Experimental Beam Blur characterization in CAR resist for E-beam lithography at 5kV and 100kV using spectral analysis

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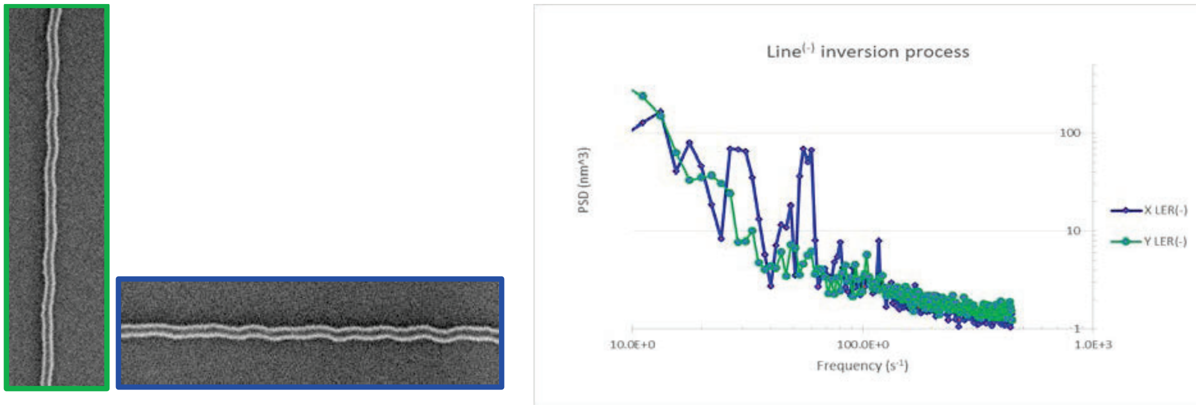
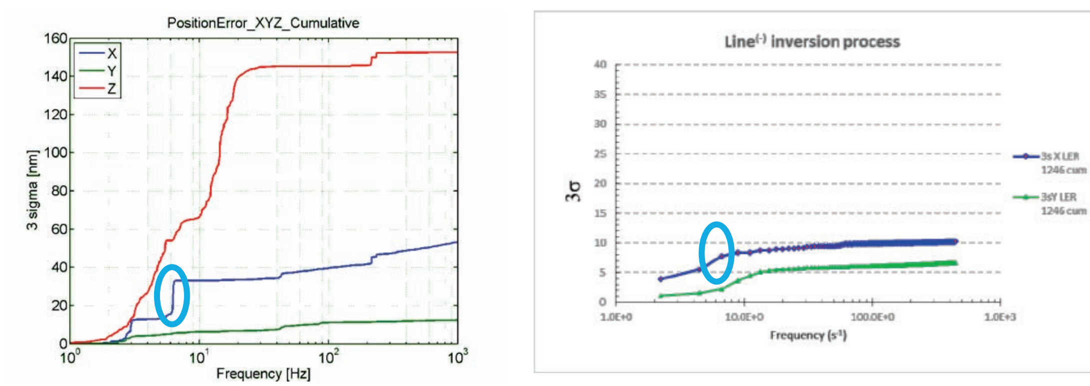
Mask less lithography with massively parallel electron writing at low voltage (5keV) has already demonstrated its capability to address high resolution target (18nmhp) and high reproducibility for 32nmhp after 5 years of demonstration with the first MAPPER prototype installed at LETI 300mm pilot line. Since one year, FLX-1200 the first MAPPER beta platform is under assessment to demonstrate the capability of this technology to print a full 300mm silicon wafer, with alignment and overlay better than 2nm (3sigma), for one hour exposure in the same configuration as mass production tool designed for a throughput of 10 wafer/hour [1].
More than the resolution limit, the CD uniformity, the roughness, the exposure latitude are key parameters to guarantee the high reproducibility and yield for future CMOS nodes. Line Width Roughness (LWR) as well as Line Edge Roughness (LER) have a direct impact on device performance. But the root causes of such CD variation are multiples and commonly known as beam blur for Ebeam lithography. We investigated the LWR and the LER with a positive tone chemically amplified resist (CAR) by using the spectral analysis from CD SEM measurements [2]. To do so we exposed isolated line with two doses ranges. A first one with a low dose range for the regular chemistry mechanism dominated by the acid catalytic deprotection. A second large dose range where the cross linking mechanism becomes prevalent leading to convert positive tone CAR to a negative non CAR resist. We have shown this method enabled us to separate the beam spot size in resist from acid diffusion [3]. Pushing this strategy in combination with the Power Spectrum Density (PSD) analysis, the standard deviation has been evaluated over a 2µm long CDSEM measurement at less than 4nm intervals. By systematic comparisons of PSD plots between horizontal, vertical exposure directions, LWR and LER, positive tone and inversion polarity we have been able to evaluate different parts of the beam blur such as vibration amplitude and frequency as well as the shot noise. This strategy has been applied to a LETI reference CAR resist process with a Leica VB6HR at 100kV and with a MAPPER tool at 5 kV.
Experimental PSD for LER obtained at 5kV with inversion polarity are reported in figure 1 and figure 2. Horizontal and vertical vibration are highlighted and compared to mechanical measurement performed during exposure on the wafer table. Vibration amplitudes of 10.3nm (3 sigma) along X axis compared to 6.7nm along Y axis have been estimated with PSD analysis in the same amplitude and frequency magnitude than mechanical positioning error estimation.
The research leading to these results has been performed in the frame of the industrial collaborative consortiums IMAGINE focused on the development of MAPPER multibeam lithography.



A) B)

Figure 1: Vertical and horizontal isolated lines printed with resist inversion polarity at high dose level, 1000µC/cm² at 5kV. B) Vertical (Y), Horizontal (X) LER Power Spectrum Density plot



A) B)

Figure 2: A) Wafer table cumulative positioning error for the 5kV exposure tool. B) Cumulative standard deviation plotted from PSD plot

[1] L. Pain et al, “E-beam System Requirements”, SEMATECH Litho forum, Sept 2012
[2] V. Constantoudis et al., “Line edge roughness and critical dimension variation: fractal characterization and comparison using model functions,” J. Vac. Sci. Technol. B22(4), 1974–1981 (2004).
[3] F. Delachat et al. “Determination of spot size and acid diffusion length in positive chemically amplified resist for e-beam lithography at 100 and 5 kV”, J. Vac. Sci. Technol. B **32**, 06FJ02 (2014)