Compensating for Aspect Ratio Dependent Etch

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Abstract: Here we describe a method of etching disparate feature sizes in silicon down to the same depth using the Bosch process. There is an inverse relationship with aspect ratio and polymer deposition rate that can be utilised to compensate for normally differing etch rates that occur across a variety of feature dimensions. For a given process condition, the CF polymer thickness between aspect ratios of roughly an order of magnitude in difference allows for selective etching across a wafer when etching of those features are isolated into separate etching steps.

Keywords: Aspect ratio dependent etch, ARDE, RIE lag, Bosch, DRIE.

1. Introduction

Deep reactive ion etching (DRIE) of silicon is commonly performed with the use of temporal multiplexed recipes that isolate passivation and etching into two or greater number of steps and repeated a number of times until the desired depth is reached [1]. In general, the Bosch process can be isolated into three steps: Polymer Deposition, Polymer Etch and then Silicon Etch. The polymer deposition step utilises a C_4F_8 plasma discharge to deposit a variety of CF related polymers on all exposed surfaces [2]. The polymer etch step includes an applied bias with an SF_6 or Ar plasma discharge to physically etch the CF polymer at the bottom surface of a feature whilst ideally leaving any deposited polymer along the walls, ideally unetched. Finally, the silicon etch step uses SF_6 to isotropically etch all exposed silicon. The end result gives the effect of an anisotropic etch even though the SF_6 etch step itself is isotropic.

As technology has moved forward, so has the need for increasingly complex etching regimes. One such regime involves etching to a specific depth regardless of aspect ratio (AR). Features will etch faster with lower aspect ratios and then slow down as the aspect ratio increases due to limited diffusion speeds [3]. There are various methods to compensate for aspect ratio dependent etch (ARDE) rates. In this work we utilise the AR influence of CF polymer deposition during the C_4F_8 plasma discharge step. Thinner films are deposited in higher AR features which can be selectively isolated from larger AR features during the polymer etch step.

2. Method

A patterned silicon <100> wafer made with a lithographic stepper on a TMMR P-W1000T positive resist with trench widths 1 – 50 µm hand scribed and broken into 1 x 1 cm chips are etched on 6" carrier wafers with Kapton tape to protect wafer etching. The samples are processed in a SAMCO 800-iPBC system, chucked by ESC and cooled by a 20°C helium back pressure. The chamber pressure is ranged from 15 Pa for the deposition step, 1 Pa for the Polymer etch steps and 2 Pa for the Silicon Etch Steps.

The etch recipe is looped with five steps:

1. Polymer Deposition
2. Partial Polymer Etch
3. Partial Silicon Etch
4. Full Polymer Etch
5. Full Silicon Etch

Where the partial Polymer Etch and Silicon Etch steps selectively etch high AR features due to their decreased deposited polymer thickness. This is followed by another polymer etch step to remove any remaining polymer in low AR features which can then be etched to the same depth as the high AR features within the same loop. The five steps in a loop are repeated until a desired depth is reached. A visual representation of the five steps is illustrated in Fig. 1. Results are imaged and measured in scanning electron microscopy.

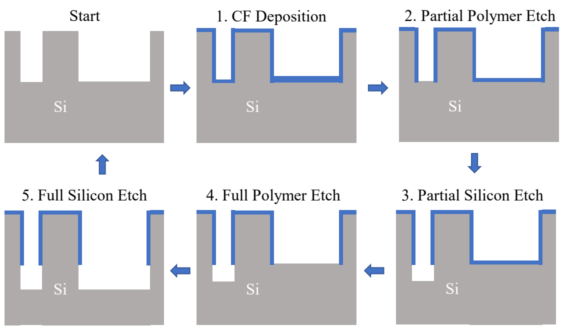

Fig. 1 Schematic illustration of a five step Bosch loop process to etch a wide and narrow trench with different AR.

3. Results

Due to how easily radicals are able to flow around large areas and are more restricted in smaller areas or high AR features, the thickness of deposited polymer will be comparatively thinner in high AR features. By utilising the disparate AR of different trench deposited polymer thickness, equal etch depths of two trenches with a minimum AR difference of an order of magnitude is possible with this method.

In Fig. 2, 1.5 and 30 µm trenches are etched to the same depth by utilising the recipe process shown in Fig. 1 where only step 3 is ramped with a linear increase in time, relative to loop count. The final etch depth is 22.9 µm for both the 1.5 and 30 µm wide trenches at 50 loops. The AR for the

1.5 µm trench increases from 3.3 to 17.3 while the etch rate decreases. To compensate for a decrease in etch rate, the step 3 time is ramped from 2 to 4.5 s over 50 loops in 0.1 s increments. The 30 µm trench AR changes from 0.2 to 0.9 at a depth of 22.9 µm, thus, no ramping of the etch time is needed and stays fixed at 2 s. After 100 loops, the etch depth is 44.5 µm and at 150 loops the etch depth is 63 µm. Increasing loop count and with it, etch time shows an increase in undesirable lateral etching as the polymer on the walls is slowly etched away, exposing the silicon during the longer etch times. This increases the trench width near the top which causes a bowing effect. At the bottom of the 1.5 µm trench, narrowing of the width with increasing AR occurs as the time needed for reactive species to travel down the trenches becomes increasingly longer.

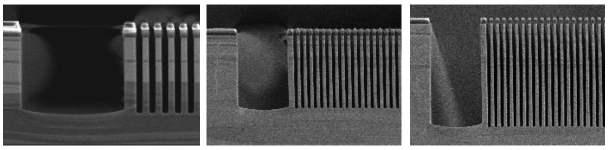

Fig. 2 ARDE compensated etching of 1.5 and 30 µm trenches at 50 (left), 100 (middle) and 150 (right) loops.

As loop count is increased and the depth of the higher aspect ratio structures are etched in the partial silicon etch step, the aspect ratio dependent etch effects becomes increasingly more obvious as seen in Fig. 3. Due to the longer etch times in the first silicon etch step the 10 µm trench begins to etch in the partial silicon etch step. This is due to the slow etching of the polymer from fluorine radicals eventually exposing the bottom trench surface and then etching the silicon before the intended etch step starts. This demonstrates the importance of ramping more than just the silicon etching step parameters. At 50 loops, the partial polymer etch step isolates the 1, 1.5, 2, 3 and 5 µm trenches.

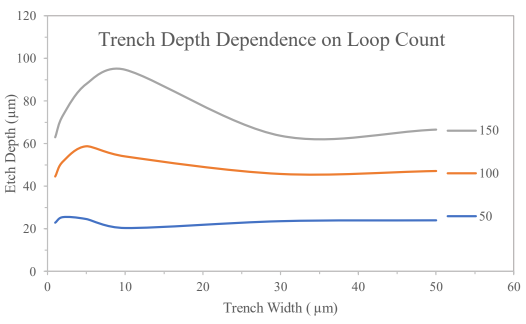

Fig. 3 Trench etch depths with increasing loop counts of 50, 100 and 150.

The AR range for the trenches in Fig. 3 at the start of the etch process is 1.0 – 5.0 (this includes the 5 µm resist thickness) and after 50 loops, the AR range increases to 5.8 – 27.4. After 150 loops, the AR increases up to 18.2 – 66.0. When the aspect ratio increases enough so that a narrower trench earlier in the process had the same AR, similar process parameters are applicable.

4. Discussion

To determine what recipe parameters are needed for ARDE compensated etching, we first being with the polymer step. The polymer thickness required needs to be sufficient enough so that when two different AR features undergo the polymer etch step, there will be a time difference to remove the polymer between the high and low AR features. Generally, a thicker polymer film deposition is better to start with. In the sample shown in Fig. 2 a time window of 2 s is available from which the 1.5 µm trench is cleaned of the polymer at the trench base while still having polymer in the 30 µm trench base. If the polymer etching parameters fall somewhere in the middle of preserving a continuous polymer layer and completely removing all the polymer, silicon needles or trenching will form. This is a result of micro-masking from remaining polymer.

Once the first polymer etch step time is realised, the polymer in the lower AR feature (in this case, the 30 µm trench) will be thicker than the higher AR feature. Then the etch step with bias is adjusted simply with time and bias power to etch the higher AR feature (the 1.5 µm trench in this work). If adjusted correctly, the silicon etch step will only etch the high AR feature. After, another polymer removal step is performed, in this case for 2 s, all remaining polymer at the bottom feature surface is removed. The final silicon etch step will etch both the small (high AR) and large trenches (low AR) but the large trench will etch at a higher rate and will quickly reach the same etch depth as the smaller trench. After adjusting the final etch step time, the etched depths will be the same across the two trenches. This technique is possible for any two features with an order of magnitude difference in AR. A smaller difference may be possible with fine tuning.

A somewhat low bias of 200W is used for the partial polymer etch step. A low bias provides better etch rate control. To improve throughput, the final polymer etch step has increased bias as a controlled polymer removal is not needed.. As the bias is increased, the window for etching a controlled thickness of polymer becomes increasingly difficult which is why the same bias value is not used for both polymer etch steps.

5. Conclusion

Isolating disparate AR features provides the ability to control the etch depth whereas a normal Bosch process would normally produce varied depths. By preserving some of the CF polymer in low AR features, high AR features can be selectively etched. Here we demonstrate two trench widths, 1.5 and 30 µm that are etched to the same depth and can be applied to any two AR features with an order of magnitude difference. We also provide an explanation as to how ARDE compensated etching process conditions are found.

6. References

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