TSV Etch Plasma Modelling from Chamber to Feature

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## Fundamental Research vs. Applications

<table>
<thead>
<tr>
<th>What do people want?</th>
<th>Fundamental</th>
<th>Application</th>
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<tbody>
<tr>
<td></td>
<td>Insights into fundamental plasma physics, precision is most important</td>
<td>Surface rates/composition/profile, speed is most important</td>
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<tr>
<td>Data for validation</td>
<td>Electron density and temperature, radical densities, EEDFs, PROES etc.</td>
<td>Surface rates/composition/profiles</td>
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</table>

Can we achieve a reasonable agreement between simulation and experiment when emphasizing speed over accuracy and with limited experimental data?
Rapier Module

- ‘Dual Source’ technology
- Recipe driven uniformity tuning
- High & uniform gas dissociation
  - Drives etch rate & uniformity
- ReVia™ *in-situ* end-point detection
  - Down to 0.01% via density
- Wafer edge protection option
  - Protect bond layer & carrier
- Si thinning & TSV etching
  - FO-WLP, interposer, via middle & via last
- Oxide etch capability
  - eg. Spacer etching for via last
Simulations with Quantemol-VT

- Based on the Hybrid Plasma Equipment Model
- In this case: fluid simulation for the reactor scale model, Monte Carlo for particle distributions at wafer
- Results are used in external Feature Profile Monte Carlo Model
- Stripped down chemistry (no “exotic” species, limited amount of neutral only reactions) imported from QDB
Quantemol database

- Developed for people working on plasma modelling with complex chemistries.
- Supports and compares multiple data sets.
- Quantemol has developed a plasma chemistry database to establish a trusted resource for plasma chemistry information.
- Chemistry sets could be used in different plasma modelling software via API.

Quantemol database provides:
- On going data updates and support
- Self consistent and validated chemistry sets
- One place to exchange data and research ideas

www.QuantemolDB.com
Absolute etch rates slightly overestimated.

Relative profiles are very well replicated. Differences between experiment and simulation are mostly observed at the wafer edge.
Etch profiles in SF$_6$

Excellent agreement for 200 mTorr. For 50 mTorr, good qualitative agreement, but absolute etch rate is underestimated.

Overall good agreement between simulation and experiment, except for pressure variation.
Simulated Bosch process

- Deposition step in $\text{C}_4\text{F}_8$ – medium pressure, no rf-bias
- Polymer removal step in $\text{SF}_6/\text{O}_2$ – lowest pressure, rf-bias of several 100 W
- Chemical etch step in $\text{SF}_6$ – highest pressure, small rf-bias
- Top power is kept constant at a few 1000 W, secondary power varies around some 100 W. For the last step, the secondary power is decreased each cycle. In the simulation, we divided the entire process into 10 subcycles with different powers on the secondary coil.
Currently, the etch is either too slow or too fast, depending on the etching probability used in the simulation. The smooth walls are replicated well, while the side walls are not as straight in the simulation as they are in the experiment.
Experimental feature profiles
Power variation

Low power → High power on secondary coil during polymer removal

Middle of the wafer

Edge of the wafer

Edge tilt ~3°  Edge tilt ~2°  Edge tilt ~0.5°
Example variation: secondary power for polymer removal

The flux of atomic shows no significant changes, as it is mainly provided by the top coil. The ion flux, on the other hand, changes significantly.
In the centre, we observe symmetrical IADFs with no significant differences for different secondary ICP powers. At the edge, there is a shift which is larger for small ICP powers.
For low ICP powers, the IEDFs shift towards higher energies. The IEDFs at the wafer and the edge differ in shape, but cover roughly the same energy intervals.
Simulation feature profiles

50 W

350 W

550 W

Middle of the wafer

Edge of the wafer
Conclusions and Outlook

Can we reproduce experimental results reasonably well with the limitations of application based simulations?

We can reproduce:
✓ Deposition on a blanket wafer
✓ Etch rates on a blanket wafer
✓ Variation of surface rates as a function of power and gas flow
✓ General feature profile shape
✓ Tilt of feature profiles as a function of secondary power

We can still improve:
✗ Variation of surface rates as a function of pressure
✗ Depth of final feature profile
✓ Effect of secondary power on side wall roughness

Answer: Careful, but optimistic yes.
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