

Contamination Cleaning of Ru-capped EUV Multilayer-Mirror with Atomic-Hydrogen

*I. Nishiyama¹, K. Motai¹, S. Miyagaki¹, H. Oizumi^{1,2},
T. Ueno², A. Izumi², and A. Namiki²*

*ASET EUV Process Technology Laboratory¹
Kyushu Institute of Tech.(KIT)²*

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Outline

1. Introduction

Optics lifetime issue in EUV Lithography

2. Experimental

- **Apparatus and treatment conditions**
- **Surface analysis method**

3. Results

- 1. Cleaning of Carbon contamination**
- 2. Cleaning of Ru oxide**
- 3. Evaluation of atomic hydrogen density**
- 4. Transportation of atomic hydrogen**

4. Summary

Status for Projection Optics Lifetime Issue

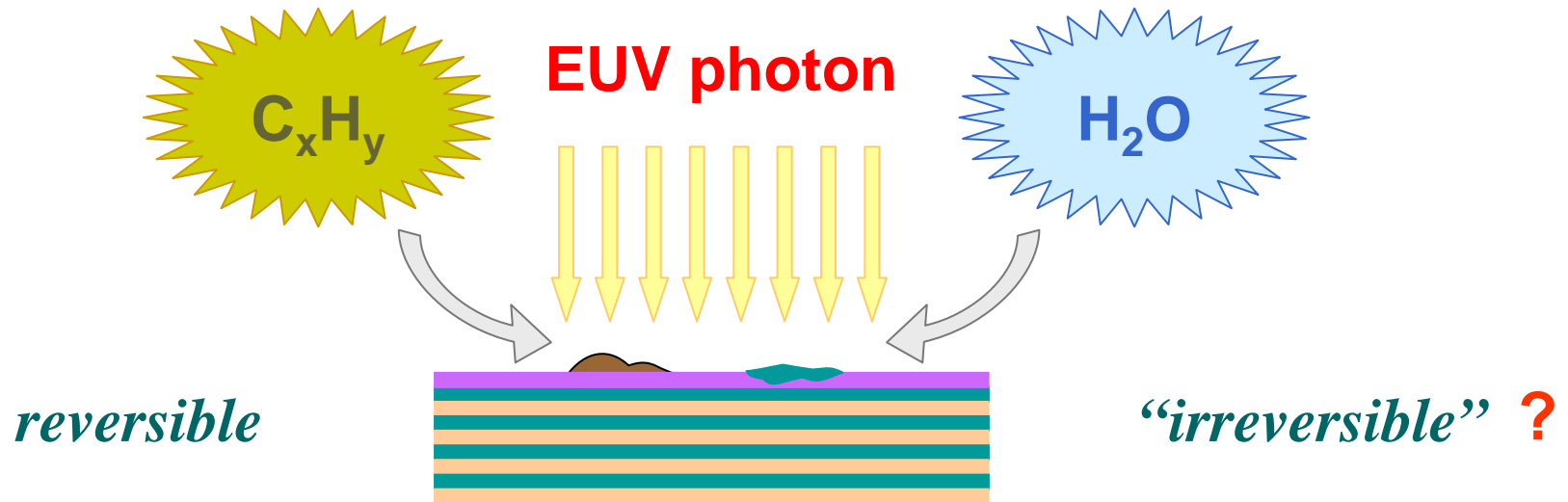
- Requirement for production tool
 - Lifetime > 30,000 hours
 - Reflectivity loss < 1.6%
- Condition
 - under unbaked vacuum
 - EUV irradiation: $I_{\text{EUV}} \leq 10 \text{ mW/mm}^2$
- Approach
 1. Environmental Control
 2. Capping layer development
 - Ru is the No.1 candidate, currently.
 - Lifetime of Ru is less than requirement in one order of magnitude
 3. Cleaning

This work

Two degradation mechanism of EUVL mirror

carbon growth on surface

oxidization of subsurface



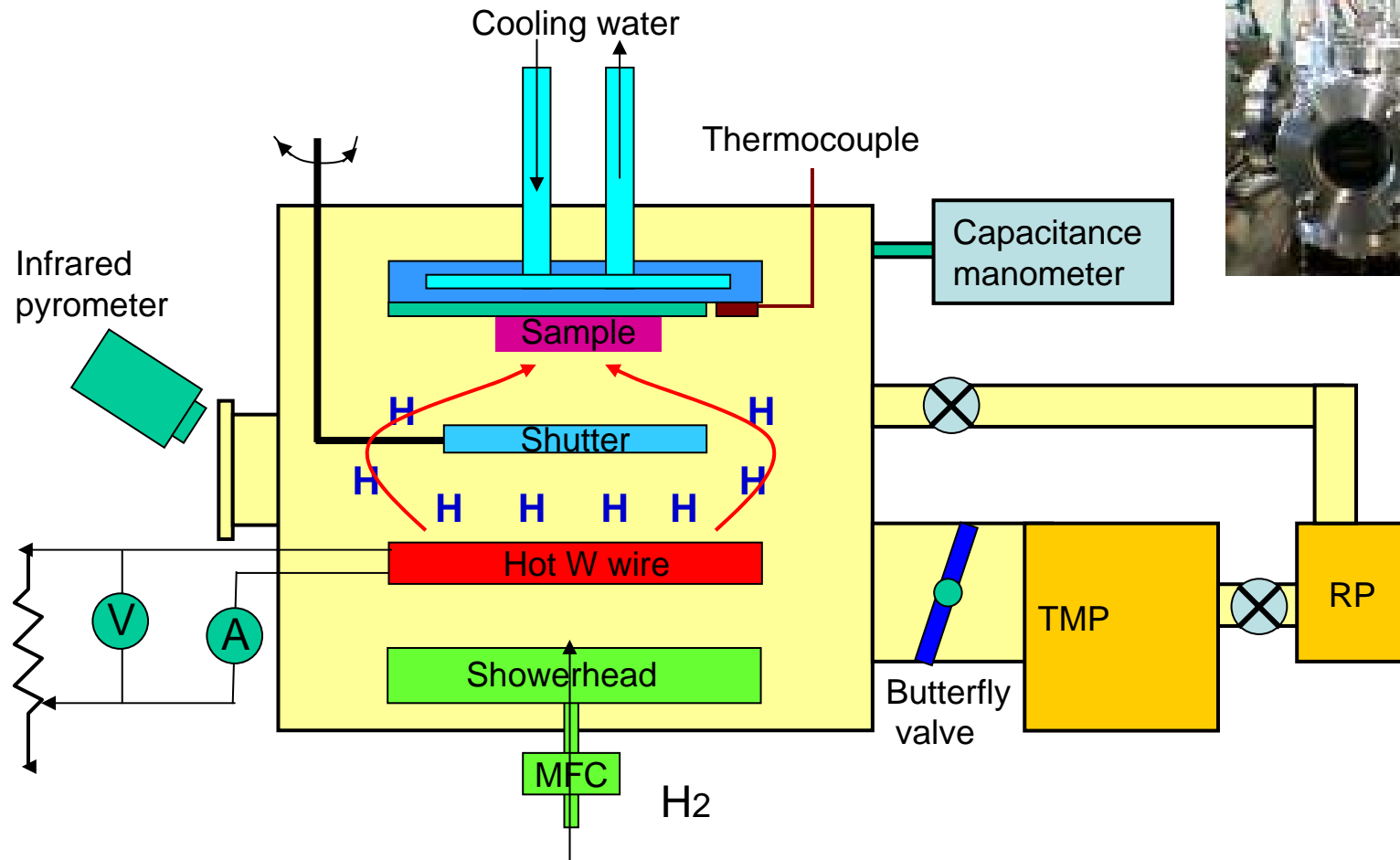
Cleaning technology is known
(Oxidization by O_2 , O , O_3)

Cleaning technology is unknown

Cleaning technology applicable for both contaminations is required.

Reductive cleaning by atomic hydrogen is a possible candidate.

Atomic Hydrogen Cleaning apparatus



Experimental

■ Sample

1. Carbon contamination

Carbon was formed on Si cap Mo/Si multilayer mirror by SR photon irradiation using Super-ALIS

2. Oxide contamination

Ru(2.7 nm) on Mo/Si multilayer mirror was oxidized by ECR O₂ plasma: (Hitachi, M-632A)

■ H-Treatment

➤ Hot-wire tungsten(1700-1900°C)

■ Analysis (*ex-situ*)

➤ XPS (X-ray photoelectron spectroscopy)

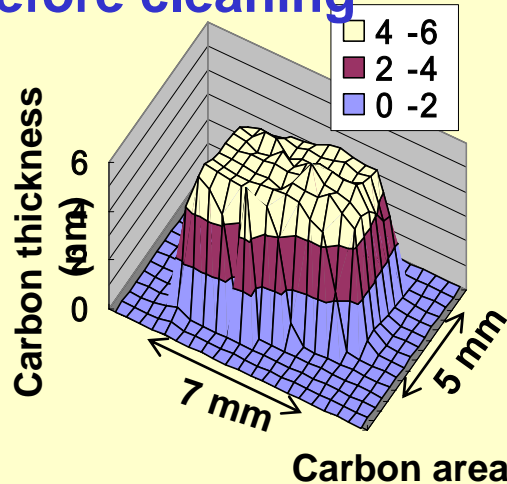
➤ AES (Auger electron spectroscopy)

➤ AFM (Atomic force microscope)

➤ Reflectivity (ASET reflectometer)

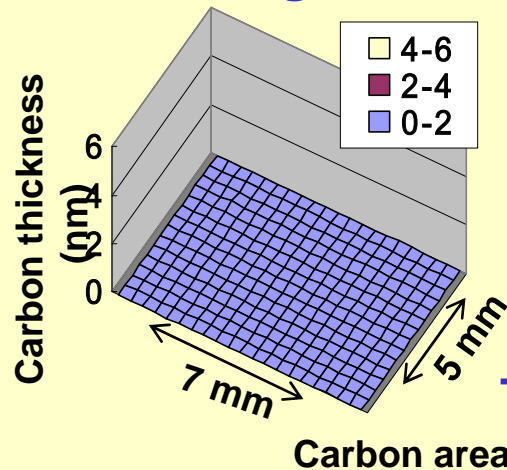
Atomic-H Cleaning of Carbon Contamination

Before cleaning



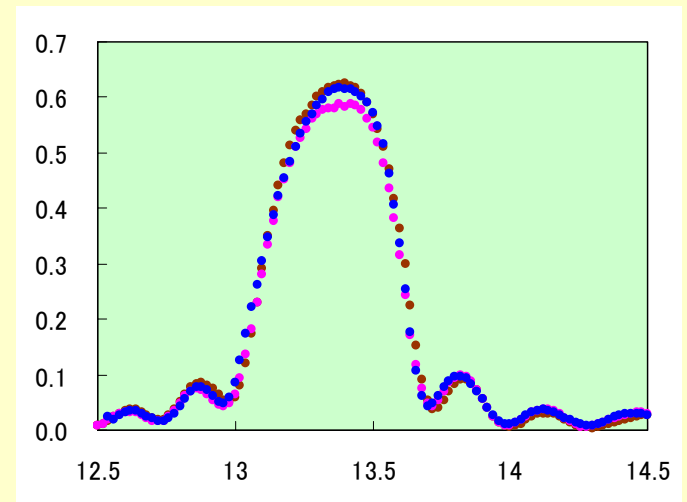
Thickness:
5.6 nm

After cleaning



Thickness:
negligible

Reflectivity recovery



As sputtered: 62.4%



C contamination: 58.9%



Atomic H cleaning: 61.9%

Oizumi et al. SPIE 2005

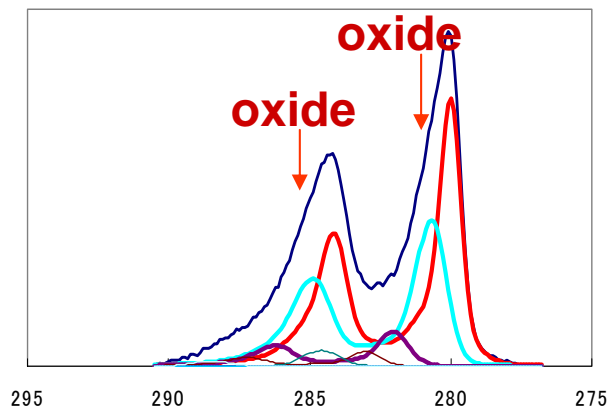


EUV Process Technology

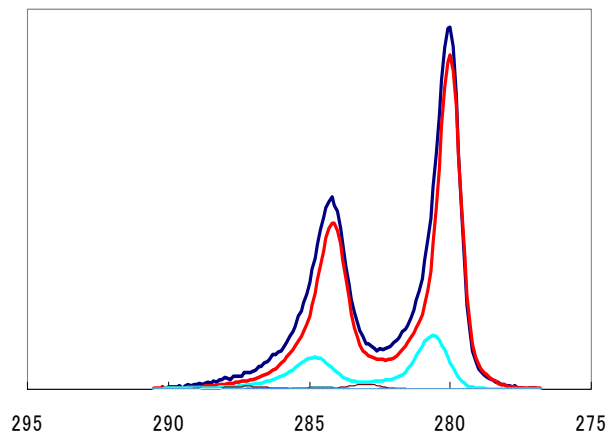
Cleaning of Ruthenium Oxide (Ru-capped ML)

XPS (Ru 3d_{3/2}, 5/2)

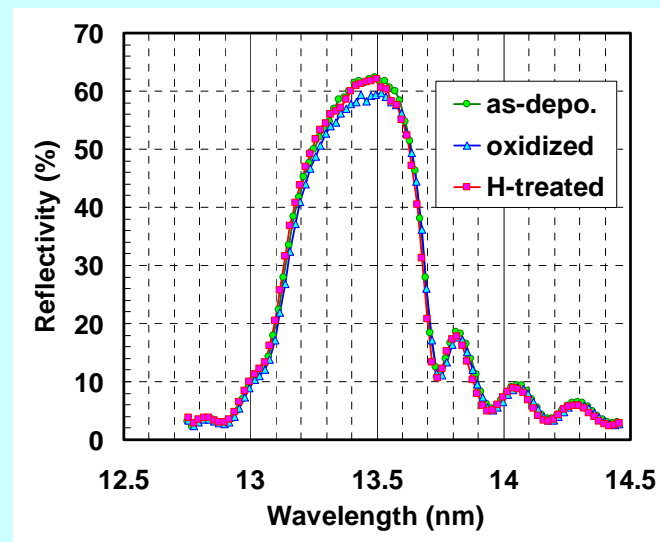
O₂ plasma treatment



After atomic H treatment



Reflectivity recovery



As sputtered: 62.3%



oxidation: 59.6%



Atomic H cleaning: 62.0%

Nishiyama et al. EIPBN 2006



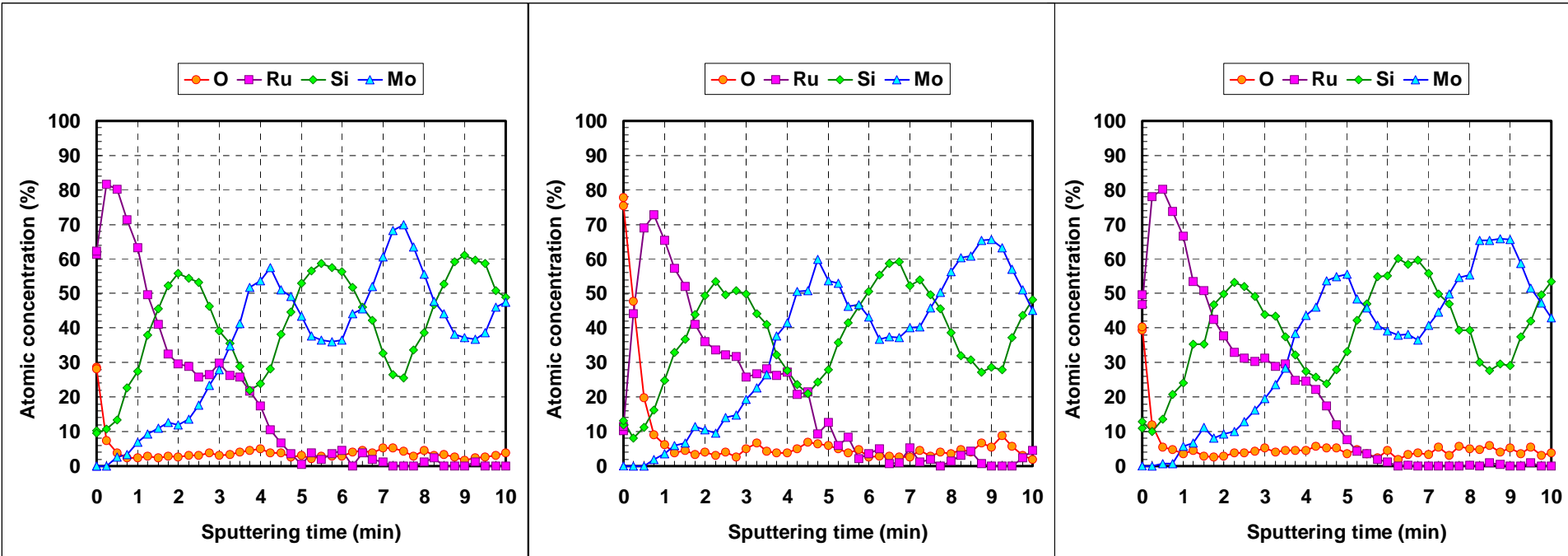
EUV Process Technology

AES Depth Profile change by oxidation and reduction (Ru capped multilayer mirror)

as-depo.

After O₂ plasma treatment

After atomic H treatment



[O₂ Plasma treatment] Pressure: 100 Pa, 60 sec, Magnetron anode current: 150 mA,
O₂ flow speed: 500 ml/min

[Atomic-H treatment] W filament: 1700°C, H₂ flow rate: 50 sccm, 20 min,

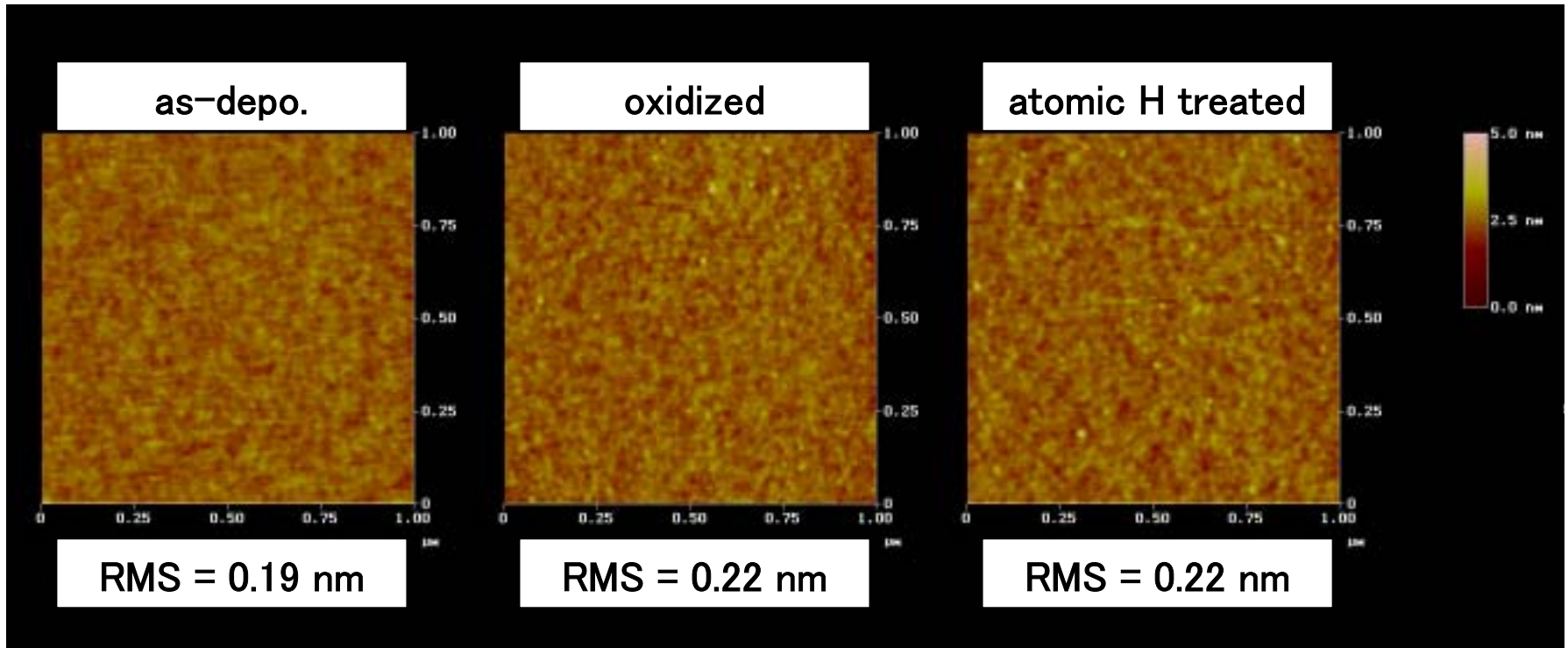
Nishiyama et al. EIPBN 2006

SET

EUV Process Technology

Surface roughness change by H-treatment

AFM measurements

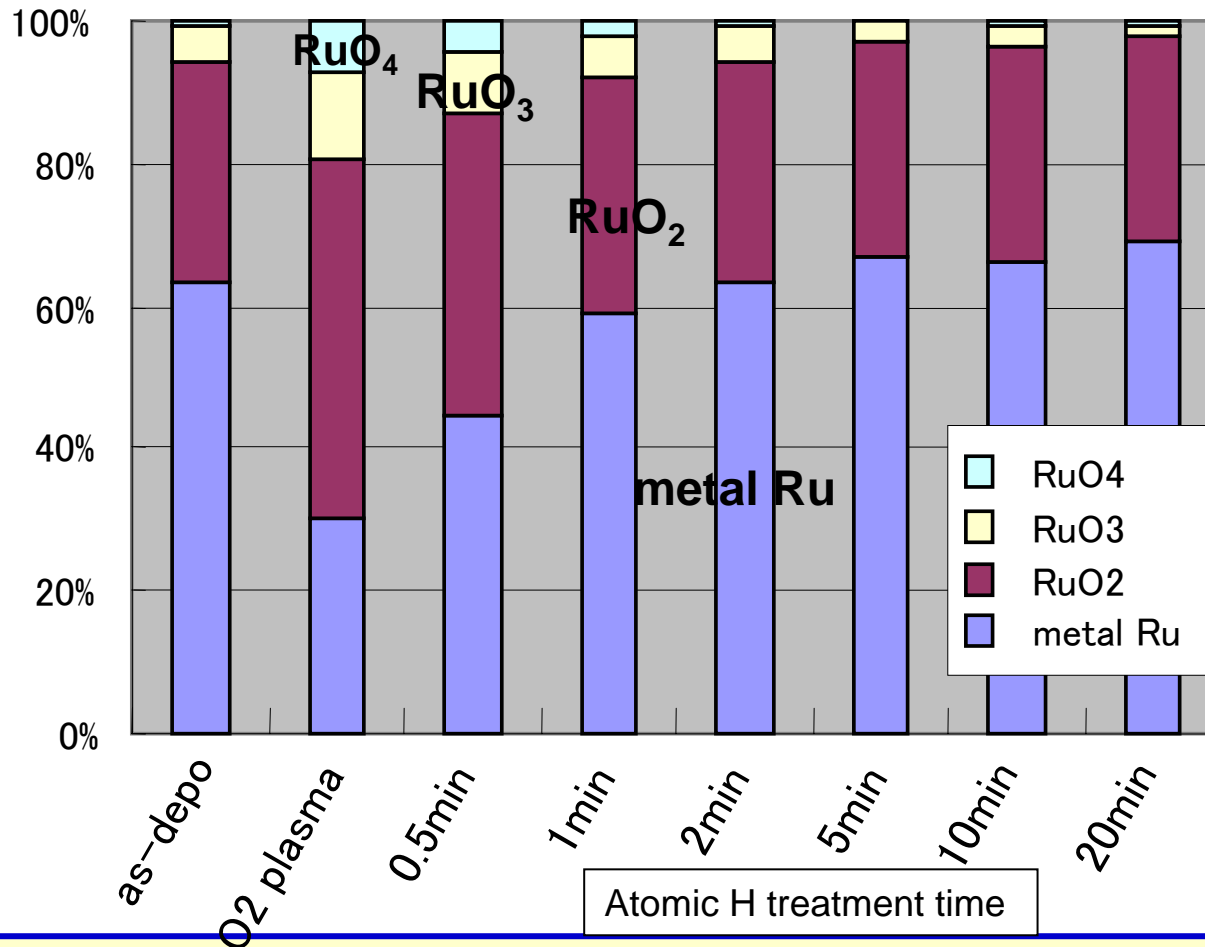


O₂ Plasma treatment : Ashing condition

Atomic hydrogen treatment : 20 min, W filament: 1700°C, H₂ flow speed: 50 sccm

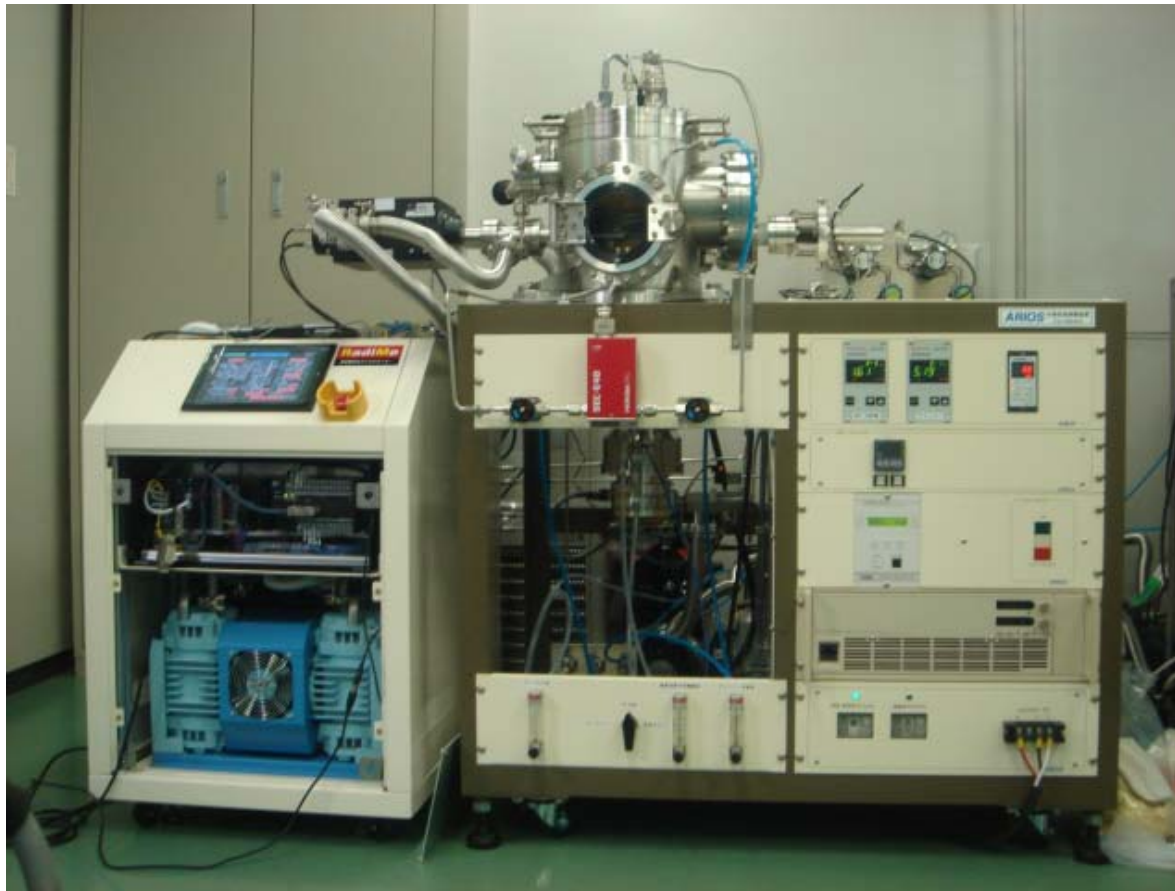
No roughening was observed by Atomic-hydrogen treatment

Surface composition change by oxidation and atomic-H



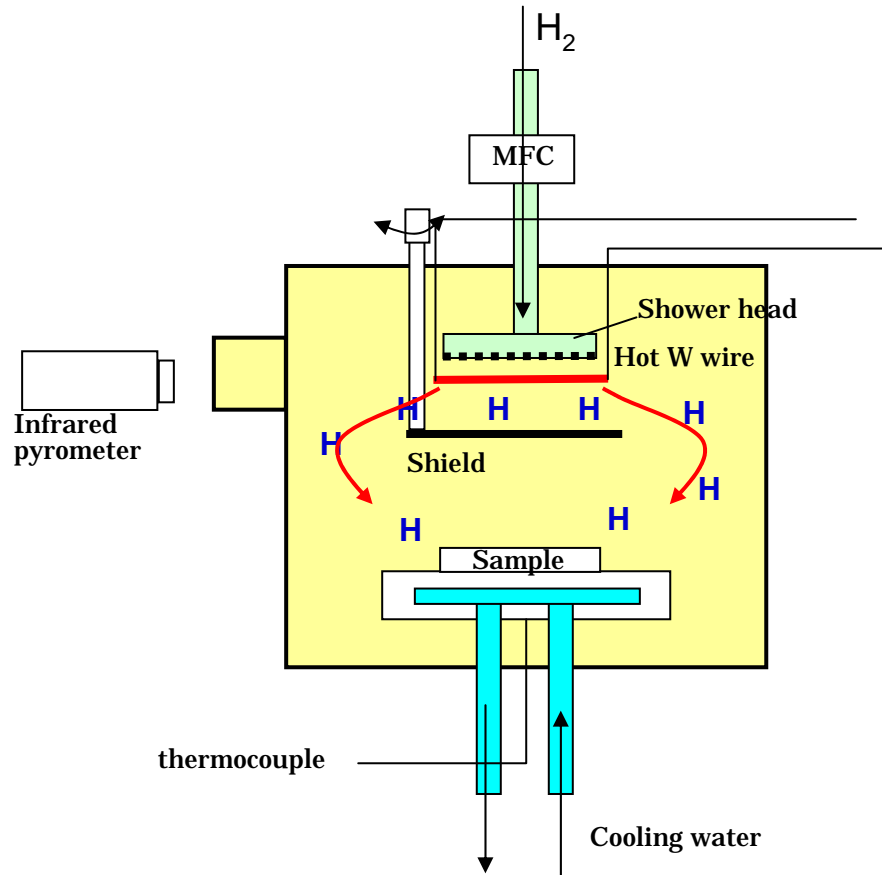
Ru surface layer produced by plasma oxidation was reduced by 5 min atomic hydrogen treatment

New apparatus for atomic hydrogen treatment



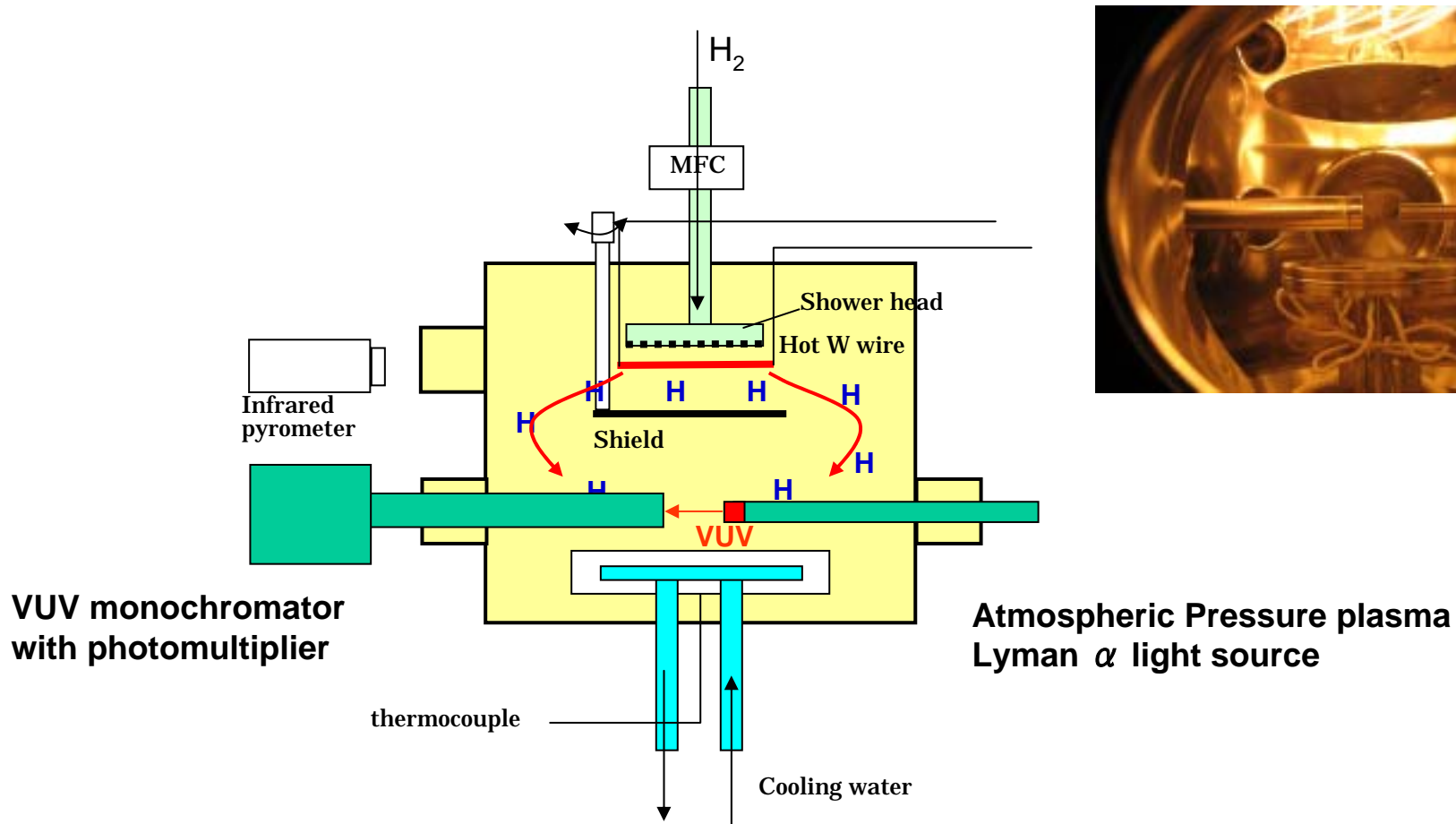
- Measurement of atomic hydrogen density
- Cleaning by transported atomic hydrogen

Atomic Hydrogen Cleaning apparatus



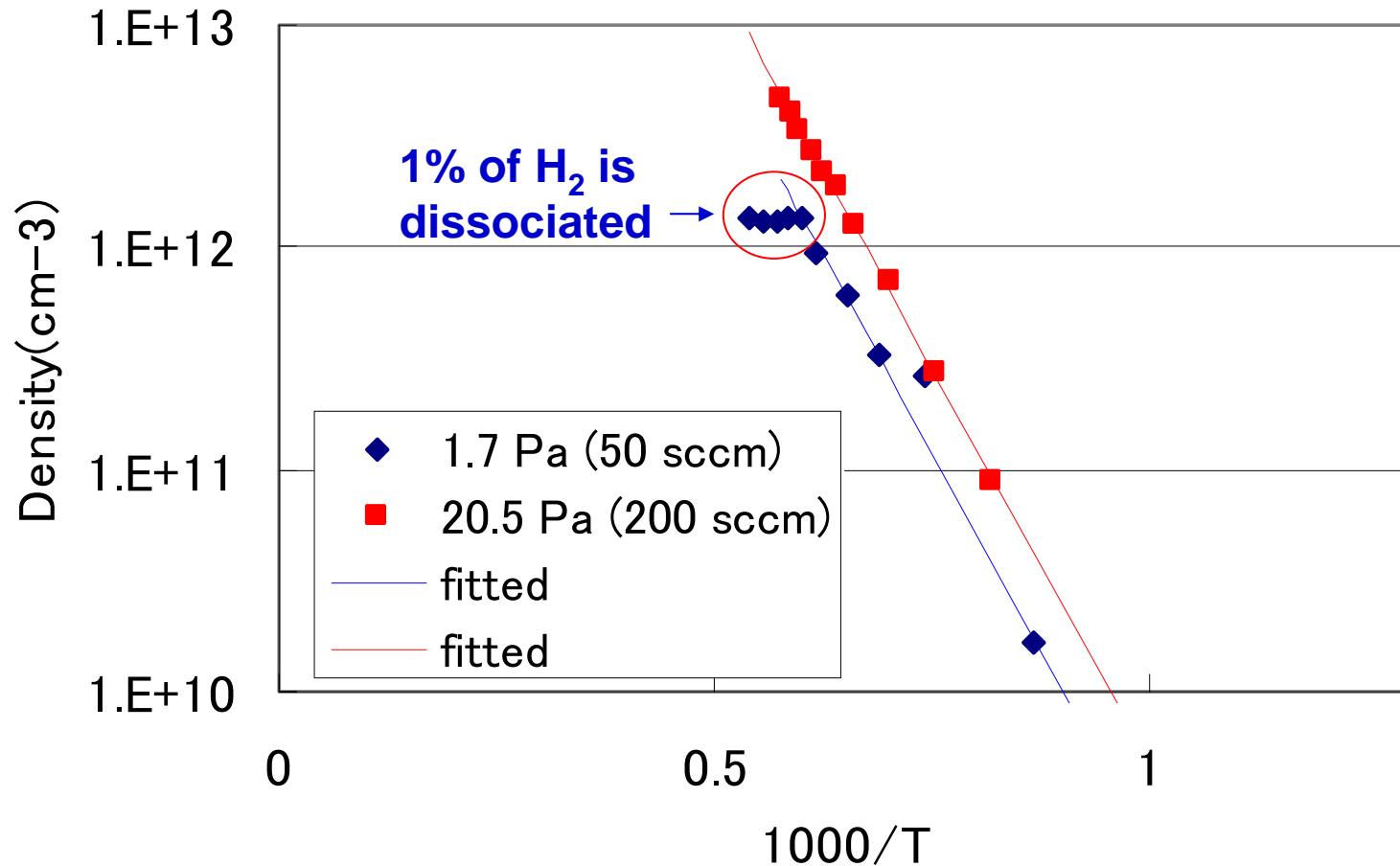
Atomic hydrogen generated by hot-wire
Filament temperature: 1700°C H₂ flow: 50 sccm

Measurement of atomic hydrogen density



**Atomic hydrogen density was measured
by atomic absorption of VUV (Lyman α)**

Filament-temperature dependence of atomic-H density



Atomic H density depend on arrhenius equation.

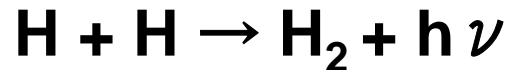
1% of H_2 is dissociated in typical treatment condition.

Atomic-H density can be increased with higher hydrogen pressure.

Feasibility test of atomic hydrogen transportation

■ Quenching reactions of atomic hydrogen

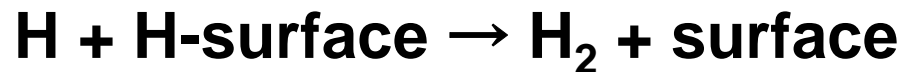
1. Radiative recombination



2. Three body reaction



3. Recombination on wall



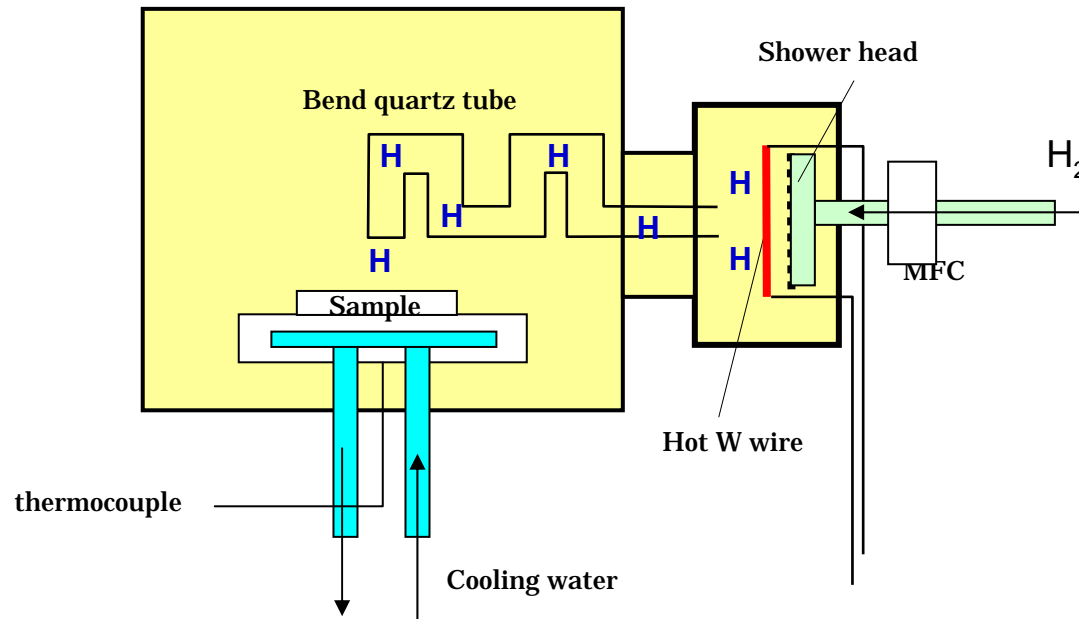
■ Experimental approach

1. Selection of surface materials

2. Demonstration of cleaning with transported atomic-H

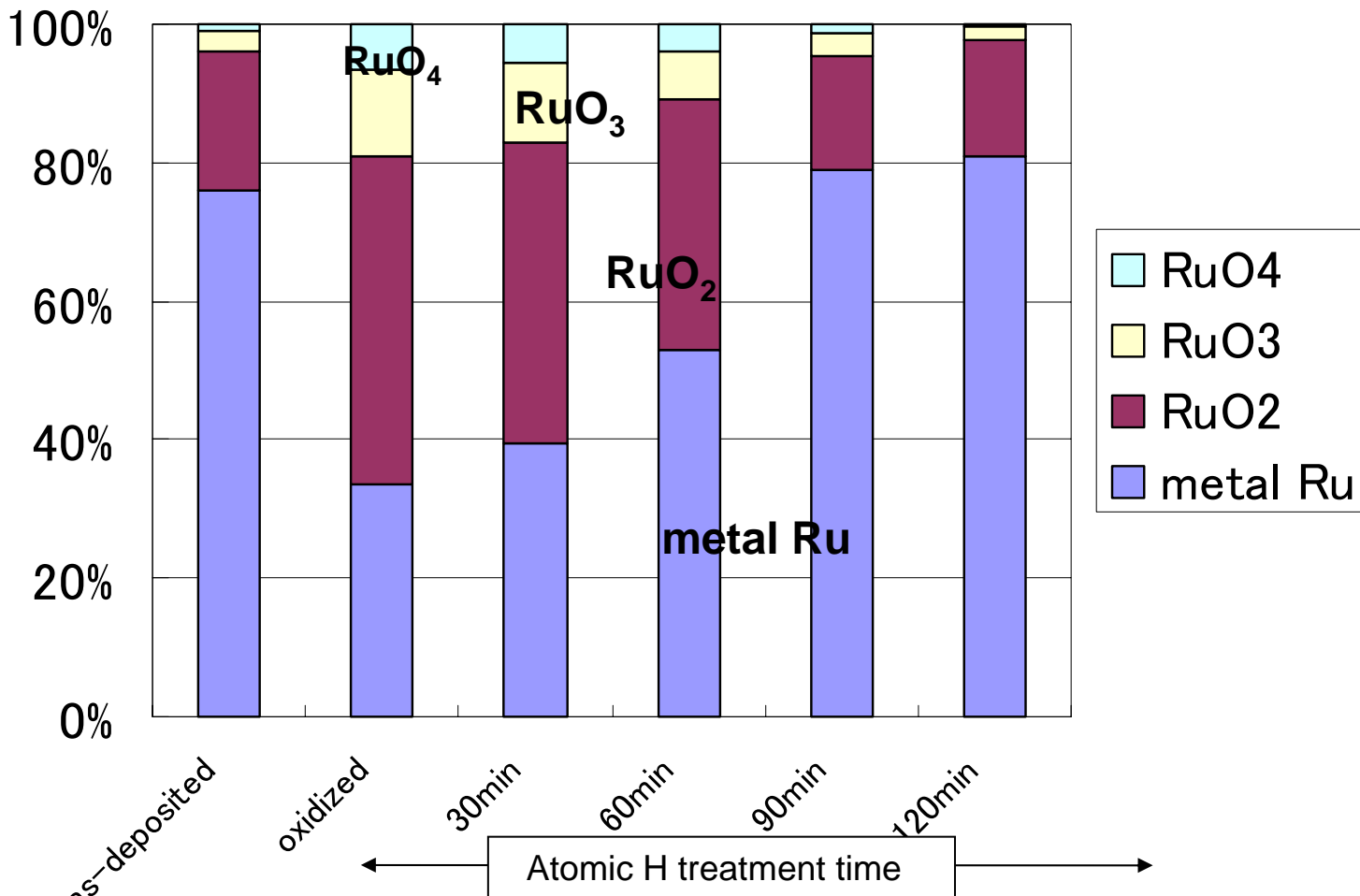
3. Measurement of atomic H density

Atomic hydrogen cleaning by transported atomic-H



**Atomic hydrogen generated by hot-wire
W filament: 1700°C H_2 flow: 50 sccm**

Transported atomic hydrogen treatment



Ru surface layer produced by plasma oxidation was reduced by 90 min atomic hydrogen treatment

Summary of Atomic Hydrogen Cleaning

Carbon Cleaning

- ◆ Carbon contamination can be removed almost perfectly and reflectivity loss was recovered.

Ru oxide Cleaning

- ◆ Ru oxide can be reduced and several minutes treatment is enough to Ru metal.
- ◆ Surface roughness was not increased by atomic H treatment.
- ◆ Reflectivity loss was recovered.

Cleaning by transported atomic H was demonstrated.
Atomic hydrogen density was measured.

Atomic Hydrogen Cleaning has a potential to remove carbon contamination and deoxidize surface oxide of Ru-capping layer simultaneously.

Acknowledgements

This work was supported by New Energy and Industrial Technology Development Organization (NEDO).