# Effect of Reactive Ion Etching on Laser-Annealed Low-k SiCOH Materials

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## Introduction:

The speed of current microelectronic devices is limited due to parasitic capacitance between wires in the back end. The dielectric constant, or κ value, of the insulator between wires can be reduced to shorten this delay. To reduce the dielectric constant of standard $SiO_2$, carbon can be added to form bonds that are not as polar, and the material can be made porous, introducing air with its low κ value. These are generally referred to as SiCOH materials. Porosity, however, is achieved at the expense of modulus, meaning that the lower the κ value of a given SiCOH material, the weaker and less useful it is in industry.

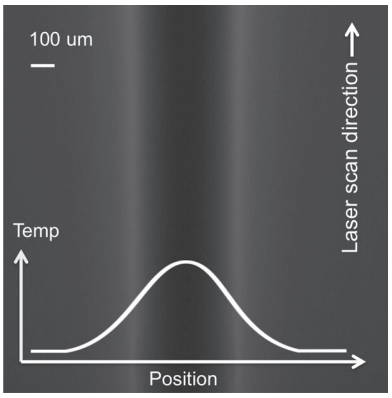


*Figure 1: A representative diagram of a laser anneal stripe.*

Our group hoped to use millisecond laser spike annealing (LSA) to produce a stronger but still low-κ material. Annealing was performed at higher temperatures than conventional thermal anneals, with the short duration limiting many of the damaging material changes.

LSA involves focusing a high-power laser, and then tracing a line across the sample. By varying the dwell (the amount of time any particular region is heated) and laser power, different maximum anneal temperatures can be achieved. The beam intensity (and therefore, anneal temperature) follows a Gaussian profile. Consequently, temperature varies with position, with the highest temperature in the center of the line, as shown in Figure 1. This project involved characterizing the etch behavior of SiCOH films after laser heating.

## Experimental Procedure:

A 2 × 2 cm sample was annealed using a $CO_2$ laser at dwells ranging from 0.2 to 2 ms, all with a maximum temperature of 1200°C. As the 1 ms and shorter dwell anneals exhibited signs of material failure, only the 2 ms dwell (power 50.2 W) and the 1.5 ms dwell (power 52.6 W) anneals were considered in subsequent steps. (The failure was likely due to heat transfer from previous anneals; had the 0.2 ms anneal been performed first and the 2 ms anneal performed last, the material may not have failed.)

Photoresist was patterned so that only a small area of the sample was exposed to any given etch process. Two reactive ion etches were performed using an Oxford 82 etcher, both typical $SiO_2$ etches: $CF_4$ etch (30 sccm $CF_4$, 40 mTorr, 150 W power) and a $CHF_3/O_2$ etch (50 sccm $CHF_3$, 2 sccm $O_2$, 40 mTorr, 240 W). Both 30 and 60 second etches were performed, each on a new region of the sample. Profilometry measurements were taken laterally across the anneal line, before and after etching, using a P10 profilometer. (During data analysis, the average of every ten values was plotted to reduce noise.)

A film appeared on the sample post resist removal. Following all $CF_4$ and $CHF_3/O_2$ etches, the part of the sample containing all of the etched regions was exposed to oxygen plasma (50 sccm $O_2$, 60 mTorr, 150 W) for two 4-second intervals in the Oxford 82 in an attempt to remove this film. The remainder of the sample was covered in thick (S1827) resist. While the film removal was largely unsuccessful, enough was removed to allow for basic profilometry measurements.

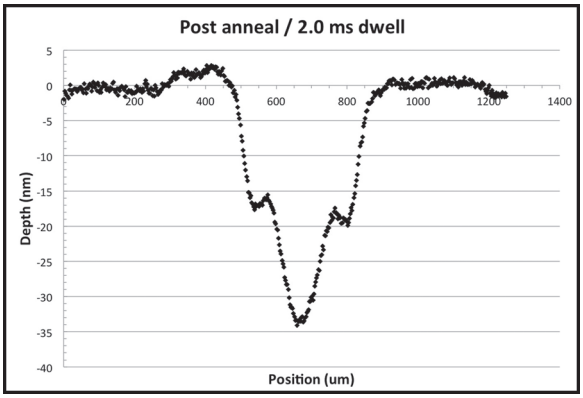


*Figure 2: Depth vs. lateral position across the laser line (position as indicated in Figure 1).*

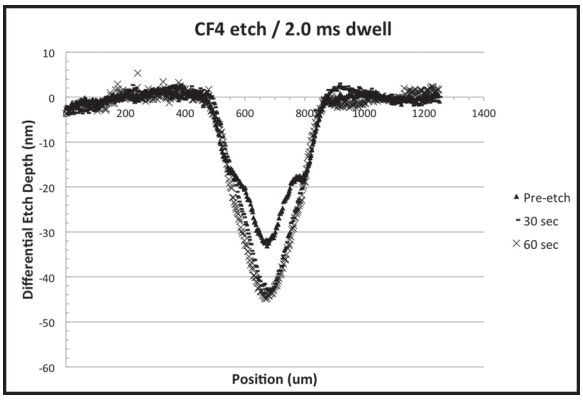


*Figure 3: Differential etch depth vs. position for 2.0 ms dwell and $CF_4$ etch.*

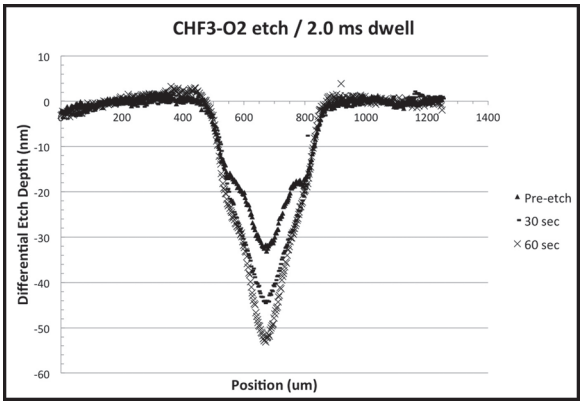


*Figure 4: Differential etch depth vs. position for 2.0 ms dwell and $CHF_3$ / $O_2$ etch.*

## Results and Conclusions:

Figure 2 shows the change in depth with respect to position (and therefore temperature) across the laser line after anneal and before etch or oxygen clean. The material densified as it was heated, and the thickness of the film (originally about 200 nm) decreased. Of particular note are the two "shoulder" threshold regions, located at about 525-575 and 750-800 nm, where for a brief interval densification did not continue with increasing temperature.

After 30 and 60 second $CF_4$ etches, the surface profiles were virtually identical (as seen in Figure 3), indicating that at or some time before or at 30 seconds, the etch rate became uniform for all previous annealing temperatures. The shoulder regions also disappeared, hinting at the presence of a residue in the high temperature region (roughly between and including the shoulders) that etched away very quickly during initial etching, leaving behind only material that etched at a constant rate. The $CF_4$ etch profiles for 2.0 and 1.5 ms of dwell (not pictured here) were extremely similar, to the point that the etch behavior appeared to be independent of dwell.

The $CHF_3/O_2$ etch displayed slightly different behavior, with the shoulder regions remaining to an extent and a significant difference in the high temperature annealed region between the 30 and 60 second etch profiles, as seen in Figure 4. The residue appeared to take more than 30 seconds in order to etch, with a continued higher etch rate in the high temperature region after 30 seconds. In addition, the 60 second etch profile for 1.5 ms dwell (not pictured here) had a maximum depth of approximately -48 nm as opposed to approximately -53 nm.

Our hypothesis is that laser annealing leaves behind a residue in the high-temperature regions, possibly decomposed organic material, which is rapidly etched away so that only a material that etches at a uniform rate is left behind.

## Acknowledgments:

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