The application of gallium oxide high power devices by etching process optimization

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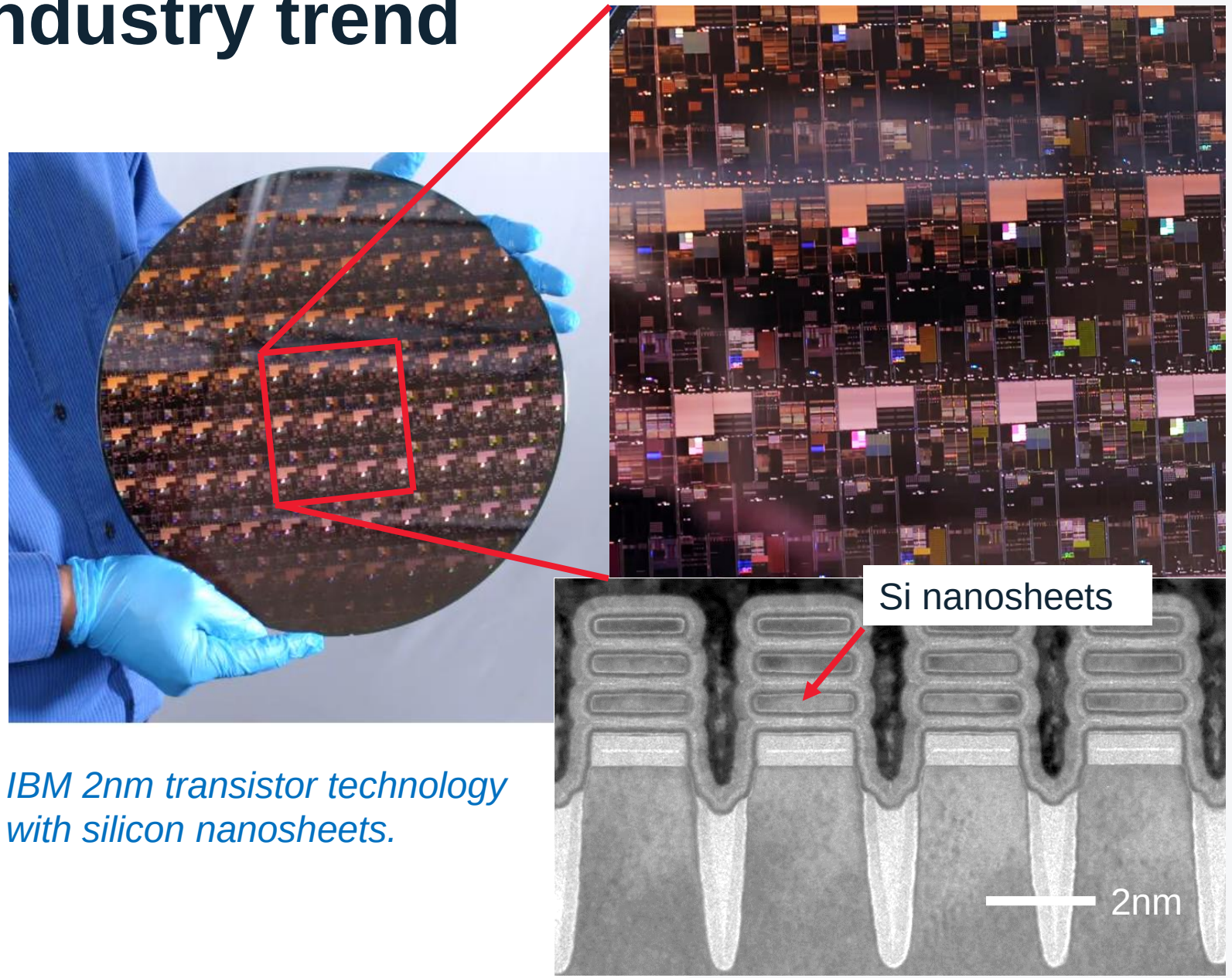
Semiconductor industry trend

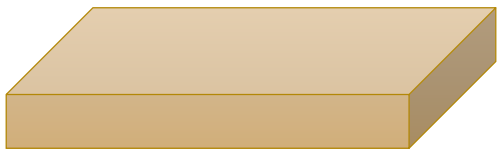
- Increasing number of devices on a single wafer
- Faster processing speed
- Lower energy consumption
- Smaller critical dimension (thousand times finer than hair)

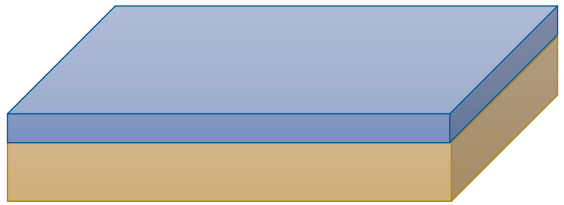
Improve the manufacturing technology is becoming more important



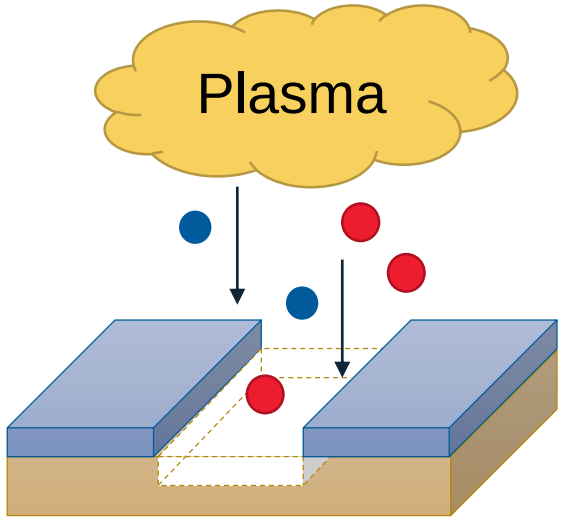
IBM 2nm transistor technology with silicon nanosheets.

Plasma etching process

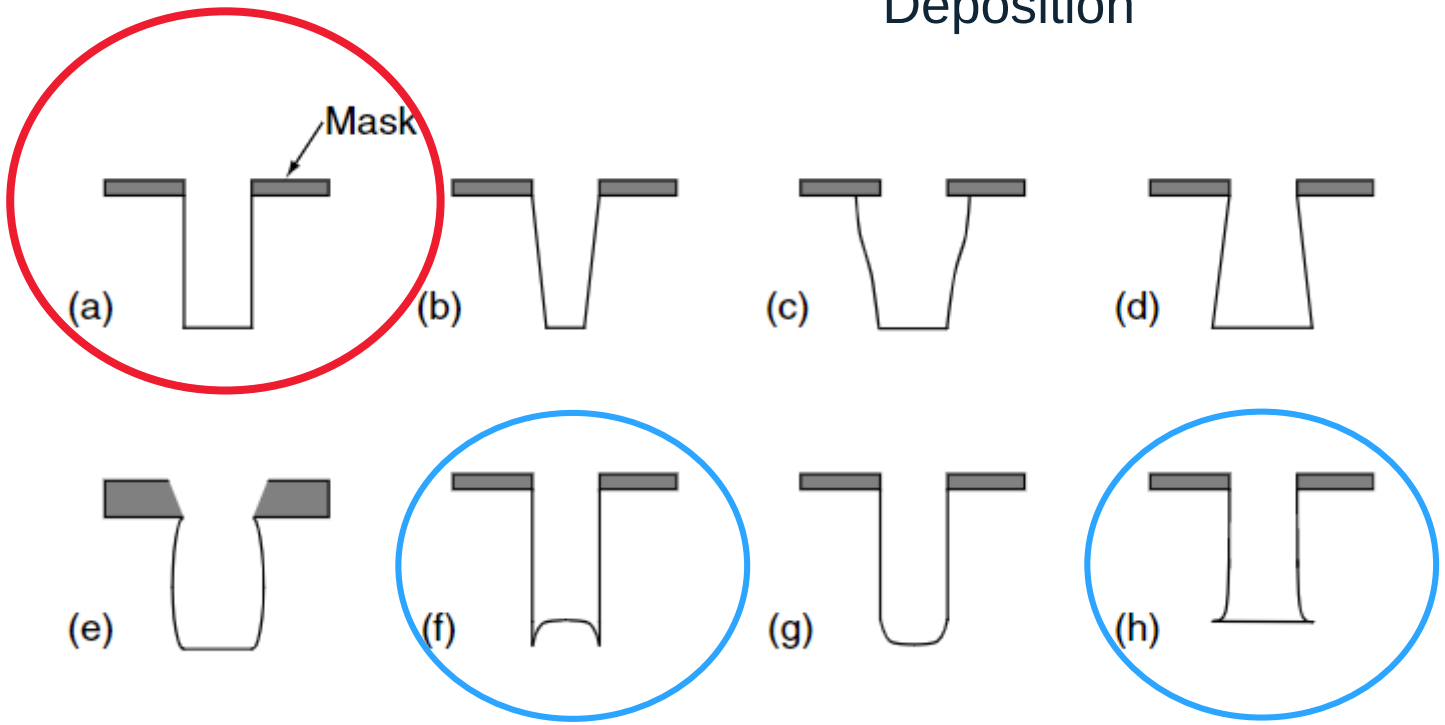




Deposition



Etching



a) Vertical sidewall
b) Tapered sidewall
c) Under-cutting
d) Re-entrant profile
e) Bowing
f) Micro-trenching
g) Curved bottom
h) Notching

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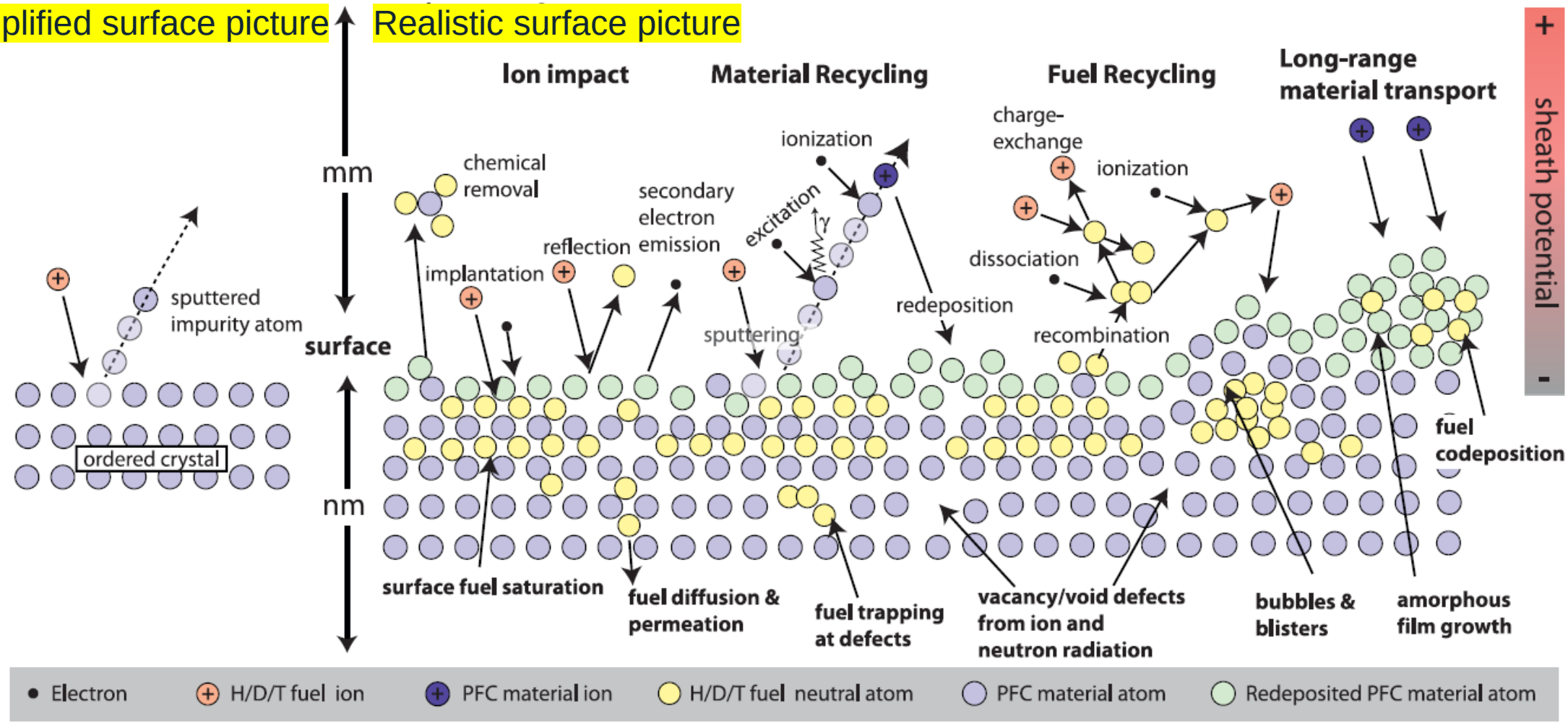
Plasma-surface interaction



Schematic diagram of surface interactions occurring at the material surface in a plasma environment[1].

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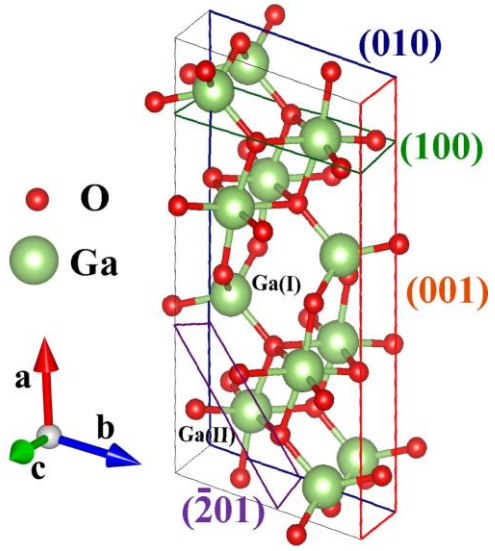
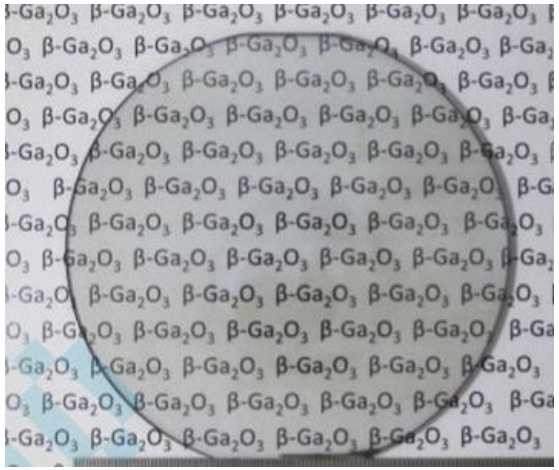
1. Wirth, B.D., et al., *Fusion materials modeling: Challenges and opportunities.* MRS Bulletin, 2011. **36**(3): p. 216-222.

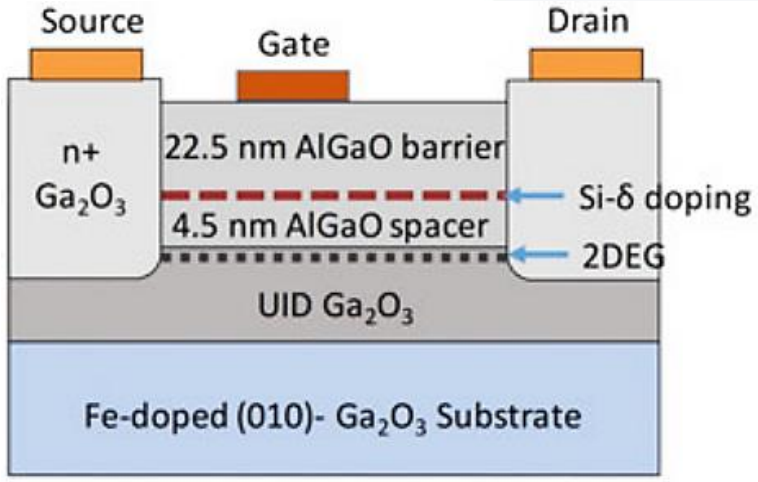
Etching materials

Ga_2O_3

- Schottky barrier diode (SBD)
- FinFET
- Solar cell
- Laser

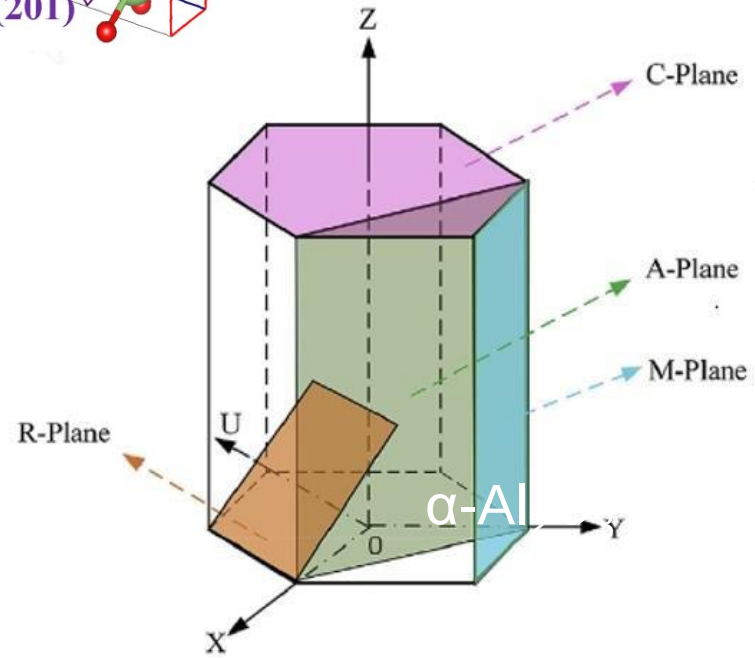






Al_2O_3 - sapphire

- Laser
- Protective window
- Microwave - RF



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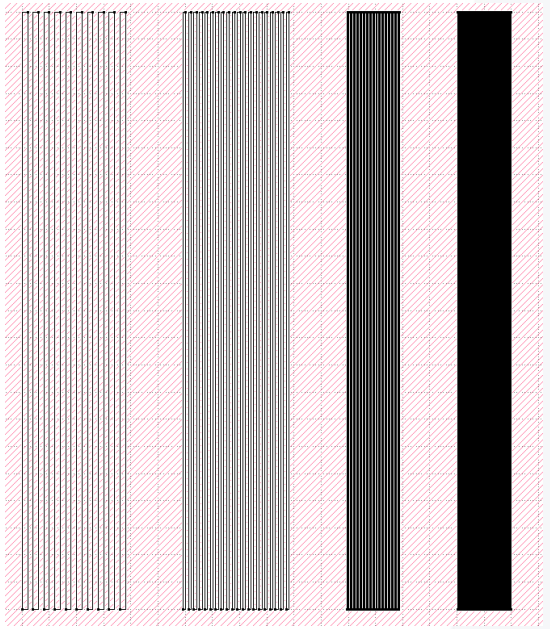
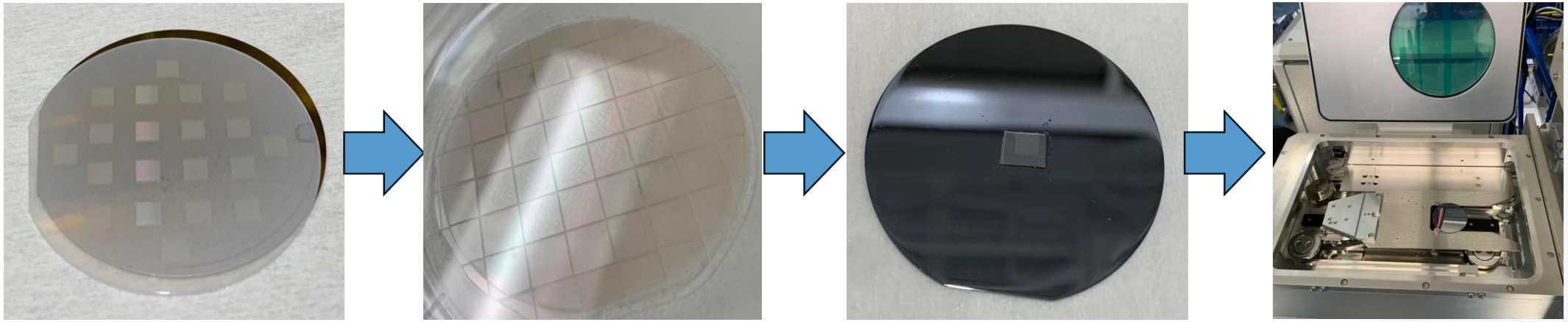
Experiment

- *ICP power*: 500-1500 W
- *RF power*: 100-300 W
- *Chamber pressure*: 5-15 mTorr
- *Gas composition*: 20-80% BCl_3 and Ar

- Etch rate
- Selectivity over covered material
- Etching profile





Process flow of etching experiment

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Results

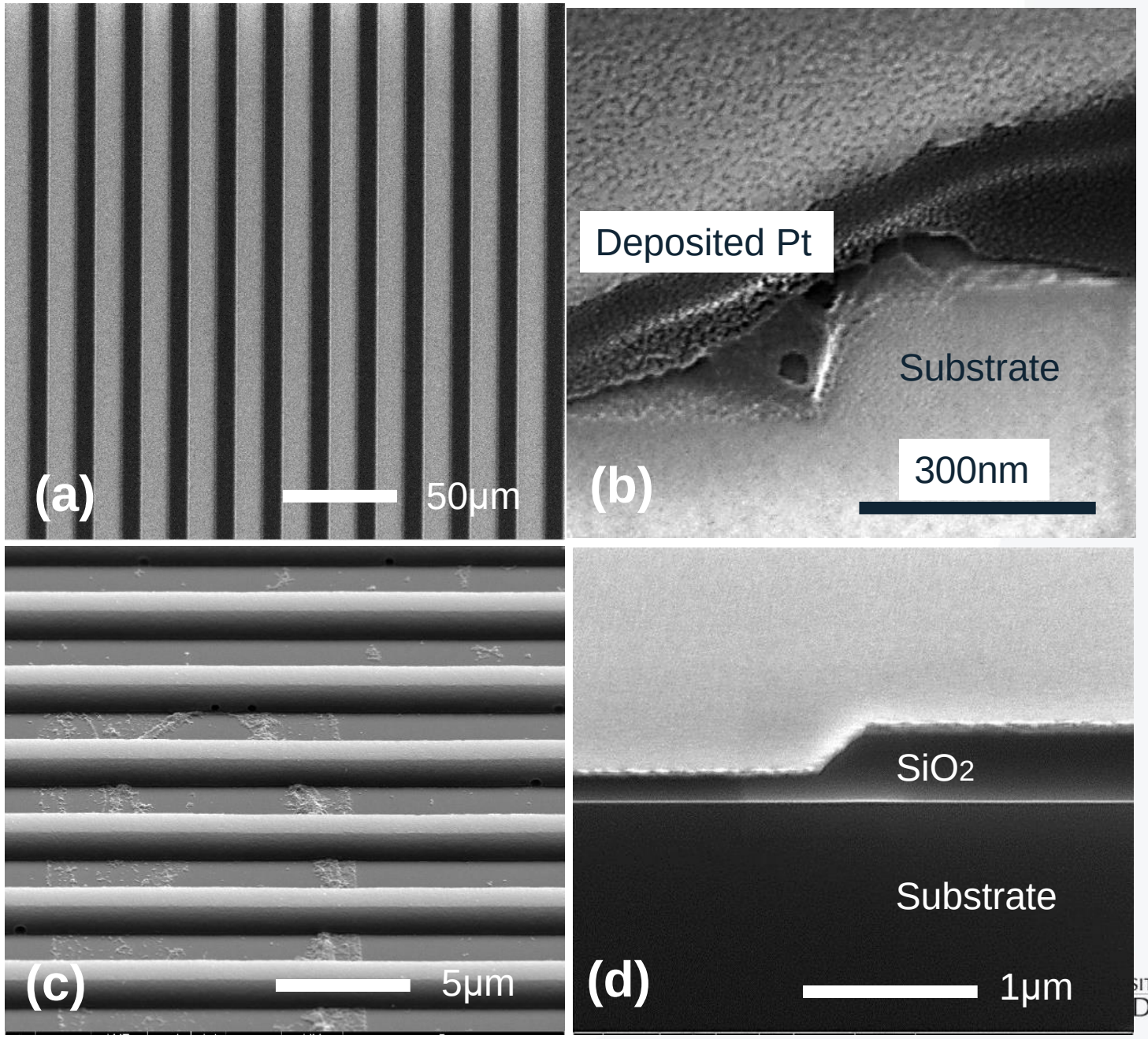
SEM images for

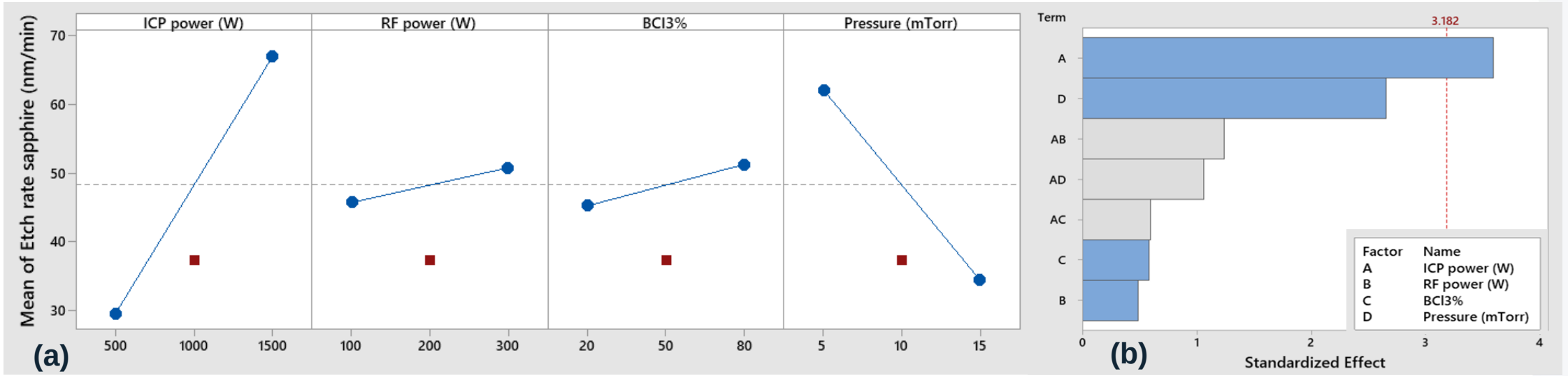
(a) 10μm features

(b) Cross-sectional view of a etched substrate

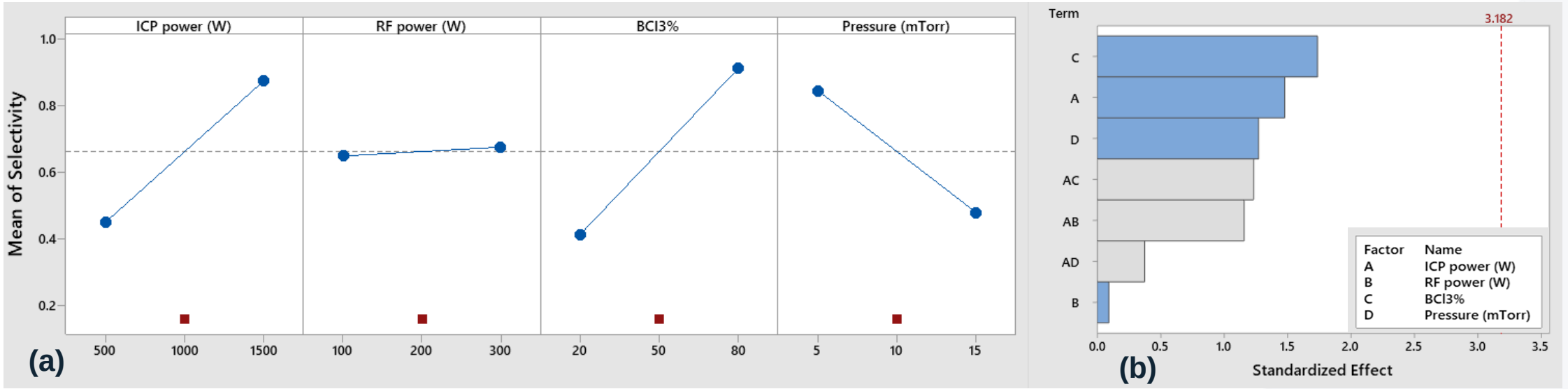
(c) Surface of 2 μm features

(d) An unclear etch of SiO_2 hard mask.





(a) Main effect plot and (b) Pareto chart for etch rate with four factors.



(a) Main effect plot and (b) Pareto chart for selectivity with four factors.

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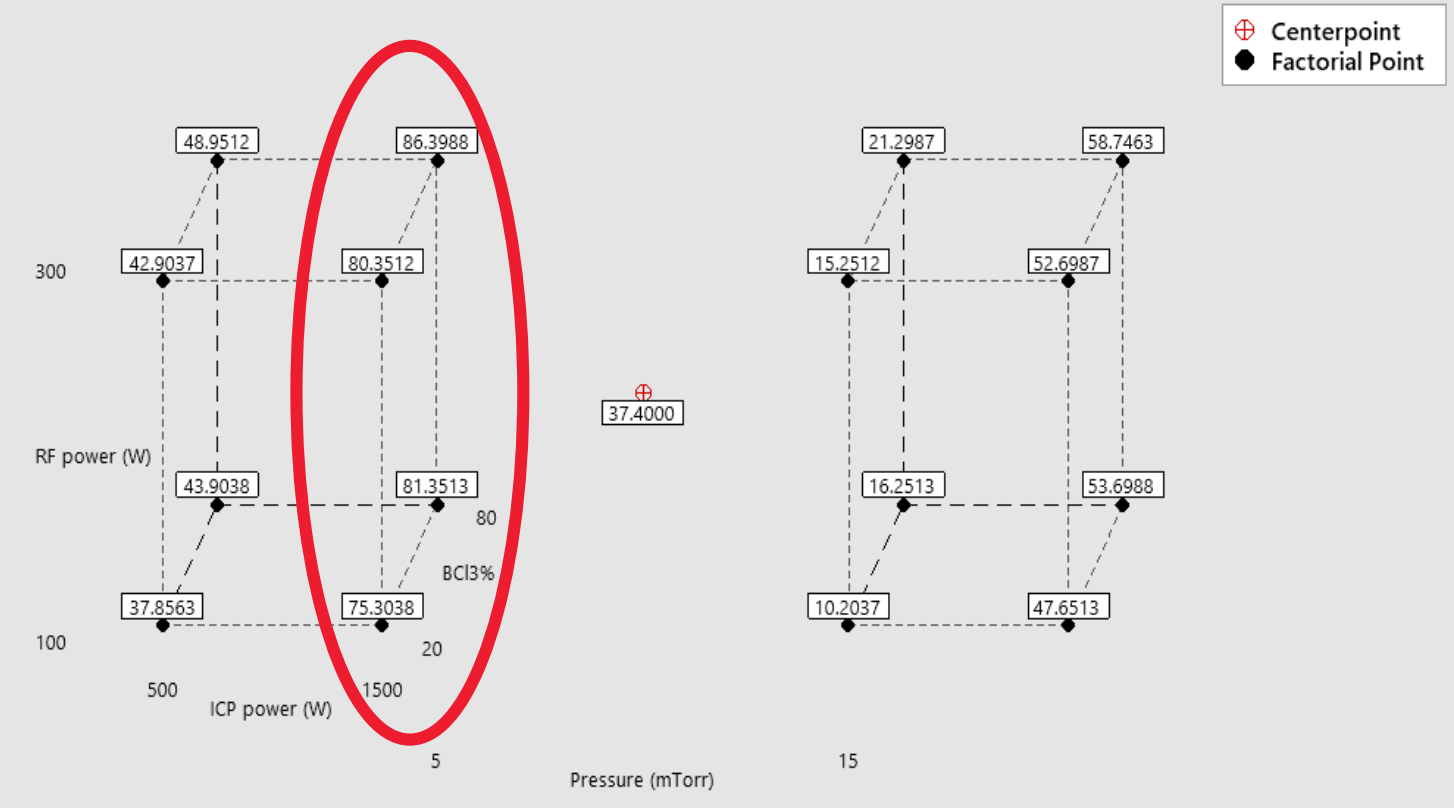
Results



Cube plot (fitted means) for etch rate (nm/min).

- ICP power has the most significant impact on etch rate.
- A lower pressure generally increases the etch rate.
- BCl_3 plays the main role of increasing selectivity.
- Combined effect of two factors cannot be neglected.

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Conclusion & Future work

- Effects of four etching parameters are understood better.
- Optimized etch rate of 96 nm/min was achieved.
- Photolithography process still needs further optimization.
- We plan to work on molecular dynamic simulation for a better understanding of plasma-surface interaction.
- Machine learning is a promising direction when the reaction mechanism is complicated.

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