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Extreme UV lithography

This schematic diagram illustrates the components of an extreme ultraviolet (EUV) lithography system. It includes a laser-driven plasma source, a series of multilayer mirrors for light transport and focusing, a mask, and a substrate where the pattern is transferred. The diagram highlights the precision required in the alignment and coating of these components.

Multilayer Mirrors

The graph shows the reflectivity of a multilayer mirror as a function of wavelength. A sharp peak is observed at approximately 13.5 nm, indicating high reflectivity in the EUV range. The schematic shows the alternating layers of different materials that create this high reflectivity through constructive interference.

High Reflectivity at 13.5 nm wavelength

Lifetime of Multilayer Mirrors without capping layer is very short
→ Oxidation
Ru deposited directly on Si or Mo is not possible
→ Interdiffusion or fast Reflectivity
→ B₂C Layer

Outline

- Interaction of H₂O with clean, O-covered and C-covered surfaces focus on H₂O / Ru(1010), adsorption, desorption, reaction
- Electron-stimulated surface processes desorption, dissociation, oxidation; H₂O on Ru(1010)
- Interaction of acetone and MMA with clean and O-covered surfaces desorption, dissociation, accumulation of C on crystal – possible surfaces in capping layers Ru(1010)

The diagram shows the atomic structure of Ru(1010) surfaces in some capping layers, comparing a clean surface with one covered by a capping layer. It notes that the (0001) and (1010) faces of an ideal hcp crystal – possible surfaces in capping layers Ru(1010).

Motivation

H₂O, acetone, MMA – model background gases or trace contaminants in unbaked EUV chamber.

Aim: characterize the thermal stability of water and acetone on clean and O-covered Ru surfaces.

General goal: processes that affect the reflectivity of Ru-coated Mo/Si EUV mirrors; possible mitigation.

Techniques: XPS, LEIS, TPD

References:

- T.E. Madey et al., Appl. Surf. Sci. (2006) in press.
- B.V. Yakshinskiy, T. Graham, T.E. Madey, in preparation.
- N.S. Faradzhev et al., Chem. Phys. Lett. 415 (2005) 165.

TPD of water from two different Ru surfaces (0001) and (1010)

The figure displays Temperature Programmed Desorption (TPD) spectra for H₂O on clean Ru(0001) and Ru(1010) surfaces. The x-axis represents temperature in Kelvin, and the y-axis represents gas coverage. The spectra show distinct peaks corresponding to different desorption states, with the highest temperature peaks corresponding to the recombination reaction: OH + H → H₂O.

Detection of Carbon on Ru

Carbon growth may inhibit oxidation – but a carbon monolayer on Ru is hard to detect in XPS

To measure onset of C reactions, a sensitive spectrometry is needed: low energy ion scattering (LEIS)

The figure shows LEIS spectra for Ru and C on Ru(1010). The x-axis is binding energy in eV, and the y-axis is intensity. The spectra illustrate the detection of carbon on the Ru surface.

Temperature programmed desorption of water from contaminated Ru

The figure compares TPD spectra for H₂O on clean Ru(1010) and Ru(1010) surfaces contaminated with carbon. The x-axis is temperature in Kelvin, and the y-axis is gas coverage. The spectra show that the presence of carbon significantly alters the desorption characteristics of water.

Binding energy and lifetimes of water on O-covered and C-covered surfaces less than on clean Ru

What do e⁻ beams and EUV do to water on Ru?

The diagram illustrates the interaction of primary irradiation sources (e-beam and EUV) with a surface. It shows the generation of secondary irradiation sources, including photo- and secondary electrons, which can lead to surface modifications.

Our goal → to quantify beam damage in water layer on Ru

Electron-induced dissociation of H₂O on Ru(1010)

Bombard ~2ML H₂O with 100 eV electrons

Thermally desorb all H₂O (TPD), measure residual O using LEIS

The figure shows TPD and LEIS spectra for H₂O on Ru(1010). The TPD spectra show the effect of electron bombardment on the desorption of water. The LEIS spectra show the residual oxygen after thermal desorption.

Electron irradiation of Ru(1010), exposed to D₂O vapor at low T

The figure shows LEIS and XPS spectra for D₂O on Ru(1010) after electron irradiation. The x-axis is binding energy in eV, and the y-axis is intensity. The spectra show the effect of electron irradiation on the surface chemistry of D₂O.

Water pressure ~10⁻⁴ Torr; T: 150 – 250 K

Electron dose: ~10²¹ cm⁻² (100eV, 1hr)

LEIS and XPS control at different T

4hr ~230 K – balance between the dissociation probability and the lifetimes of the adsorbed D₂O molecules

Accumulated oxygen is stable at 600 K

Desorption of acetone from clean Ru (1010)

The figure shows TPD spectra for acetone and CO on Ru(1010). The x-axis is temperature in Kelvin, and the y-axis is TPD intensity. The spectra show the desorption of acetone and its dissociation products (CO, H₂).

CO, H₂ – dissociation products of (CH₃)₂CO

50% of the surface is covered by C following deposition of single dose of acetone

Carbon contamination of Ru by adsorbed acetone: effects of repeated adsorption/desorption sequence on carbon accumulation

The figure shows TPD and LEIS spectra for CO and H₂ on Ru(1010). The x-axis is temperature in Kelvin, and the y-axis is TPD intensity. The spectra show the effect of repeated adsorption/desorption sequences on carbon accumulation.

Top two panels: Each shows selected TPD spectra for a series of (CH₃)₂CO doses on Ru(1010).

Bottom panel: LEIS spectra for clean Ru, and for C-covered.

After 12 adsorption/desorption cycles, the surface is covered with a C layer and reactivity is greatly reduced

Surface chemistry of acetone on fractional monolayer of oxygen on Ru(1010)

The figure shows TPD spectra for acetone on O-covered Ru(1010). The x-axis is temperature in Kelvin, and the y-axis is TPD intensity. The spectra show the effect of oxygen coverage on the surface chemistry of acetone.

(CH₃)₂CO + SO_{ad} → CO + 3H₂O + 2CO

acetone decomposes completely on 0.5 ML of oxygen on Ru(1010)

acetone reacts to remove oxygen as H₂O, CO upon heating

repeated heating leads to carbon accumulation on surface

Thermal desorption of MMA and its reaction products, for clean Ru and O-covered Ru

The figure shows TPD spectra for MMA on clean Ru and O-covered Ru. The x-axis is temperature in Kelvin, and the y-axis is TPD intensity. The spectra show the thermal desorption of MMA and its reaction products.

One monolayer of MMA dissociates on both surfaces.

MMA reacts and completely removes adsorbed O monolayer upon heating.

Electron irradiation of Ru at 180K, exposed to MMA vapor

The figure shows LEIS spectra for clean Ru, O-covered Ru, and Ru 3d & C 1s. The x-axis is kinetic energy in eV, and the y-axis is intensity. The spectra show the effect of electron irradiation on the surface chemistry of Ru.

A thick C film (~5 nm) is formed by electron bombardment of Ru exposed to gaseous MMA at T=180K

Thermal stability of a thick MMA film (7-10 nm) under electron irradiation: polymerization evidence

The figure shows XPS spectra for Ru 3d & C 1s before and after electron irradiation. The x-axis is binding energy in eV, and the y-axis is intensity. The spectra show the evidence for polymerization of MMA.

NO POLYMERIZATION: Ru 3d & C 1s

POLYMERIZATION: Ru 3d & C 1s

Electron irradiation: 2.4x10²¹ e⁻/cm², 180 K

Electron irradiation of an adsorbed MMA film (100eV, 2.4x10²¹ e⁻/cm²) leads to polymerization of MMA

Secondary electron yield of Ru(0001)

The graph shows the secondary electron yield of Ru(0001) as a function of photon energy. The x-axis is photon energy in eV, and the y-axis is secondary electron yield. The yield is high at low energies and decreases at higher energies.

Measured with synchrotron radiation source at NSLS

Summary

- Water adsorbs molecularly and dissociatively on Ru(1010), Ru(0001)
- Two e⁻ induced dissociation processes on Ru
 - fast (e⁻ + H₂O → H + OH)
 - slow (e⁻ + OH → O + H)
- Acetone and MMA dosed onto O-covered Ru react to remove O upon heating
- Acetone and MMA adsorb dissociatively on Ru resulting in the accumulation of surface carbon.
- Electron irradiation of adsorbed MMA causes the growth of strongly bonded C-contained fragments as well as polymerization

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