XPS tool matching and Optimization for EUV optics Contamination Studies

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Introduction

The lithography industry is making a transition from Deep Ultra Violet (DUV) lithography using 193nm radiation to EUV (Extreme Ultra Violet) radiation using 13.5nm (92 eV) of radiation. EUV radiation has very little transmittance in air and requires high vacuum for operation. EUV radiation is ionizing and can be absorbed by trace amount of contaminants present on the optics surface, hence adversely affecting the performance of the exposure tool. Photoresist, a radiation sensitive polymer coating, outgasses in vacuum during the exposure which can leave residue on the optical surfaces. Some of the residue can be cleaned while some residue may be permanently left behind. It is necessary to measure the amount of non-cleanable residue left after exposing each photoresist so a proper evaluation could be made on the contaminating properties for each sample. This is paramount to the protection of expensive optics.

An evaluation procedure was designed and developed according the specification from ASML at a custom Resist Outgassing and eXposure (ROX) tool at the College of Nanoscale Science and Engineering. A witness plate is impinged with 800µA/cm² 300 eV electron beam. At the same time a wafer coated with photoresist under evaluation is exposed using EUV photons in the same chamber. During exposure the outgassed byproduct gets deposited onto the surface of the witness plate. The thickness of the contamination is measured using a spectroscopic ellipsometer and then cleaned with atomic hydrogen. The remaining, residual contaminant on the witness plate is what we classify as the non-cleanable contamination. We then use XPS to measure the atomic concentration of the non-cleanable contamination.
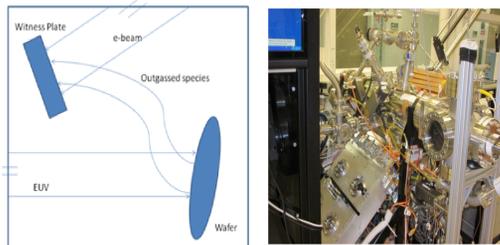
Basic Process Flow

Figure 1: Schematic (left) showing basic contamination mechanism. The actual exposure tool at our site (right).
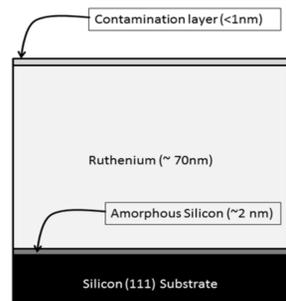

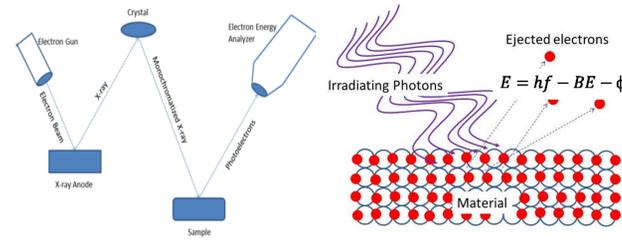**Figure 2**: Schematic showing the composition of witness plate sample.

XPS

Figure 3: Schematic of an XPS tool (left), Cartoon of photoelectric effect (right)

$$dI = \Phi\sigma NT \exp\left(-\frac{x}{\lambda\cos\theta}\right)dx \quad (1)$$

$$I^{total} = I^s + I^b,$$
$$I^{total} = \Phi\sigma NT\cos\theta \left\{\lambda_s\cos\theta\left[1-\exp\left(-\frac{d}{\lambda_s\cos\theta}\right)\right] + \lambda_b\exp\left(-\frac{d}{\lambda_b\cos\theta}\right)\right\} \quad (2)$$

$$N_i = \frac{I_i}{F_i}, F_i = \sigma_i \cdot L(\varphi, \beta_i) \cdot \lambda_i \cdot T_i \cdot \exp\left(-\frac{c_i}{\lambda_i}\right) \quad (3)$$

$$\frac{d\sigma_{nl}(E)}{d\Omega} = \frac{\sigma_{nl}(E)}{4\pi}\left[1 - \frac{\beta_{nl}(E)}{2}P_2(\cos\varphi)\right], \; P_2(x) = (3x^2-1)/2, \quad (4)$$

$$L(\beta,\varphi) = \frac{1}{4\pi}\left[1 - \frac{\beta}{2}\left(\frac{3}{2}\cos^2\varphi - \frac{1}{2}\right)\right] \quad (5)$$

$$R_i^{a\%} = \frac{N_i}{\sum_j N_j} \times 100 \; (\%) \quad (6)$$

Equation (1) gives the intensity of electrons at a specified energy from a given depth x from a homogeneous sample, (2) is the integral of (1) from top of the sample to a depth covered by surface layer and from that boundary to the rest of the bulk, (3) gives a way to calculate the number of atoms of a type in the volume sampled. (4) and (5) define photoionization cross section. (6) explicitly gives a way to calculate the atomic percentage of each species present.

Sources of major errors
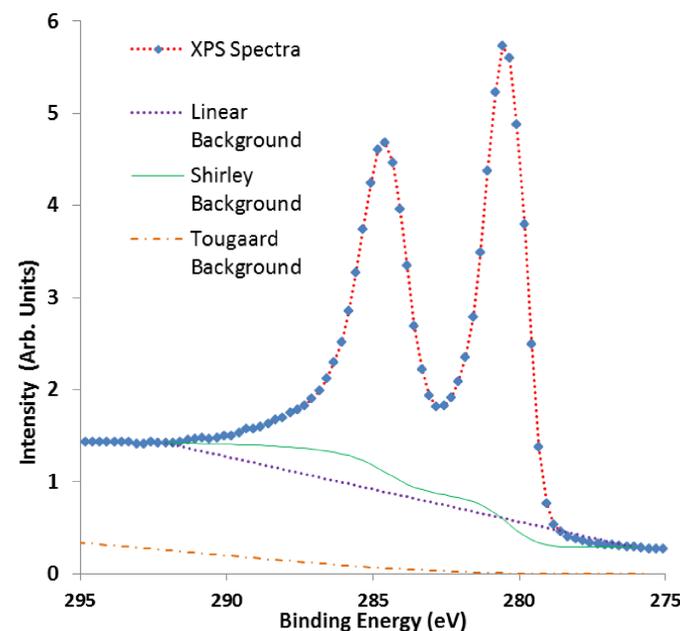
1. Peak intensity determination

Figure 4: Depending on the choice of the background user would infer different peak intensity.
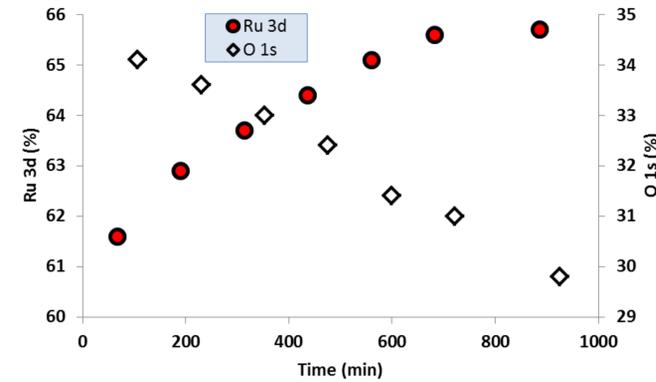
2. Sample stability

Figure 5: In a back to back measurement of Ruthenium and Oxygen, sample shows clear variation with time suggesting sample modification with x-ray irradiance.

3. Sample handling and aging

Time passed	Atomic %						
	S 2p	W 4d5	Ru 3d	O 1s	N 1s	Zn 2p3	Si 2s
30 mins	0.5	0.0	69.1	29.3	1.2	0.0	0.1
7 days	0.5	0.0	63.5	34.3	1.5	0.0	0.1
14 days	0.5	0.0	62.6	35.2	2.0	0.0	0.1
21 days	0.4	0.0	62.1	35.2	2.3	0.1	0.1

Table 1: Changes in sample composition with time just from storing in clean plastic container in air.

4. Relative sensitive factor determination

(a) Validity of measurement with respect to equation (2) for determining percentage coverage of trace contaminant.
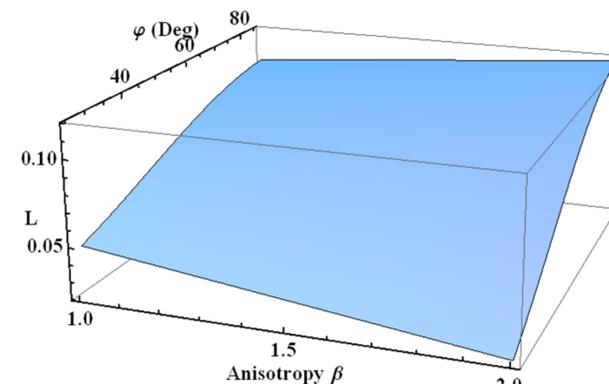(b) Tool setup error [see equation(5)]

Figure 6: Plot of eqn.(5) showing the variability that can occur from not considering angle change.

- Same peak intensity determination method needs to be used during the sample analysis as the RSF determination.
- Same RSF needs to be used for calculating tool transmission function.
- Results for thin flim (<10nm) needs to be interpreted with caution.

5. Tool Transmission function determination

As mentioned in 4, consistent peak determination and appropriate RSF is necessary. Use of retarding ratio gave 10% mismatch with the result based on stoichiometric samples.
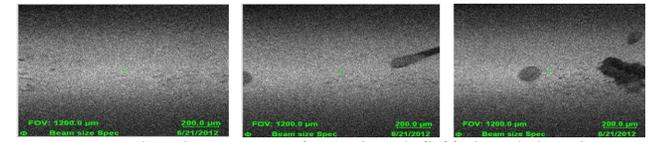
6. XPS tool drift

Figure 8: Secondary electron images for good anode (left), degraded anode 1 (center) and degraded anode 2 (right).
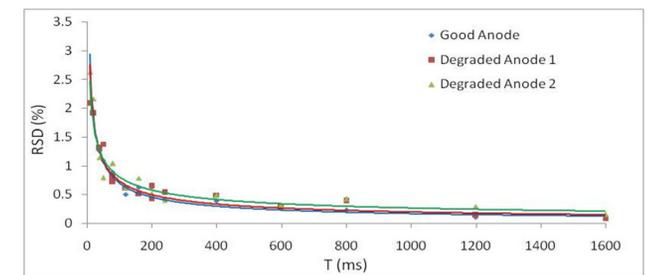

Figure 9: RSD as a function of total acquisition time for the good and the degraded anodes. Average RSD for degraded anodes 1 and 2 are 5% and 13% worse respectively as compared to average RSD for the good anode.

7. Statistics

From pure Au 4f peak experimentally calculated C in (7).

$$RSD = C\frac{1}{\sqrt{n}} \quad (7)$$

Now from (6) using simple error propagation:

$$\bar{N} = \sum_j N_j; \; \frac{\sigma_{R_i}}{R_i} = \sqrt{\left\{\frac{\sigma_{N_i}}{N_i}\right\}^2 + \left\{\frac{\sigma_{\bar{N}}}{\bar{N}}\right\}^2} \quad (8)$$

Now combining (7) and (8)

$$\left\{\frac{\sigma_{R_i}}{R_i}\right\}^2 = \left\{\frac{C_i^2}{n_i}\right\} + \frac{1}{\bar{N}}\sum_j\frac{C_j^2 N_j^2}{n_j} \quad (9)$$

Equation (9) allows one to optimize the number of scans for a desired accuracy where one already knows a typical composition.
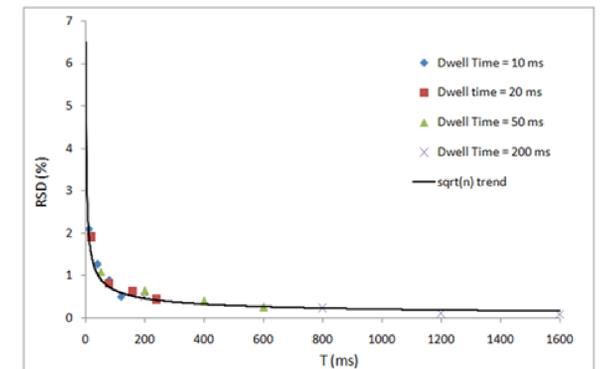

Figure 10: Plot of Gold signal for equation (7). This gives C = 0.46 for gold.

Summary

We identified the major source of errors in tool to tool matching. Found a way to reduce major source of errors. We also found a robust method for reducing variability by the same tool.

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