Preliminary Results of Contamination Control Development in EUVA

March. 3rd, 2005, SPIE Microlithography at San Jose

Extreme Ultraviolet Lithography System Development Association (EUVA) Contamination Research Group

T. Aoki, H. Kondo, S. Matsunari,

Y. Gomei, H. Takase and S. Terashima,

EUVA Contamination Control Project: Tasks

1. Capping Layer Development

- Estimation of oxidation speed and its dependency to H_2O partial pressure, light intensity, …
- Optimization of Ru coating conditions
- Listing up other candidates and screening by EUV/E-beam irradiation

2. Carbonization Mitigation/Cleaning

- UV (172nm Xe_2 lamp)+O2 cleaning
- EUV+O2 cleaning
- Estimation of carbon film growth/removal speed and its dependency to O_2 partial pressure, light intensity, cleaning time, …

EUVA Contamination Control Project: Sites

Research Sites

1. Himeji (Univ. Hyogo)
2. Sagamihara (Nikon)
3. Utsunomiya (Canon)

Research Laboratories

1. SR “Super-ALIS” in Atsugi (NTT)
    - light intensity/dose dependency test
    - H_2O/C_xH_y partial pressure dependency test
    - cleaning test
2. SR+Undulator “NewSUBARU” in Himeji (Univ. Hyogo)

    high power irradiation (Long Undulator)
    - accelerated experiments
    - material screening

See the poster by Kakutani *et al.*

Apparatus at NTT Atsugi Laboratory

folding mirror

source

Zr filter

monochromatic light

PD

LL

Irradiation chamber

sample mirror

Super-ALIS beam-line & Apparatus @Atsugi

Apparatus: Irradiation Chamber

- ✓ Direct EUV light and reflected can be also monitored with the identical photo-diode.
- ✓ Constructed with UHV components and has few plastic components to mitigate the H_2O/C_xH_y outgassing.
- ✓ TMP, cryo-sorption pomp, load-lock chamber.

Degree of vacuum 5E-7 Pa (6E-9 Torr) is achieved after baking.

Residual Gas Analyses of the Chamber

Irradiation Chamber RGA Spectrum:

RGA Spectrum
irradiation chamber
2×10^{-6} Pa, 1,300V, 2mA

Current [A]
1.E-09
1.E-10
1.E-11
1.E-12
1.E-13
1.E-14

H2O
N2, CO
O2
CO2

1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191 201
Mass Number [amu]

H2O and CxHy is less than those of ETS by about one and a half order.

No significant C_xH_y peak (>45amu)

EUV Light Intensity & Beam Shape

SEM Image

0.5mm

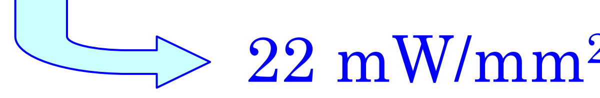
3.0kV 41.3 X 500.0um

Photoresist Image

exposed area

Estimation of EUV intensity on TP

- Light source: Φ1.6mm
- Solid angle: H35mrad, V1mrad
- SR Current: 350 mA max.
- Electron energy: 0.6 GeV
- Two grazing-incident mirrors
- One multi-layered folding mirror
- One Zr filters for band restriction



22 mW/mm^2

100 times greater than those on exposure tool mirror surface

Beam Size: 1.6mm × 1.0mm

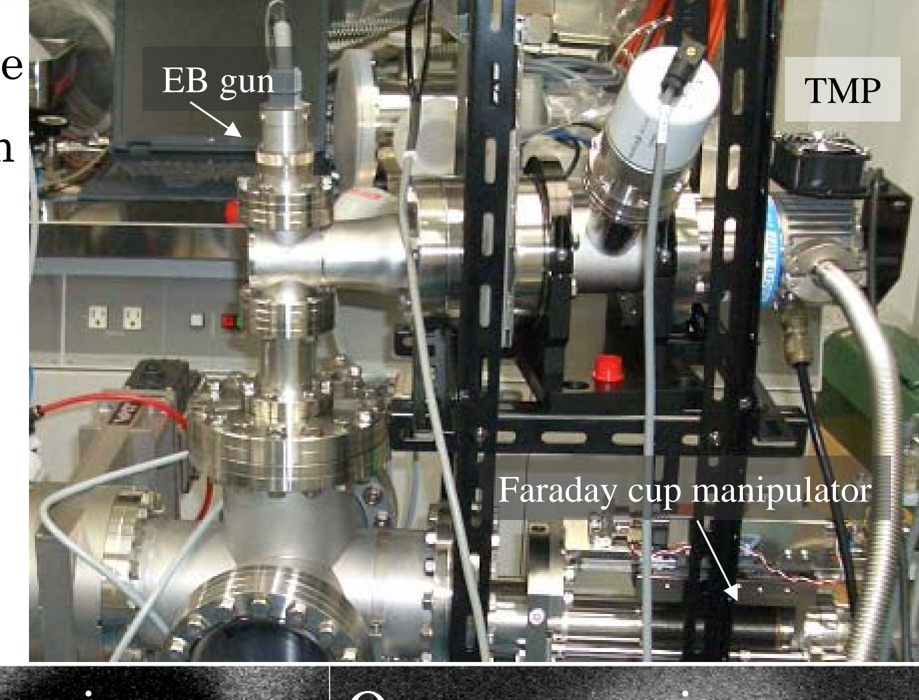
E-Beam Irradiation for Accelerated/Off-line Test

H_2O: 1E-4Pa, Si-Cap, 6hrs exposure

Beam Diameter (AES) about 400µm

EB Irradiation Results

- Oxidation speed by EB is faster than that by EUV.
- No carbon deposition and oxidation 1.5mm away



SEM image

200µm

10.0kV 150.0 X 100.0µm
Si-Cap i041007 H2 #1

Carbon mapping

10.0kV 150.0 X 100.0µm
C Mapping

Oxygen mapping

10.0kV 150.0 X 100.0µm
O Mapping

Test Piece

- ✓ Si/Mo 50 pairs on Si wafer.
- ✓ With/without Si, Ru & other capping layer
- ✓ Anti-diffusion layer

Experiment

- ✓ On-line (in-situ) analysis
  EUV reflectance measurement
- ✓ Off-line (ex-situ) analysis
  Surface analysis with XPS (AES), SIMS, AFM, TEM, …

More sensitive than reflectance

Analysis (XPS)

- ✓ Atomic Abundance
  - Amount of Oxygen
  - Amount of Carbon
- ✓ Chemical State
  - Degree of Oxidation
- ✓ Depth Profile with sputtering
  - Oxygen Distribution
  - Mixing Evaluation (Diffusion Layer)

See the poster by Takase *et al.*

Capping Layer Development

Candidate Materials

- ✓ Ru
  - Optimization of coating condition
- ✓ Noble Metals
  - Resistance properties against oxidation
  - Lower electron mobility
- ✓ Oxides
  - Barrier for oxygen transfer
  - Catalytic effect
- ✓ Diffusion Barrier Layer
  - Mitigation of oxygen transfer

Oxidation Resistance Test by EUV Irradiation

XPS Results: Ru-cap, 1E-6Pa, 6hours EUV Irradiation

Ru/C

C1s

C1s:C−C,C−H等

Ru3d:金属Ru

Ru3d:RuOx

Ru3d3/2 Ru3d5/2

Intensity (Counts/ s)

Binding Energy(eV)

Si

Si2p

SiO2 (RuSixOy)

SiOx

Si−Si (Si−Mo)

Intensity (Counts/ s)

Binding Energy(eV)

Mo

Mo3d

金属Mo

Mo3d3/2 Mo3d5/2

Intensity (Counts/ s)

Binding Energy(eV)

O

O1s

Si−O Ru−OH等

C=O, C−O−C

Ru−O等

Intensity (Counts/ s)

Binding Energy(eV)

EUV Irradiation under H2O Introduction

H2O: 1E-6 Pa

H2O: 9E-4 Pa

Exposure: 3hours

Si

(a) SiOx/nm vs Time/hour — EUV, REF

(b) SiOx/nm vs Time/hour — EUV, REF

(c) SiOx/nm vs Pressure/Pa — EUV, REF

Ru

(d) RuOx/(Ru+RuOx) /% vs Time/hour — EUV, REF

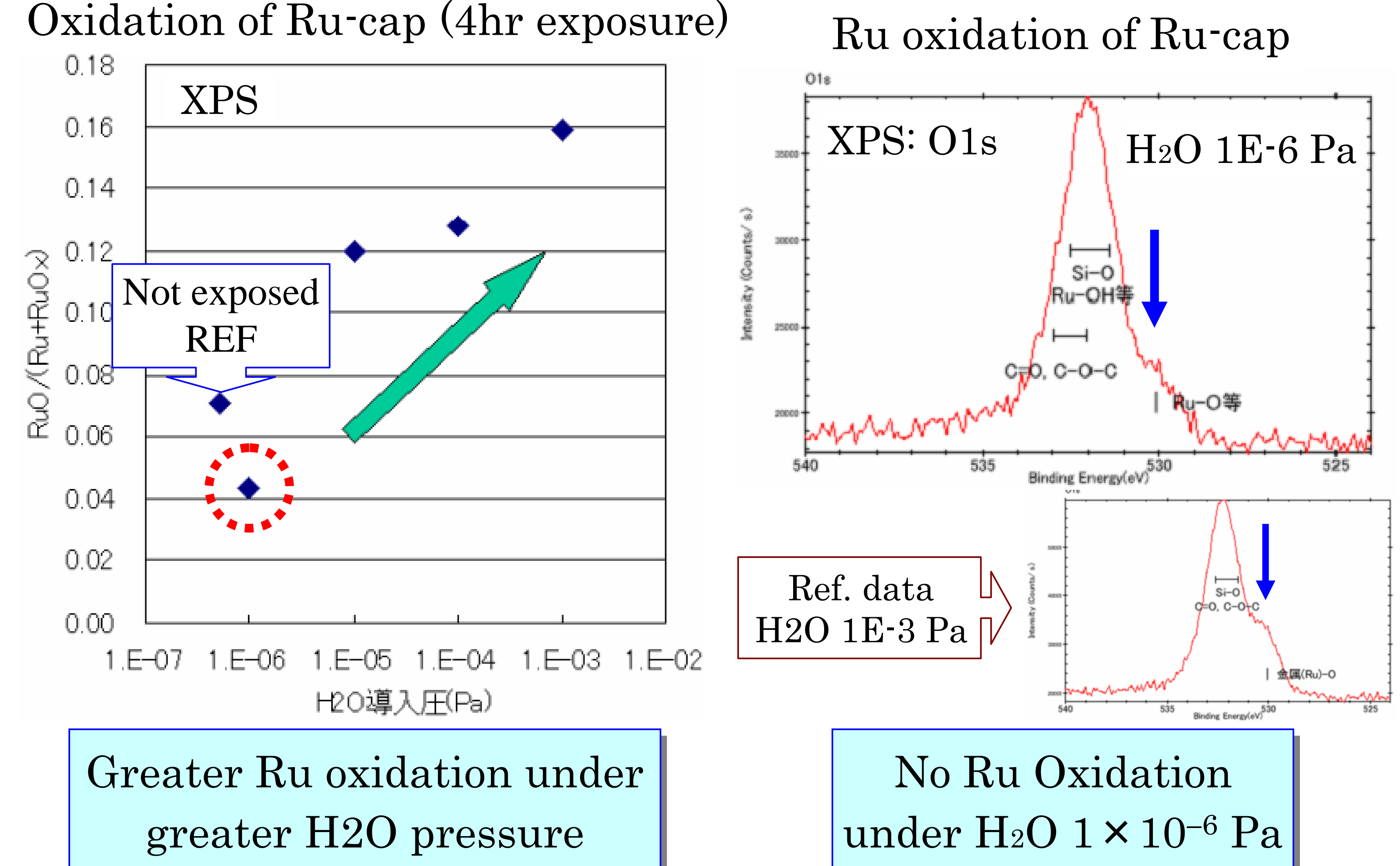
(e) RuOx/(Ru+RuOx) /% vs Time/hour — EUV, REF

(f) RuO/(Ru+RuOx)/% vs Pressure/Pa — EUV, REF

Oxidation at irradiated area

Oxide thickness increase as irradiation time and H2O pressure increase

EUV Irradiation under H2O Introduction



Greater Ru oxidation under greater H2O pressure

No Ru Oxidation under H_2O 1×10^{-6} Pa

EUV Irradiation under H2O Introduction

Si oxidation of Ru-capped

XPS

4 hr exposure

SiO2

Si

Si/(Si+SiO2), SiO2/(Si+SiO2)

0 10 20 30 40 50 60 70 80 90 100

1.E-07 1.E-06 1.E-05 1.E-04 1.E-03 1.E-02

H2O (Pa)

Si oxidation of Si- and Ru-capped

Ru-cap

Si-cap

XPS

4 hr exposure

SiOx/(Si+SiOx)

0 0.5 1 1.5 2 2.5 3

1.E-07 1.E-06 1.E-05 1.E-04 1.E-03 1.E-02

H2O (Pa)

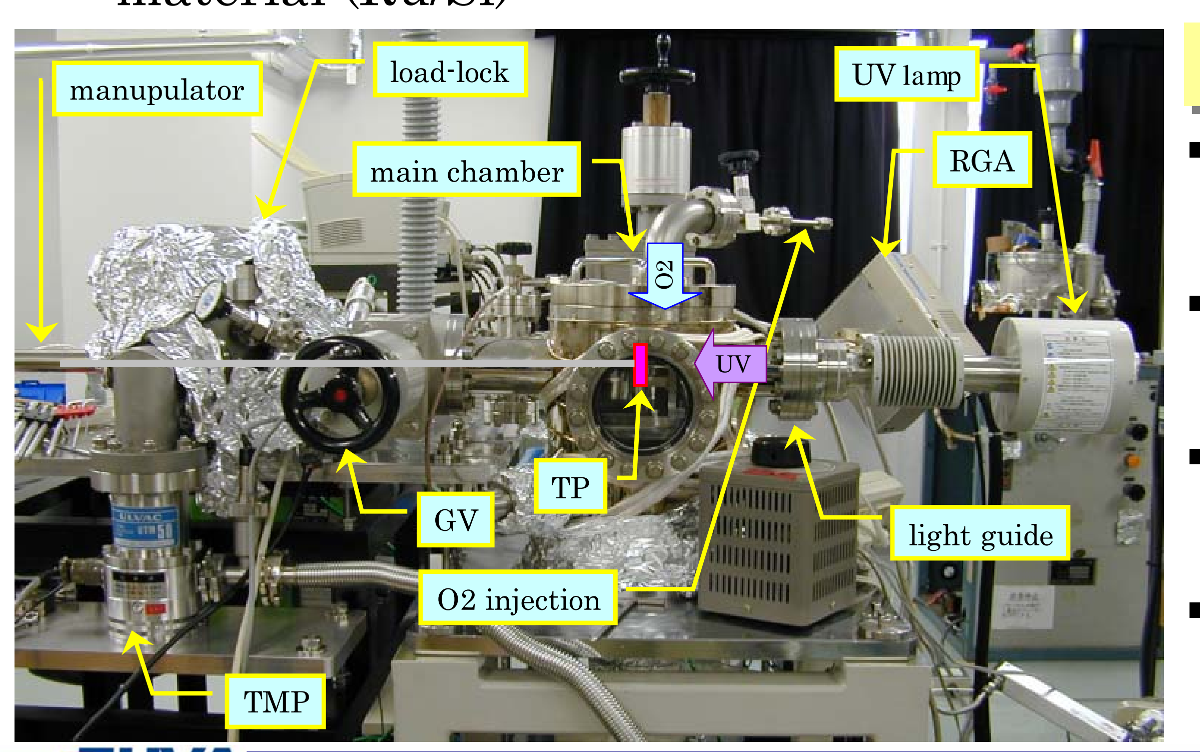
Greater oxidation of Si below Ru-cap under greater H2O increased	Oxidation of Si under Ru-cap is reduced than that under Si-cap

Si: Partial oxidation, Ru: no oxidation

UV+O2 Cleaning: Apparatus

Removing carbon film with UV exposure under O_2 containing condition

- ✓ Estimation of cleaning speed and surface damage
- ✓ Dependency to O_2 partial pressure, light intensity, dose, cap material (Ru/Si)



Performance

- Xe_2 excimer lamp (172nm)
- Intensity: 50 mW/cm² (max)
- Residual gas pressure: 2E-6 Pa
- O2 pressure: 1E-1~1E3 Pa

UV Cleaning with O2: Experimental Conditions

Cleaned C film	sputtered: 1nm
O_2 pressure	100 Pa
UV intensity	3.9 mW/cm^2

Test Piece

No C
C
test piece

no C
C
C
Si
Mo

Raman Spectrum

amorphous
diamond
graphite
1581
1332
cm^{-1}

Sputtered

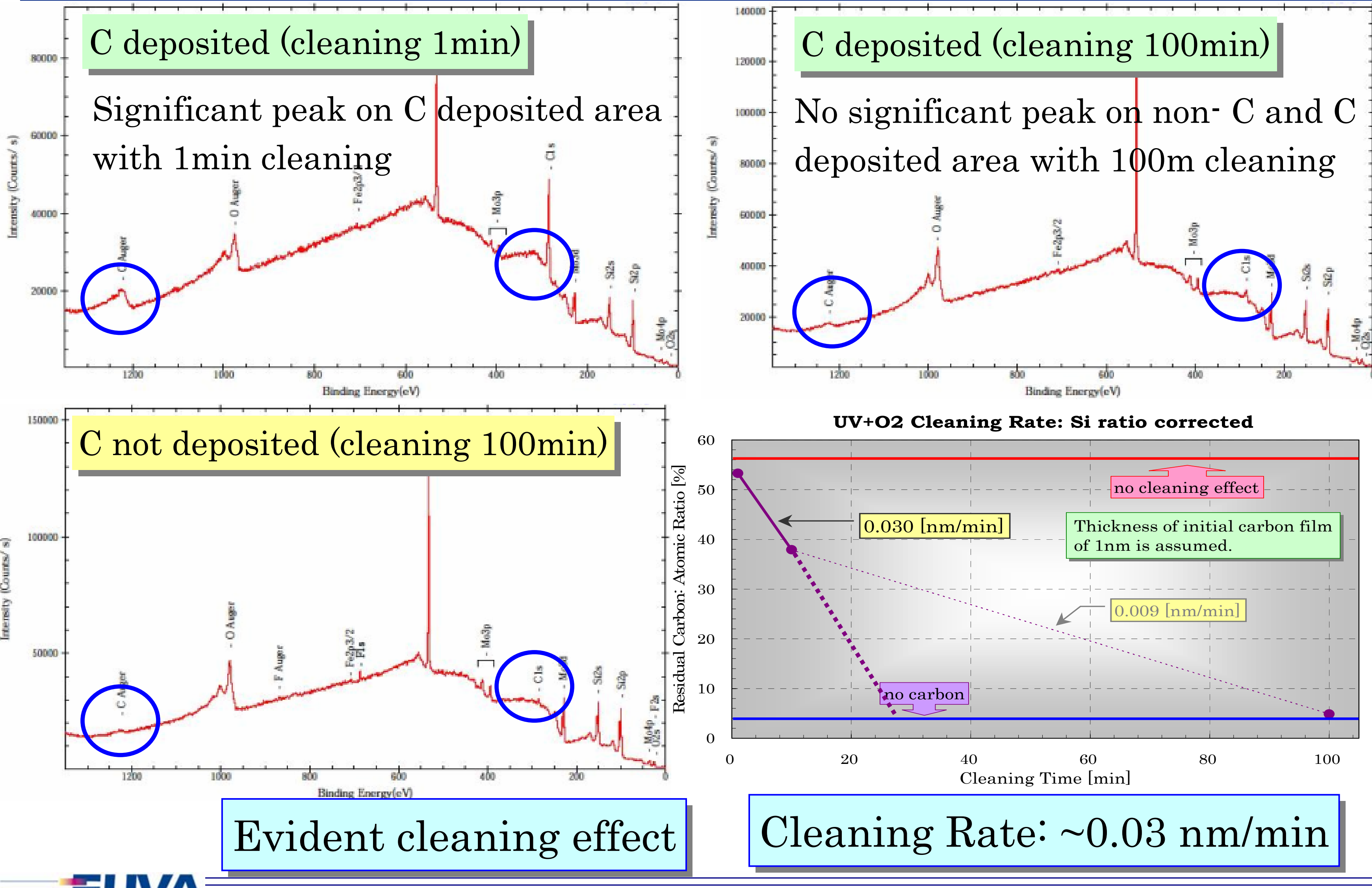
As Contaminated

Published Results

- Meiling *et al.* (2000): 4nm/min
- Hamamoto *et al.* (2004): 2nm/min

- Both are in amorphous states.
- Sputter C can be replaced.

UV Cleaning with O2: Results



Evident cleaning effect

Cleaning Rate: ~0.03 nm/min

Summary

- **Apparatus was Installed onto Synchrotron Facility**
  - ✓ Setting-up of the system had been completed.
  - ✓ Sub-systems for EB irradiation, H_2O introduction had been installed. CxHy gas introduction can be made near future.
- **Preliminary Experiments had been Started**
  - ✓ High degree of vacuum (5E-7 Pa) in the chamber.
    RGA spectrum shows low contaminants partial pressure.
  - ✓ Brighter EUV light irradiation is available than commercial exposure tool mirror surface.
  - ✓ Oxidation acceleration with H2O introduction is confirmed except for H2O pressure of 1E-6 Pa. ➔ Possible criterion ?
  - ✓ Si oxidation under non-oxidized Ru ➔ Coverage ? O transfer ?
  - ✓ It is confirmed that EB irradiation is available for capping layer materials screening with our setup.
  - ✓ Cleaning rate of UV+O2 is about 0.03 nm/min in 100 Pa O_2.
    Discrepancy ➔ Carbon density ?

Acknowledgments

This work was performed under the management of Extreme Ultraviolet Lithography System Development Association (EUVA) in the Ministry of Economy Trade and Industry (METI) program supported by New Energy and Industrial Technology Development Organization (NEDO).