used a total flow rate of 60 sccm, which allowed us to barely reach 4 mTorr. The etch rate for the three pressure cases are shown below.

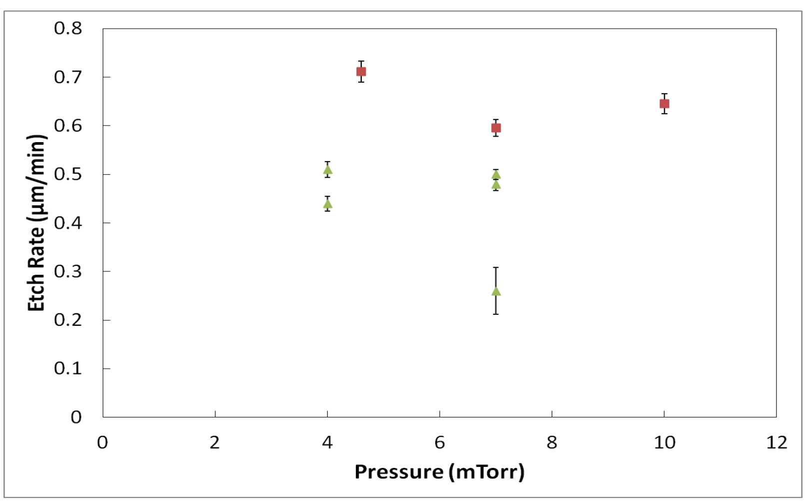


Figure 4.3 Etch Rate as a function of pressure

4.4 Oxygen Concentration

Oxygen was tested for cases at 0%, 10%, and 20%. The following graph shows the etch rates for these varied concentrations.

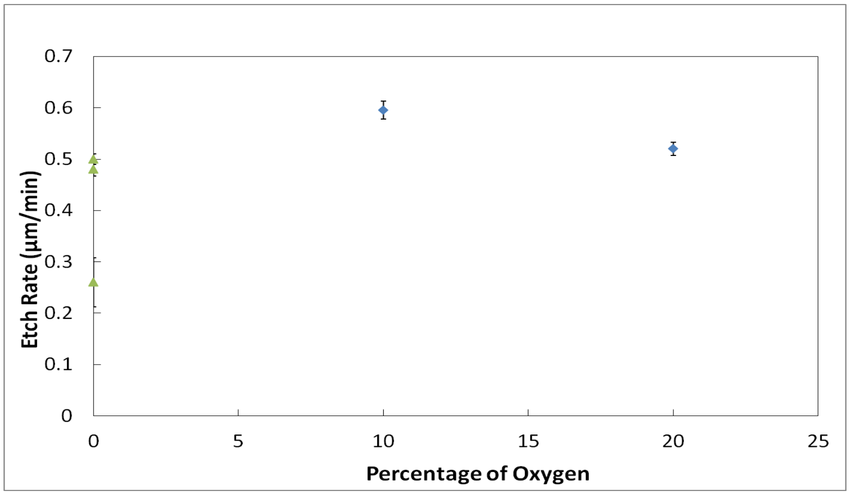
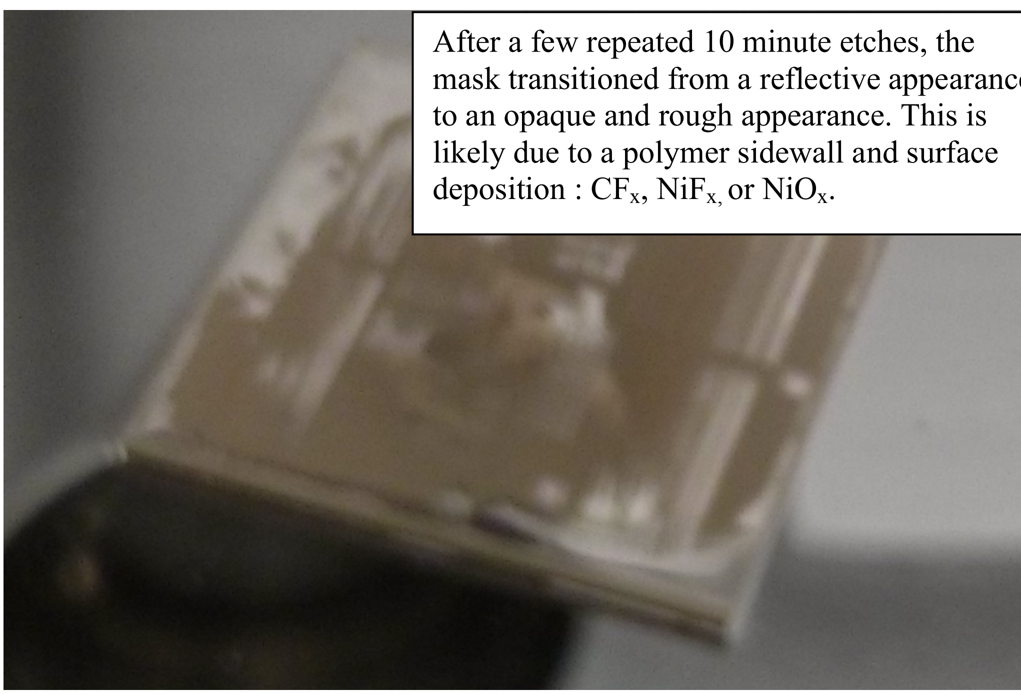


Figure 4.4 Etch rate as a function of % O_2

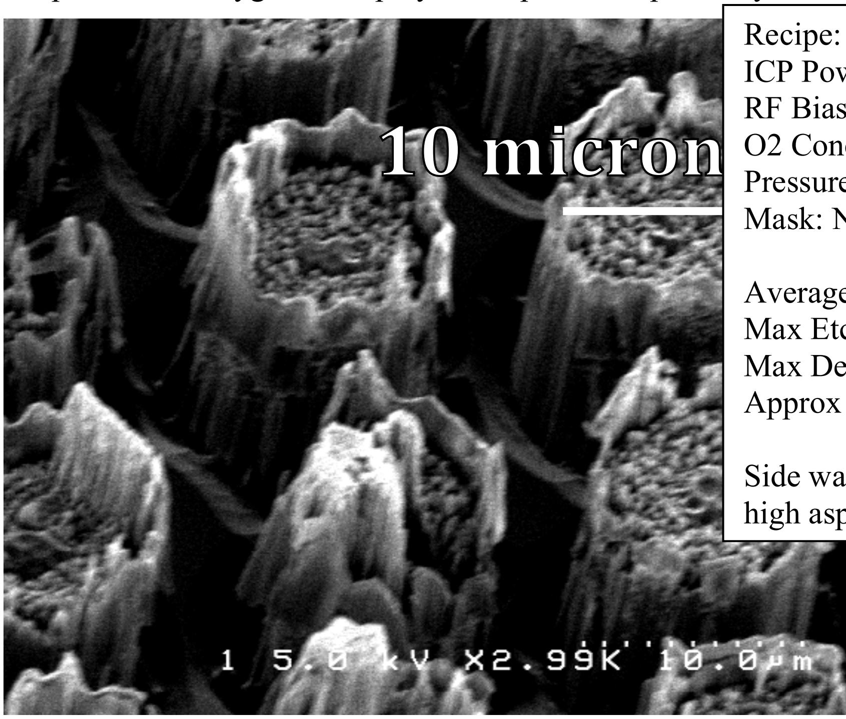
4.5 Qualitative Results

Some samples were analyzed using the SEM to investigate some aspect ratio tendencies, as well as etch stop mechanisms. After 20-30 mins of etching, a white, chalky layer appeared on the samples, very similar to the sample shown in the picture below.



After a few repeated 10 minute etches, the mask transitioned from a reflective appearance to an opaque and rough appearance. This is likely due to a polymer sidewall and surface deposition : CF_x, NiF_x, or NiO_x.

In Particular, large amounts of sidewall deposition can be seen in the following SEM for a high bias recipe with no Oxygen – the polymer deposited is primarily a carbon fluoride.

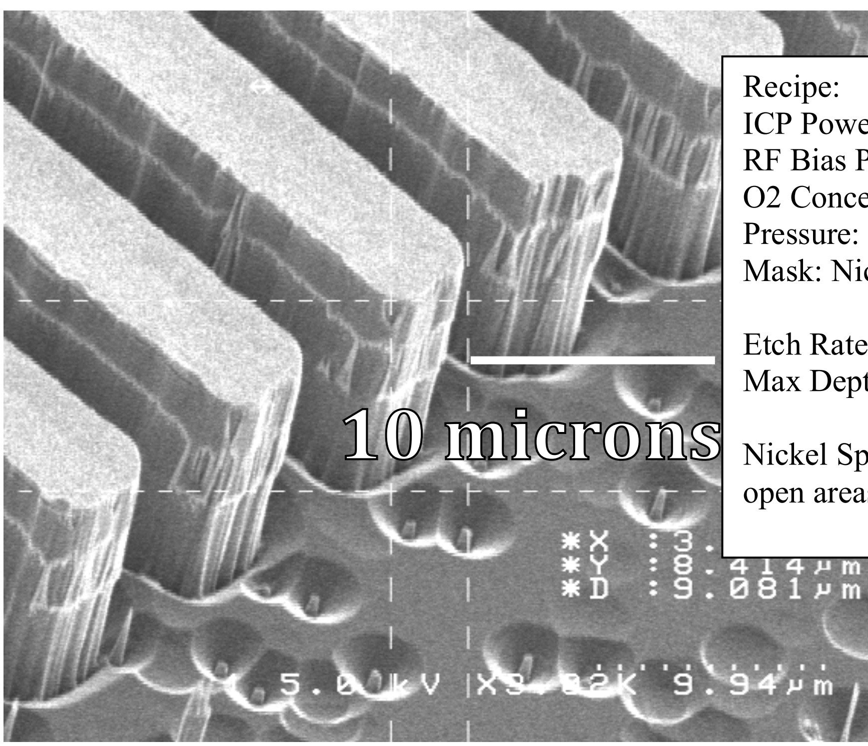


Recipe:
ICP Power: 1000W
RF Bias Power: 200W
O2 Concentration: 0%
Pressure: 7 mTorr
Mask: Nickel

Average Etch Rate: 0.71 um/min
Max Etch Rate: 0.89 um/min
Max Depth Etched: 15.9 um
Approx Selectivity: 82:1

Side wall polymer deposition can inhibit high aspect ratio etches

In addition, even at lower bias powers, Nickel sputtering can still occur, and "grassing" can be an artifact of these etches. The following image shows this effect:

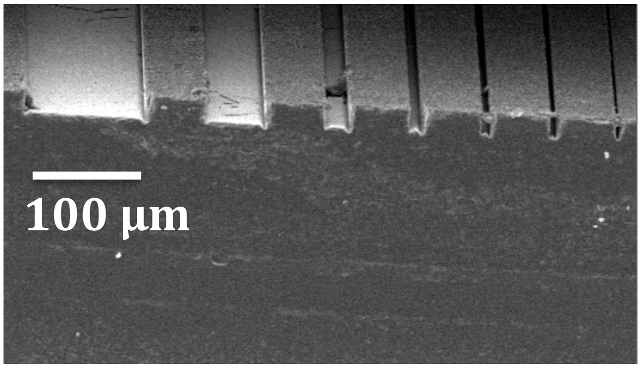


Recipe:
ICP Power: 1000W
RF Bias Power: 100W
O2 Concentration: 0%
Pressure: 7 mTorr
Mask: Nickel

Etch Rate: 0.5 um/min
Max Depth Etched: 10.58 um

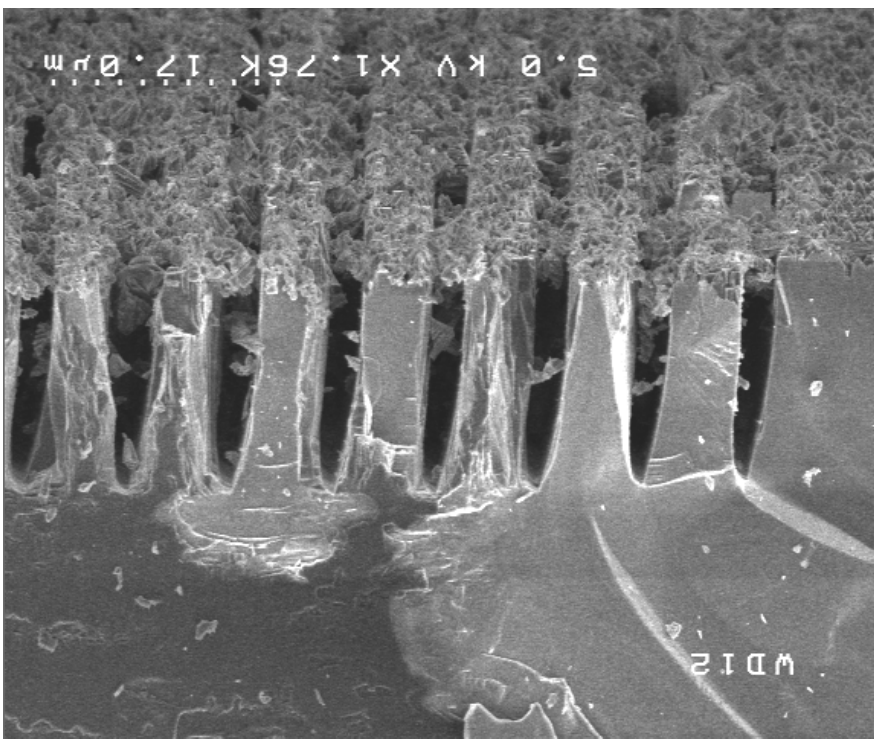
Nickel Sputtering can cause "grass" in large open areas of an etch

The next image shows the different effects based on aspect ratio. Smaller channels become affected by micro trenching – when the corners etch deeper due to higher particle deflections.



Recipe:
ICP Power: 1000W
RF Bias Power: 100W
O2 Concentration: 0%
Pressure: 7 mTorr
Mask: Nickel

Finally, the polymer deposition/growth can block further etches with narrow openings. The final image shows this effect.



Recipe:
ICP Power: 1000W
RF Bias Power: 100W
O2 Concentration: 0%
Pressure: 7 mTorr
Mask: Nickel

Polymer deposition can affect the aspect ratios achievable for deep etches.

5. DISCUSSIONS

5.1 ICP Power

Inductive coupled plasma power drives the etching process in the chemical regime. Increase in ICP power leads to an increase in plasma concentration in the etching chamber and visa versa. The increase in plasma concentration is reflected in the increasing etch rate of the silicon carbide.

5.2 RF Power

RF Power dictates the physical nature of the etch process. Increasing RF power increases the energy of the bombarding plasma on the sample. Increasing energy is reflected in improved etch rate but also etches the metal hard mask causing sputtering and quick depletion of the hard mask.

5.3 Pressure

Pressure has a complex effect on the etch process. Decreasing pressure increases the mean free path of particles in the plasma gas, which can allow for more effective bombardment in the etch mechanism. Alternatively, higher pressures lead to higher concentrations of plasma reactants, which also can increase the mean free path. Previous literature shows a preferable trend towards smaller pressures for increased etch rates and deep etches. However, there are some challenges with drastic pressure changes in the PT-MTL tool. If too many variables are altered from the lighting step to the main step, source impedance errors can occur in the tool. It is advised to add intermediate steps that vary one parameter at a time.

5.4 Oxygen concentration

Oxygen is an important component for this recipe because its interaction with etch materials causes radical by-products that can be removed from the sample surface. While high etch rates can be achieved with or without its presence, longer etches can occur with the presence of oxygen. As shown in the literature, there is an optimal concentration for oxygen around 10%. Future studies could be performed around this point to optimize the best etch rates possible.

5.5 Moving Forward

Given the data from these etch studies, the next recipe we want to try will have ICP power of 1200W, RF Power of 50 W, Pressure of 5 mTorr, and Oxygen concentration of 10%. This will allow for decent etch rates, lower sputter yields and polymer deposition to attempt deep etches in the silicon.

Additionally, Nickel has proved to be a challenging mask to work with. We plan to try new methods for thicker mask deposition, such as thicker evaporated films with thicker photoresist for effective liftoff. We may also try “electroless nickel”, where a nickel compound can be deposited chemically through a redox reaction. In addition, characterizing etches to reduce the effects of polymers deposited in the process will allow for higher aspect ratios to be achieved.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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