Improving Etch Rates in Deep Silicon Etching

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The Micro-Electro-Mechanical Systems (MEMS) arena is a rapidly growing field. Many applications exist, the majority of which require deep silicon trench etching. The Bosch technique is one process that has been successfully used for deep trench etching. Silicon trenches can range from several hundred microns in width to a few microns with aspect ratios over 40:1. An example of trench etching is shown in Figure 1. Here, a series of silicon trenches, from 10um down to 2um were etched with the Bosch process, where the etch stopped on a buried oxide layer within the substrate.

The Bosch process is centered around an alternating chemistry utilizing both etch and deposition steps. A good balance between the time spent in the etch and dep phases is prudent to achieve high rates and good profiles of trenches. In an effort to reduce the etch time associated with the Bosch process, this paper will concentrate on increasing the actual rate of the etch step to make up for time lost during deposition.

Theory

The role of ions during the etch phase is minimal. Consequently, the importance of neutrals, specifically free fluorine radicals, and their arrival to the wafer surface is of extreme importance for etching. We don't want to completely ignore the role of ions, because they are essential in removing any remaining deposition on horizontal surfaces prior to etching, but for overall etch performance, the neutrals are the key. Knowing this, we can proceed to estimate very simply, through a mass balance relation, the important terms in raising the etch rate. Mass balance simply accounts for the number of gas molecules entering and leaving a reaction chamber. Specifically, consider an SF_6 molecule entering an ICP chamber. How many free fluorine atoms are dissociated from this molecule? In reality, there are many combinations of radicals, each with their own generation rate and reaction rate at the wafer surface, but for our analysis we will concentrate on single fluorine atom dissociation from SF_6.

To determine the overall efficiency of an etch, both with regards to process and hardware, we now define a new efficiency term as follows. For 100% single fluorine dissociation, each SF_6 molecule entering the chamber would yield six fluorine atoms. If all six of these fluorine atoms arrived at the silicon wafer surface, i.e. none were lost in recombination before reaching the wafer, and all six reacted once there, this would represent 100% efficiency in terms of the combined dissociation and reaction rates. A comparison of this figure to actual measured values would then provide a baseline for tool efficiency in terms of both process and hardware.

Experimental Description and Results

All experiments were performed on a Plasma Therm 770 SLR tool. The tool is equipped with a loadlock for easy wafer handling in and out of the reaction chamber. This tool also packages an Inductively Coupled High Density Plasma Source operated at 2MHz. Independent ion energy control is possible through an RF bias applied to the substrate electrode at 13.56 MHz. For the experiments mentioned here, all wafers were 4-inch silicon.

For a fixed pressure of 40mT and 200 sccm SF_6 flow, Figure 2 depicts the efficiency ratio as a function of ICP power. Clearly, higher powers improve the overall efficiency. For the same gas flow, more power will dissociate more fluorine. There will be a leveling at the point where the rate of dissociation equals the rate of recombination. This level has not been reached in the graphs, but there does appear to be a trend towards leveling as the slope of the curve diminishes with increases in ICP power. Also, the efficiencies are higher on any power curve if the source to wafer spacing is made smaller and if we operate with a Type 2 reactor configuration.

The effect of pressure (not shown here) was also investigated for a fixed ICP power of 2000W and 200sccm of fluorine. The pressure was varied from 15 to 50mT. The 4-inch spacing showed a peak in efficiency at 25mT and then leveled off with further increases in pressure. As before, the smaller 1-inch spacing with the Type 2 configuration gave the best efficiency, but no peak was seen.

Conclusions:

We have demonstrated the effects of source power and pressure and their associated role in the etching of silicon. To make enhancements in the rate of silicon removal is an important goal in improving the Bosch process for deep trench etching, especially when throughput becomes a driving factor. One of the methods that can be utilized to check the effectiveness of a tool is its efficiency in removing silicon for a given gas input. We have developed a new efficiency term that has enabled us to enhance our system's etch rate and implement a new hardware design to achieve our goal. This newly defined efficiency is general enough to be applied to other chemistries and applications.

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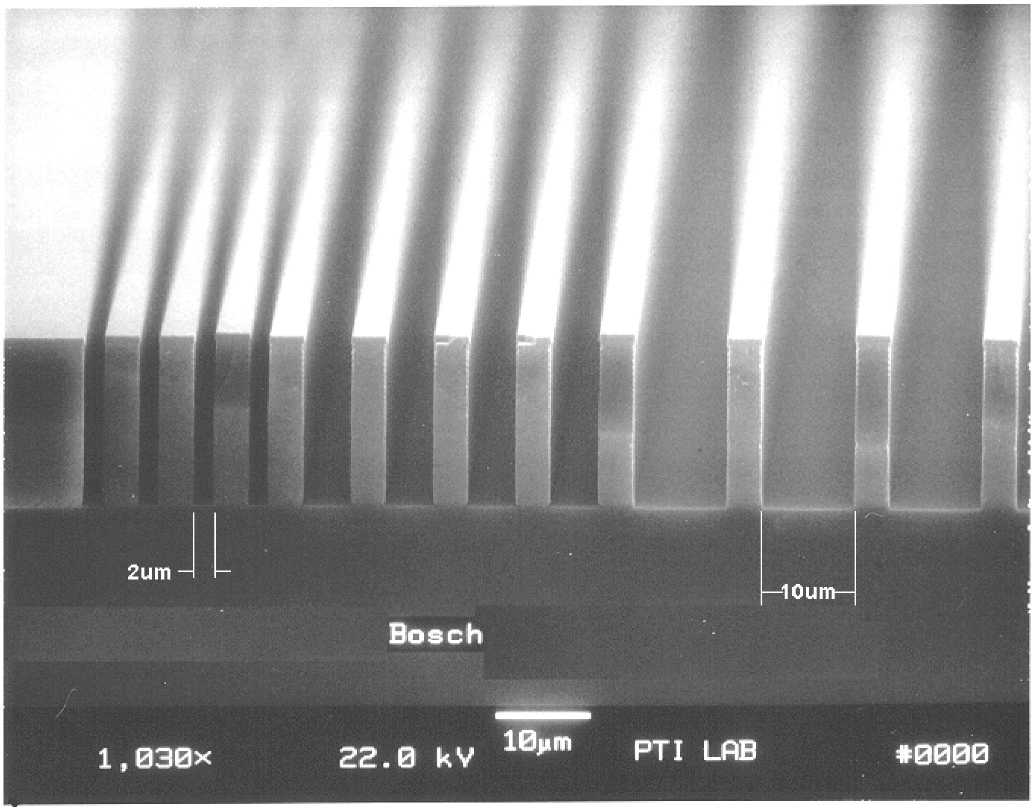

Figure 1. **SEM micrograph of etched trenches (2 to 10um in width) down to SiO2.**

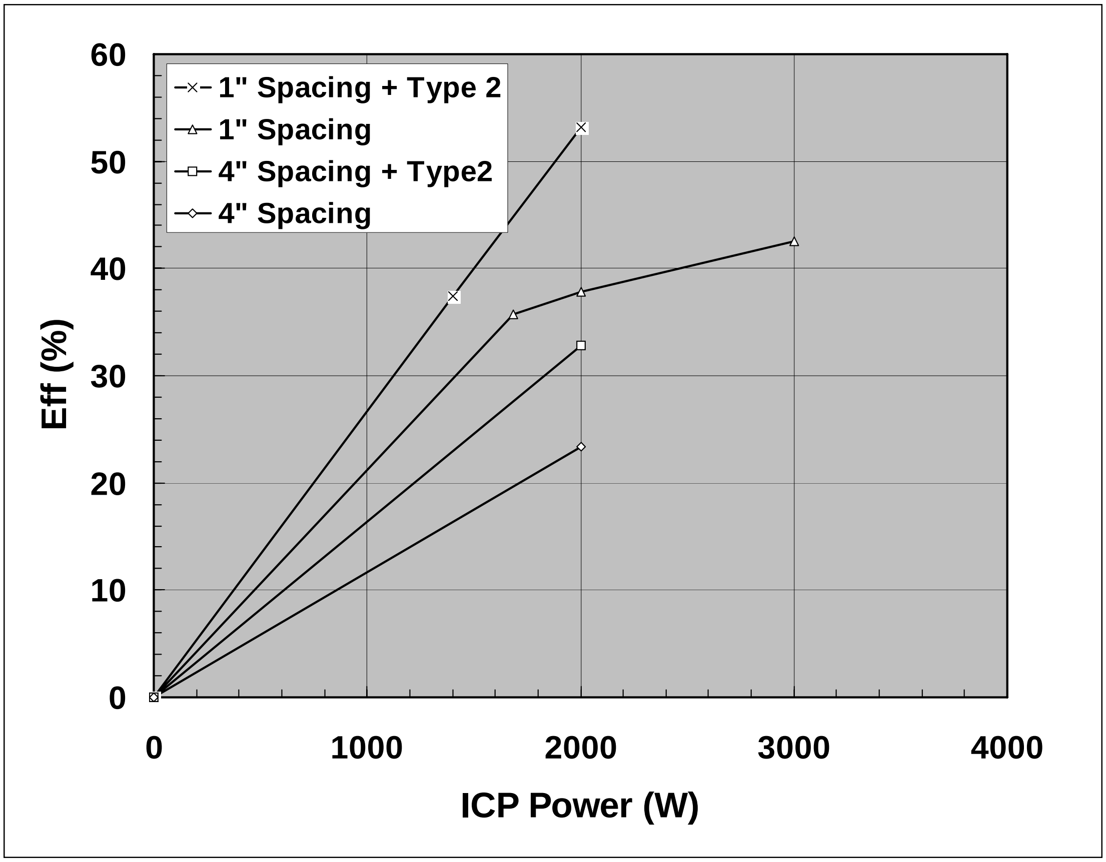

Figure 2 Tool Efficiency as a function of ICP power.