

# EUV-induced oxidation of thin $\text{CrO}_x$ films on $\text{SiN}_k$ free-standing windows

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For advancements in EUV lithography, the behaviour of thin film materials during EUV exposure in various background gas conditions is key to find the optimal material properties. Therefore, we investigated the EUV- and radical-driven degradation mechanisms of chromium oxide ( $\text{CrO}_x$ ) cap layers (3-5 nm) on  $\text{SiN}_k$  free-standing windows in a vacuum, hydrogen and water background. In this manner, the effects of EUV photons, and hydrogen and oxygen radicals can be decoupled. Additionally, the samples were thermally treated before EUV exposure to remove thermal effects due to the high power EUV beam.

During EUV exposure at the BESSY II synchrotron, the addition or removal of atoms is monitored using in-situ EUV transmission (EUVT) measurements. The EUVT was stable in vacuum and hydrogen background conditions, indicating that the  $\text{CrO}_x$  cap layer is stable in high temperature and EUV (Figure 1). However, in a water background the EUVT decreased, which is typically explained by the oxygen absorption resulting in an increase in EUV absorption (EUVA). To calculate the EUVA, the EUVT and EUV reflection (EUVR) were measured ex-situ vs wavelength. Contrary to expectations, the EUVA did not increase, instead, the EUVR increased.

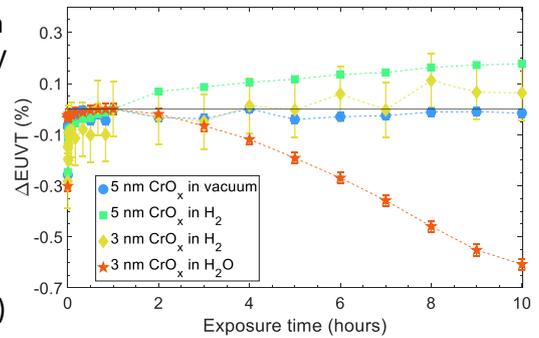


Figure 1: in-situ EUV transmission over time during EUV exposure

To investigate what processes occurred, the depth-dependent chemical composition was analysed with angle-resolved X-ray photoelectron spectroscopy (AR-XPS). First, the effect of the thermal treatment was investigated, which showed that the  $\text{CrO}_x$  cap layer intermixed with the underlying  $\text{SiN}_k$  layer during the thermal treatment. Therefore, the cap layer is not purely  $\text{CrO}_x$  but an intermixed layer of  $\text{CrSi}_x\text{O}_y\text{N}_z$ .

AR-XPS analyses of the EUV exposed samples revealed that a  $\text{SiNO}_2$  peak was formed in EUV + water but not in EUV + hydrogen. This  $\text{SiNO}_2$  was formed in the intermixed cap layer. The oxygen probably originates from the water, but the EUVA did not increase because the Si and N content at the surface decreased. This probably desorbed as  $\text{SiH}_x$  and  $\text{NH}_x$  or  $\text{NO}_x$  (Figure 2). So, explaining the EUVT decrease is more complex than only oxygen addition to the cap layer.

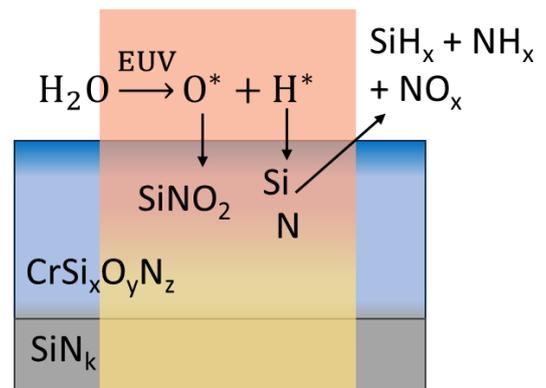


Figure 2: Schematic overview of the hypothesized EUV-induced degradation of a 3 nm thin  $\text{CrO}_x$  film intermixed with  $\text{SiN}_k$

To test this hypothesis, the cap layer composition will be modelled to explain the EUVR increase. Additionally, offline oxygen radical exposures will test if these radicals also form  $\text{SiNO}_2$  without EUV.