Evaluation of EUV resist performance below 20-nm CD using helium ion lithography

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Introduction

For EUV lithography, development of high performance EUV resists is of key importance[1]. This development involves studies into resist sensitivity, resolving power and pattern uniformity[2]. We have used a sub-nanometer-sized 30 keV helium ion beam to expose chemically amplified (CAR) EUV resists.

We aim to show that Scanning Helium Ion Beam Lithography[3] (SHIBL) is a useful and economically attractive technique to pre-screen novel EUV resists prior to their final performance evaluation in an EUV scanner.

Mechanism for EUV Chemically Amplified Resists

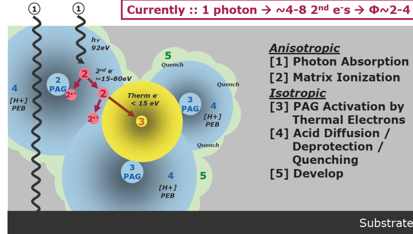

Figure 1 Info graphic on the activation mechanism of an EUV Chemically Amplified Resist. In SHIBL, step 1 and 2 are combined: the inelastic collision of a 30 keV He⁺ ion with a resist atom generates low-energy secondary electrons directly. Figure by courtesy of T.R. Younkin (Intel).

EUV & 30-keV He⁺ interaction in CAR resist

There are remarkable similarities in the response of resists to He⁺ ions and EUV photons: both create low-energy Secondary Electrons that activate the resist[4-7] (see Fig. 1).

The main difference is that each He⁺ ion has multiple inelastic collisions with the resist atoms, generating hundreds of SEs along its trajectory in the resist[8], see Fig. 2.

The weak backscattering of the He⁺ ions, (Fig. 2), results in ultra-low proximity effects. This enables the exposure of dense and detailed patterns by a focused He⁺ ion beam without the need for proximity correction.

Also EUVL capitalizes on low proximity, being it from a different origin.

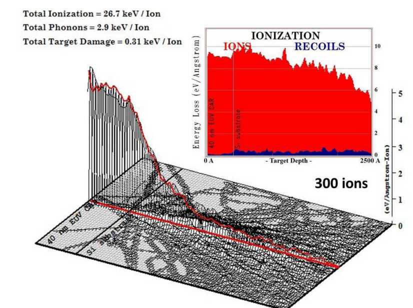

Figure 2 Energy loss of 30-keV He⁺ ions through ionization of 40 nm thick EUV CAR resist on a Si substrate, computed by SRIM[8]. The inset shows the energy loss through ionization (red) and recoil (blue) as a function of depth.

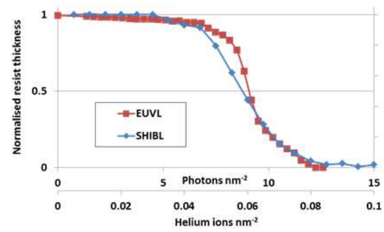

Figure 3 Large-area dose-response curves for EUV CAR resist of type A exposed to EUV and 30-keV He⁺. The EUV dose-to-clear is 18 mJ cm⁻², the contrast is 3. The He⁺ ion dose-to-clear is 1.36 uC cm⁻² or 41 mJ cm⁻², the contrast is 2. Hence, compared to EUV photons, 150 times less He⁺ ions are required for a same resist modification.

Methods

A 40 nm thick EUV CAR resist was exposed to 30-keV He⁺ ions in a Zeiss Orion Plus™ Helium Ion Microscope and to EUV in an ASML NXE:3300 scanner. Analysis was done using a Bruker Dektak NXT profilometer and a Hitachi CG-4000 CD SEM.

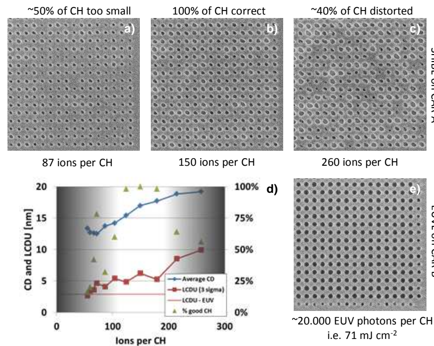

Figure 4 CD SEM images of three dense arrays of point exposures, made in CAR resist of type A using SHIBL (a-c) and CAR resist of type B using EUVL (e). The results of the CD analysis are shown in panel d. The ion dose ranged from 60 – 260 ions per hole (in 9 steps with a dose-multiplication factor of 1.2), equal to 0.62 – 1.17 ion nm⁻² or 10 – 19 uC cm⁻². The EUVL contact hole CD is 20.2 nm. At low dose the smallest contact holes (CHs) are rejected as closed, at high dose as distorted. Hence, only LCDU values between 100-180 ions per CH can be regarded as reliable.

Results and Discussion

The dose response curves from EUVL and SHIBL are rather similar, despite a different contrast (2 vs. 3). Per area, 150 times less ions than photons are needed for the same effect on the resist. He⁺ ions are estimated to generate 4 times more SEs per nm² than the EUV.

Fig. 4a-c reveals considerable variations in the contact hole CD. However, the measured CD and LCDU (Fig. 4d) do not show strong variations, as many holes did not meet either the *minimal-size* or *correct-shape* criterion of the CD evaluation SW[9]. Experiments at better conditions are necessary to draw final conclusions on SHIBL's hole printing capabilities.

Fig. 5 shows there is an ion dose that yields a 1:1 ratio of the line-and-spaces CD for each pitch. At low dose some bridging is seen. The trench CD and LWR are almost pitch-independent.

Fig 6. shows EUVL results from EUV resist B, with a highly comparable LWR as obtained with SHIBL.

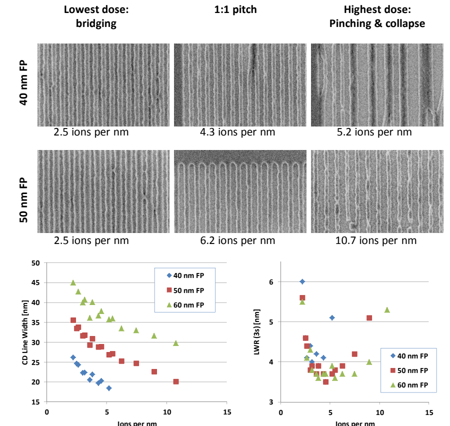

Figure 5 CD SEM images of lines-and-spaces at 40- and 50-nm pitch, exposed with SHIBL in CAR resist A at too low, optimal and too high dose. The graphs show line CD and LWR as a function of dose.

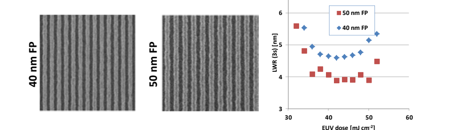

Figure 6 CD SEM image and LWR analysis of lines-and-spaces at 40- and 50-nm pitch, exposed with EUVL in CAR resist B at optimal dose.

Conclusions

1. Scanning Helium Ion Beam Lithography is a promising novel method for the pre-screening of EUV resists on fundamental properties like resolution, sensitivity and pattern uniformity. EUVL and SHIBL both activate resist through low-energy secondary electrons. In SHIBL, these SEs are generated directly by the He⁺ ions, enabling more insightful studies of EUV CAR activation by SEs.
2. Using SHIBL, contact holes and trenches at sub-20 nm resolution were exposed in CAR EUV resist. The results are alike EUVL exposures, although the obtained pattern uniformity is worse. Especially for the CHs, this is at least partly attributed to sub-optimal settings of the SHIBL expose tool.
3. Since SHIBL neither shows proximity effects nor requires a physical mask, the printability of more complex patterns can be evaluated, potentially enabling early device R&D...

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