PHOTORESIST TREATMENT USING AN ICP H_2 PLASMA AND LOW ESC TEMPERATURE: LWR STUDY

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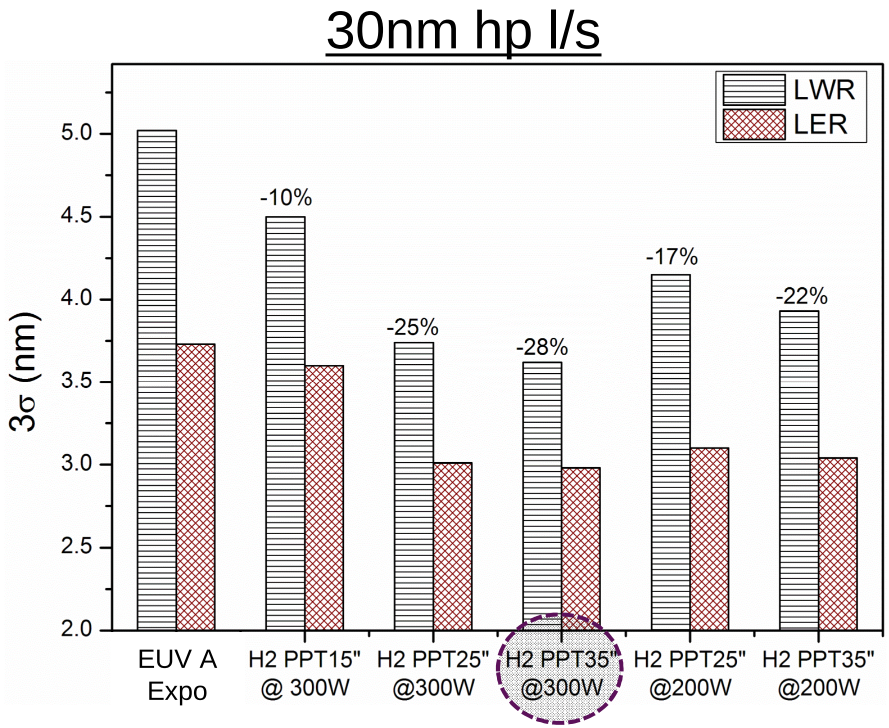
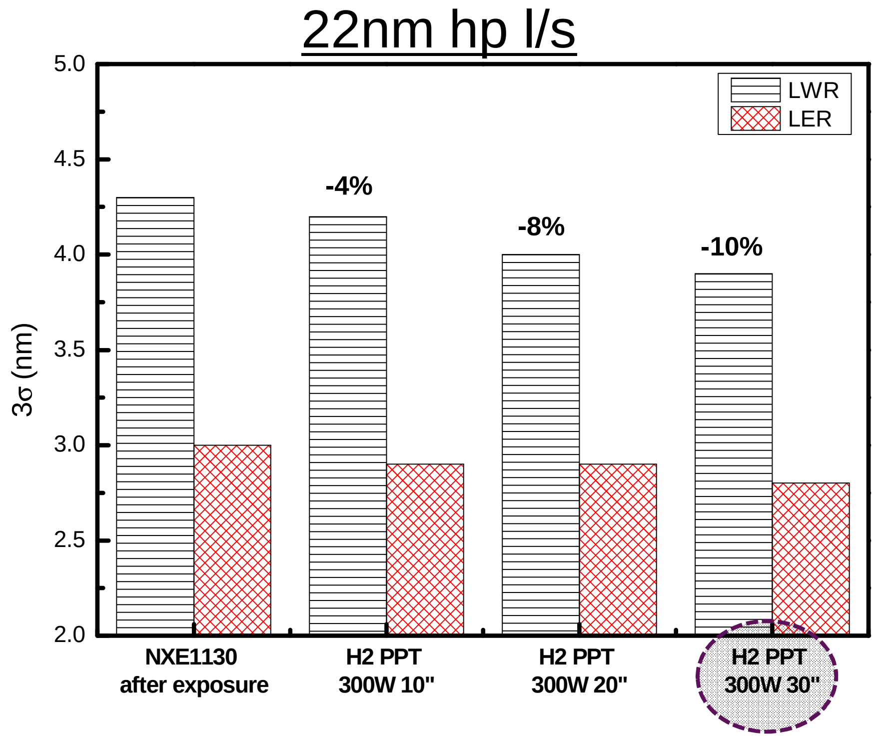
PESM2014
GRENOBLE
13/05/2014

LWR SMOOTHING: 30NM L/S VS. 22NM L/S



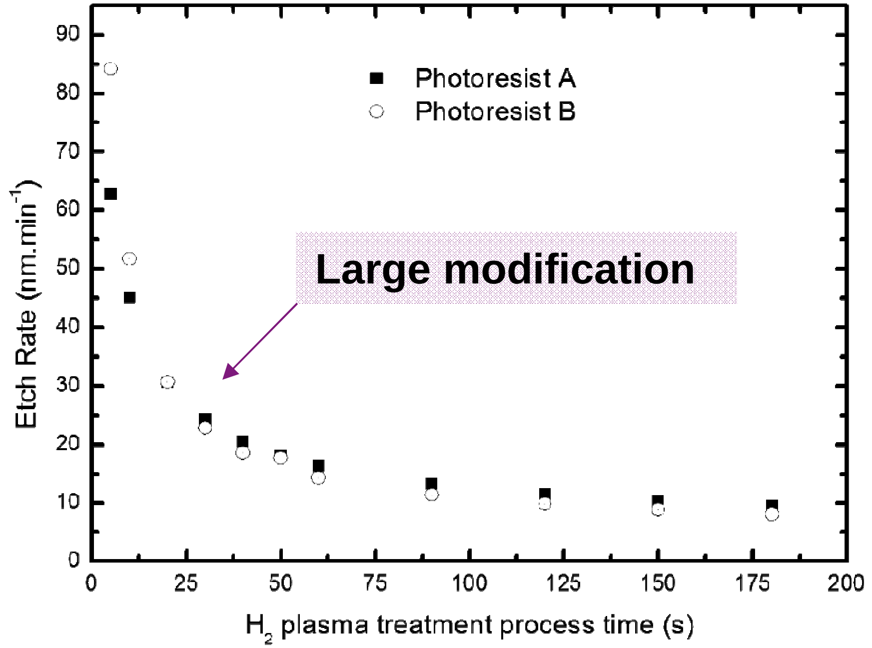


Less LWR improvement for smaller features

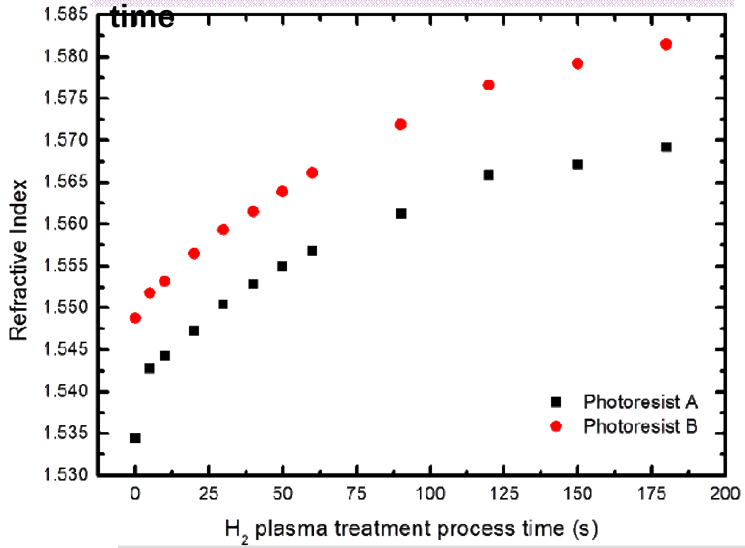
What is limiting the LWR improvement?

*E. Altamirano-Sanchez et al., **Proc. SPIE**, vol. 8685, pp. 868505 (2013)*
*P. De Schepper et al., **Proc. SPIE**, vol. 8685, pp. 868507 (2013)*

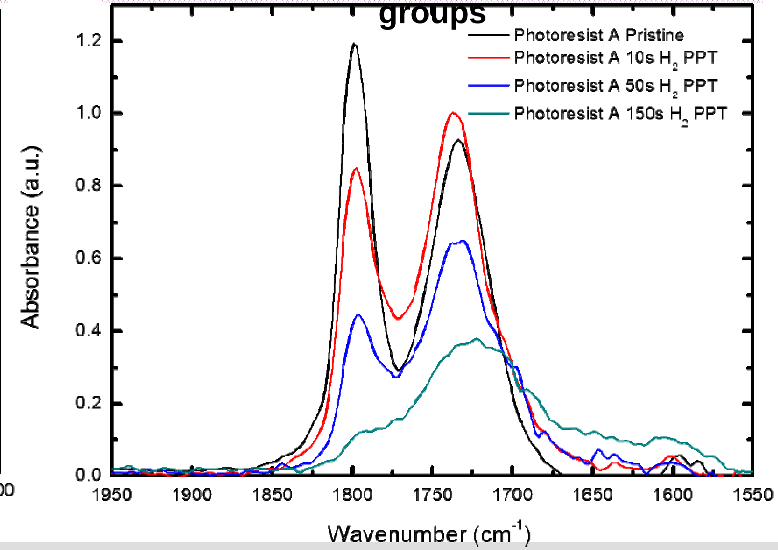
WHAT IS H_2 PLASMA DOING TO THE RESIST?



Densification in function of process time



Depletion of ester functional side groups



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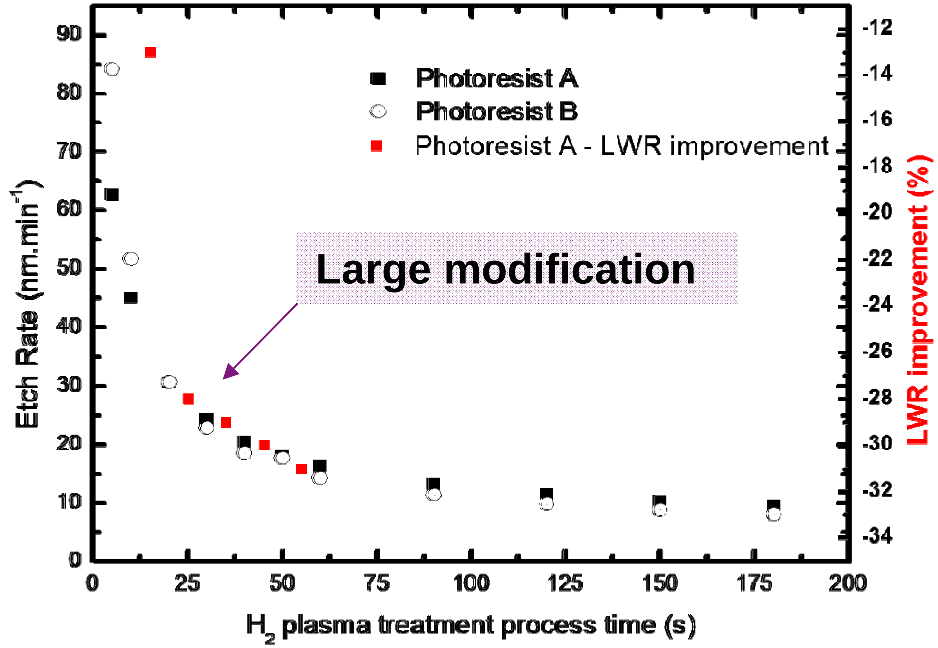

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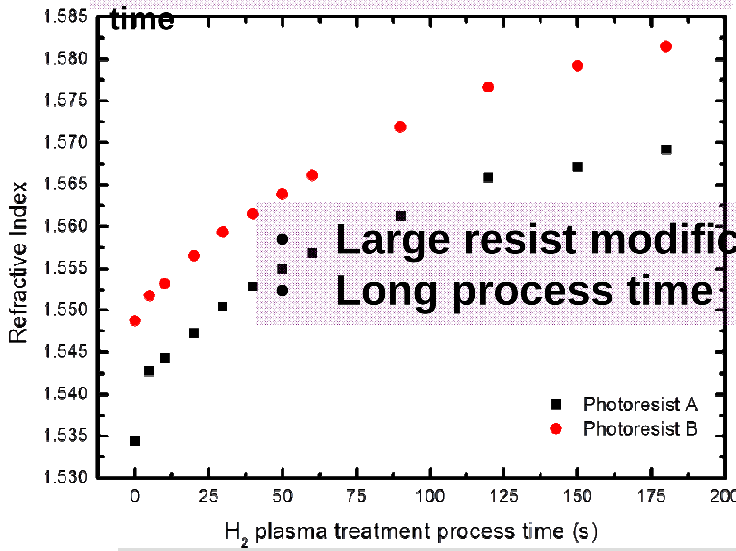
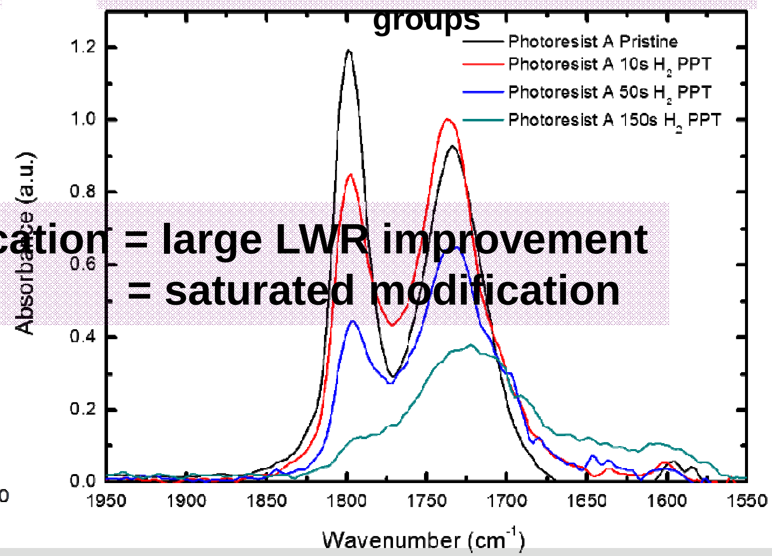
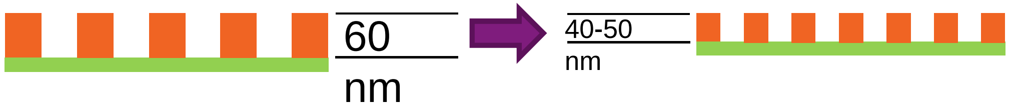


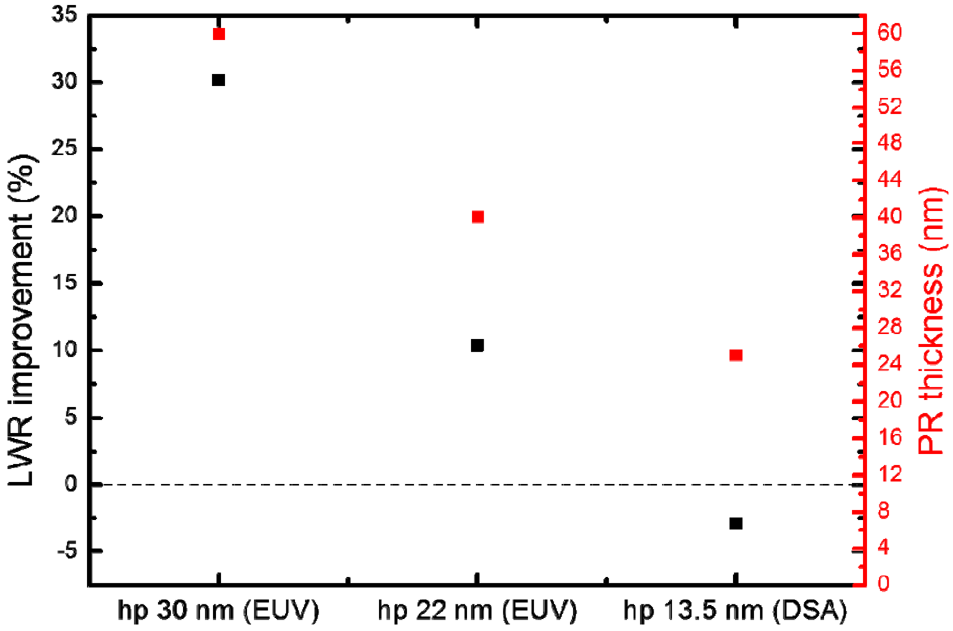
Depletion of ester functional side groups

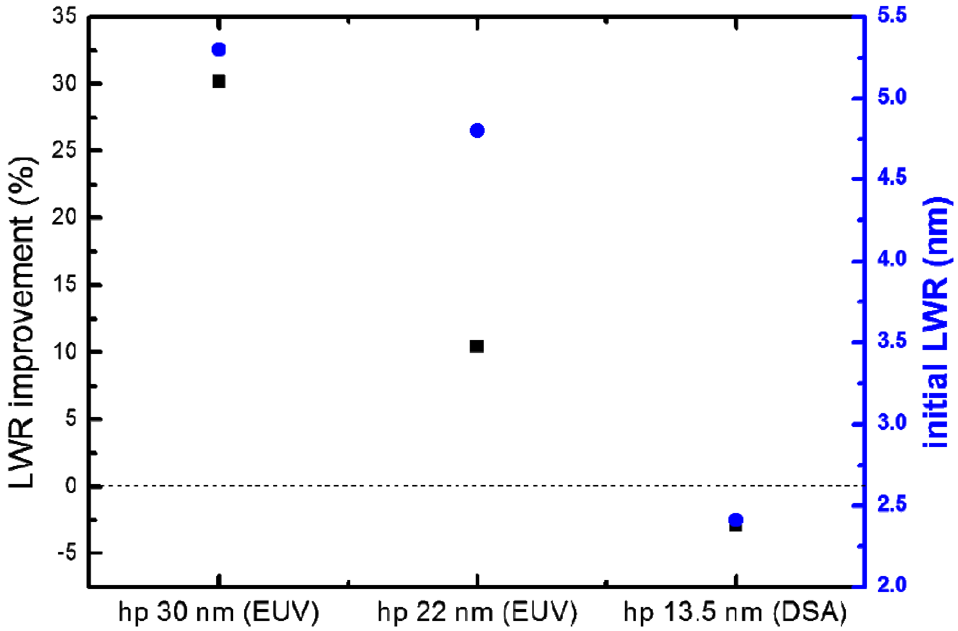


- **Large resist modification = large LWR improvement**
- **Long process time = saturated modification**

INFLUENCE OF RESIST THICKNESS AND LWR$_{INITIAL}$







- **LWR improvement = correlated with initial LWR**
- **LWR improvement = correlated with photoresist thickness**

  ➔ Photoresist modification is important

How is the LWR linked with resist modification?

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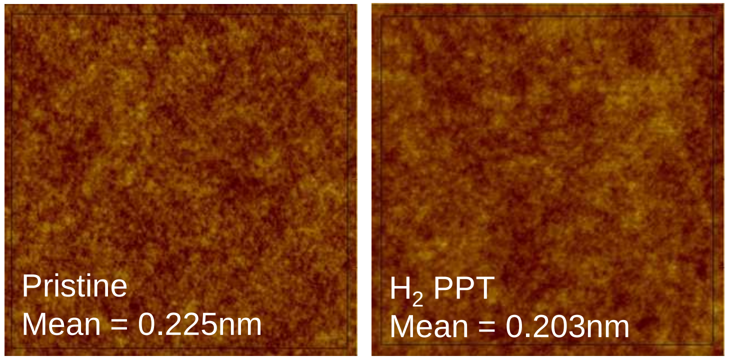
EUV RESIST MODIFICATION

Photoresist A

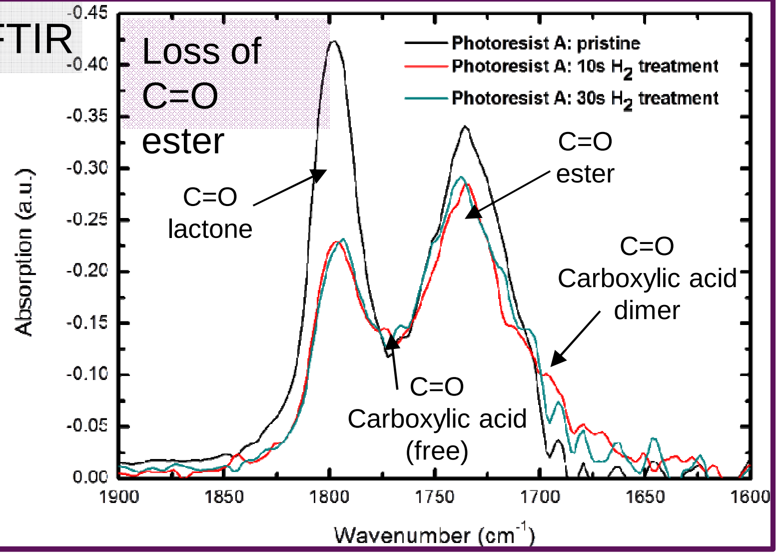
P. De Schepper et al., Proc. SPIE, vol. 8685, pp. 868507 (2013)
E. Altamirano-Sanchez et al., Proc. SPIE, vol. 8685, pp. 868505 (2013)

AFM

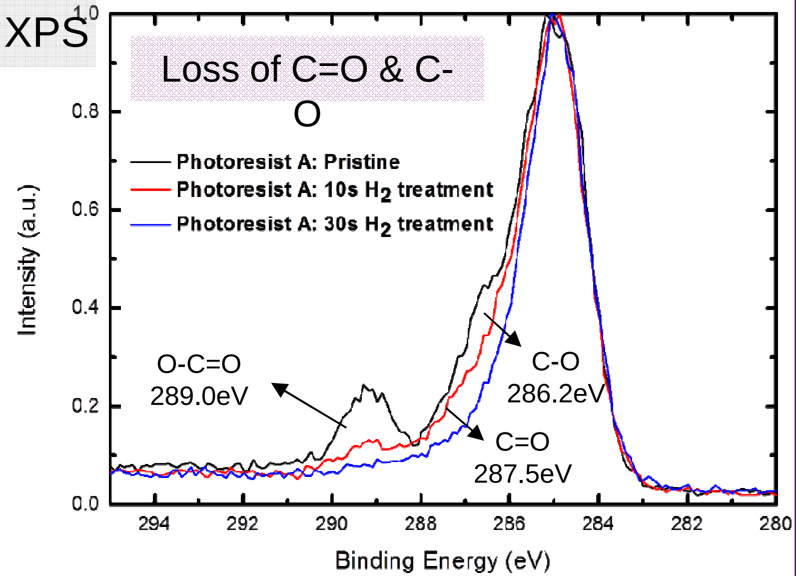
No induced surface roughness



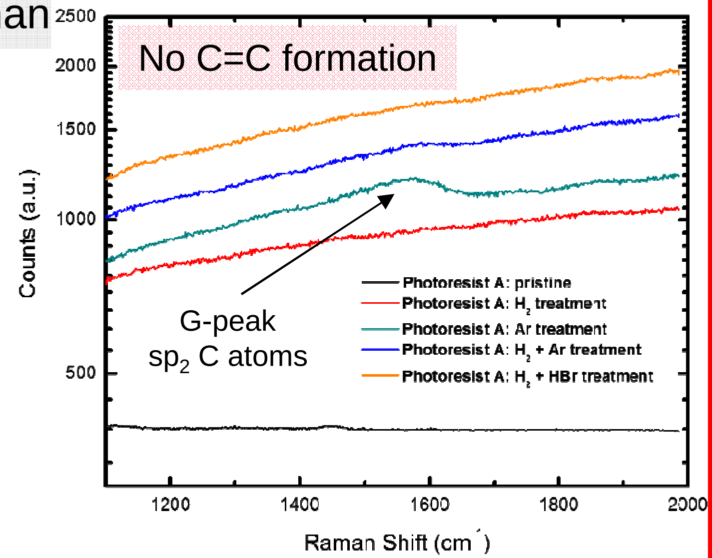
FTIR



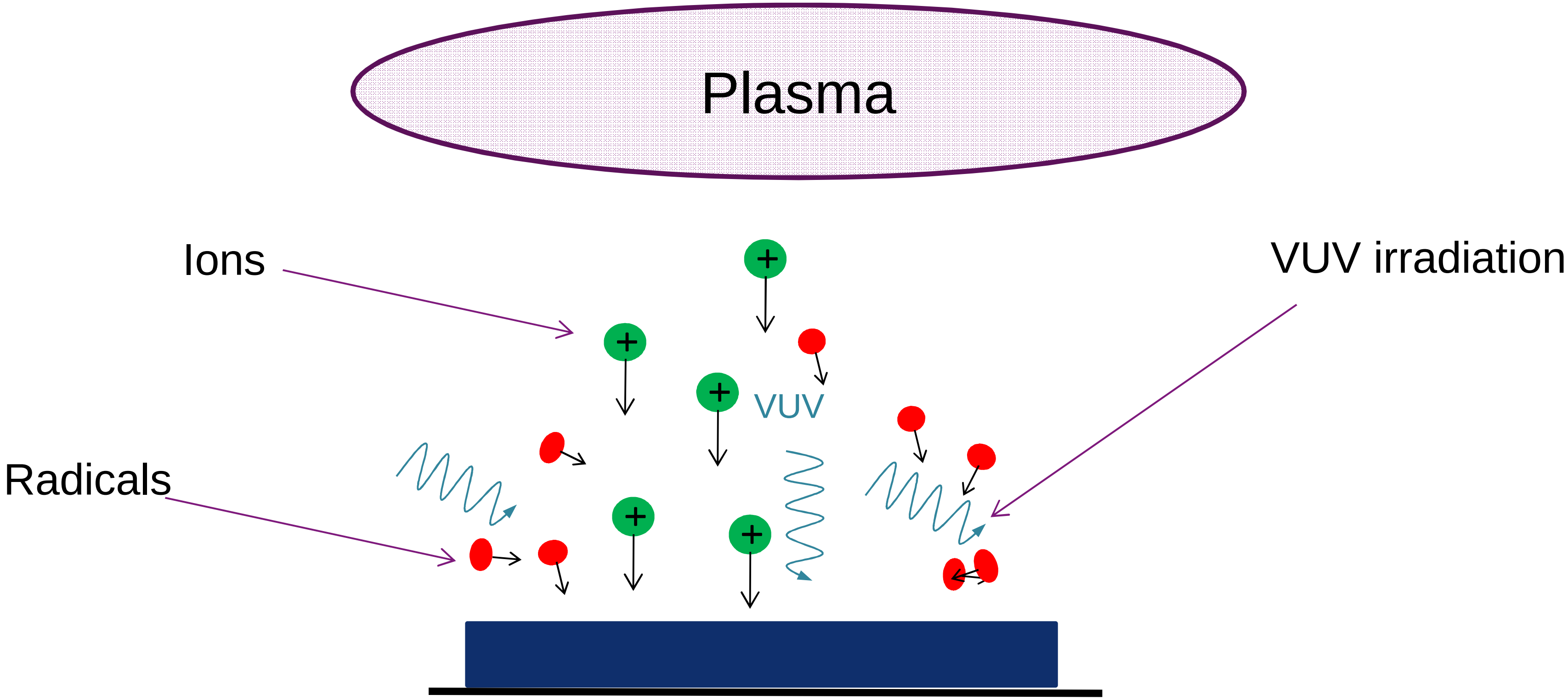
XPS



Raman



PLASMA SMOOTHING PARAMETERS

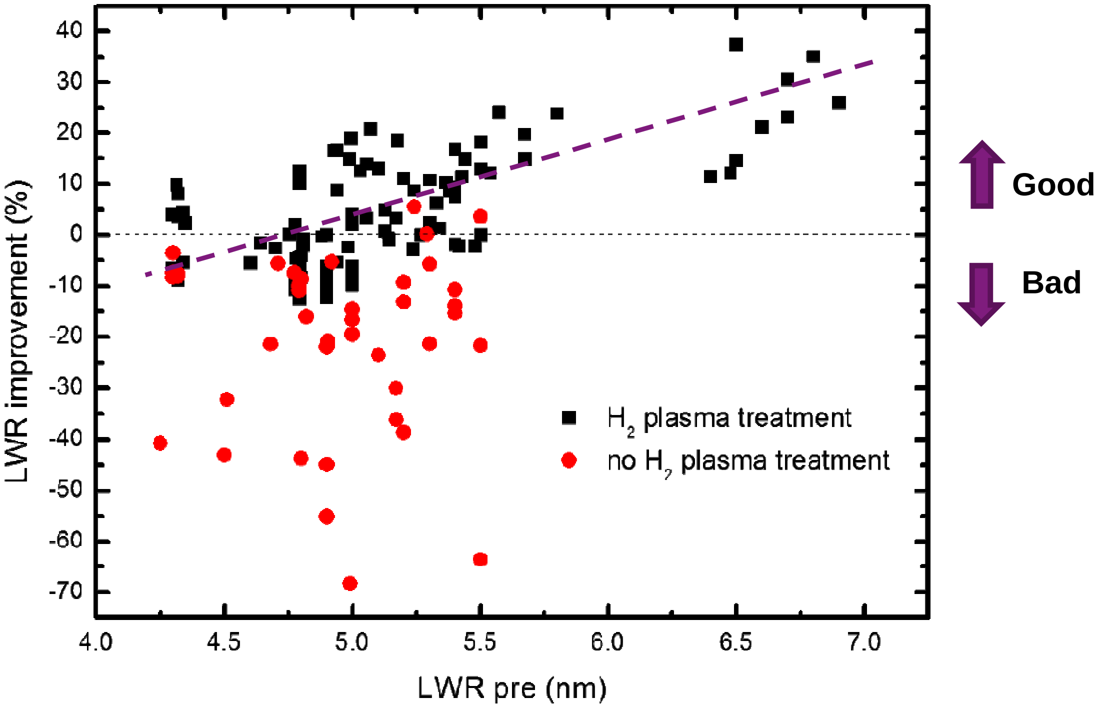


Pargon et al., Appl. Phys. Lett. 94, 103111 (2009)
Weilnbroeck et al., J. Vac. Sci. Technol. B28(5), Sept/O (2010)
Chung et al., Plasma Process. Polym. , 8 (2011)
Oehrlein et al., J. Vac. Sci. Technol. B 291, (2011)

- Literature indicates a synergy among these parameters only induces the roughness changes
- It has been proven that VUV provokes a significant (193 nm) resist modification

22NM L/S: BEST LWR_{POST} = 3.8NM

Process variables	
Type of RF discharge	ICP, CCP
Type of EUV Resist	**EUV-A & EUV-B**
Plasma Chemistry	H_2, HBr, Ar, He and mixtures
Process Parameters	Pressure, total gas flow, source and bias power
Optical Window	MgF_2 (λ_c = 120nm)



Hydrogen plasma smoothing has the highest impact

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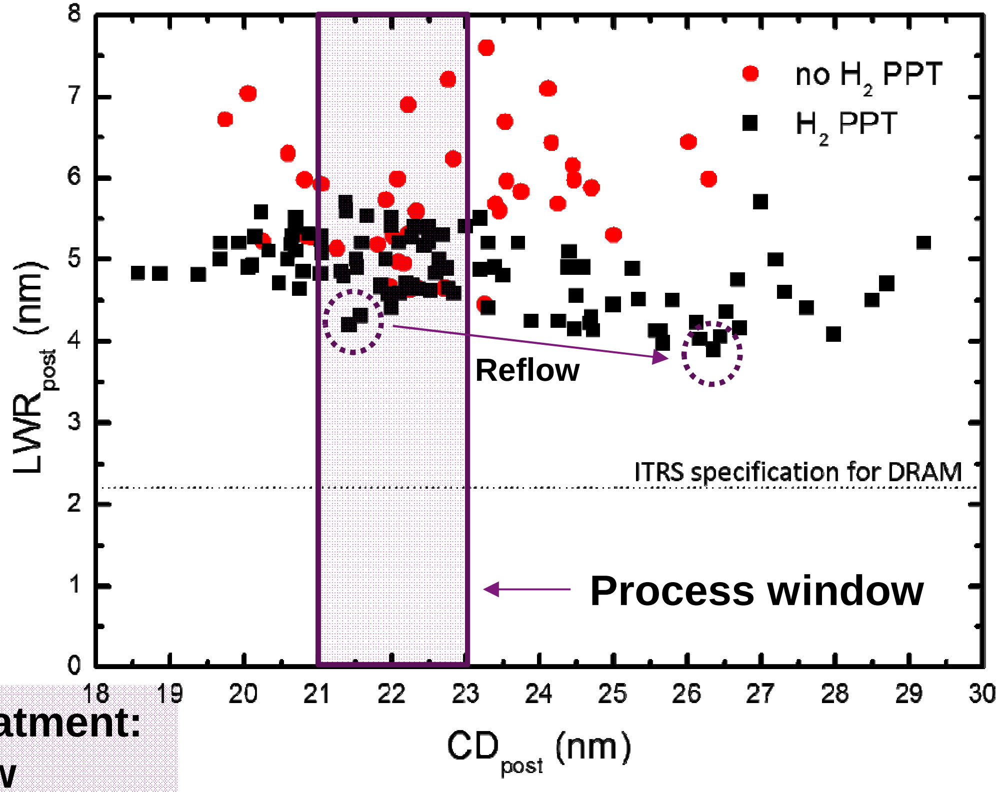
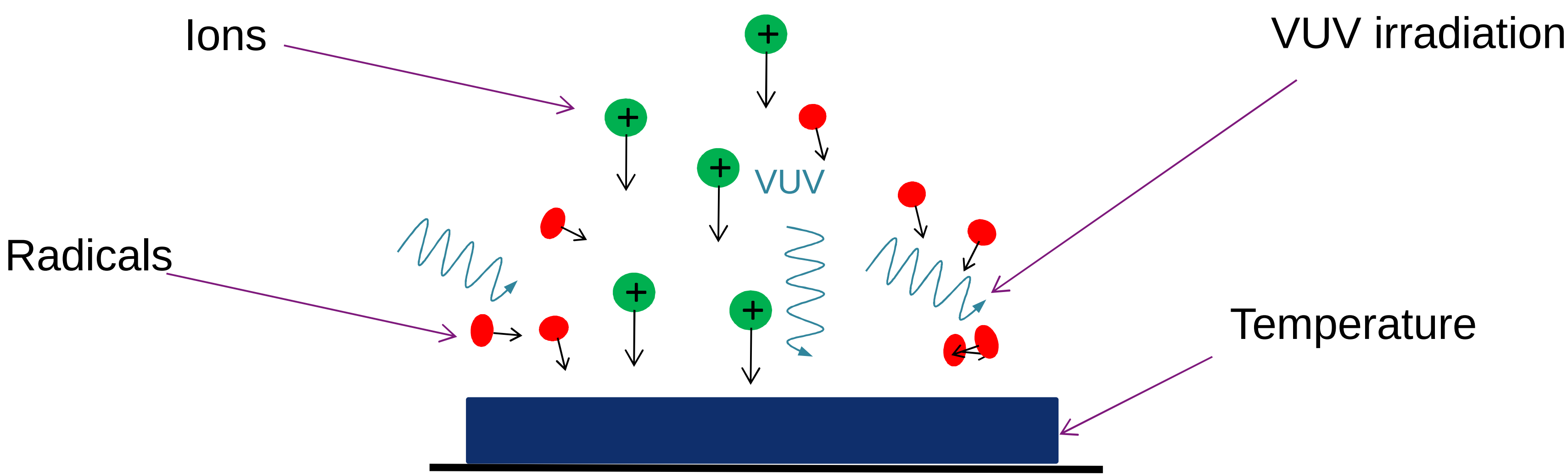


Best LWR post treatment:
➔ 4.2 nm no reflow
➔ 3.8 nm 20% reflow

INFLUENCE OF TEMPERATURE



How can we influence the reaction kinetics?

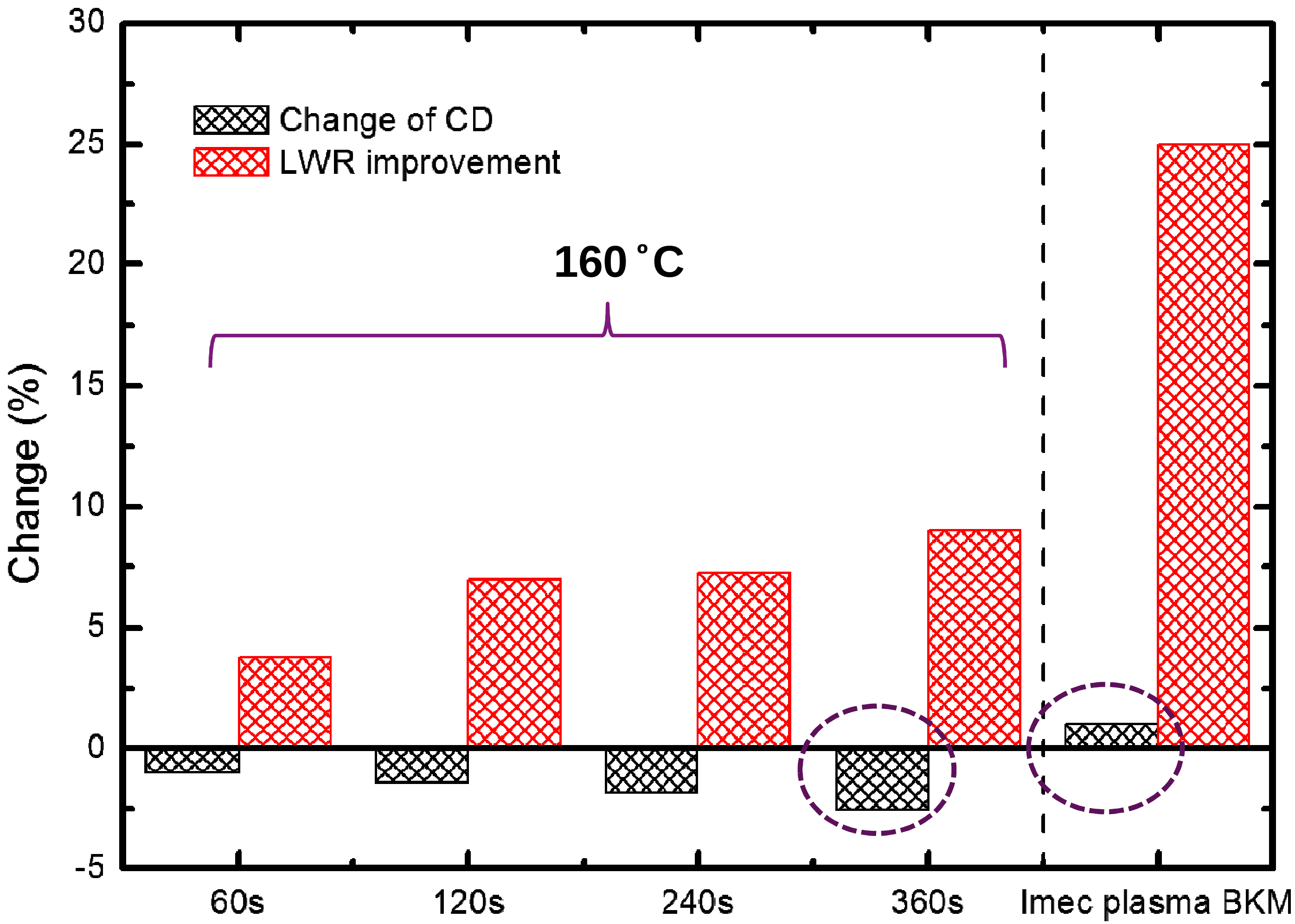
→ Photoresist chemistry

→ **Temperature**

Will this have an influence on LWR mitigation?

T-enhanced LWR improvement

Photoresist A



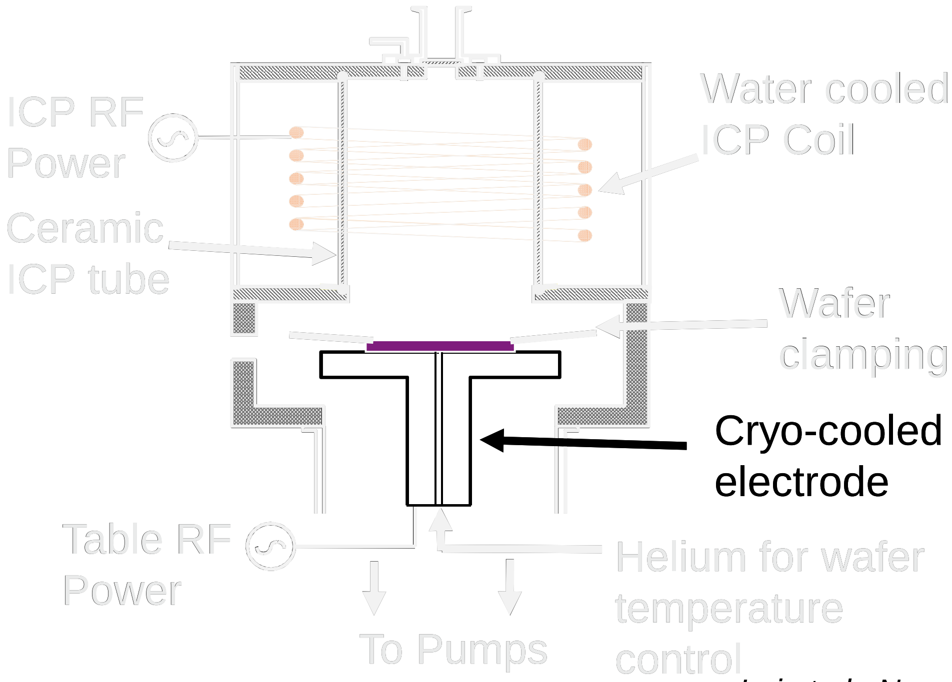
- Thermal enhanced LWR improvement by
- $T_{deprotection} < T_{glass\ transition}$ ➔ no reflow
- If $T_{deprotection} < T_{glass\ transition}$ lowered by plasma ➔ reflow

What about plasma treatment at lower substrate temperatures ?

PLASMA TREATMENT AT LOW-TEMPERATURES

Photoresist A

Plasmalab133 ICP380

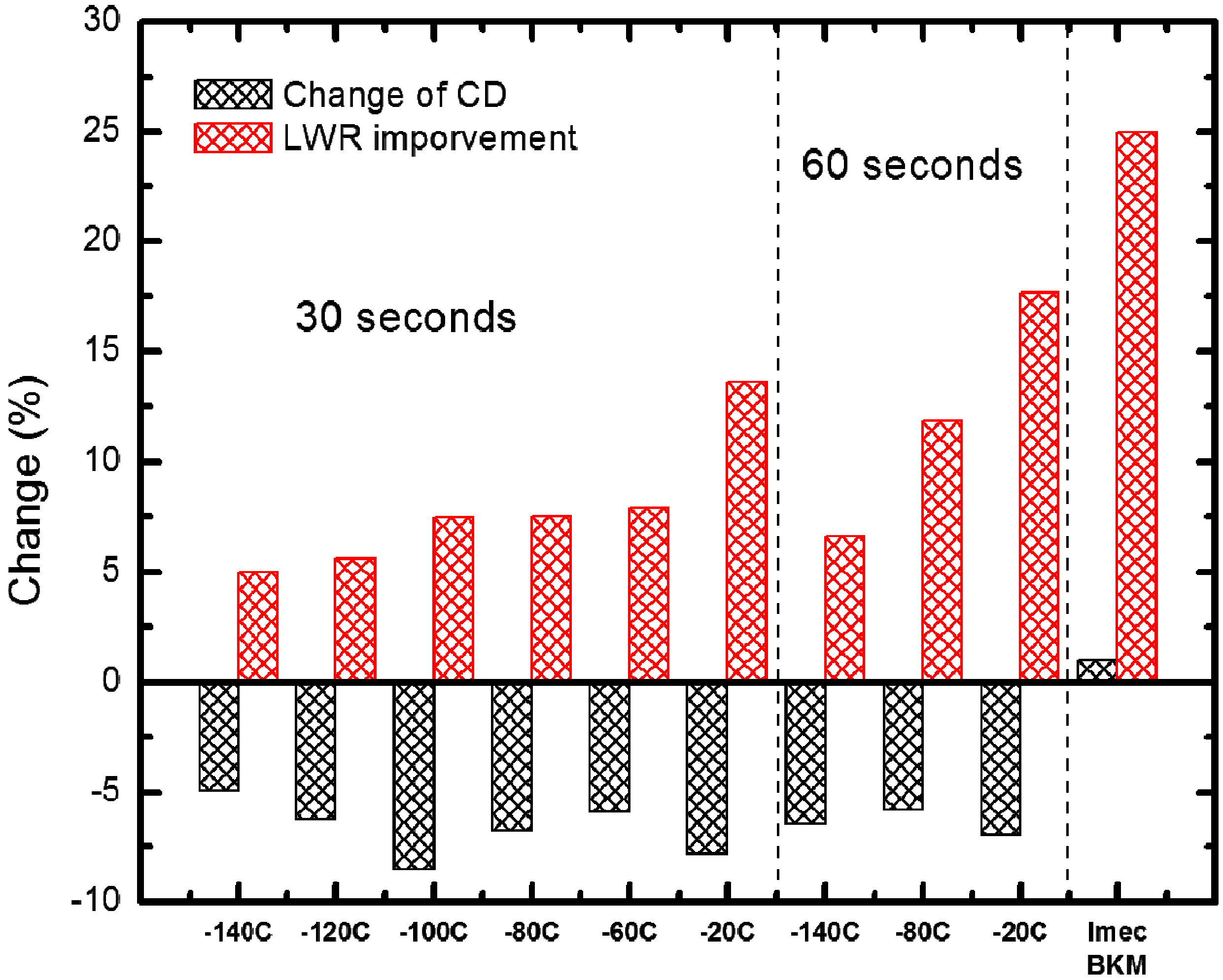


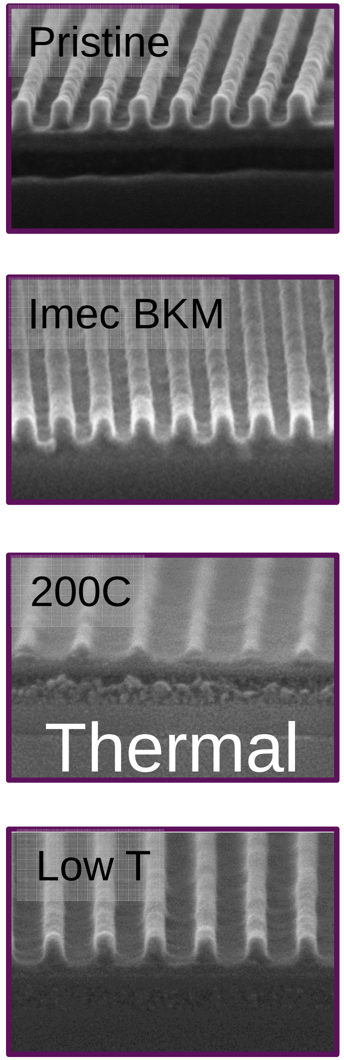
Lui et al., Nanotechnology 24 (2013) 015305

- lower $T_{substrate}$ = slower chemical reactions
- $T_{substrate} < T_{glass\ transition}$ = no reflow

PLASMA TREATMENT OF LOW-SUBSTRATE TEMPERATURES

Photoresist A

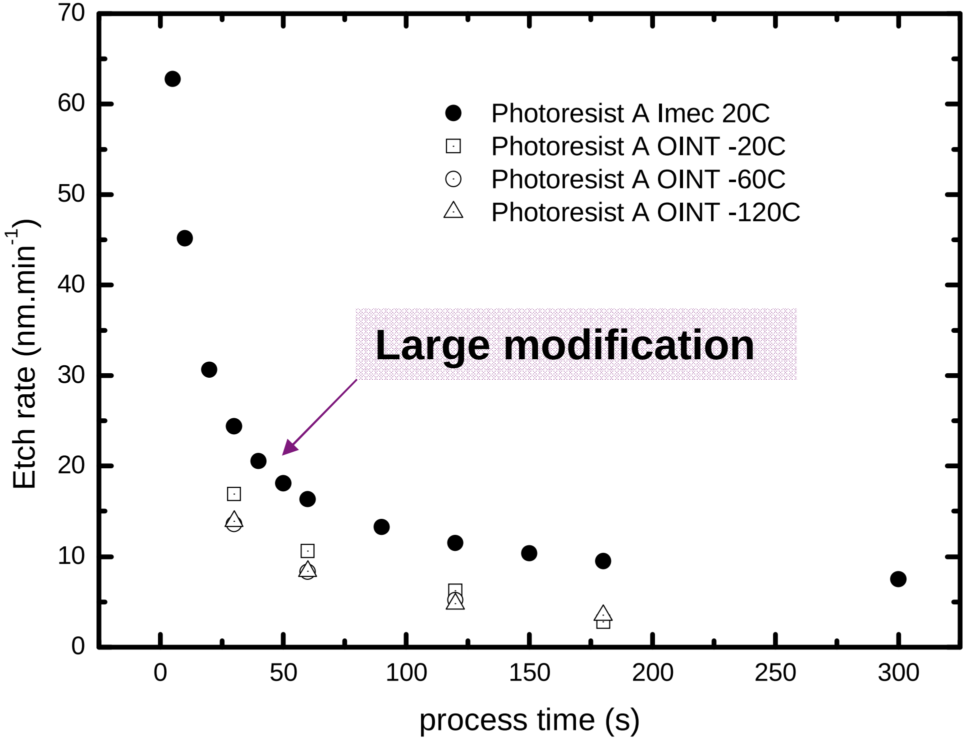


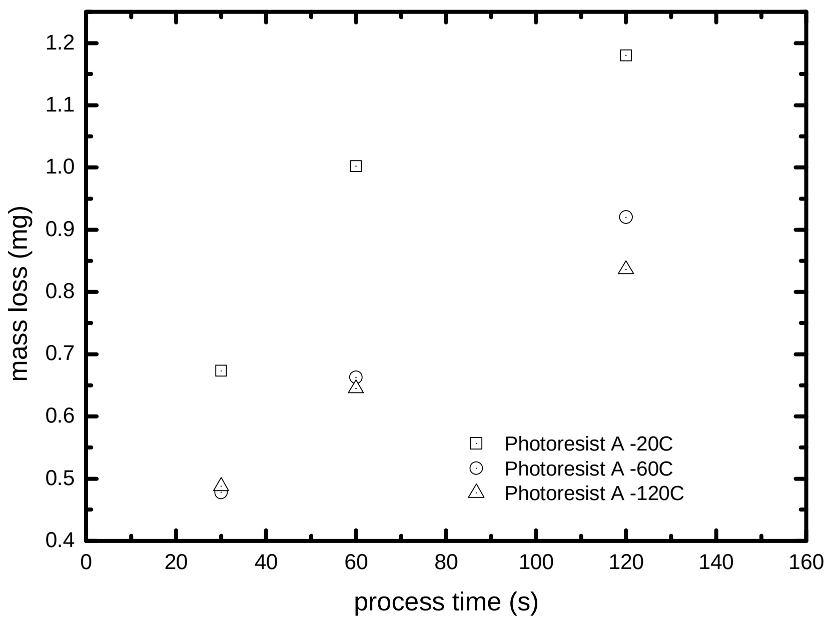


What makes the difference in CD change?

RESIST MODIFICATION AT LOW TEMPERATURES

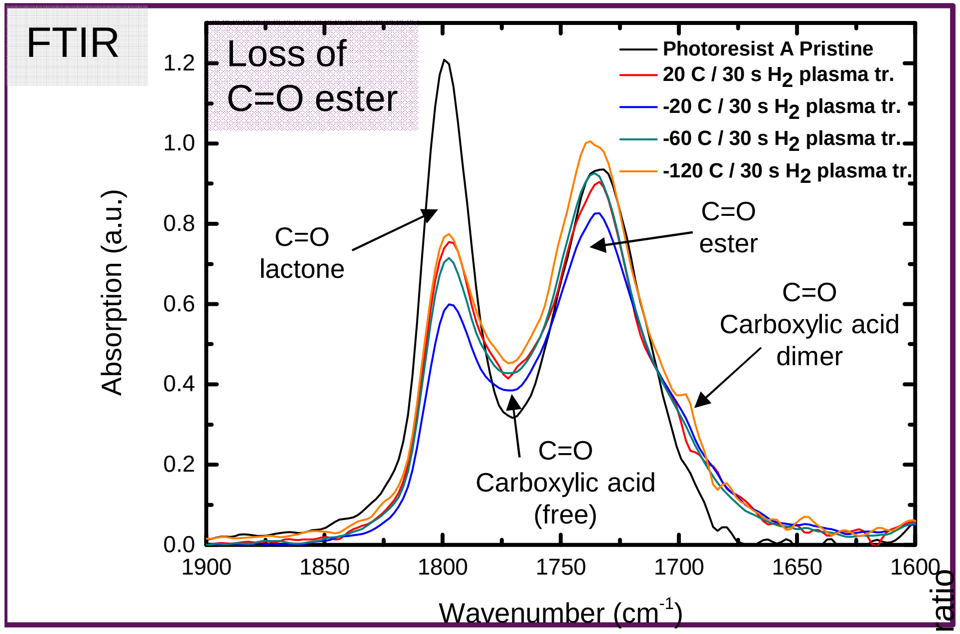
Photoresist A



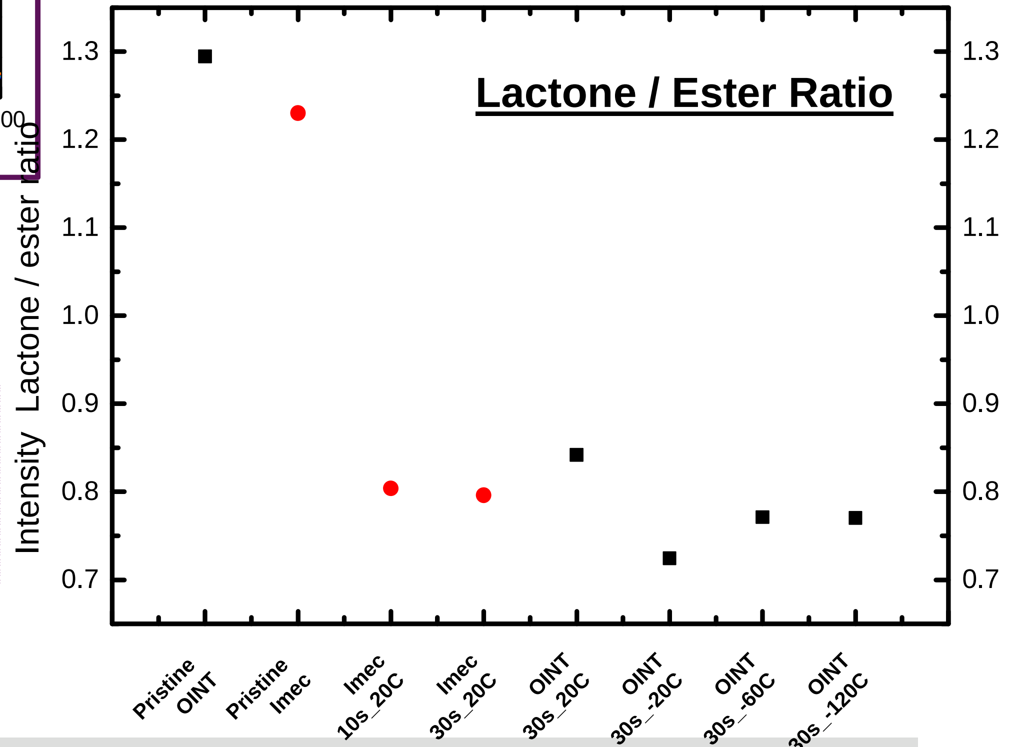


- **Low temperature process follows the same modification trend as highlighted**
  ➔ Plasma process time remains critical
- **Mass loss and etch rate larger for higher temperature**

CHEMICAL MODIFICATION: LACTONE / ESTER RATIO

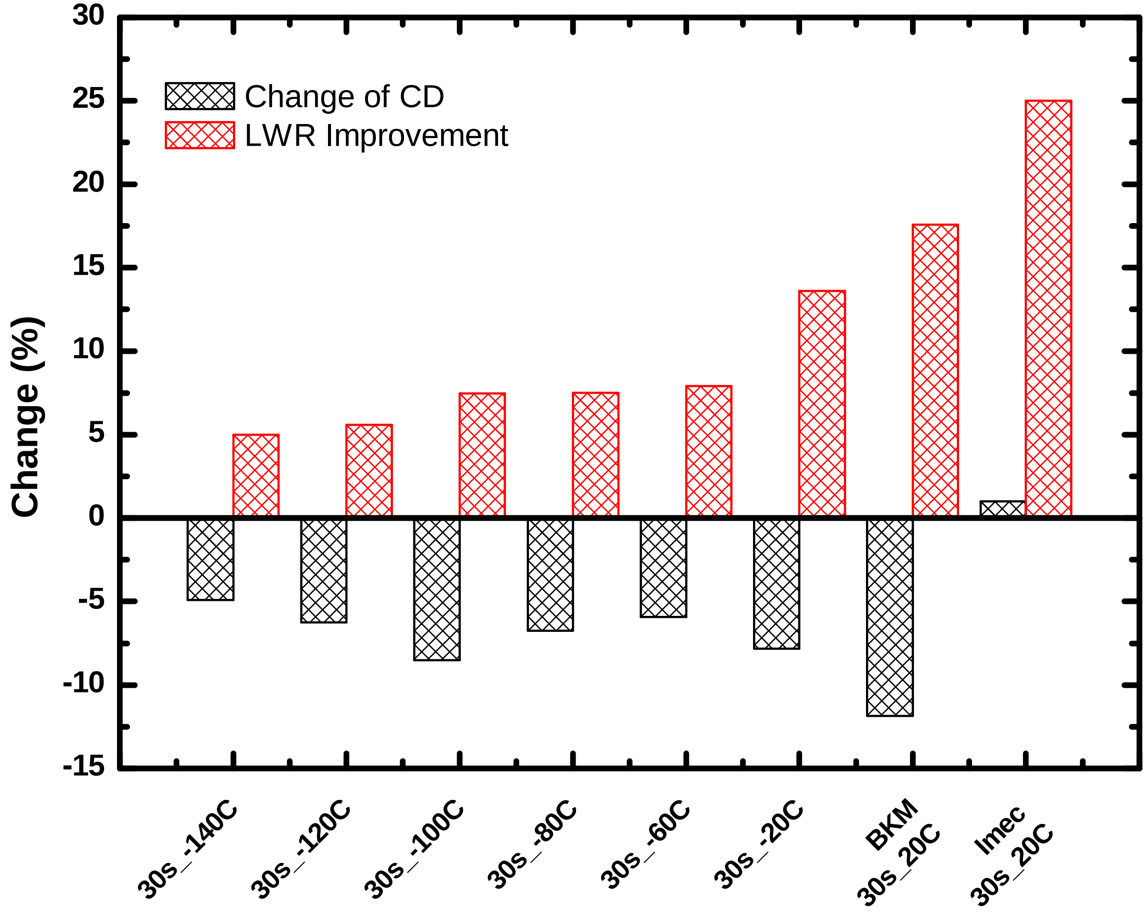


- **Chemical changes due to lower electrode temperature are limited**
- **Lactone / ester ratio remains comparable after treatment**

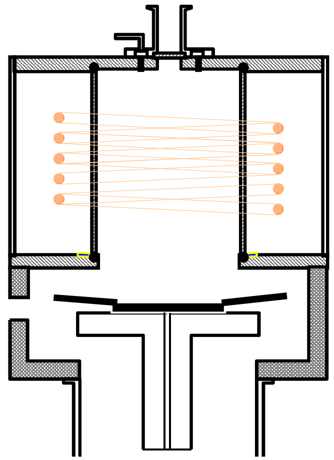


PLASMA REACTOR COMPARISON

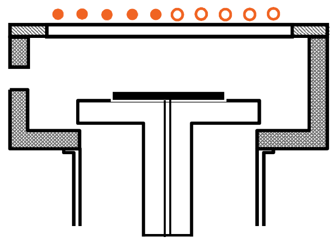
Photoresist A



ICP reactor (OINT)



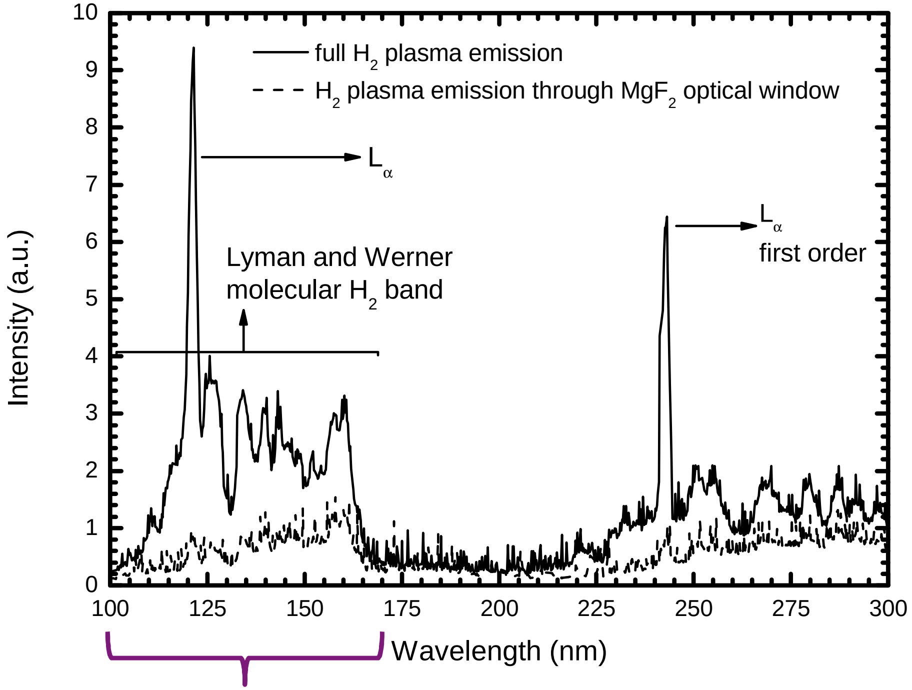
TCP reactor (Imec)

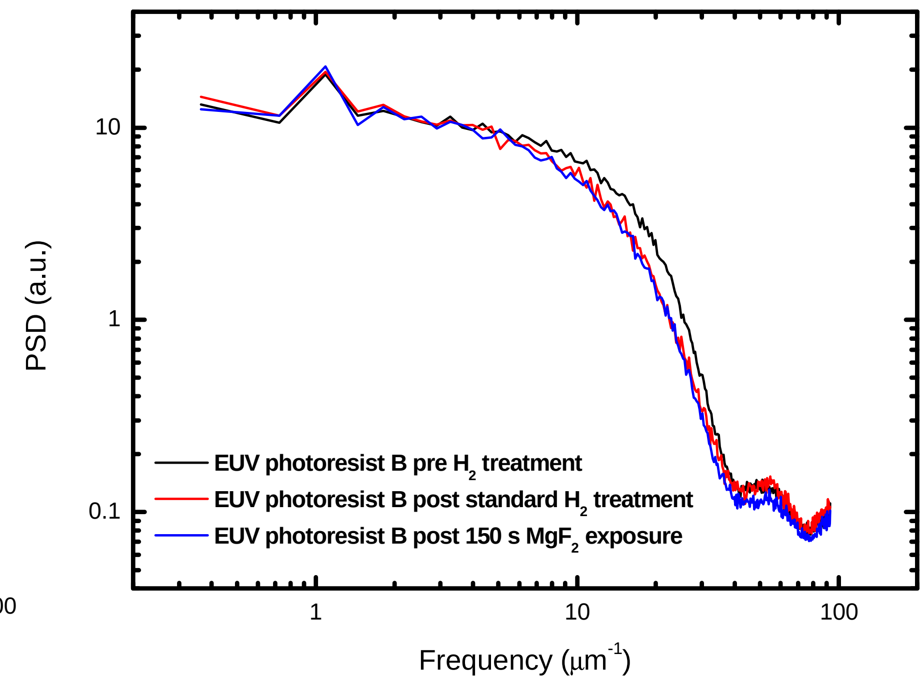


- **Large difference under same conditions in various reactors**
- **Difference in plasma parameters:**
  - ➔ **Lower VUV photon flux?**

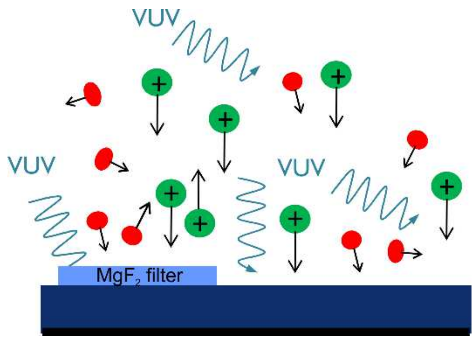
What is the influence of VUV photon flux?

INFLUENCE OF PHOTON FLUX AND INTENSITY



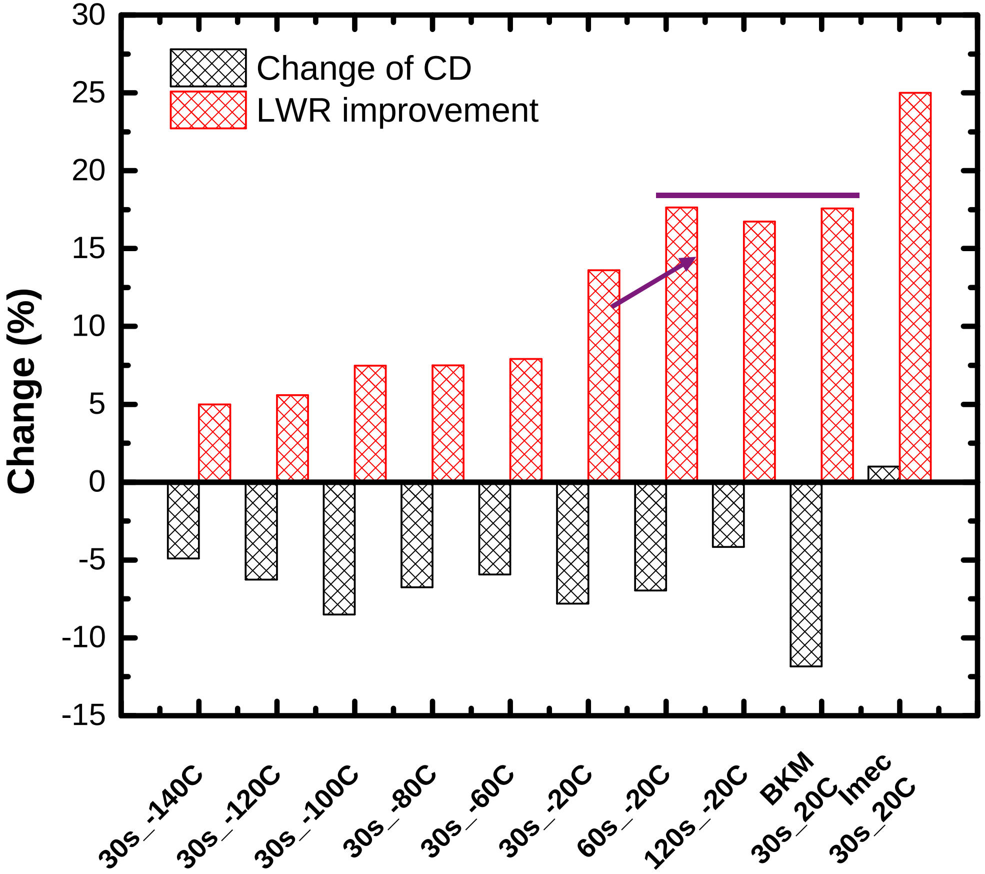


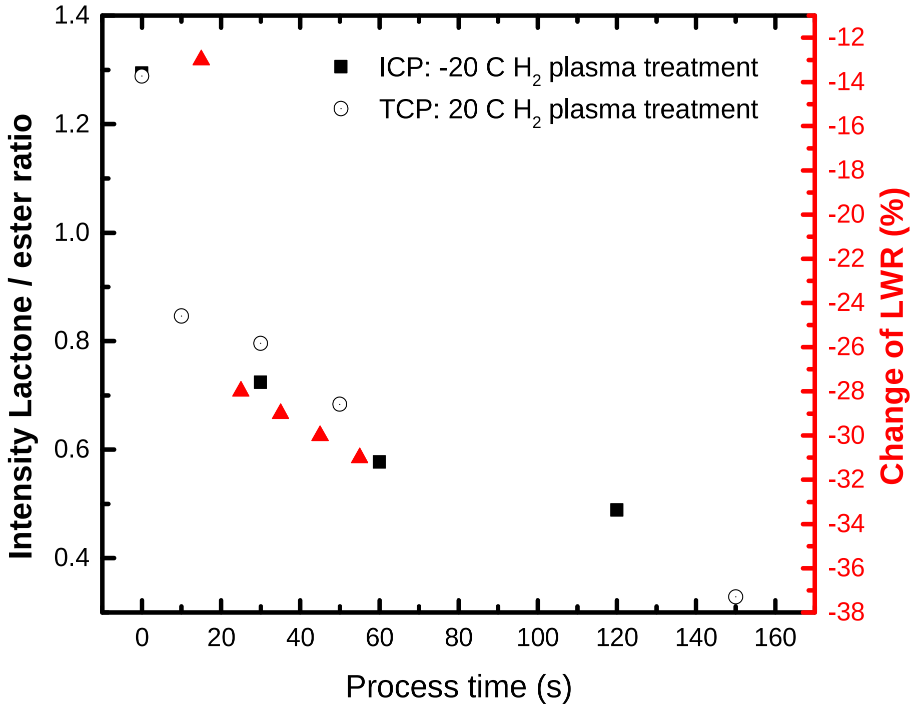
H_2 plasma treatment with MgF_2 window
Only 10 – 30 % transmittance between 100 and 175 nm
➔ Increase the process time five folds to compensate for loss of photons



VUV emission seems to be the main responsible for LWR improvement

PROCESS TIME INCREASE TO ACCOUNT FOR PHOTON FLUX





- **Increased process time compensates for the VUV photon intensity**
  - **➔ VUV does not triggers the reflow.**
  - **➔ Lower concentration of reactive species at surface does?**
- **Lactone / ester ratio decreases as function of process time**
  - **➔ Long process times do not improve the LWR significant**

CONCLUSIONS

- LWR improvement is limited by
  - Process Time / Initial LWR / Amount of photoresist material
- Thermal deprotection:
  - Slightly improved LWR & no reflow
- Plasma treatment for low substrate temperatures
  - Significant improved LWR & no reflow
  - VUV irradiation is main contributor LWR improvement
  - No reflow due to lower active species density at surface ?
  - Low T for the moment seems not to be an extra knob for further LWR improvement.

Best achievable LWR is observed for H_2 plasma processes

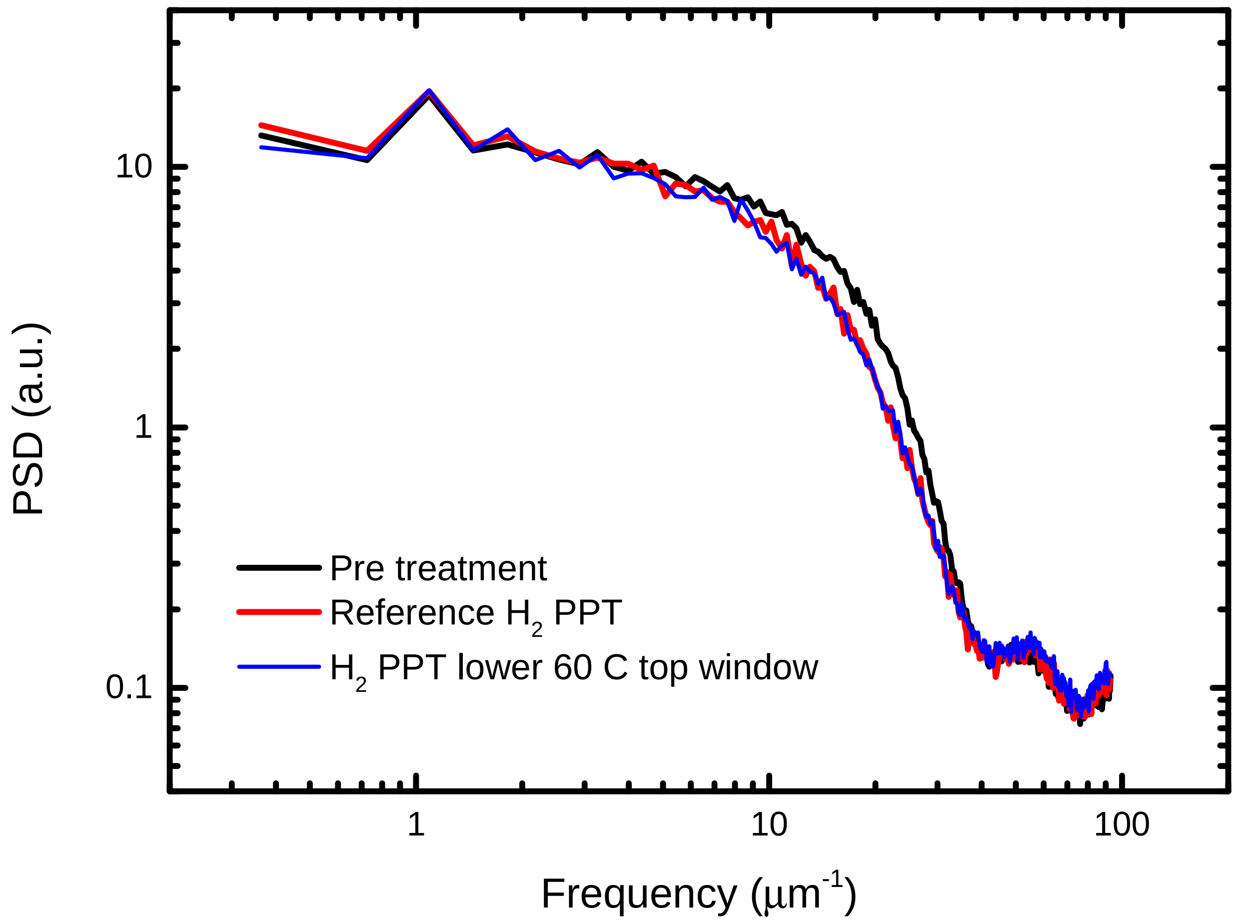
THANKS TO

- Plasma modeling and MD-simulations
  - Stefan Tinck – University of Antwerp
  - Geoffrey Pourtois
- Polymer characterization
  - Thierry Conard
  - Thomas Nuytten
  - Kai Arstila
- Plasma treatment
  - LAM Research team Belgium
  - Oxford Instrument Plasma Technology etch team
- Useful discussions
  - Stefan De Gendt
  - Zaid El Otell
  - Jean-Francois de Marneffe
  - Vladimir Samara

ASPIRE
INVENT
ACHIEVE

imec

IR-IRRADIATION FROM TOP WINDOW



- **No difference in lowering top window temperature**
  ➔ Photon flux and plasma species density at the surface?