EUV and Electron Beam Testing of Ruthenium Capped Multilayer Optics

Dean Buchenauer, W. Miles Clift, Ken Williams, and Lennie Klebanoff
Sandia National Laboratories

Shannon Hill, Charles Tarrio, and Steve Grantham
National Institute of Standards and Technology

Sasa Bajt
Lawrence Livermore National Laboratory

Eric Gullikson
Lawrence Berkeley National Laboratory

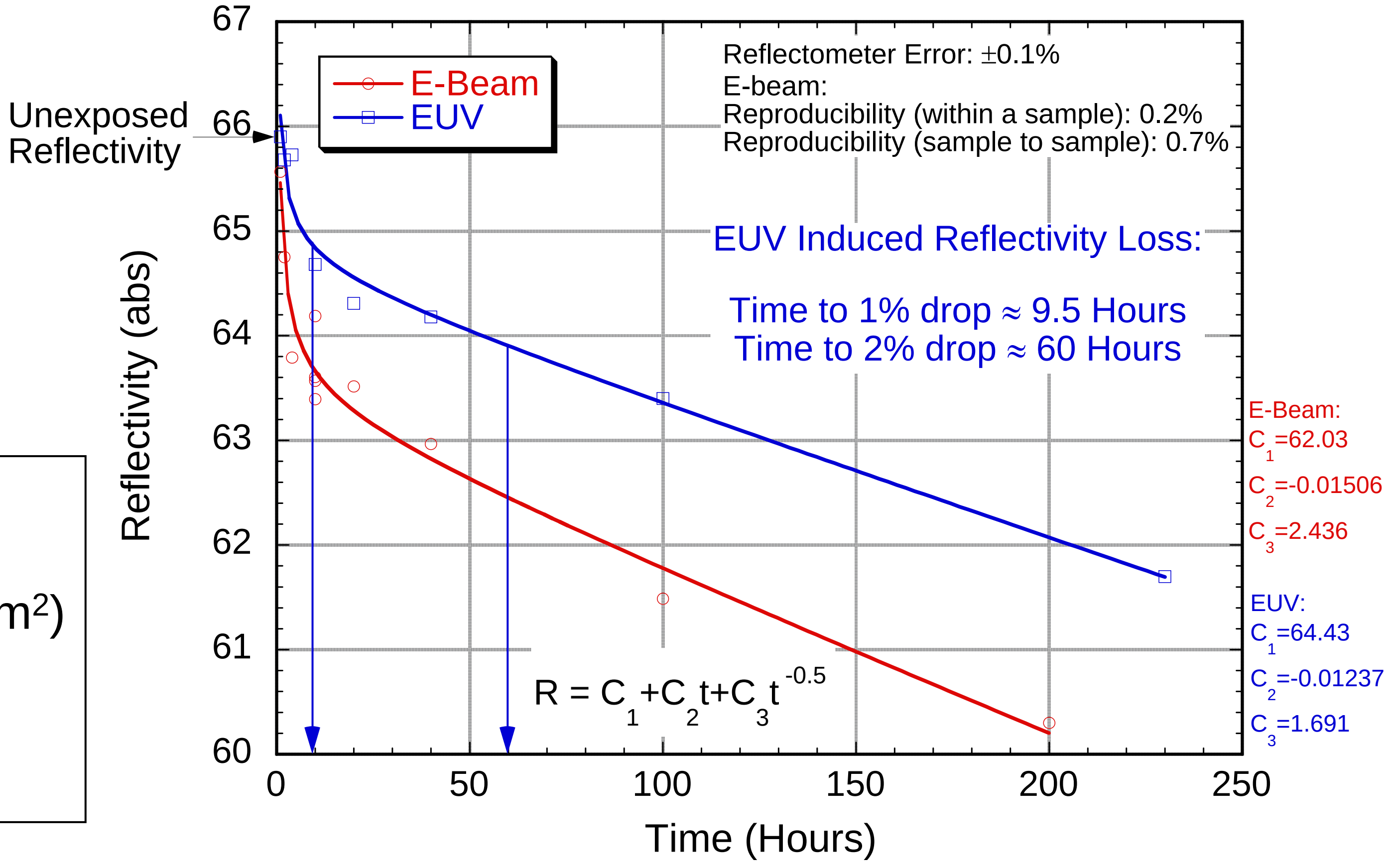
Ginger Edwards, Obert Wood, and Stefan Wurm
International SEMATECH

Oxidation of multilayer mirrors

- Oxidation of MLM's occurs during exposure to either a flux of electrons or EUV photons in the presence of water vapor.
- Previous work
  - 5 mW/mm^2 of 13 nm photons ⇔ 5 μA/mm^2 of e^- at 1 keV (Silicon)
  - Dependence of oxidation on electron energy is weak
  - Ru-capped MLM's showed improved reflectivity loss / oxidation resistance
- ETS experience (water vapor dominant residual gas species)
  - 5×10^{-7} Torr at the projection optics; 2×10^{-8} Torr in the Illuminator
  - In a commercial stepper (EUV flux ≤ 10 mW/mm^2) ⇒ rapid oxidation (for a silicon capped MLM).
- Sandia E-beam study (1.5 keV) of Ru-capped MLM aging
  - Perform time history exposures (1, 2, 4, 10, 20, 40, 100 hour) under several conditions (≤ 5 μA/mm^2 e- flux, ≤ 5×10^{-6} Torr water vapor)
  - Measure reflectivity loss and oxide thickness
  - Evaluate EUV - electron correspondence (for Ru-capped MLM's)

E-beam induced reflectivity loss is larger than EUV induced loss

E-Beam and EUV Induced Reflectivity Loss for Ru-capped MLM



Reflectometer Error: ±0.1%
E-beam:
Reproducibility (within a sample): 0.2%
Reproducibility (sample to sample): 0.7%

EUV Induced Reflectivity Loss:

Time to 1% drop ≈ 9.5 Hours
Time to 2% drop ≈ 60 Hours

$R = C_1 + C_2 t + C_3 t^{-0.5}$

E-Beam:
$C_1 = 62.03$
$C_2 = -0.01506$
$C_3 = 2.436$

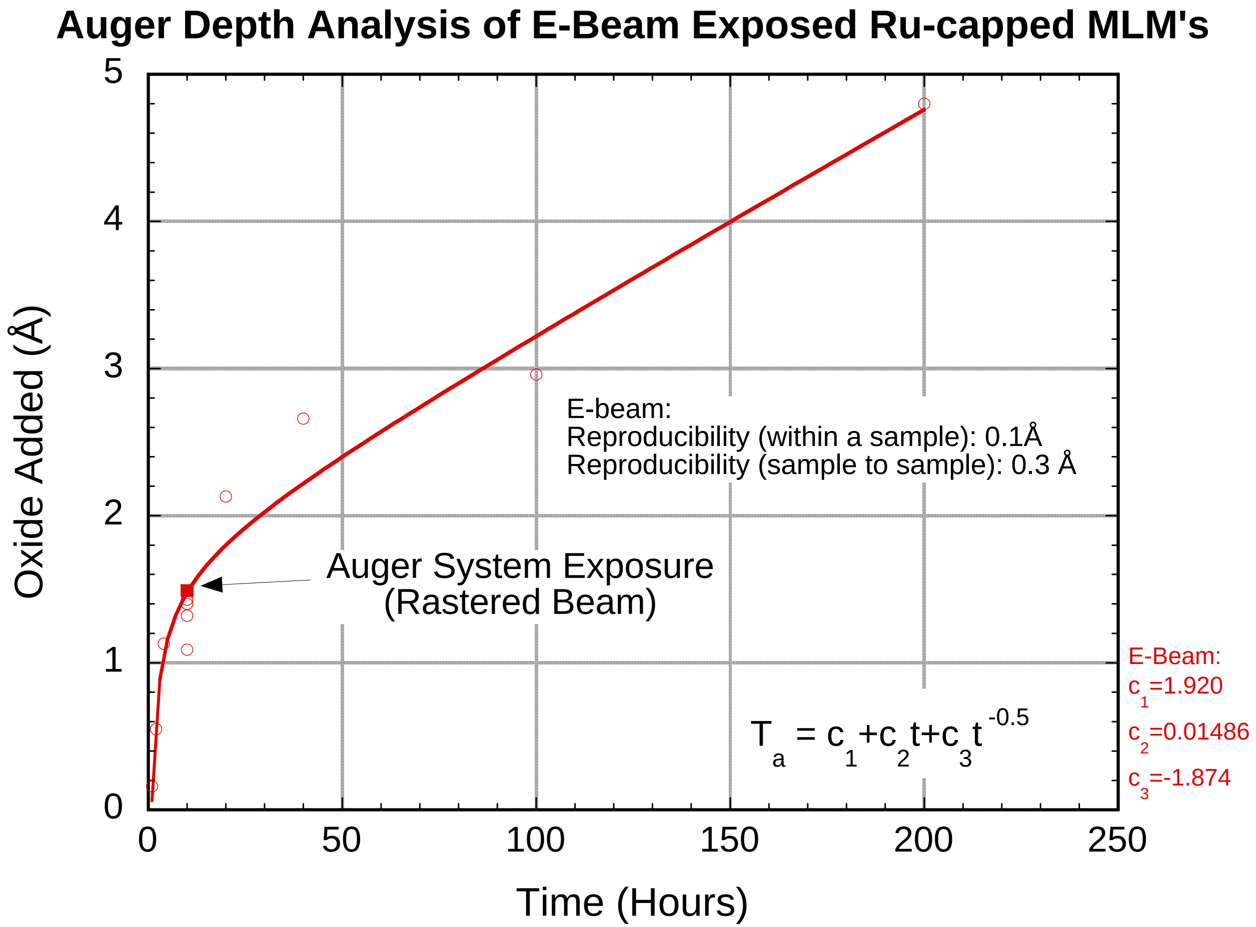
EUV:
$C_1 = 64.43$
$C_2 = -0.01237$
$C_3 = 1.691$

First round data:

5 μA/mm² (5 mW/mm²) incident flux at 2×10^{-6} Torr water vapor pressure

The data suggests a different electron-photon correspondence for Ru

Added oxide thickness also shows rate change behavior



E-beam:
Reproducibility (within a sample): 0.1Å
Reproducibility (sample to sample): 0.3 Å

$T_a = c_1 + c_2 t + c_3 t^{-0.5}$

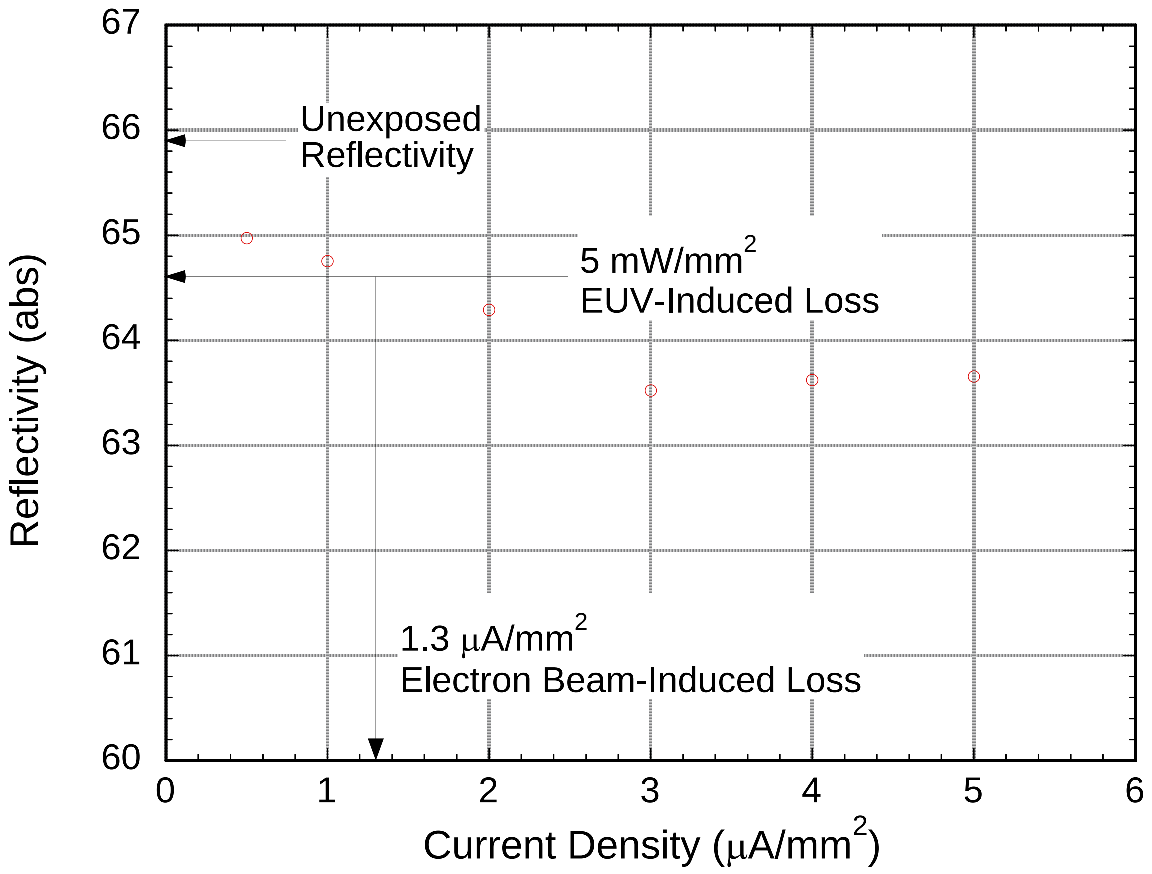
E-Beam:
$c_1=1.920$
$c_2=0.01486$
$c_3=-1.874$

First round data:

5 μA/mm² (5 mW/mm²) incident flux at 2×10^{-6} Torr water vapor pressure

E-beam current scaling determines electron-photon correspondence for Ru

E-Beam Induced Reflectivity Loss for Ru-capped MLM



2×10^{-6} Torr water vapor pressure

5 mW/mm^2 of 13 nm photons ⇔1.3 μA/mm^2 of e$^-$ at 1.5 keV

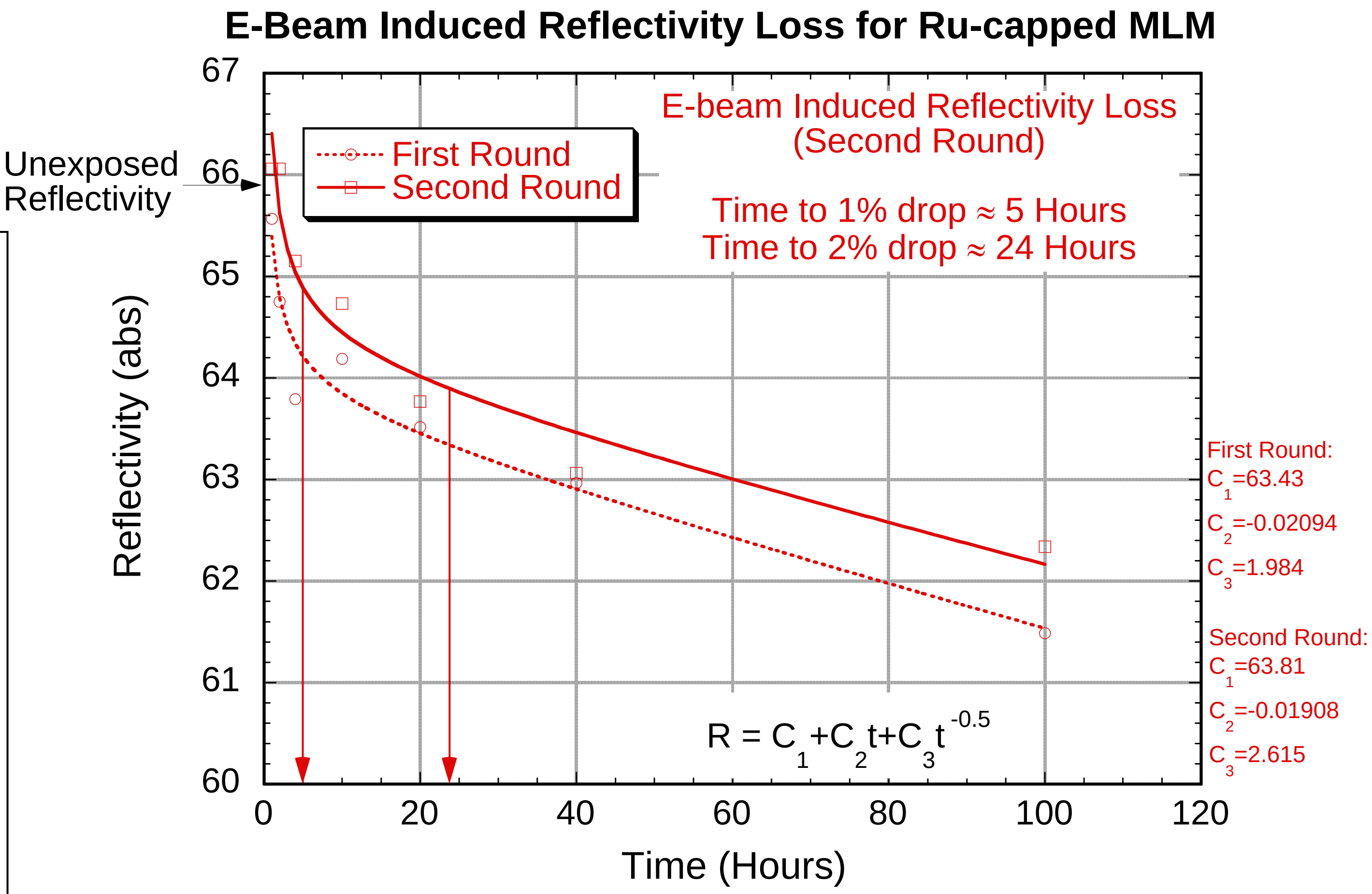
Reflectivity loss under two conditions are similar, but indicate near-saturation

First round data:

5 μA/mm^2 incident flux at 2×10^{-6} Torr water vapor pressure

Second round data:

1.3 μA/mm^2 incident flux at 2×10^{-7} Torr water vapor pressure


E-Beam Induced Reflectivity Loss for Ru-capped MLM

Oxide thickness measurements show similar behavior

Areas for cooperation (Ginger's)

- Share data on scaling laws; divide parameter space; use consortia to benchmark testing capabilities
- Perform testing in all three regions on a known, neutral ML
- Share general data on fundamental understanding; have European, Japanese and American surface science experts unite to share data, expertise
- Toolmakers to develop list of contaminant materials to be studied (coming from the source and resist)
- Consortia to work together to develop scaling laws for oxidation of broad classes of materials (i.e., work together and share data)
- White paper on one of the top three critical tasks

Areas for cooperation (Dean's)

- Fundamental measurements / modeling of capping layer oxidation and reflectivity loss (others?)
- Atomic H cleaning of ruthenium to remove oxide
- Round robin testing of candidate materials in Europe, Japan, and U.S.
- Variation of environmental conditions (H_xC_y levels?)
- Investigation of time varying fluxes and annealing effects
- Increased communication of results