

Inductively Coupled Plasma Etching of Benzocyclobutene with SF₆ Chemistry

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ABSTRACT

Inductively coupled plasma (ICP) etching of Si-containing benzocyclobutene patterned with a photo-resist soft-mask was investigated with fluorine/oxygen based plasmas. The effects of chamber pressure, reactive ion etch (RIE) power, ICP power, and SF₆ concentration were studied on etch rate, selectivity, and sidewall morphology. Highly anisotropic features were achieved with sidewall slopes $\sim 88^\circ$ for almost all conditions. Grass-like residue was observed under certain etch conditions and is shown to be dependent on pressure, ICP power, and feature dimensions.

MOTIVATION

Numerous applications currently exist:

- Interlayer dielectric
- Integrated circuit packaging
- Wafer level bonding
- Optical waveguides
- Biocompatible neural implants, etc.

As applications extend to N/MEMS, the need exists for highly anisotropic, CMOS compatible fabrication.

EXPERIMENTAL

Non-photosensitive BCB (Cyclotene 3022-35, Dow Chemical) etched in Inductively Coupled Plasma (ICP) Reactive Ion Etcher (RIE). A 1.7 μm thick BCB film was spun on and hard-baked at 250°C under vacuum. AZ 4330 soft mask was used.

Etch chemistry: SF₆/O₂/Ar

Temperature: 25 °C

Variables

Chamber Pressure = 3 mTorr to 10 mTorr

% SF₆ (SF₆ / (SF₆ + O₂)) = 0% to 100%

RIE Power = 50 W to 300 W

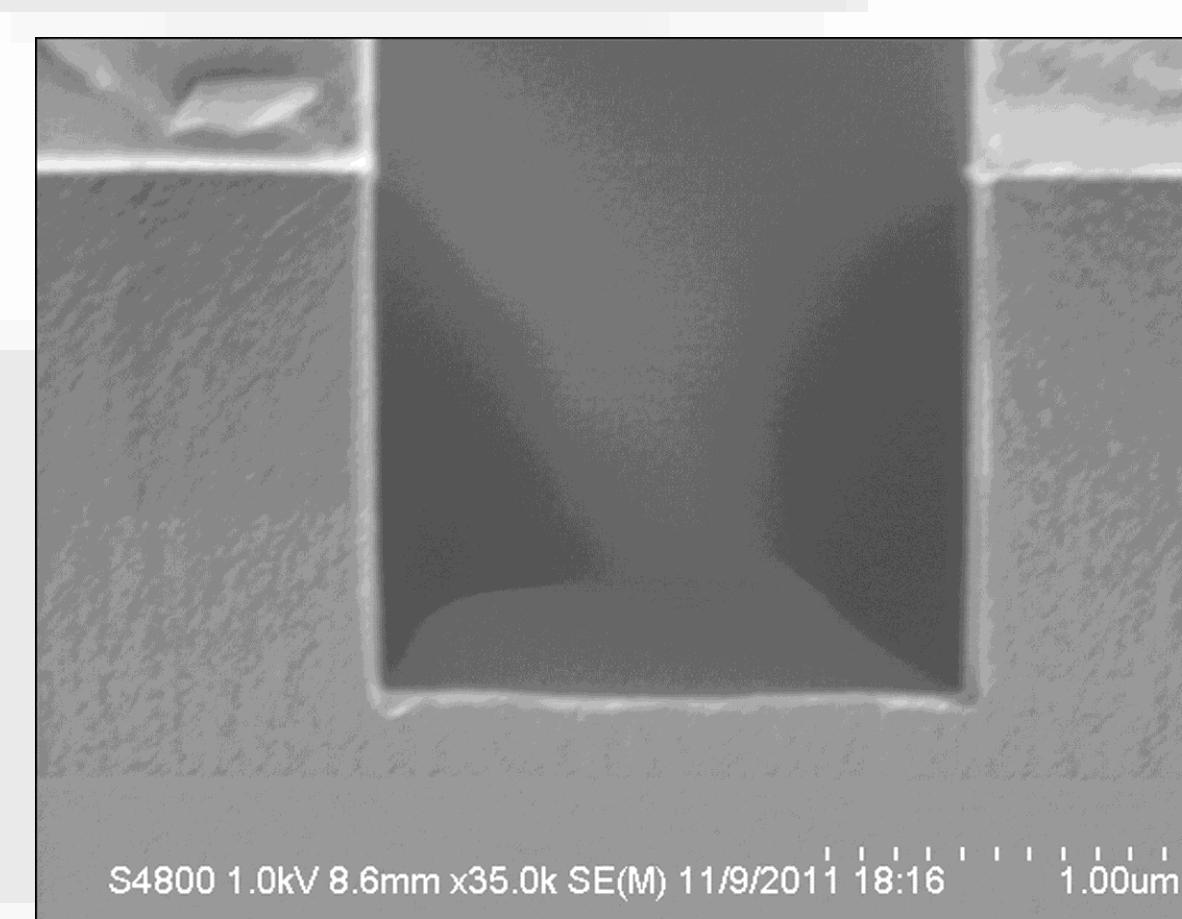
ICP Power = 0 W to 1000 W

Observables

Etch Rate

Selectivity

Profile Slopes



RESULTS

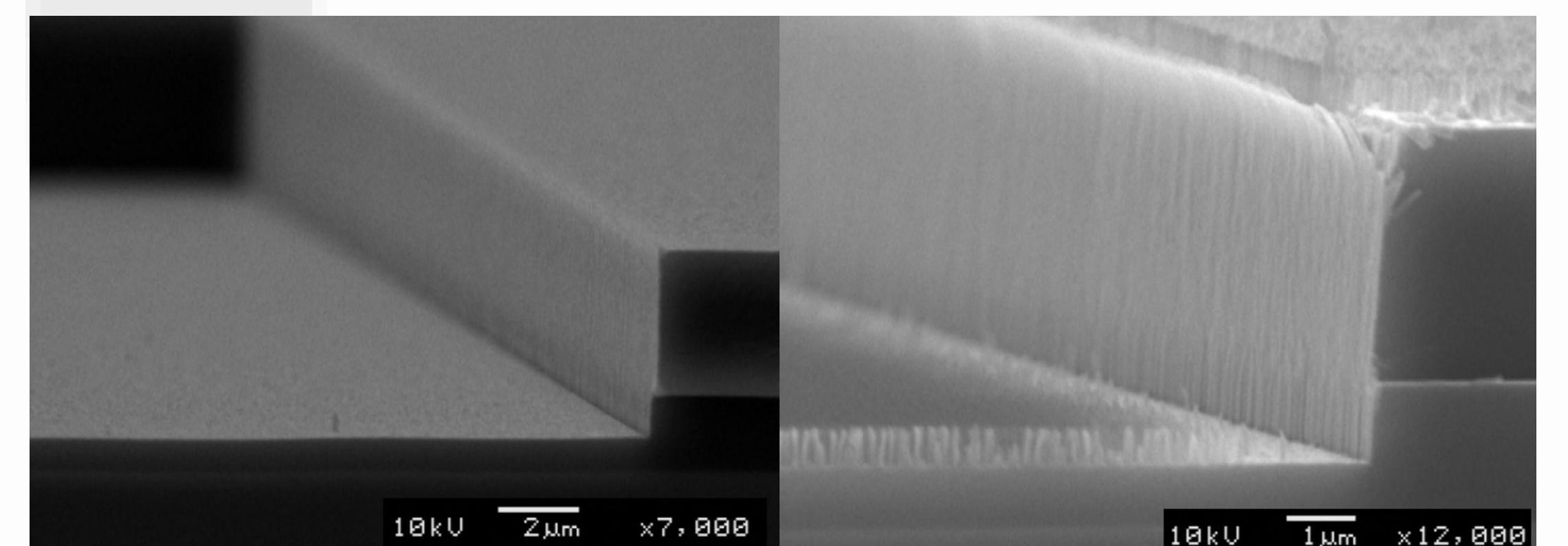
Effect of Pressure

At low pressures (<50 mTorr), micro-masking and grass-like residue is common when etching polymers due to fluorocarbon polymerization^{1,4, 7-9}.

Residue formation can adversely affect:

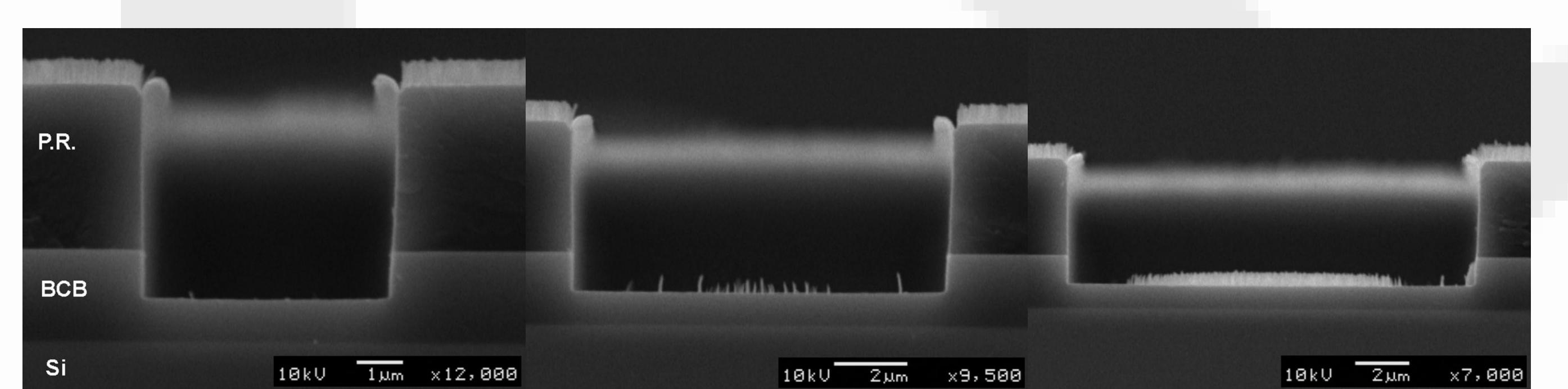
- Profile Morphology
- Etch Rate
- Contact Resistance (lead to interconnect failure)

Residue can not be removed by O₂ plasma



SEM cross-sections of grass-like residue after etch at ICP power of 300 W, RIE power of 300 W, 50 % SF₆, (left) 3mTorr and (right) 7.5mTorr.

- At very low pressures, increase in mean free path and DC bias improves ion etching effects, preventing residue formation.
- Grass-like residue only observed with aspect ratios > 10.



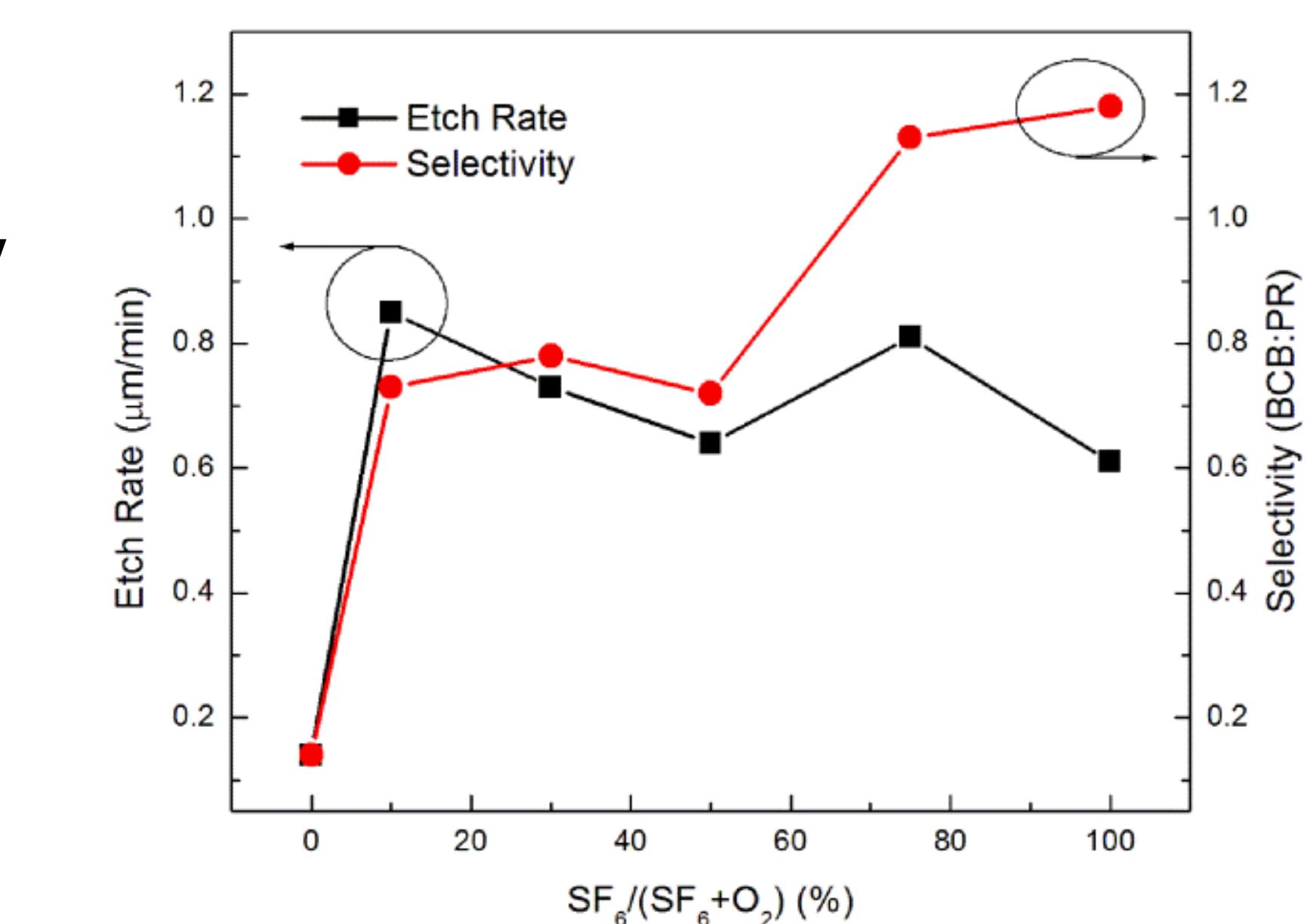
SEM cross-section image of sample etched at 7.5 mTorr, RIE power of 175 W, ICP power of 300 W, and 30 % SF₆ with feature sizes of (left) 5 μm , (middle) 10 μm and (right) 15 μm .

Effect of SF₆ Concentration

Due to the fact that BCB is a silicon containing polymer, the etch rate of BCB with 100 % oxygen is extremely low, 0.14 $\mu\text{m}/\text{min}$.

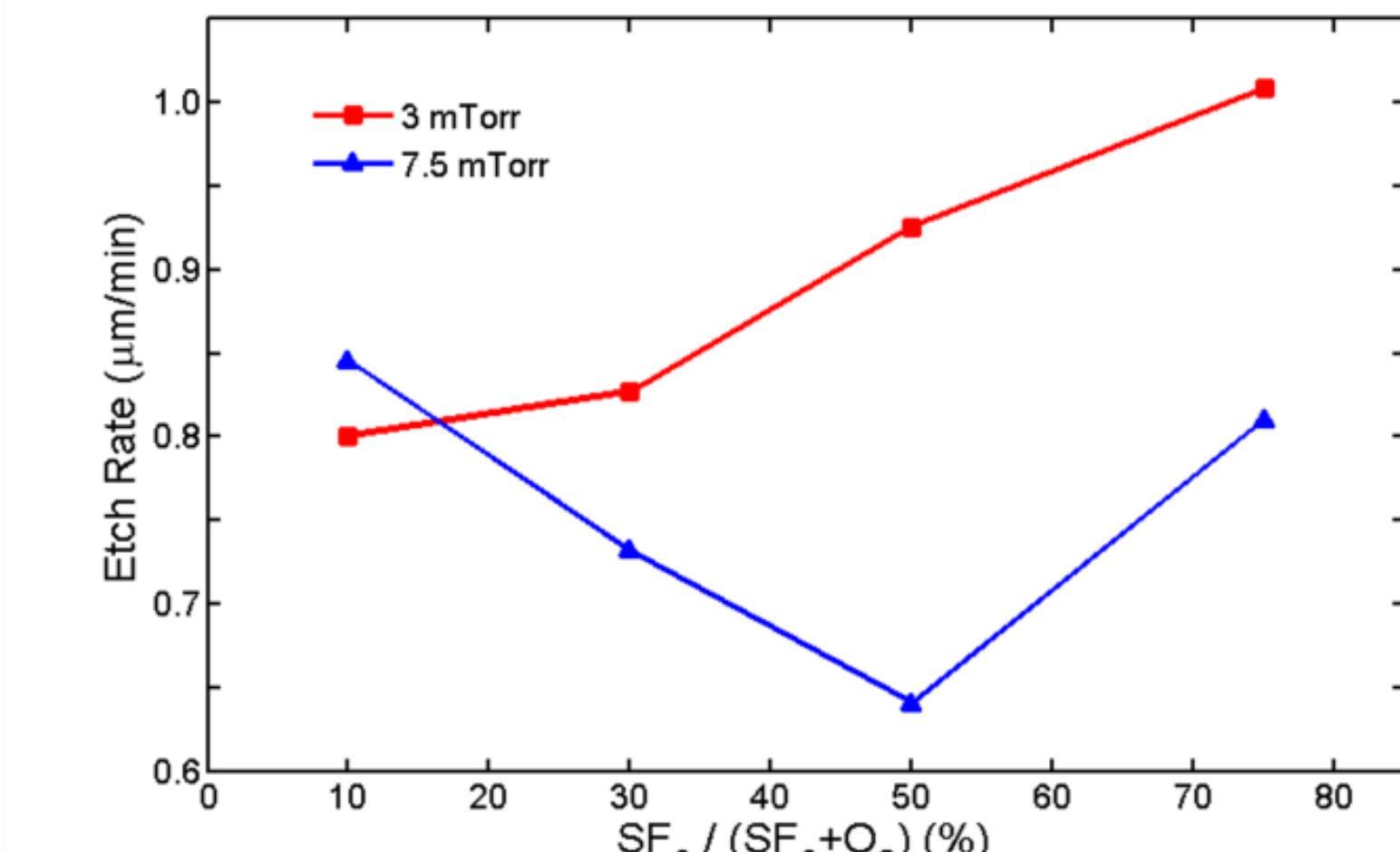
- Inability to convert silicon into the volatile SiF₄, quickly leading to a silicon rich surface.

The addition of just 10% SF₆ increases the etch rate to 0.85 $\mu\text{m}/\text{min}$.



Residue Formation

- Etch rate at 3 mTorr steadily **increases** from about 0.8 $\mu\text{m}/\text{min}$ to 1 $\mu\text{m}/\text{min}$.
- At 7.5 mTorr, etch rate **decreases** from 10% to 50% SF₆.
 - Correlated with residue formation.

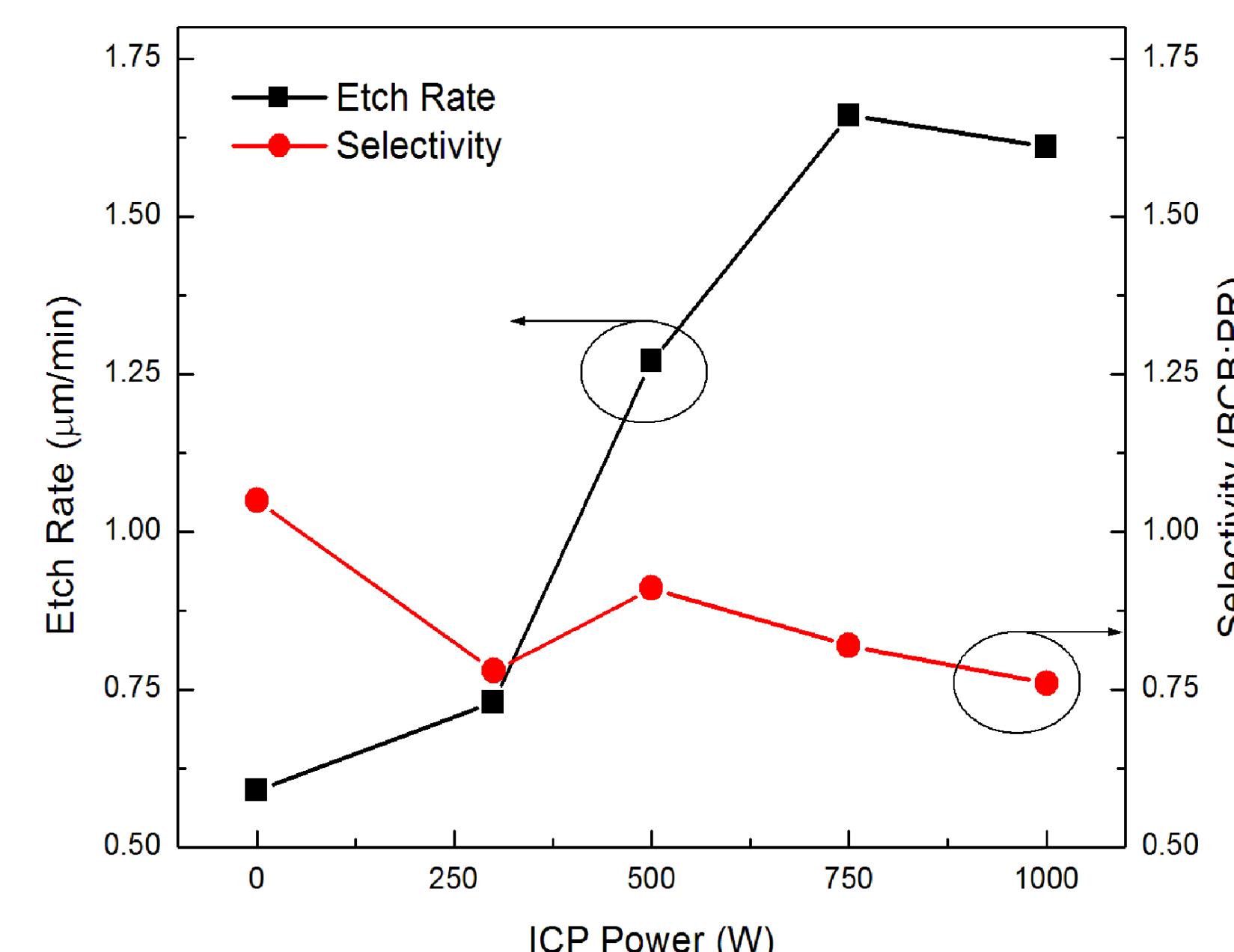


Comparison of etch rates at 3 and 7.5 mTorr with varying SF₆ concentration.

Effect of ICP Power

ICP power ranged from 0W to 1000W at an RIE power of 300W, 30% SF₆ concentration, and 7.5 mTorr.

- Etch rate is the lowest with no ICP applied.
- Increasing ICP power results in an increase in plasma density.



Below 750 W, etching of BCB is likely ion and radical limited. At 750 W and above, the etch rate is likely limited by the transport rate of reactive species to the substrate surface or even chemical reaction rate at the surface.

Increasing the chemical reaction occurring at the surface of the substrate by increasing ICP power will limit or prevent fluorocarbon formation and re-deposition.

CONCLUSIONS

Optimal etch conditions were obtained with ICP power of 300W, RIE power of 300 W, pressure at 3 mTorr, and 10 % SF₆ concentration.

This condition prevented the formation of micro-masking while obtaining:

- **significant etch rates (0.8 $\mu\text{m}/\text{min}$)**
- **selectivity of BCB:PR (0.9)**
- **sidewall morphology ($\sim 88^\circ$)**

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