Ru Etching by ICP with O_2- and Cl_2- Containing Plasma

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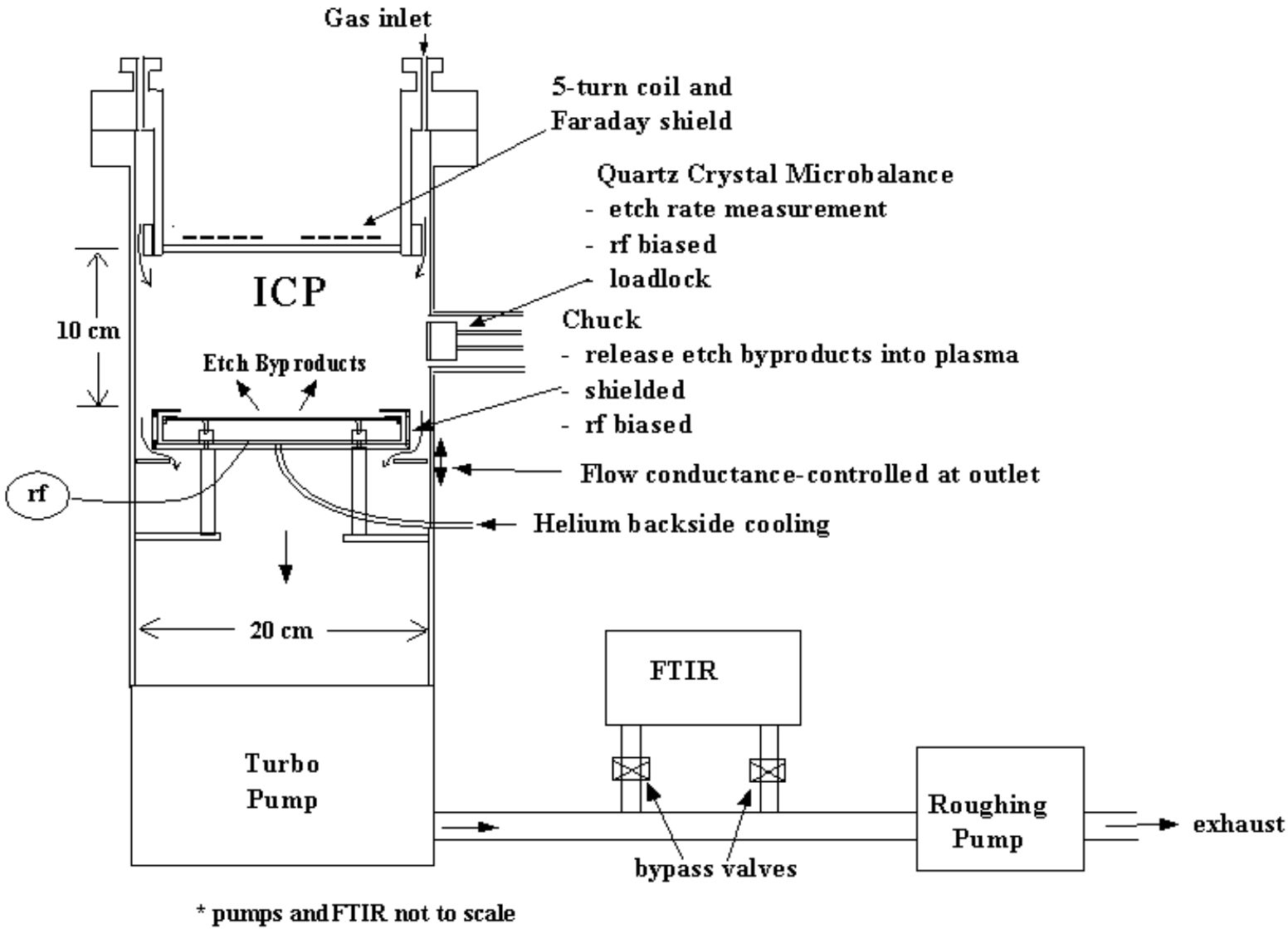
Talk Outline

- Why Ru: Model for ESH/Etch Issue
- Experimental Apparatus
- Experimental Approaches
- Studies of Ru etching and the Effect of Cl_2 Addition
- Conclusions
- Acknowledgement

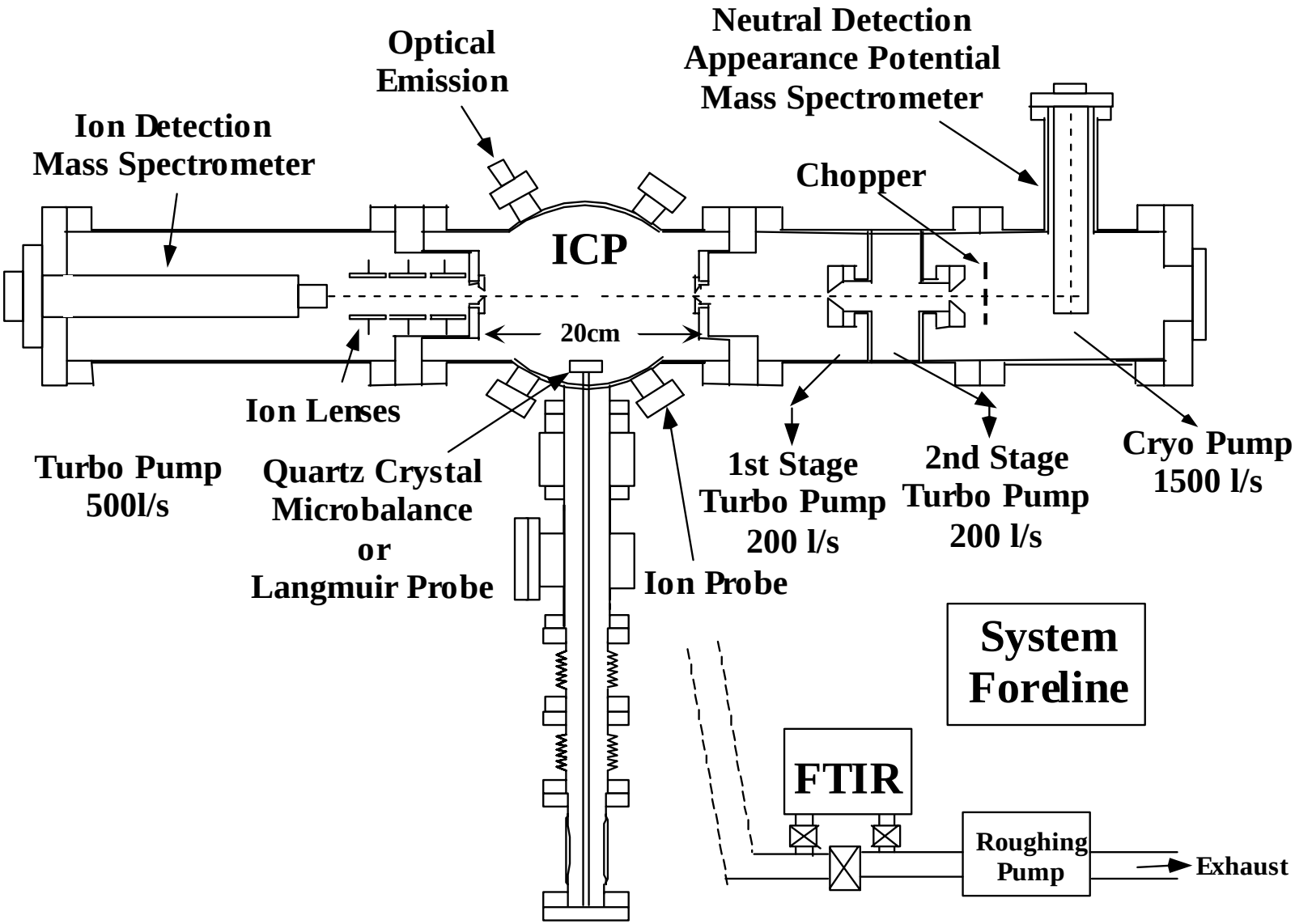
Ru Etch as Model for ESH/Process Interactions

- Why Ru?
  - Ru and RuO_2 are both conductors and have been proposed as new metal gate electrode materials
  - Proposed metal gate materials include: Ta, Ti, Zr, Ni, Mo, Ru, Pt, Ir, Ni, W; MoN, WN, TiN; In_2O_3, SnO_2, RuO_2 ;CrSi, WSi_x
  - Many new materials: need to develop ***systematic procedures*** to assess **process** and **ESH impacts** of etching.
- Ru Etching
  - Ru can be etched readily by O_2 based plasma and forms volatile etching by-product RuO_3, and RuO_4. What about etch by-product interactions with walls? Where do etch products go? How does this depend on chemistry/operating conditions?
- ESH
  - By-product RuO_4 may be toxic; Chose Ru etch as model etch by-product study.

Experimental Apparatus (side view)



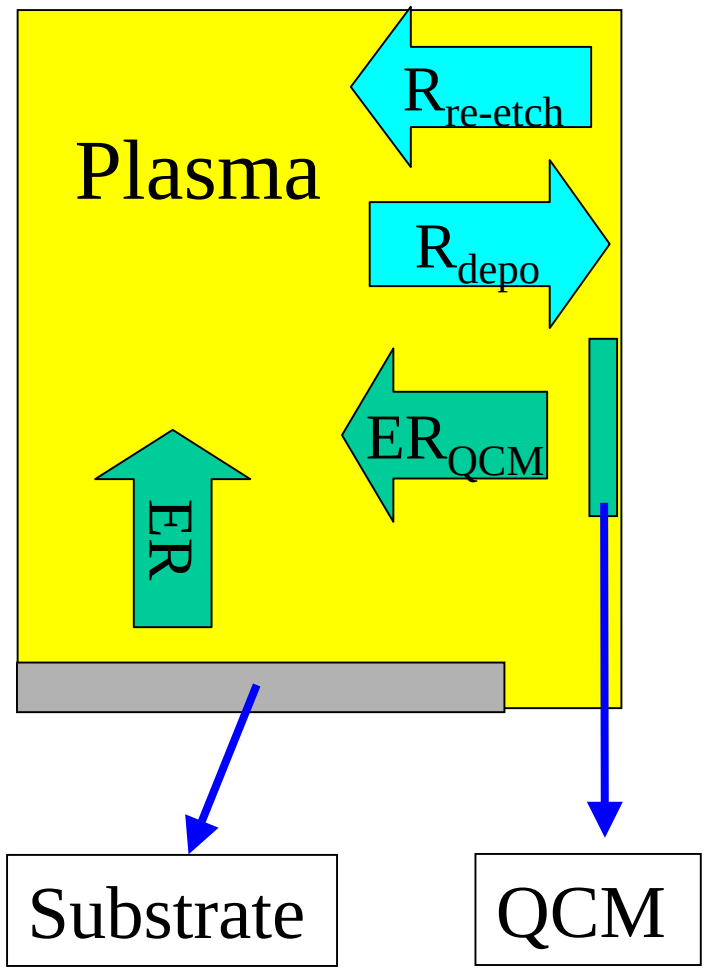
Experimental Apparatus (Top View)



Experimental Approach

- Apparatus
  - ICP with *in-situ* diagnostic tools: ion MS, neutral MS, QCM, OES downstream FTIR
- Conditions
  - Ar/O_2 containing plasmas with or without Cl_2 addition
- Etching Rate Measurement
  - Film Etching Rate
    - 150mm wafer with Ru film prepared by sputtering
    - Film thickness measurement before and after etching with 4-point probe
    - Substrate can be biased up to 150V
  - Etching Rate on QCM
    - Ru coated QCM crystal, *In-situ* E/R measurement
    - Etching by floating potential plasma (not biased)

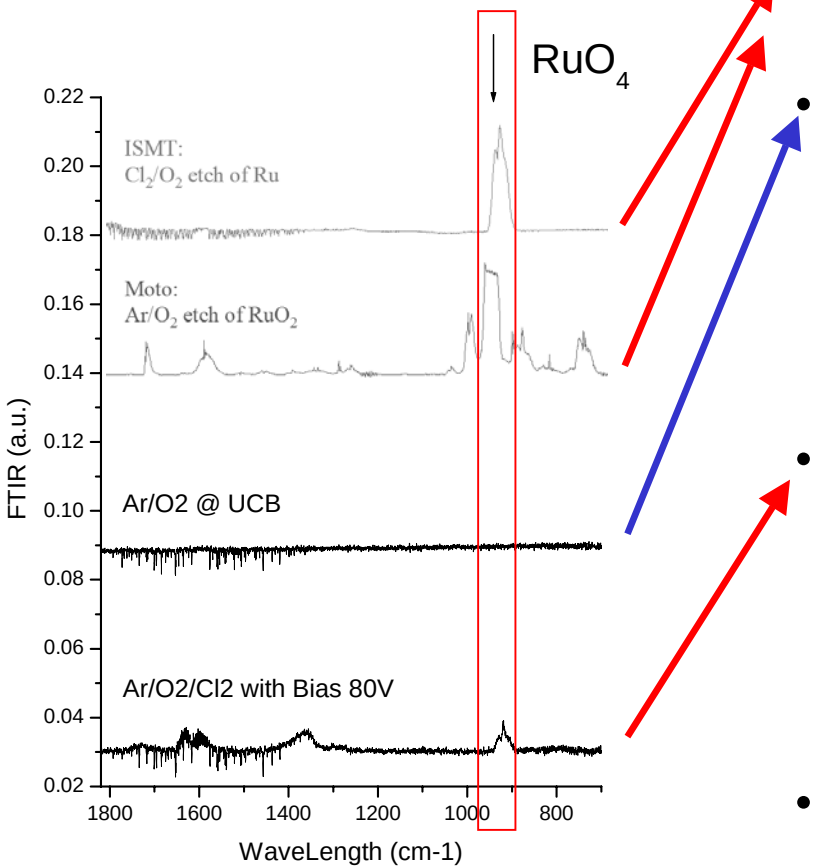
Experimental Approach, cont.



- **Case 1 (Film Etching Rate)**
  - Substrate: Ru film, QCM: Bare Crystal
  - Measure ER (film etching rate), and Wall Deposition Rate ($R_{QCM}=R_{depo}-R_{re\text{-}etch}$)
  - Generate significant etch by-products, hence possible be detected by FTIR, ion MS, or Neutral MS.
- **Case 2 (Etching Rate on QCM)**
  - Substrate: Copper Plate, QCM: Ru Coated Crystal
  - Measure ER_{QCM} (*in situ*)
  - Very small exposed Ru coated area, ~0 R_{depo}, hence ~0 $R_{re\text{-}etch}$
  - Only small amount of etch gas was consumed, hence inlet gas chemistry was studied.

Cl_2 addition effect: wall deposition rate, film etching rate and effluent species

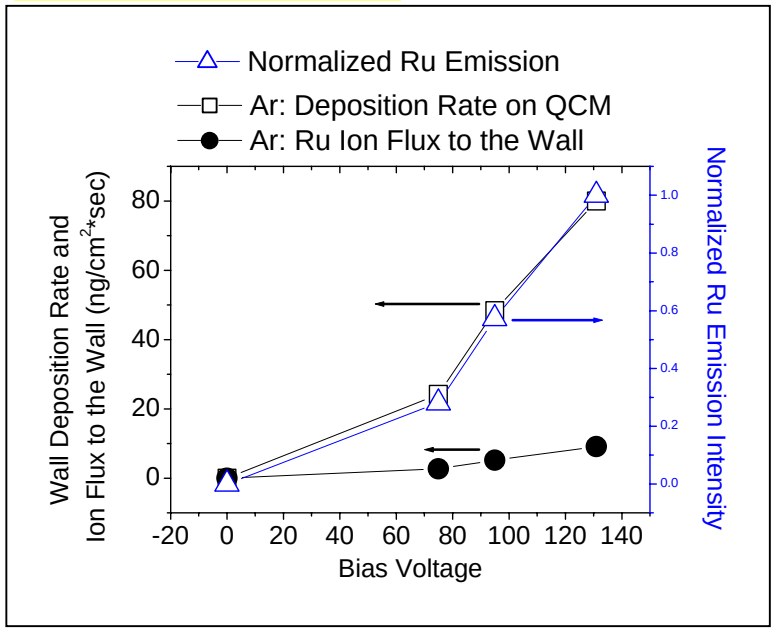
Effluent: downstream FTIR



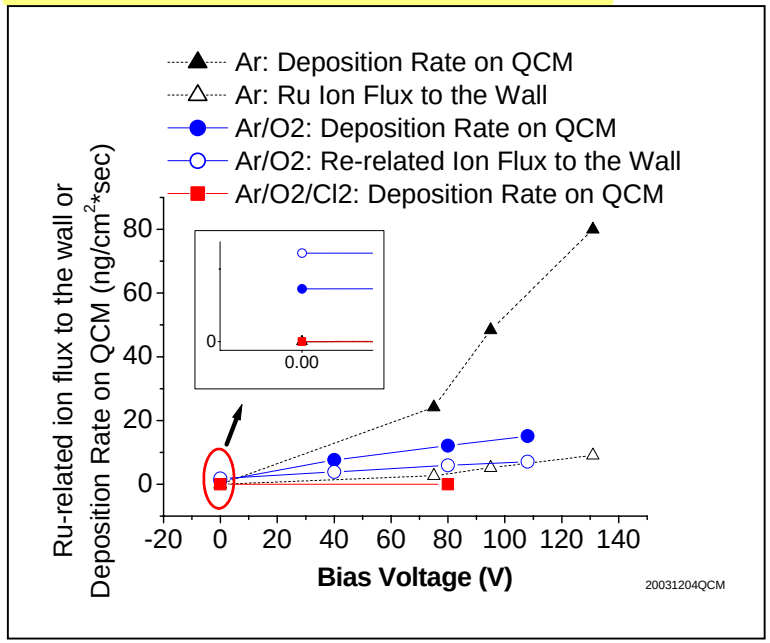
- **RuO_4 was found at the down-stream FTIR in other systems.**
- **UCB Results <u>without</u> Cl_2 addition**
  - Etching Rate ~ 60 A/min
  - Most of the etching by-product deposits on the wall.
  - No RuO_4 was found at the downstream FTIR
- **UCB Results <u>with</u> Cl_2 Addition**
  - Etching Rate ~ 300 A/min
  - Zero Wall Deposition Rate, i.e. all etching by-products leave the chamber.
  - RuO_4 was detected at the downstream FTIR
- **Literature suggests that by Cl_2 addition, RuO_2 etching rate increases due to increasing of O radical density.**

Wall Deposition and Re-etching Processes

Ar sputtering



O_2 Containing Plasma



-In Ar sputtering, Ru neutrals dominate the wall deposition process

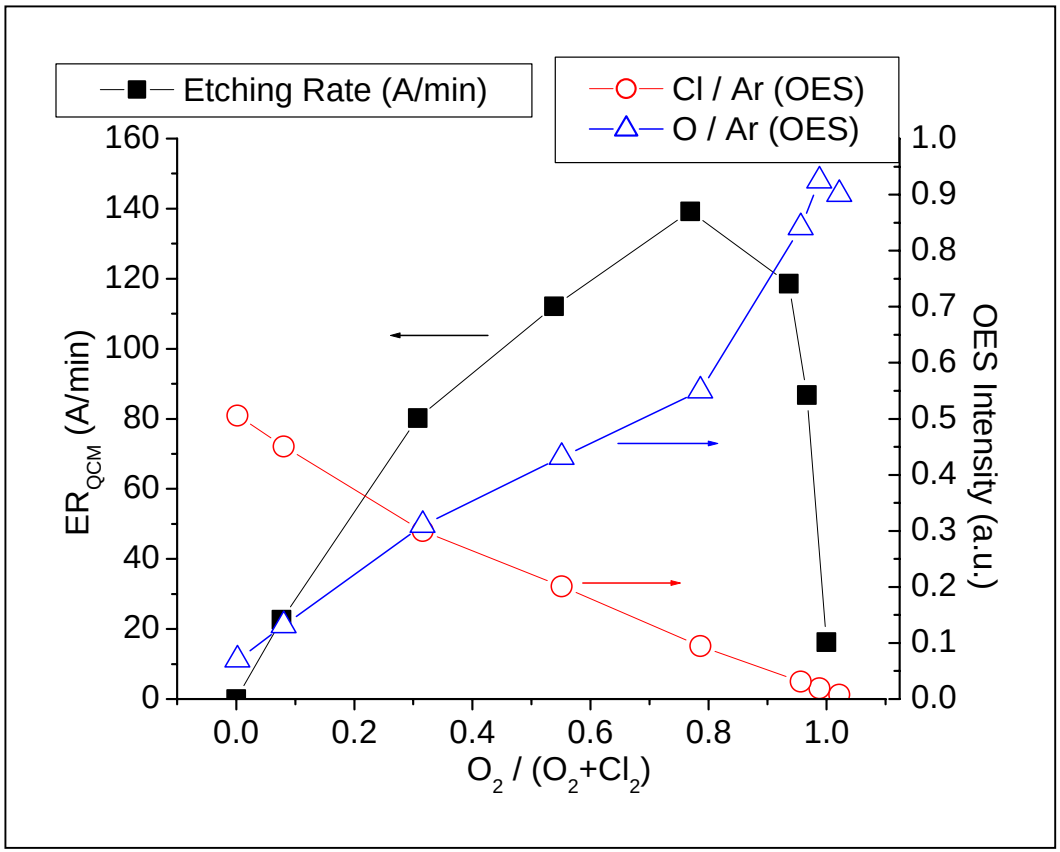
-In Ar and Ar/O_2 plasma, ion flux only contribute partially to wall deposition

- In Ar/O_2 plasma, at zero bias: Ru-containing ion flux to the wall > wall deposition rate. Comparable re-etching process.

- Cl_2 addition: zero wall deposition rate, i.e. high $R_{re\text{-}etch}$ or low R_{depo}. (volatile etch by-product)….Which implies different mechanism dominates etching with Cl_2 addition.

Effect of Cl_2 Addition

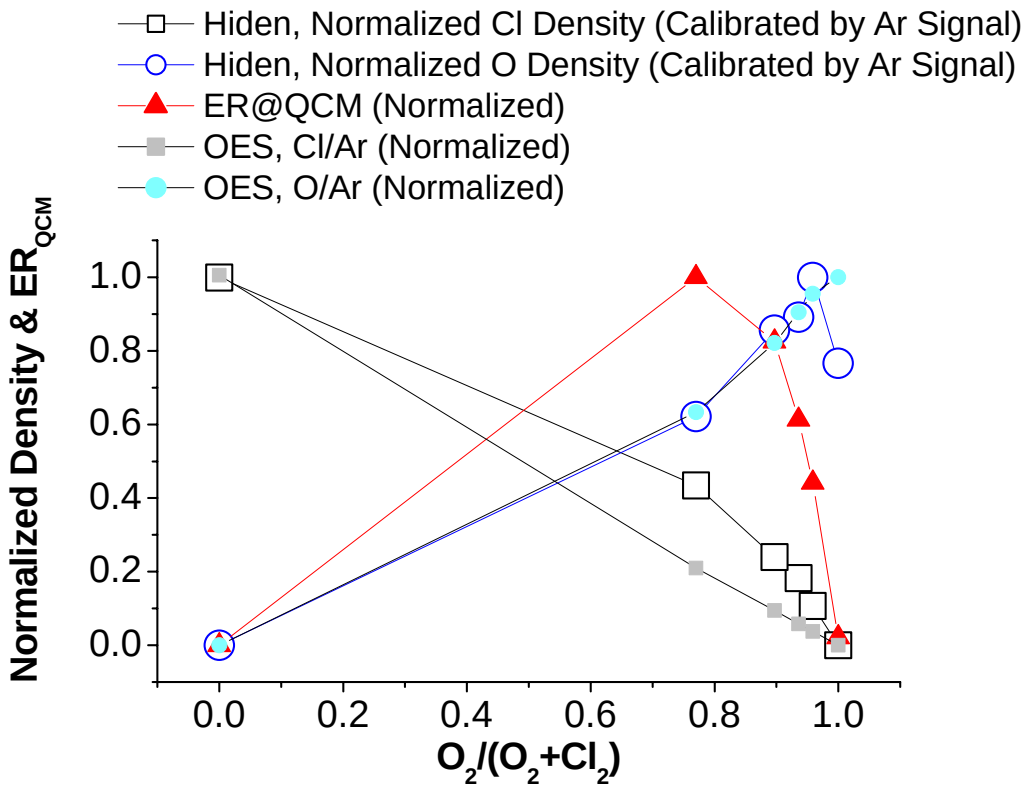
- Condition: Power 150W, Pressure 10mT, Ar 15 sccm, O_2+Cl_2 39 sccm,
- Copper plate on the chuck, Ru coated QCM crystal
- Constant Ion Current (1.3 mA/cm^2)



- Small Cl_2 addition increases E/R significantly
  - **Not** due to O density increases
- As increasing Cl_2 addition, E/R reaches maximum at $O_2/(O_2+Cl_2) \sim 0.8$
- But, reliability of OES?

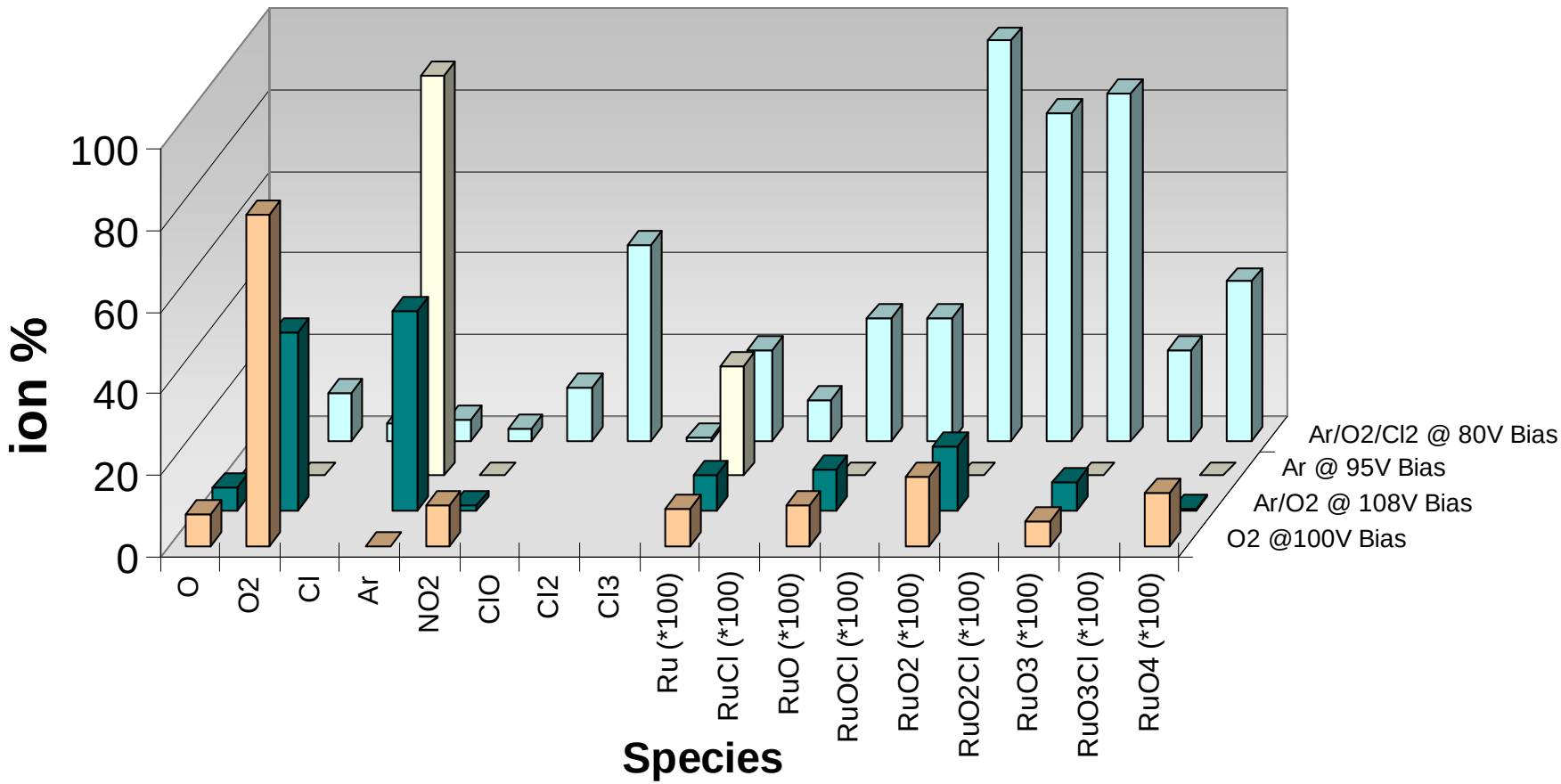
Neutral Density: OES vs. Neutral MS

Identical Condition as Previous Page



- Atomic O and Cl densities measured by neutral MS match actinometry by OES.
- Oxygen radical density and ER_{QCM} do not show the same trend, which implies that the reason that causes ER increases is contrary to what was thought in the literature.

Plasma Composition: ions



- Cl_2 Addition
  - Densities for Ru-containing species increase significantly.
  - Ru-containing oxychloride ions were detected.

Conclusion

- In Ru etching:
  - In Ar sputtering, neutral species dominate the wall deposition process.
  - Ru can be etched readily by O_2 containing plasma.
  - With Cl_2 addition,
    - E/R increases significantly
    - Zero wall deposition, i.e. all etching by-products leave the chamber.
    - RuO_4 can be found at the effluent
    - Ru-containing oxychloride possibly plays important role in Cl_2-containing O_2-base etching.
- Etch by-product composition and wall deposition/etch rate are sensitive functions of plasma conditions.
- Wall deposition characteristics affect feature profile critical dimension control: etch by-products used to engineer CD control and selectivity.
- Process control and ESH issues are **coupled** and must be **optimized simultaneously**

Acknowledgments

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