Fault Classification for Deep Si Etch

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PESM
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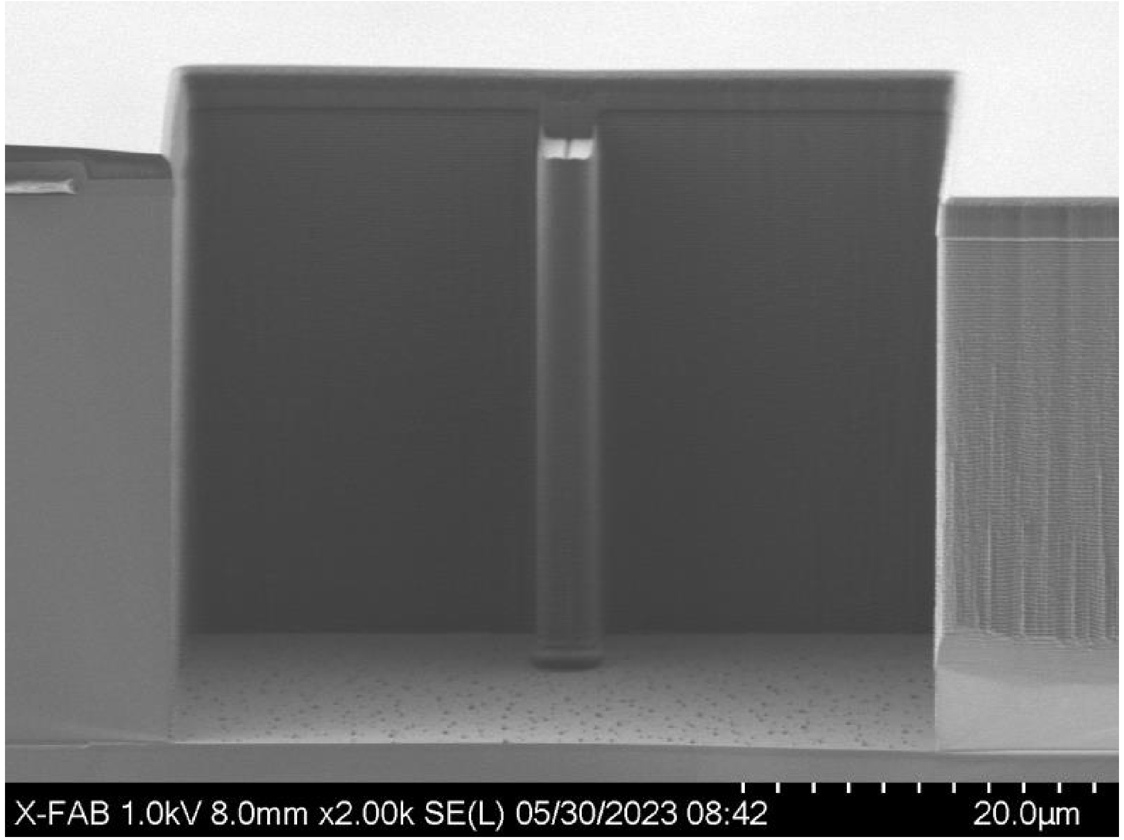
Content

Current Production Recipe for Si DRIE and Normal Result

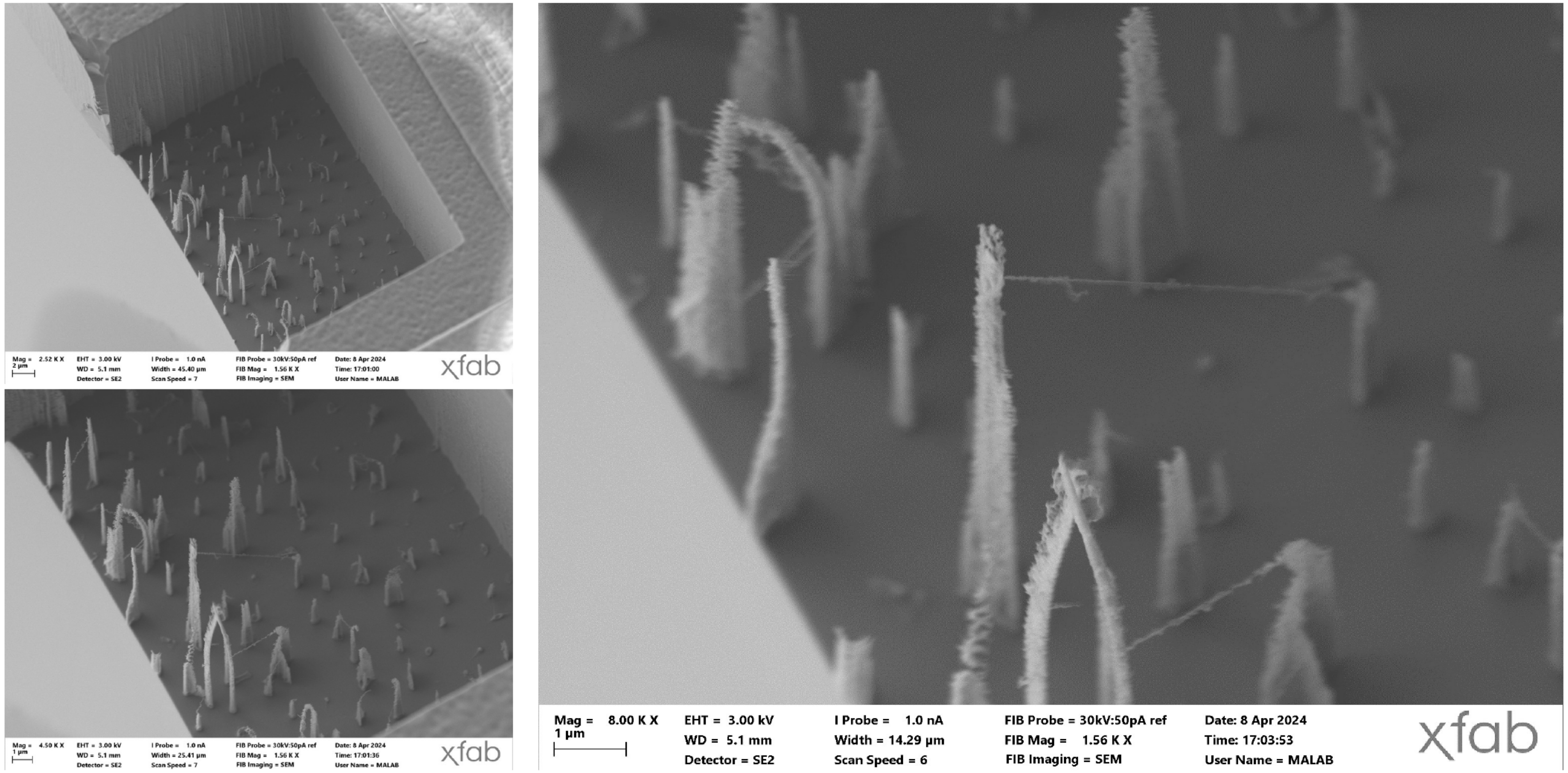


Deep reactive ion etching process (Bosch), alternating with these steps in so-called loops:

- Polymer deposition at sidewall
- Polymer etch at bottom of feature
- Si etch

Process Issue – SEM at 12 o’clock

- Running stable some years
- Silicon grass
- Change within three days
- New process state?



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Digital Twin

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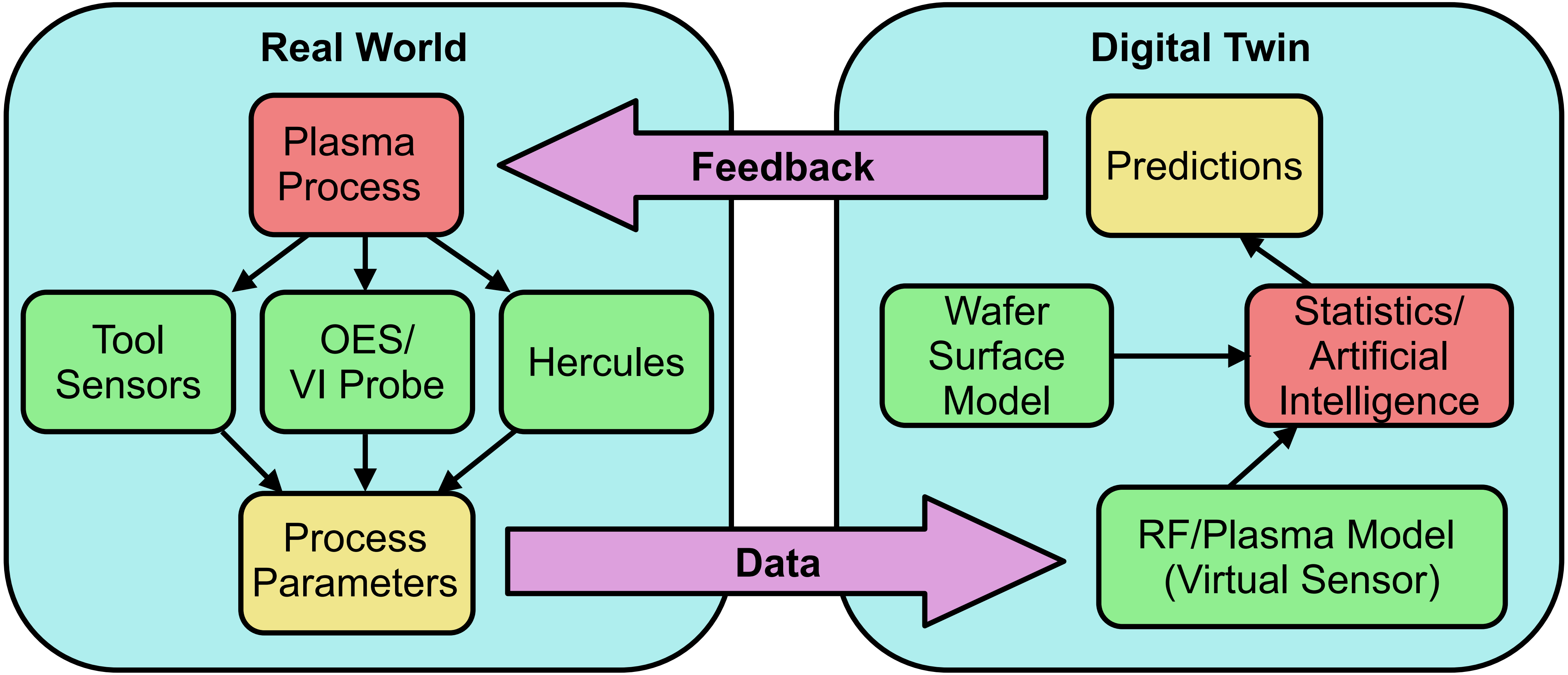

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Analysis

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Questions

- What did really change?
- Why did it change?
- Problem solution?

- What are the right approaches to answer to questions above?

Potential root causes:

- Phase angle between source and bias power
- RF power in plasma
- Chamber conditioning
- Software update (done within three day before problem occurs)
- Maintenance measure? …

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Tool: SPTS DSi

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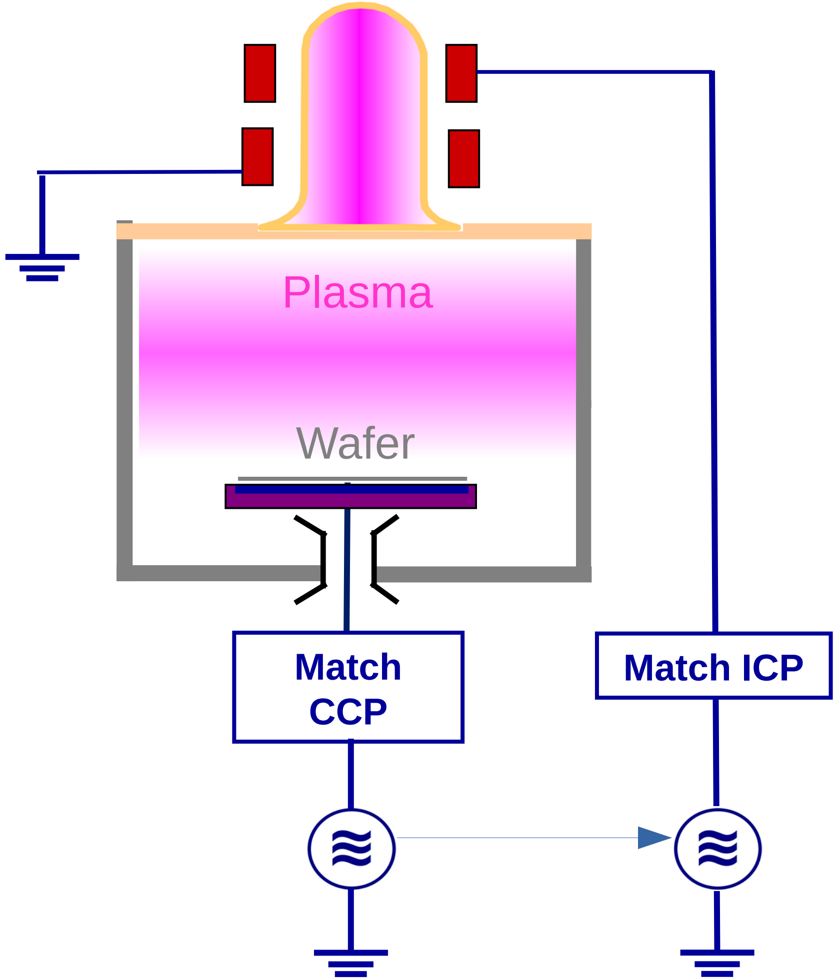
- Three power dissipation mechanisms
  - Inductive by coil
  - Capacitve by coil
  - Capacitive at wafer (bias power)

- Needs frequency synchronization and phase adjustment.



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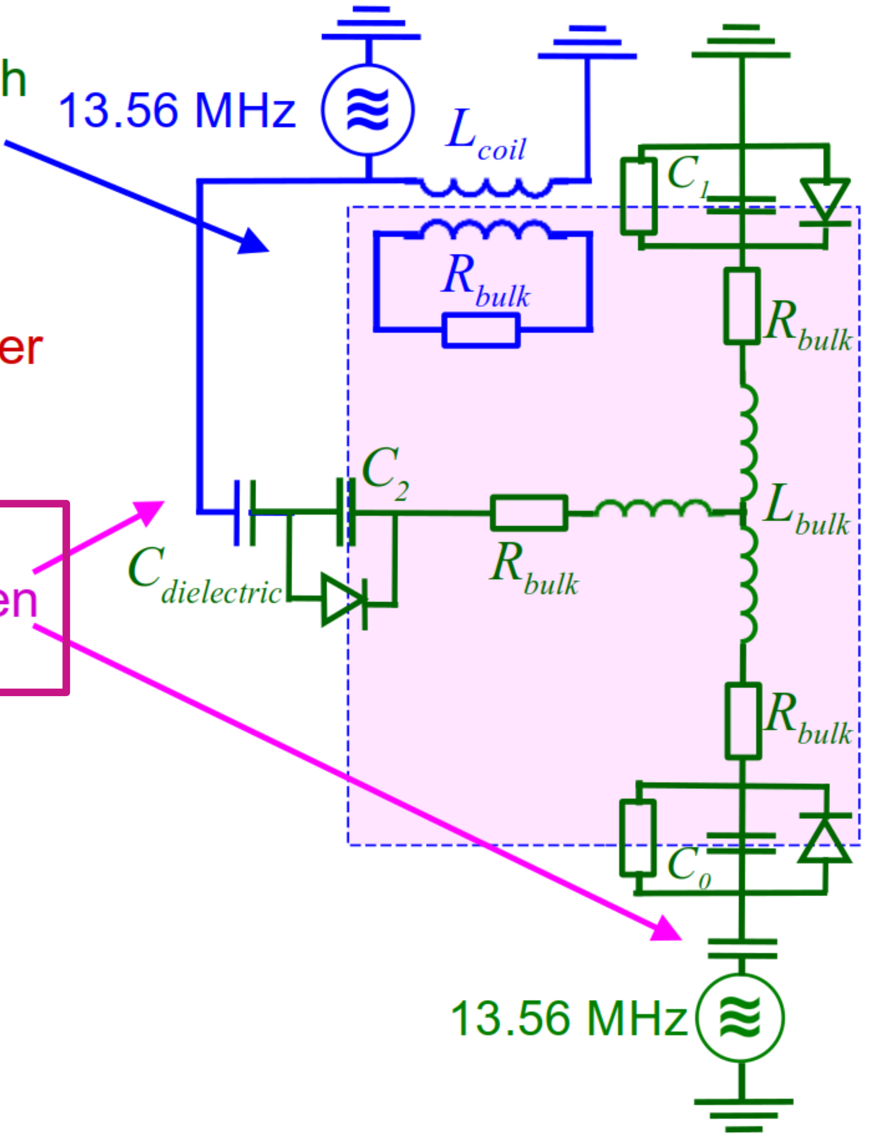
Equivalent Circuit ICP / TCP®: Master-slave Control

- Additional capacitive coupling through dielectric window(up to 1/3 under normal conditions)
- Phase angle between upper and lower capacitive coupling affects sheath potentials!
  Phase angle between currents or voltages (coil and chuck), not between voltage and current!
- **Attention:** Please check the compatibility of the CEXIN and CEXOUT of generators! (Sinus or rectangle, signal level, Impedance 50 Ω, TTL signal?)



Source: ©Plasmetrex Plasma School Plasma Fundamentals

How to Determine the Phase Angle in Plasma ?

- Challenge
  - Tool data? Except C_{load} of bias matchbox, they do not help!
  - Phase angle between generators is set but contributions to the relative phase shift in the plasma may be cable length and mismatch of the matchboxes.
  - The phase change does influence the plasma sensor Hercules directly, but the model for the parameter calculation.
- Solution
  - The relative phase angle can be varied by the bias generator settings.
  - Analysis of plasma sensor data by a nonlinear process model.

Model for Variation of Relative Phase φ

- RF wall current measured by Hercules
- Assumption: Bias power is constant. during the phase variation, $\alpha_1 \approx 0.1$ is the area ratio of electrode A_0 and wall area A_1.
- The nonlinear model predicts a superposition of two RF currents from driven electrode and coil and is used for parameter estimation.
- I_+ denotes the ion flux and $P_{+,tot}$ the total ion/bias power.
- The RF current driven by the bias power at wafer results can be reduced to and allow bias power supervision

$$I_{bias} = \omega \sqrt{\frac{3 \cdot 2^{3/2}}{13} \frac{A_0 \epsilon_0}{\sqrt{e_0}}} \sqrt[4]{I_+ P_{+,tot}}$$

$$I_{wall} = I_{bias} \sqrt{\frac{I_{bias}^2 + I_{coil}^2 + 2 I_{bias} I_{coil} \cos\phi}{I_{bias}^2 + \alpha_1 \left(I_{bias}^2 + I_{coil}^2 + 2 I_{bias} I_{coil} \cos\phi \right)}}$$

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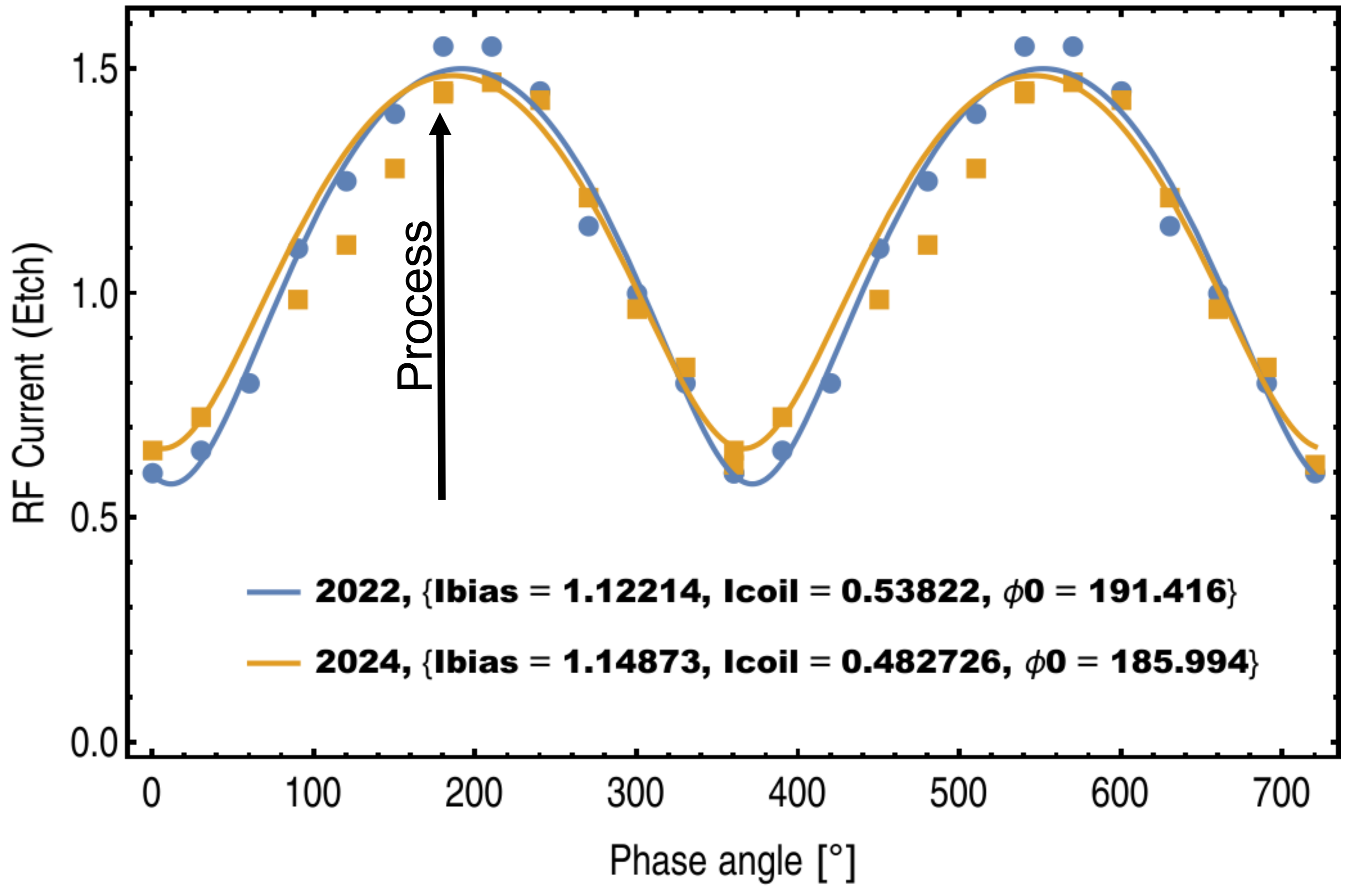
Etch Step: RF Wall Current vs Phase Angle

- Curve fitting provides parameter estimation, φ_0 describes the phase of the maximum RF current.
- Phase angle and current from wafer (bias) basically the same
  → No change of bias power!

$$I_{bias} = \omega \sqrt{\frac{3\cdot 2^{3/2}}{13} \frac{A_0 \epsilon_0}{\sqrt{e_0}}} \sqrt[4]{I_+ P_{+,tot}}$$



Reduced RF current from coil drops from 0.54 A to 0.48 A.
→ Less coil V_p → source power ↓

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Etch Step: Phase Angle vs Hercules Asymmetry

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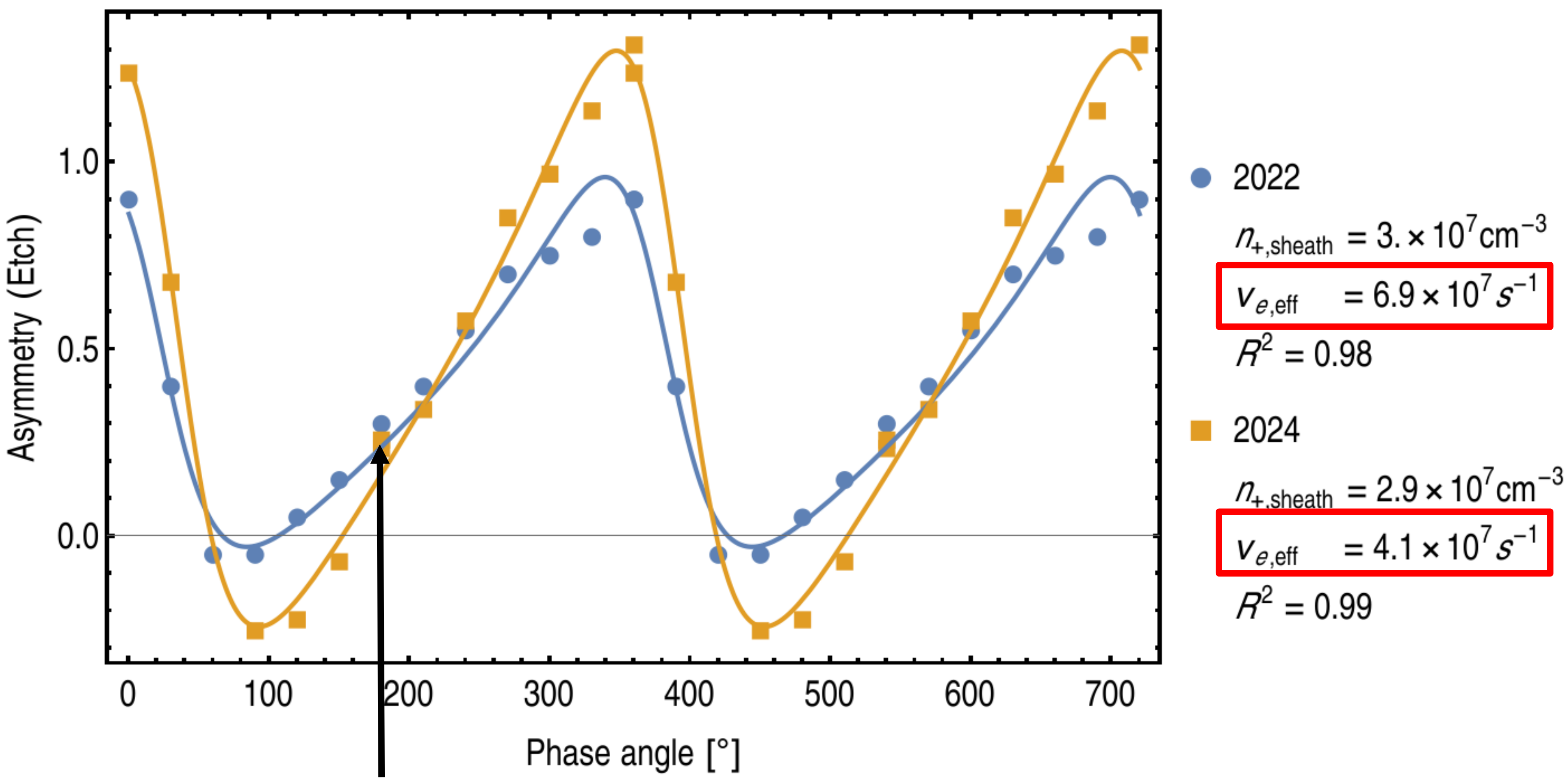
- No change in electron density
- But the local collision rate decreases.
- Electron collisions drive the local physics and chemistry → less ions and radicals.
- Background: Lower electron temperature (due to source power loss) or lower gas density.



Process runs at 180°, difference is tricky to observe without phase variation!

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Interim Conclusion

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Etch rate similar

Less current from coil → Less source power

Local chemistry in front of wafer different!
More polymer deposition with test process!

Is there a transition point, E-H mode transition?

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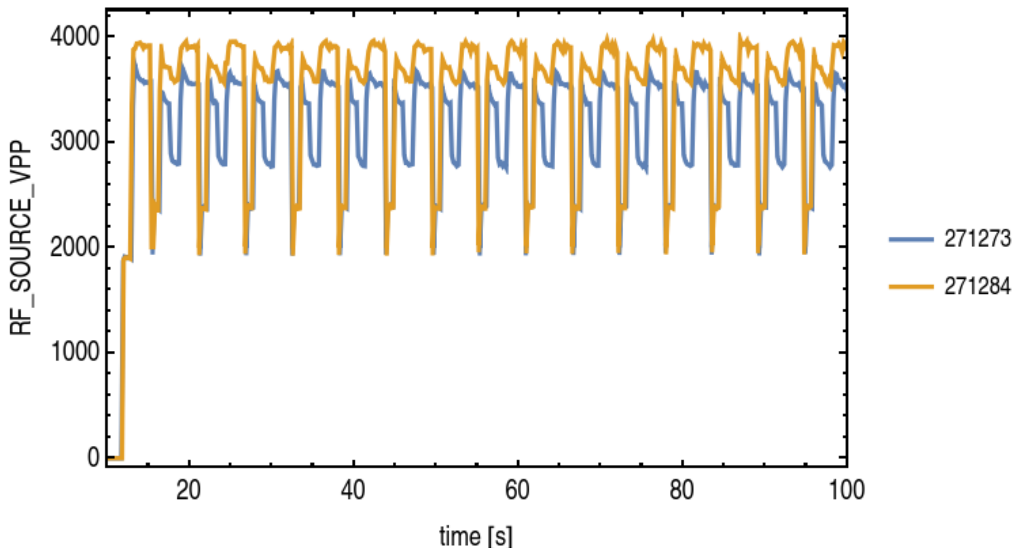
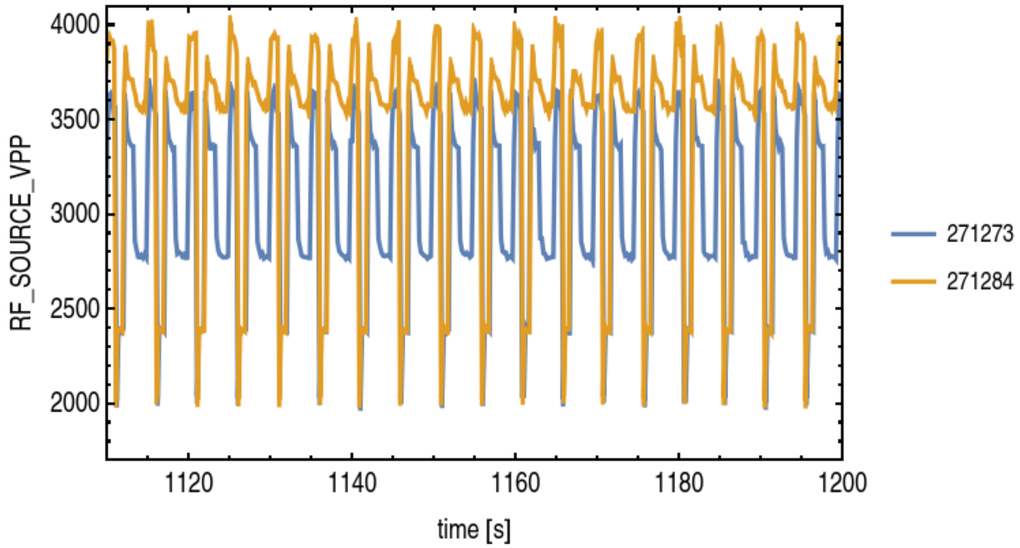
Problem Solved by more Source Power ?

- Source Power Increase 2500 W → 2900 W → No E-H-Mode Transition
- Vpp grows with power → no E-H-mode transition but time ramp in recipe from begin to end.
- Now again more Vpp → more capacitive coupling → again more current from coil.
- Also no grass any longer!





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RF Wall Current by plasma sensor Hercules

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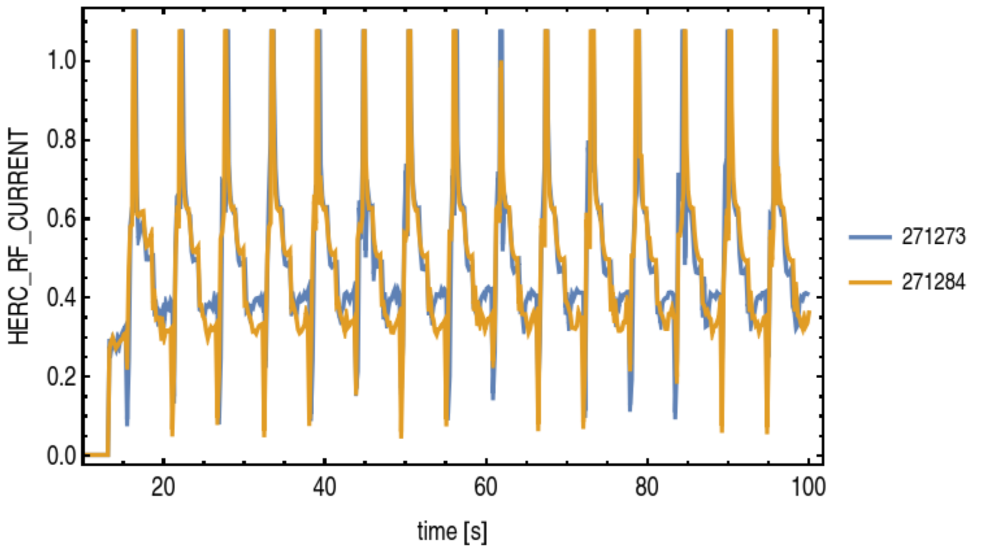
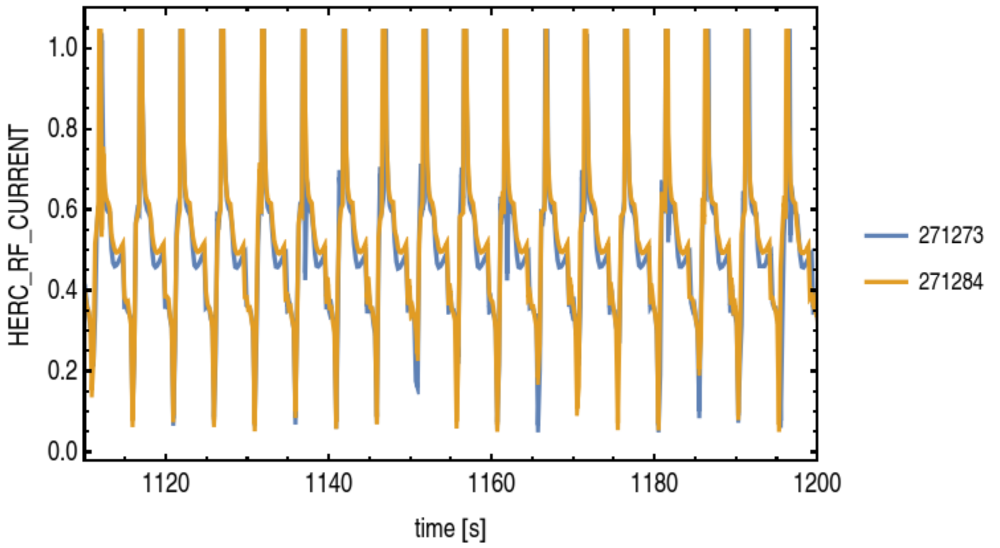
- Structure of process visible in RF wall current.
- Current peak in Ar flush step with 1000 W source power.
- But finally only little changes due to $I_{\text{wall}} \propto P_+^{1/4} \approx P_{bias}^{1/4}$
- Verified: No E-H mode transition!





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Interim Conclusions

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Grass away with higher source sower

New process more stable

No E-H mode change but process transition by internal source power loses

Recover with more source power

Mechanisms/Background

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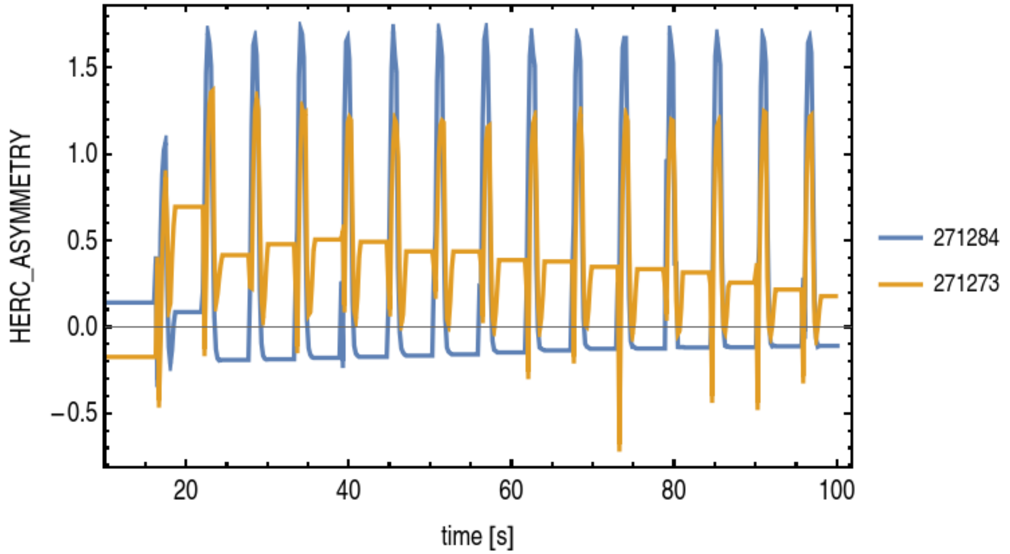
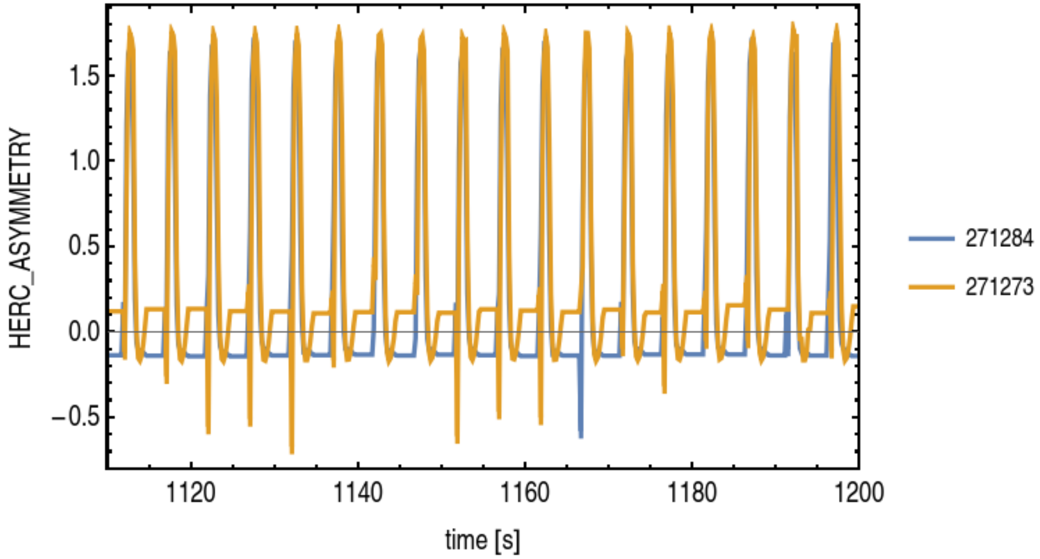
Hercules Asymmetry

- Well pronounced jump in Hercules plasma parameter Asymmetry with higher source power. In every single loop step back to the original value.
- Main issue: Different local electron heating in front of wafer.
- Excellent fault indicator, as already shown in the phase variation!





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Summary and Conclusions

- A deep Si etch process, running well for some years, leaves grass = black Si at the bottom of the feature
- Defect detection: SEM, plasma parameters
- Faults classification and deeper understanding:
  - Phase angle variation between source and bias shows that the coil current reduced. This points to a loss of source power .
  - Process model based of tool and sensor parameter Asymmetry provides key parameters. One of them, the collision rate, indicates less power dissipation in front of the wafer.
- Solution: Increase of source power, verified by process, understood and verified Hercules Asymmetry.
- Lesson learned – supervision by FDC
  - Hercules Asymmetry. → Clear fault pattern, support classification!
  - C_{load} of bias matchbox, reduced temporal resolution.
  - Likely Vpp at source, needs more investigation.