Limits to accelerated MLM lifetime testing: TiO_2 in hydrocarbons and Ru in H_2O

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Outline

1) Damage of Ru-cap MLMs in H_2O environment

- Inverse dependence of damage rate on H_2O pressure
- NIST results confirmed by PTB

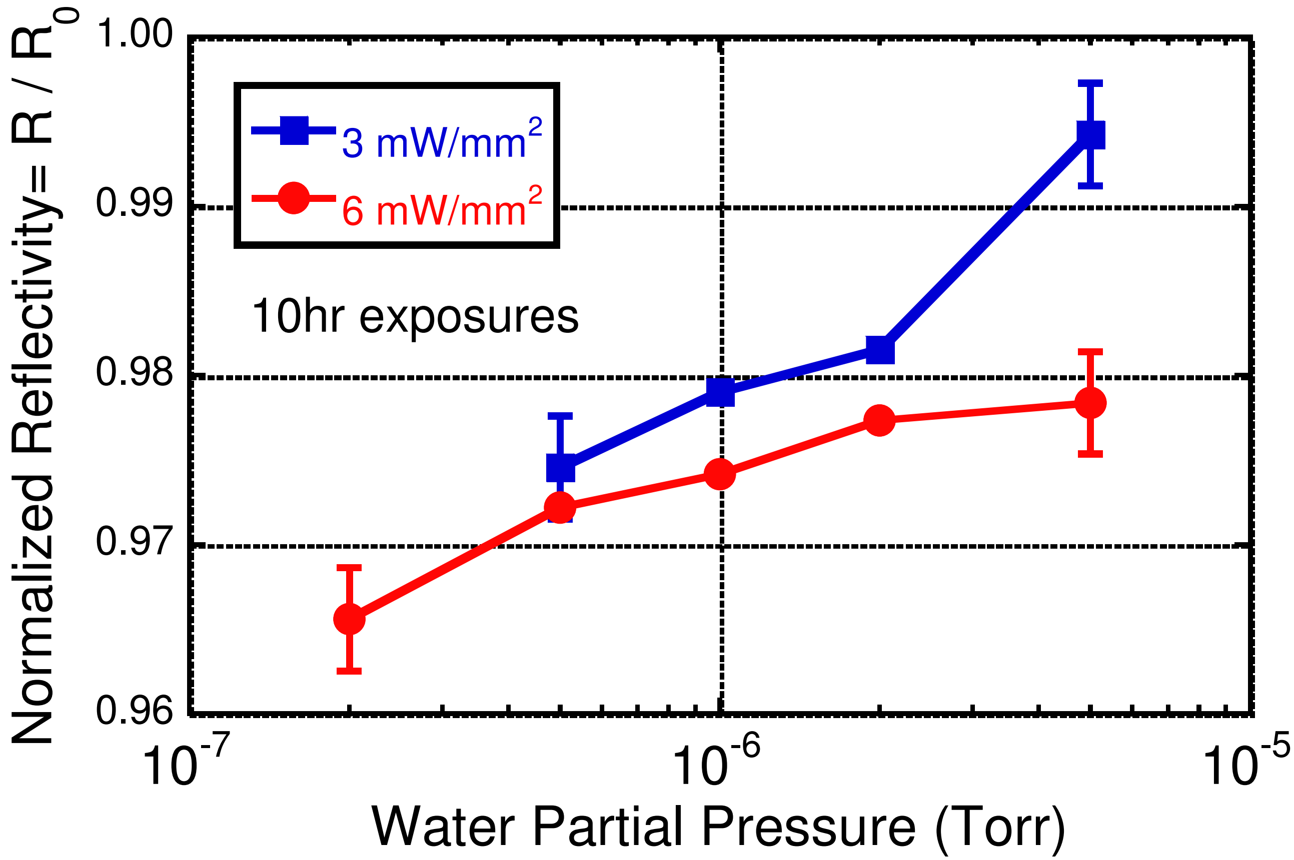
2) C-deposition on MLMs with non-optimized TiO_2-cap

- Resist-related HCs: acetone, benzene, MMA, toluene
- Non-linear behaviors observed

3) Simple thick-C-growth model

- Application to NIST and Intel MET data
- Limits of model: thick C-growth only

Inverse dependence of Ru-cap MLM damage on H_2O level (Early 2005)



- Hypothesized that competition between oxidation and C-deposition responsible
- But RGA showed no significant hydrocarbon presence
- XPS not available at the time for confirmation

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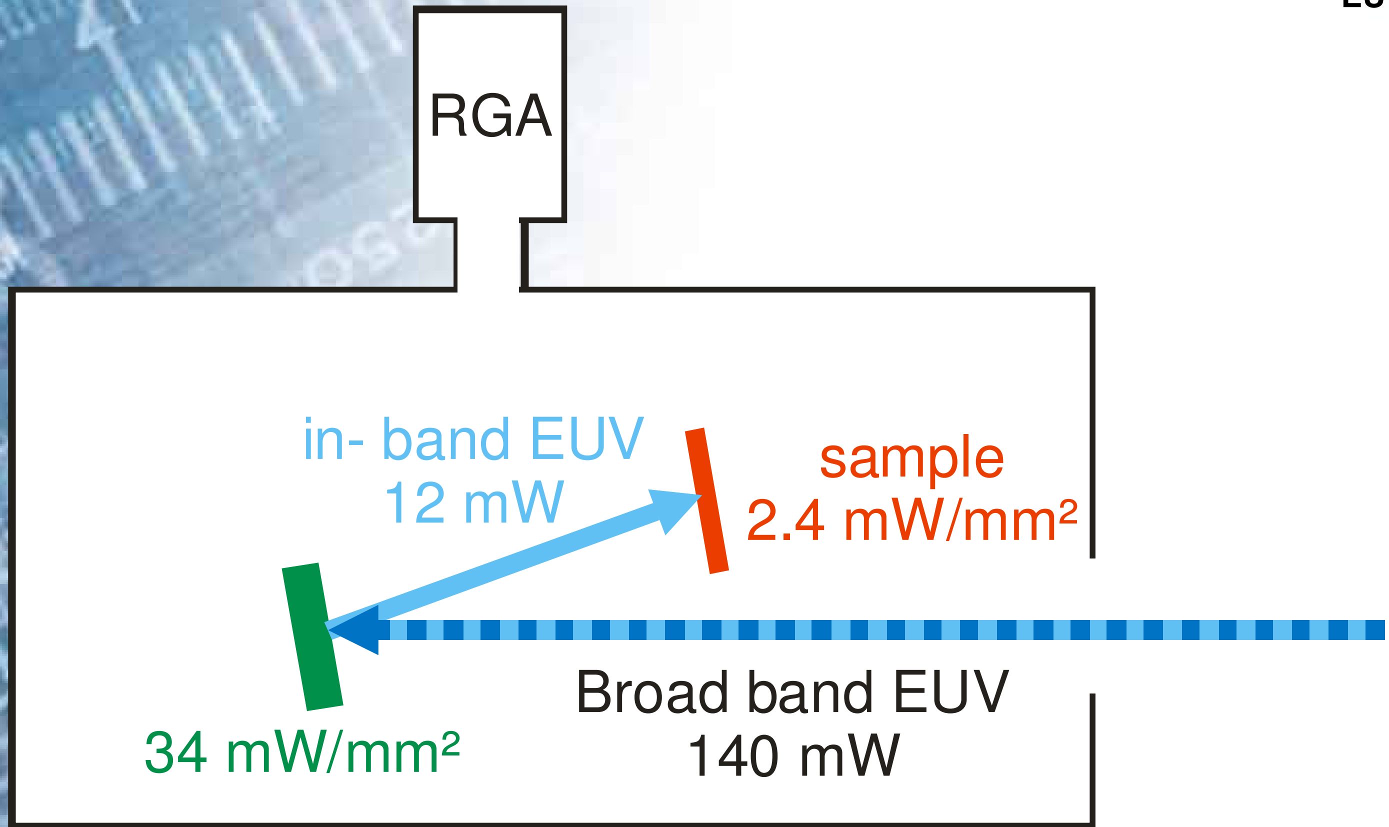
Recent EUV irradiation at PTB

EUV Radiometry

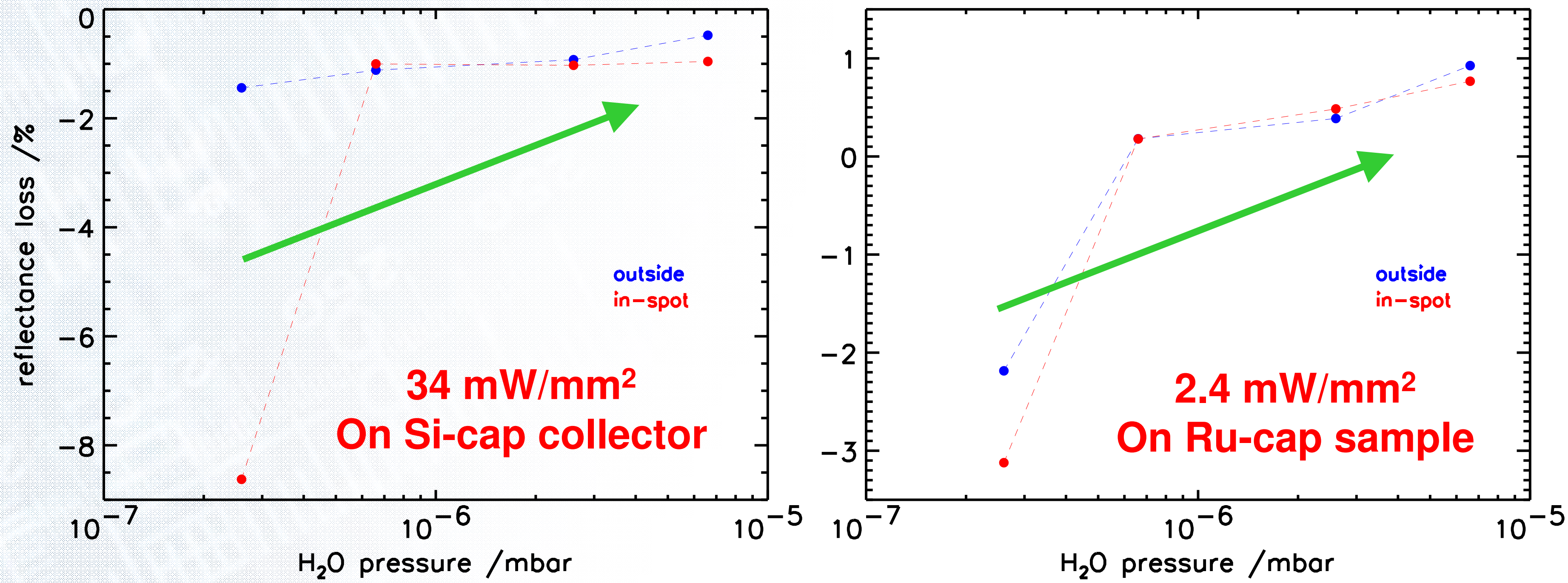


Irradiation test chamber at PTB:

- broad band EUV radiation (10° grazing incidence mirror and Si-Filter)
- in-band EUV filtering by Mo/Si mirror inside irradiation chamber

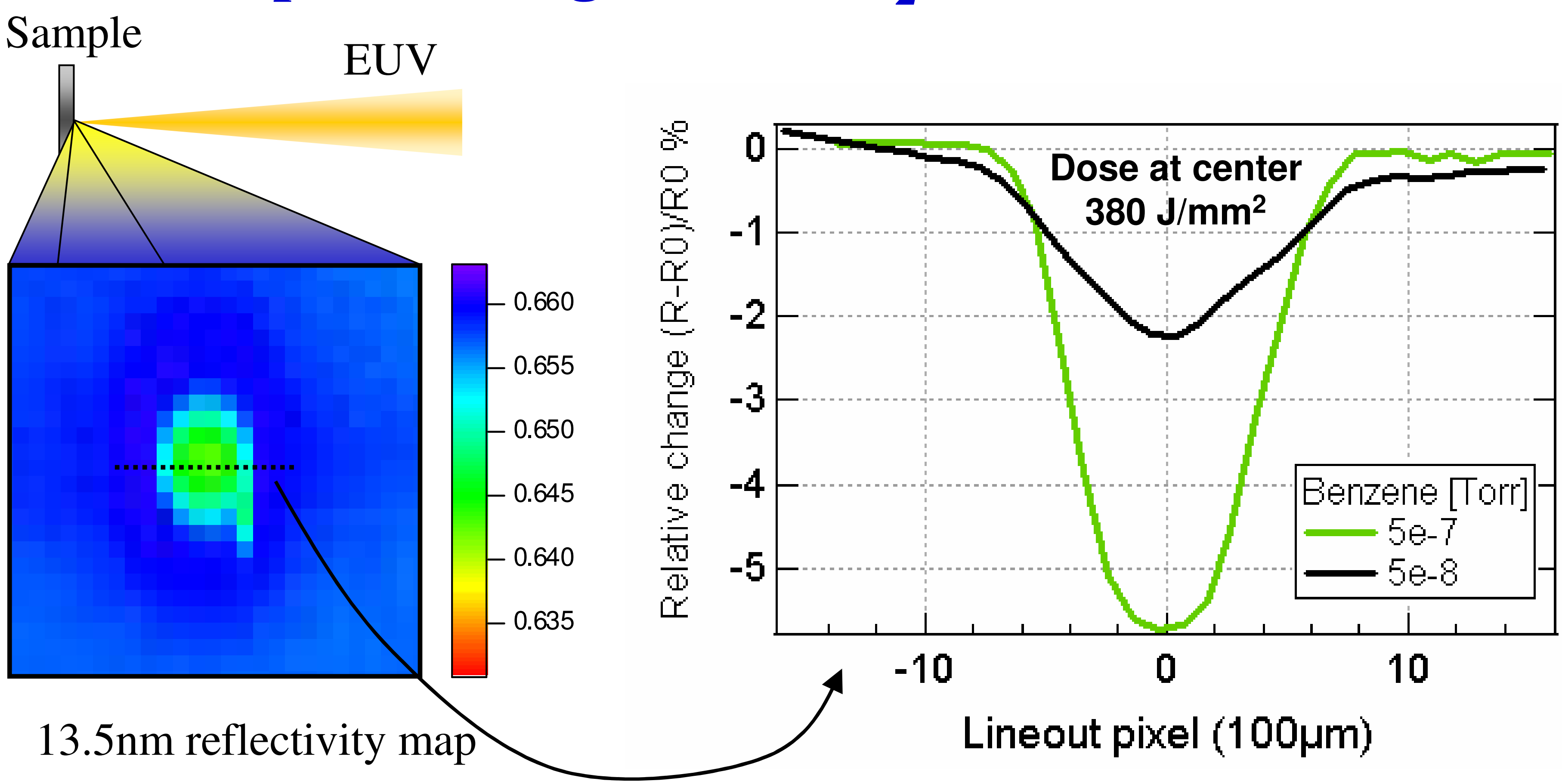
PTB results consistent with NIST

PTB
EUV Radiometry



- Same trend of less damage at greater water pressures in PTB system
- Similar behavior for both LLNL Ru-cap MLM and Si-cap collector mirror
- XRF analysis confirms
  - C deposition at low H2O pressures
  - C deposition mitigated by intermediate H2O pressures
  - Oxidation begins to dominate at highest H2O pressures

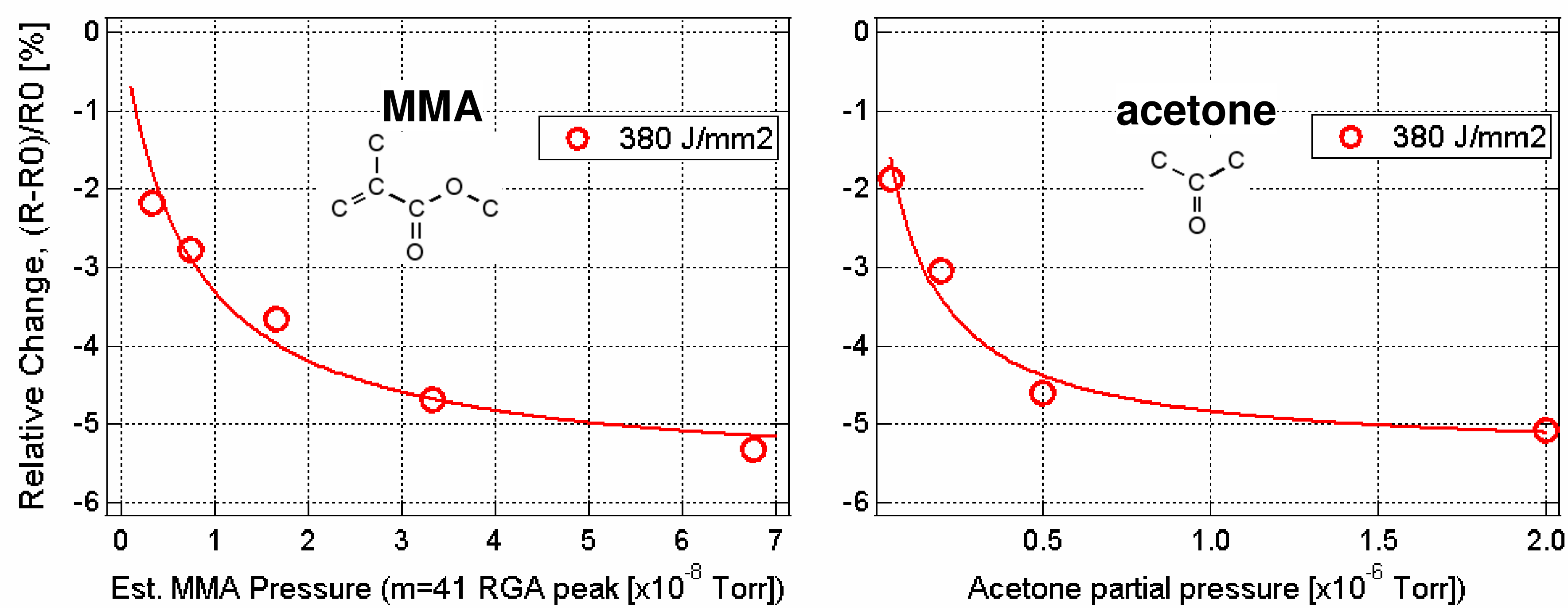
NIST exposures of generic TiO_2 in resist-related HCs



13.5nm reflectivity map

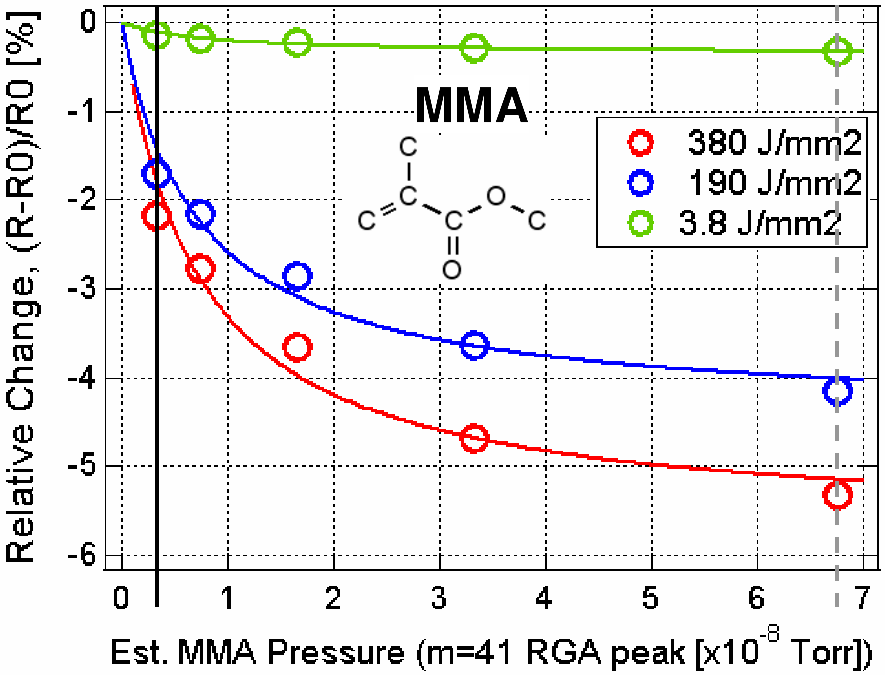
- Generic TiO_2 cap layer was not optimized to resist C deposition
- Reflectivity loss **nonlinear in pressure**: (10×pressure ≠ 10×loss)
- Significant (>0.5%) loss at low doses (<10 J/mm^2) in tails of intensity distribution

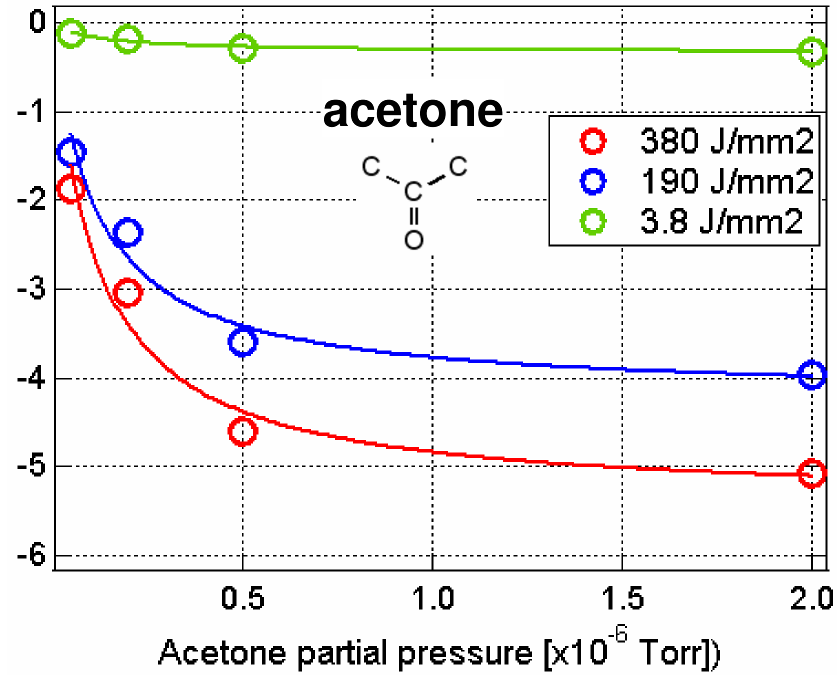
Generic TiO_2-cap MLMs exposed in resist-related HCs

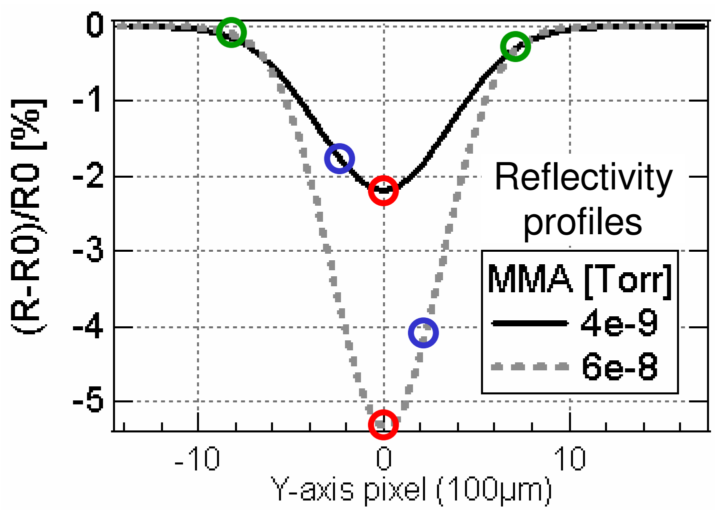


- Significant losses for all species, doses and pressures examined (<10^{-8} Torr)
- Saturation possibly due to site competition as coverage approaches 1 ML

Generic TiO_2-cap MLMs exposed in resist-related HCs

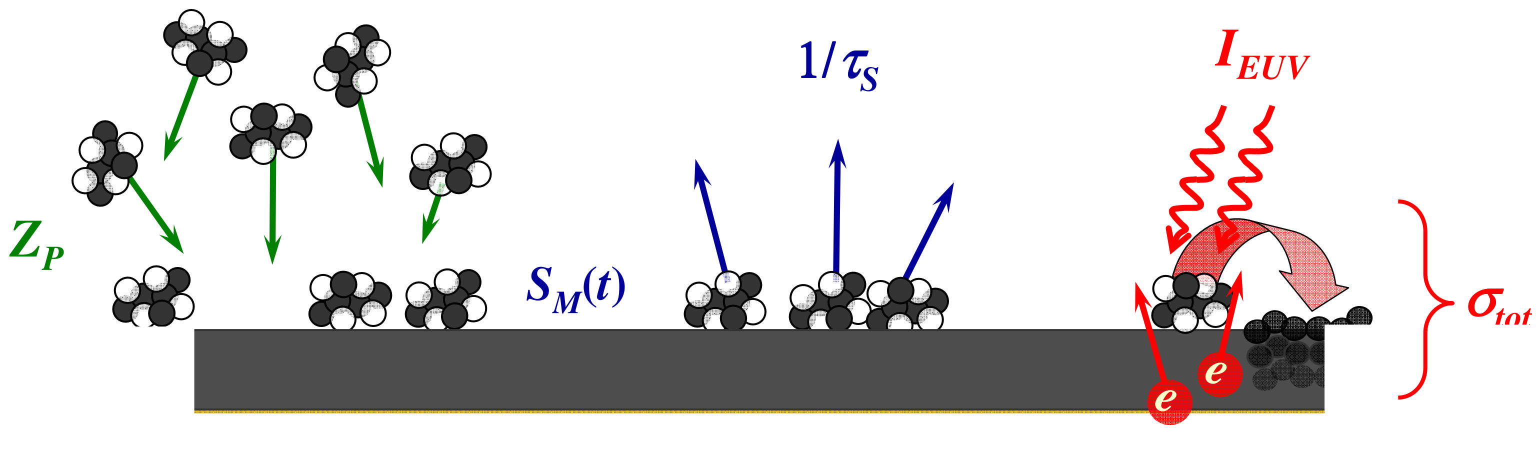






- Significant losses for all species, doses and pressures examined (<10^{-8} Torr)
- Saturation possibly due to site competition as coverage approaches 1 ML
- Widths of Gaussian reflectivity profiles suggests square-root dependence on intensity – similar to Canon's results!
- **Suggests low-intensity exposures should not be accelerate by increasing pressure**

NIST simple thick-C-growth model



Single-species contaminant

- Coverage of adsorbed intact molecules, $S_M(t)$ [molecules cm^{-2}]
- Site-limited max coverage S_{max} ~ 1 ML
- Impingement rate Z_P [molecules cm^{-2} s^{-1}]
- Surface-residence time τ_S [s]

First-order photo reaction

- Incident EUV intensity I_{EUV} [photons cm^{-2} s^{-1}]
- Total cross section σ_{tot} [cm^2]
  - Secondary e$^-$ dissoc. dominates
  - Photo-desorption negligible
- Linear in S_M and I_{EUV}

$$\frac{dS_M(t)}{dt} = Z_P\left(1 - \frac{S_M(t)}{S_{\max}}\right) - \frac{S_M(t)}{\tau_S} - I_{EUV}\sigma_{tot}S_M(t)$$

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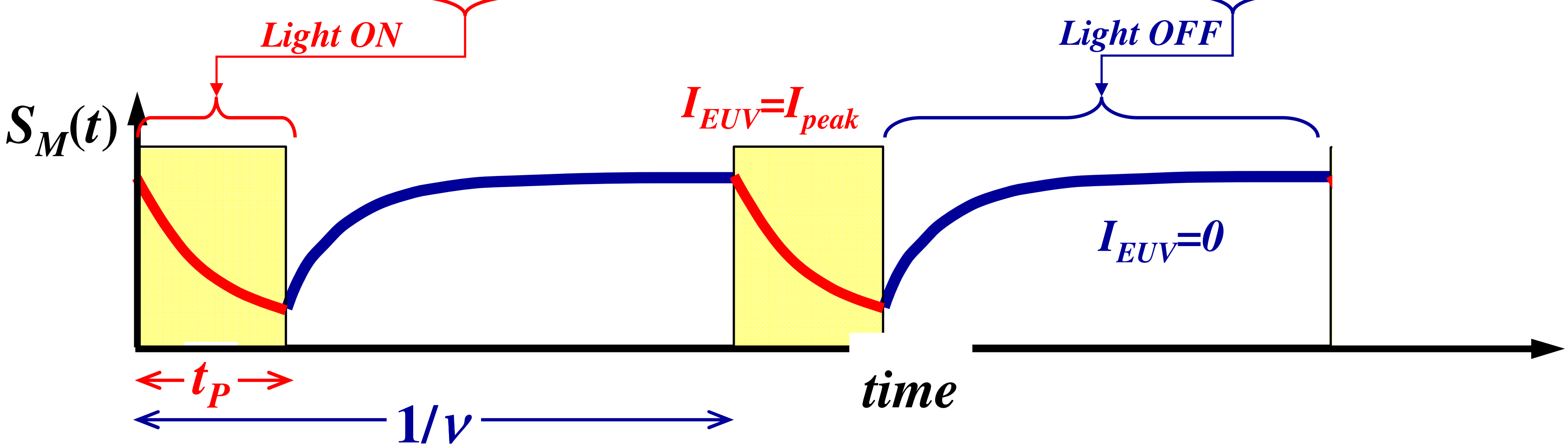
Evolution during pulsed irradiation

$$\frac{dS_M(t)}{dt} = Z_P\left(1 - \frac{S_M(t)}{S_{max}}\right) - \frac{S_M(t)}{\tau_S} - I_{peak}\sigma_{tot}S_M(t)$$

$$\frac{dS_M(t)}{dt} = Z_P\left(1 - \frac{S_M(t)}{S_{max}}\right) - \frac{S_M(t)}{\tau_S}$$



Carbon-growth rate, *k* [C atoms cm^{-2} s^{-1}]

$$k = \nu N_C \int_0^{t_P} I_{peak}\sigma_{tot}S_M(t)\,dt$$

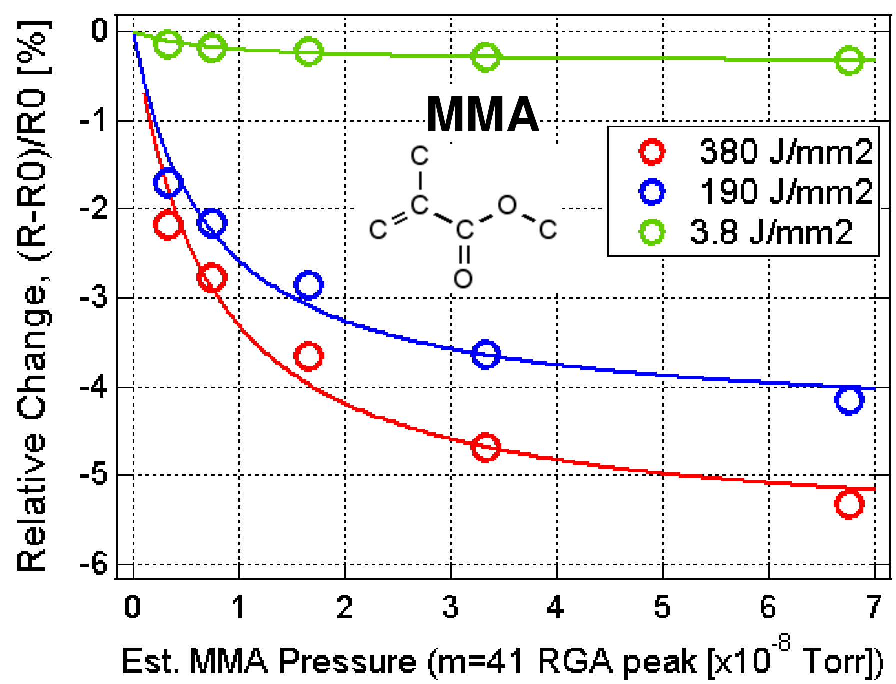
Damage rate for Equilibrium Approximation

Carbon-growth rate: $$k = \nu N_C \int_0^{t_P} I_{peak}\sigma_{tot} S_M(t)dt \cong (\nu t_p) I_{peak}\sigma_{tot} S_{eq}$$

$$k = N_C \frac{Z_P \tau_S I_{avg}\sigma_{tot}}{1 + I_{avg}\sigma_{tot}\tau_S + Z_P\tau_S / S_{\max}}$$

Assuming: Duty << 1, and residence time, τ_S << pulse period

- Equilibrium approximation: photon-induced reactions produce only small perturbation of light-off equilibrium coverage
- Independent of time structure
- NOT useful as *ab initio* predictor due to exponential uncertainties in τ_S and σ_{tot}
- Predicts observed "pressure saturation"
- Application to MET contamination data predicts reasonable residence times of 10-100s and contaminant pressure ~10^{-10} Torr



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Summary

1) Initial non-intuitive damage rates of Ru in H_2O confirmed by PTB

2) Exposures of generic TiO_2-cap MLMs (not designed for optimal C-growth resistance) in resist-related hydrocarbons
   - Damage rate not linear with HC pressure at high levels
   - Saturation of damage can occur at surprisingly low pressures (10^{-8} - 10^{-7} Torr)
   - Accelerated testing should only be performed at pressures below saturation regime for each gas.

3) Simple thick-C-growth model
   - Only applicable after first few MLs of C have been deposited
   - Predicts non-linear pressure and intensity dependences

4) Ongoing work to explore resonance effects and growth of first MLs