Substrate effects in EUV lithography

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In x-ray and e-beam lithography substrate materials are known to have a strong influence on exposure of photoresists through photoelectrons or secondary electrons which are created in the substrate and diffuse into the photoresist film. This effect has not been explored for EUV lithography so far because of the expectation that electrons created by the relatively low energy EUV photons (~92 eV) would not travel far enough to cause significant exposure. In this study we set out to confirm whether there is a measurable influence of the substrate on EUV exposures.

Four different substrate materials (Si, Cr, Au and Ni) were chosen in order to cover a large range in terms of EUV absorption coefficients. A 30 nm thick PMMA film was spin coated on the substrates. PMMA is used due to its uniform, single-component chemistry and to avoid chemical interaction between the substrate and resist. The samples were exposed at the EUV interference lithography beamline at the Swiss Light Source to obtain dense line/space patterns with a half-pitch of 40 nm. After development in 1:3 solution of MIBK:IPA the samples were sputter coated with a several nanometer thick metal layer in order to avoid charging during the SEM inspection. Typical images obtained from two of the samples are shown in Figure 1 and the measured linewidth as a function of dose is plotted in Figure 2 for all materials.

In Figure 2 we observe a surprisingly strong dependence of linewidth on the substrate material. We can rule out reflection of EUV light at the resist-substrate interface as a contributing factor as we estimate the reflectivity at this interface to be less than 0.25% for all materials tested here. Secondary electrons generated in the substrate, especially those having energy less than 10 eV may be responsible for this effect as they may have the necessary travel range to expose significant volumes of the PMMA resist. This is supported by the trend that we observe in Figure 2 in that the dose required to obtain a certain linewidth is highest for the least absorbing substrate (Si) and the dose is lowest for the highest absorbing substrate (Ni). The curves for Au and Cr lie in between these two extremes as one can expect from their absorption coefficients (Table 1). Other factors, such as the interface chemistry also play a role in the secondary electron yield which may influence the observed behavior.

The observed substrate effects may have important consequences in terms of achievable contrast in EUV exposures and therefore the ultimate resolution as well as throughput of EUV lithography tools.

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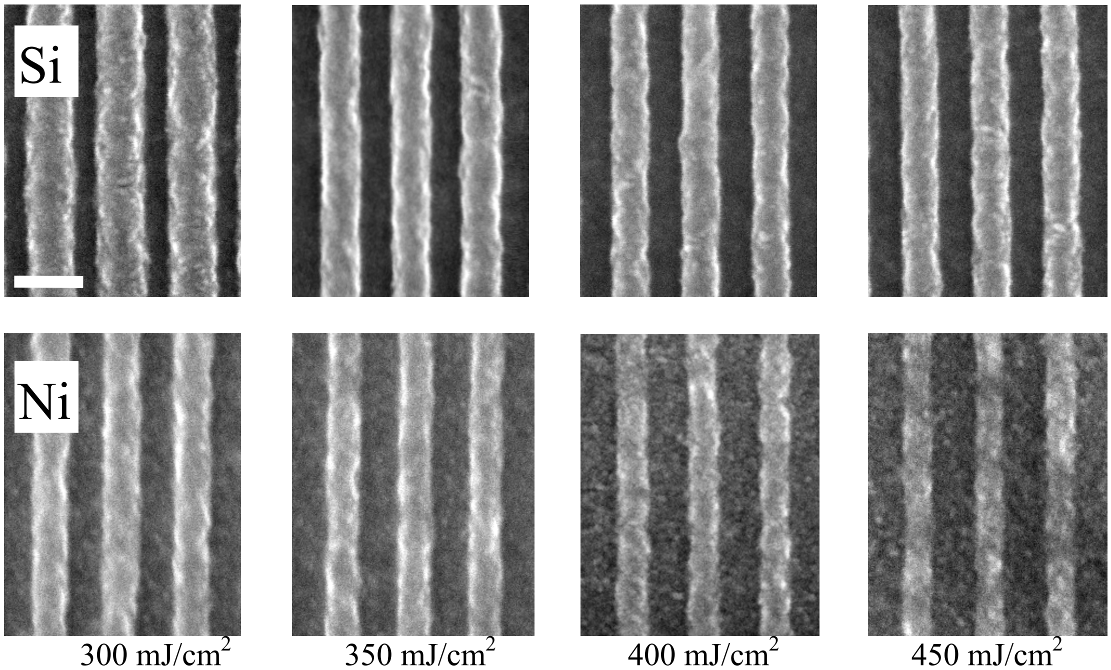

Fig. 1. SEM images of 40 nm half-pitch patterns in PMMA on Si (upper row) and Ni (lower row) substrates shown for the same dose range of 300-450 mJ/cm^2. Scale bar on the first image is 80 nm long.

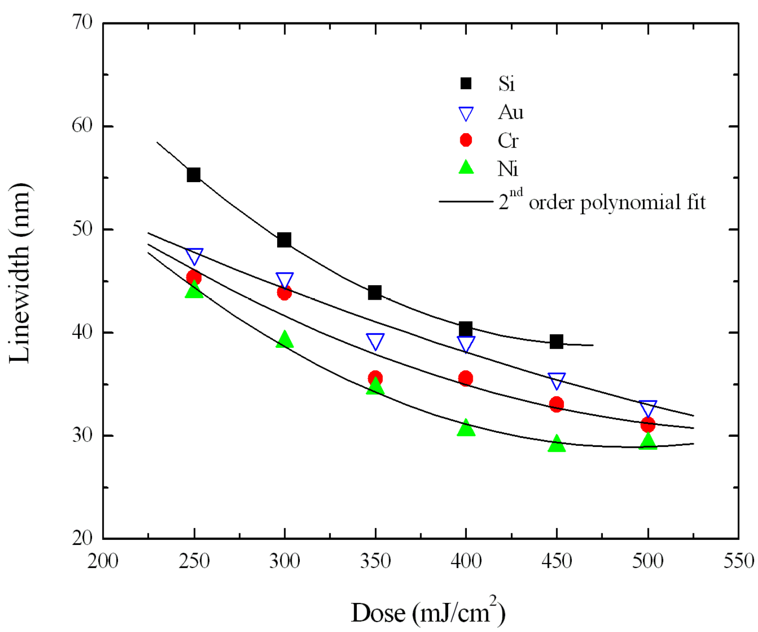

Fig. 2. PMMA linewidth as a function of dose delivered to the mask in the EUV interference lithography exposure.

	Absorption length (nm)
Si	585
Cr	28
Au	21
Ni	15

Table 1. Distance for attenuation of EUV light to 1/e of its initial intensity.