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Optimization of PMMA 950KA4 resist patterns using Electron Beam Lithography

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Introduction

Poly Methyl Methacrylate (PMMA) is the positive tone resist and it is most popular and promising resist for very high resolution patterns in electron beam lithography. It is available with different solvents with many concentrations. In the present work various high resolution e-beam patterns are optimised using PMMA 950KA4 (Molecular weight:950K, A: Anisole solvent, Resist Concentration: 4%) and mainly focused on area lines optimization at various resolutions using different EHT.

Objectives

1. To understand the optimum electron dose for various high resolution patterns in electron beam lithography
2. To investigate the impact of electron beam dose on critical dimensions at different EHT voltages

Experimental details

E-Beam Lithography exposures is carried out in Raith PIONER system. PPMA950KA4 resist spin coated on Si wafer with the speed of 6000rpm for 45 seconds and thickness is about 180 to 200nm. Sample is prebaked on hot plate at 170°C for 120 seconds. Area lines of different width and different spacing are exposed at 10kV, 20kV and 30kV EHT using 20µm aperture. Some specific high resolution patterns like squares, hexagon structures and circles optimised using 20kV EHT with 10µm aperture. After e-beam exposure, samples are developed in MIBK: IPA (1:3) developer for 45seconds and 15sec dip in stopper(IPA). Impact of electron beam dose on critical dimensions is studied and plotted as shown in Figure.3 and Figure.4.

Results and discussion

Optimization of Area mode line patterns:

The Critical dimensions(CD) using 20kV and 30kV EHT are optimized and shown in below figures and CD Vs Dose results are shown in Figure.3&4

figure.4.. High resolution Patterns at 10Kv EHT are much broader than the targeted feature size some features are completely merged. At 20kV EHT patterns are little broader than the targeted critical dimensions even at the optimum electron dose see figure1 and 2. At lower electron doses patterns are under exposed then pattern width is increasing from the optimum electron dose to higher dose. Some of targeted critical dimensions are achieved using 30kV EHT. This could be due to the penetration of electron beam through the resist with less scattering at higher EHT. Impact of EHT on critical dimensions is shown in figure.7.

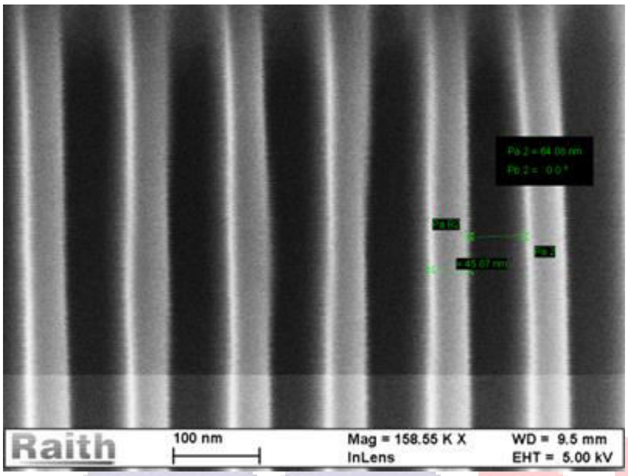


Figure.1 Features at 20kV EHT; Targeted L/S:60nm/60nm, Achieved : 64nm/47nm

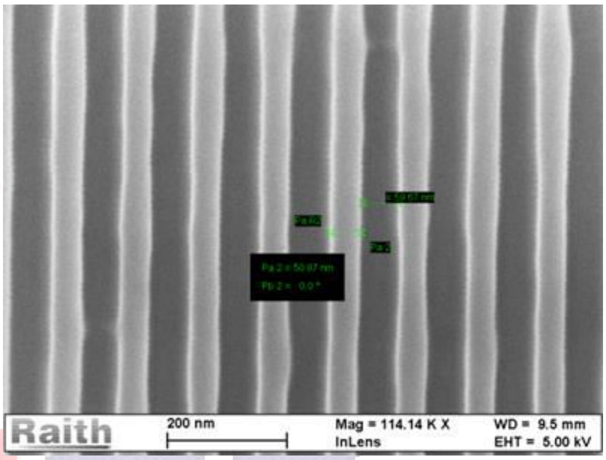


Figure.2 Features at 20kV EHT; Targeted L/S:40nm/80nm, Achieved : 59nm/51nm

Same critical dimensions with different spacing have different optimum electron doses. As shown in figure 3, the optimum electron dose for L/S=60/60 is ~160$\mu C/cm^2$ and for L/S=60/120 is ~195$\mu C/cm^2$. This variations in dose could be due to the proximity effect. The optimum dose for L/S=60/60 pattern at 20kV EHT is ~160$\mu C/cm^2$ and the optimum dose for L/S=60/60 pattern at 30kV EHT is ~220$\mu C/cm^2$. This indicates that the optimum dose for a pattern is varies with EHT. This is also is due to less scattering at higher EHT. Higher dose is required to cover the targeted feature at higher EHT.

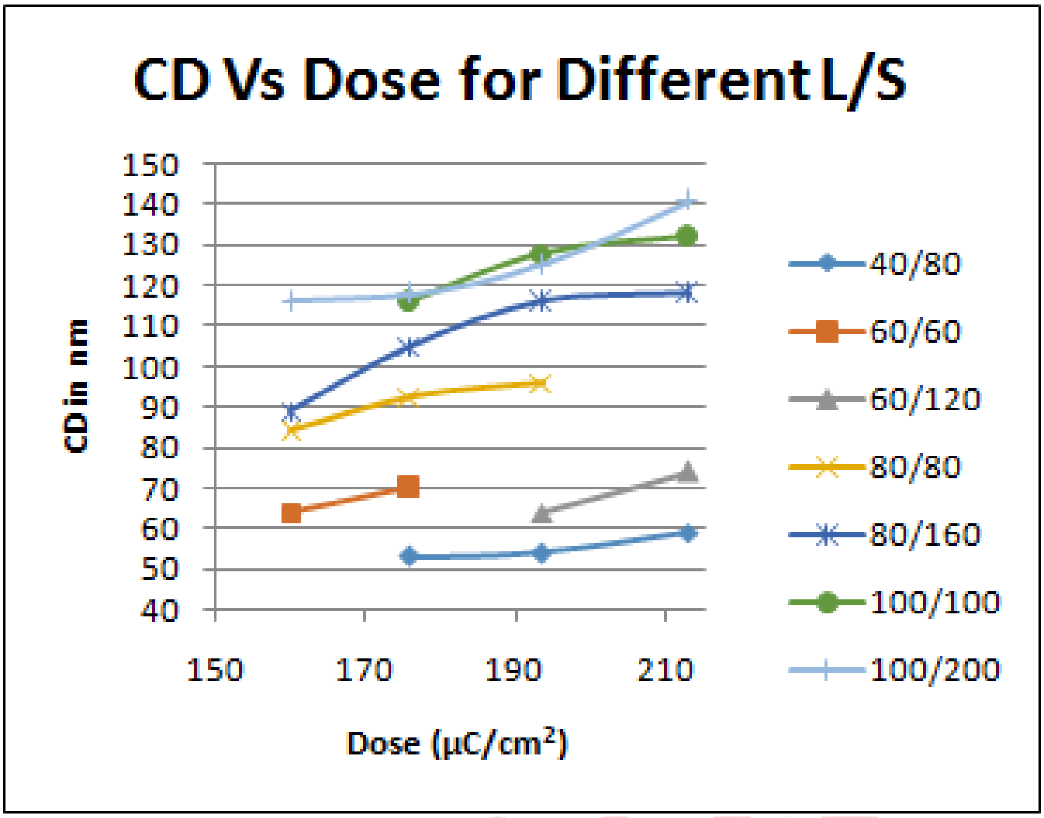


Figure 3. Impact of electron beam dose on critical dimensions at 20kV EHT with different L/S

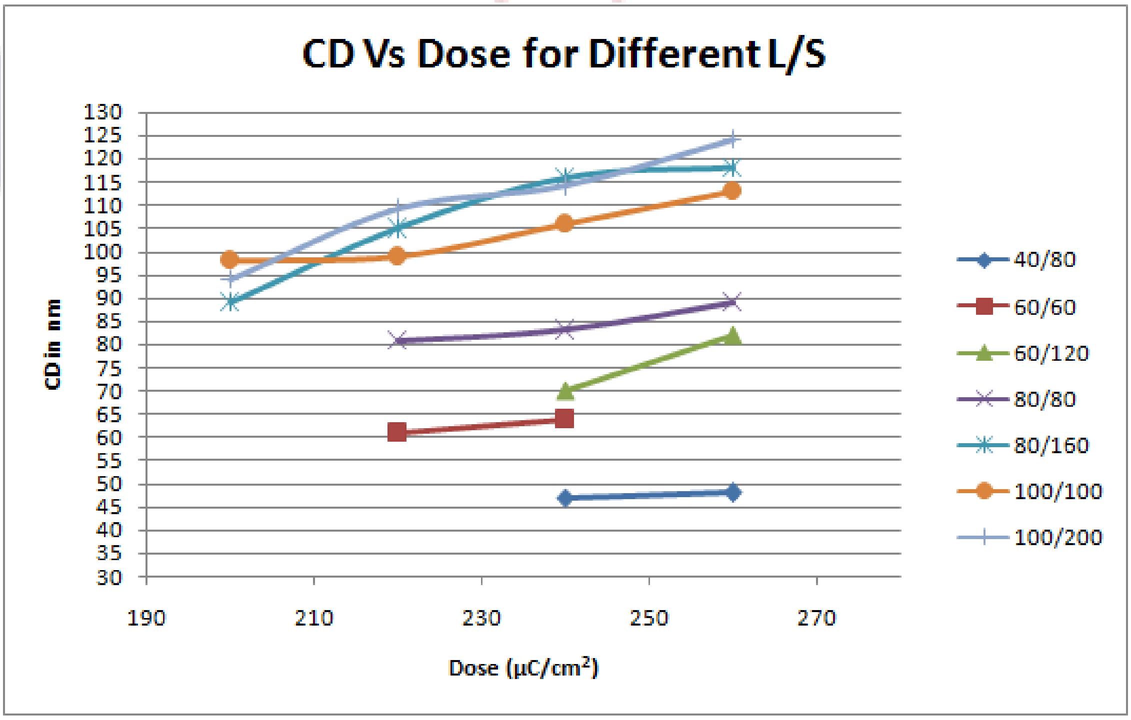


Figure 4. Impact of electron beam dose on critical dimensions at 30kV EHT with different L/S

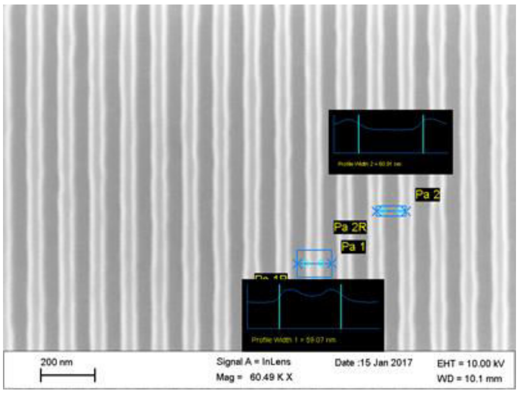


Figure.5 Features at 30kV EHT; Targeted L/S:60nm/ 60nm, Achieved : 61nm/59nm

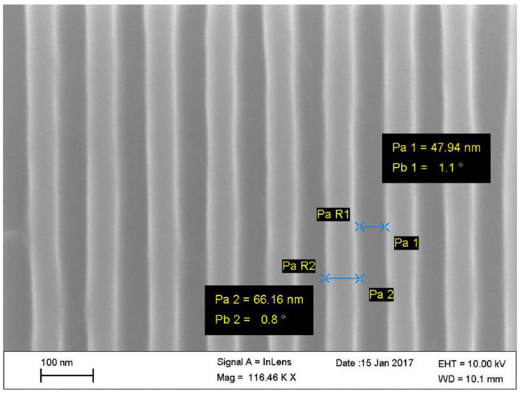


Figure.6 Features at 30kV EHT; Targeted L/S:40nm/80nm, Achieved : 48nm/66nm

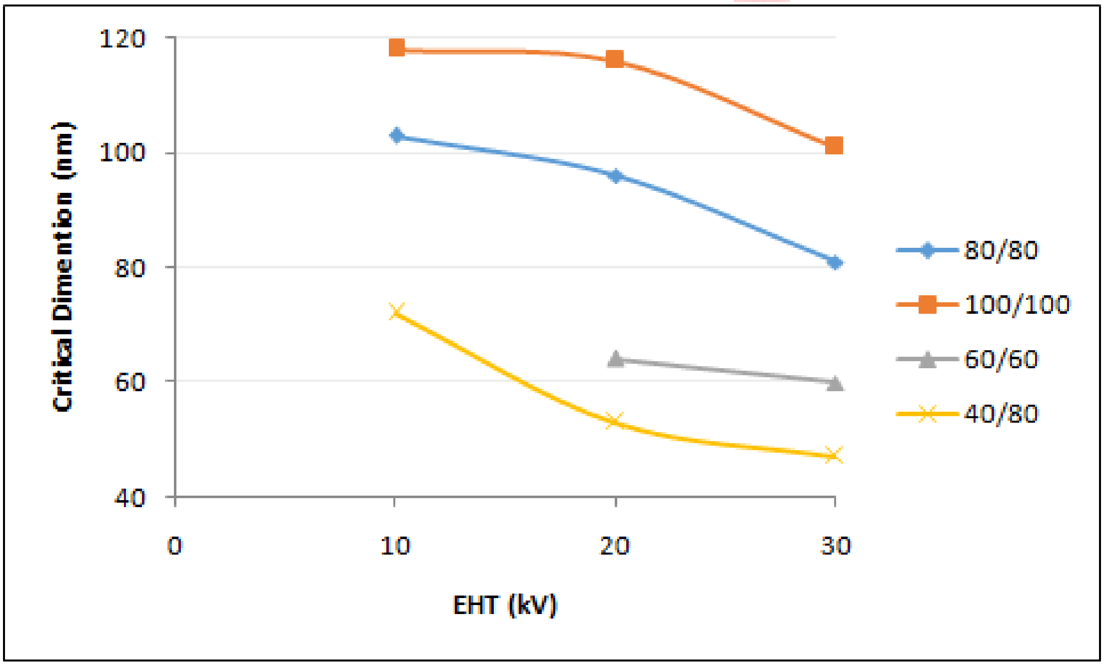
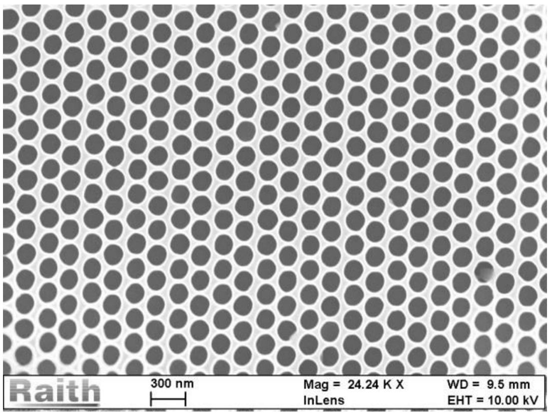


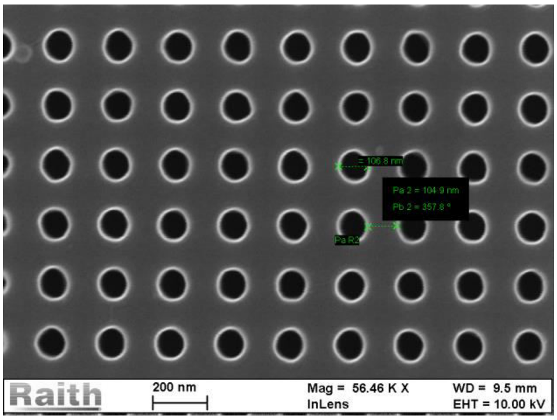
Figure 7 Impact of EHT on critical dimensions with different L/S

Optimization of other typical E-Beam lithography patterns:

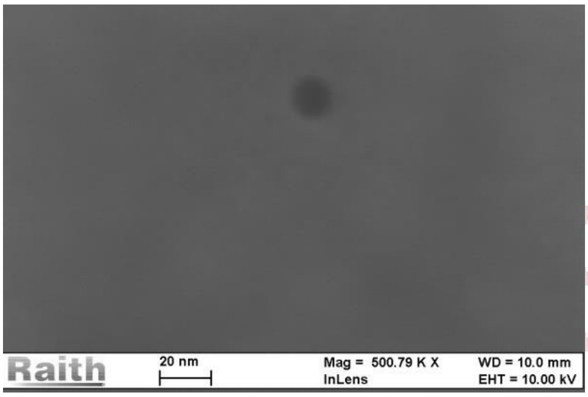
Other than the area line patterns, some of other typical high resolution structures like squares, circles and hexagons are optimized. Dimensions and patterning parameters are tabulated below. Circles can be patterned by two exposure methods, one is area mode exposure another one single pixel dot exposure method. Among the two methods , single pixel dots can give minimum features compared to area mode circles .



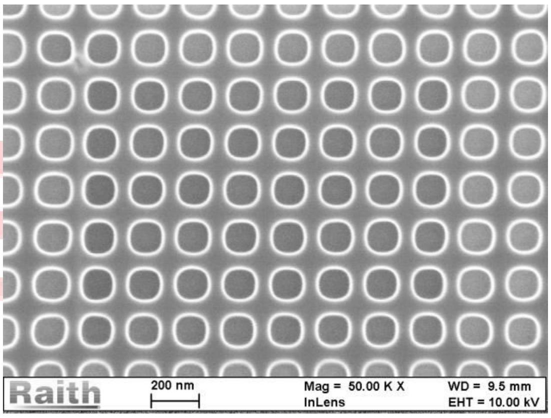
A) High resolution Hexagon structures



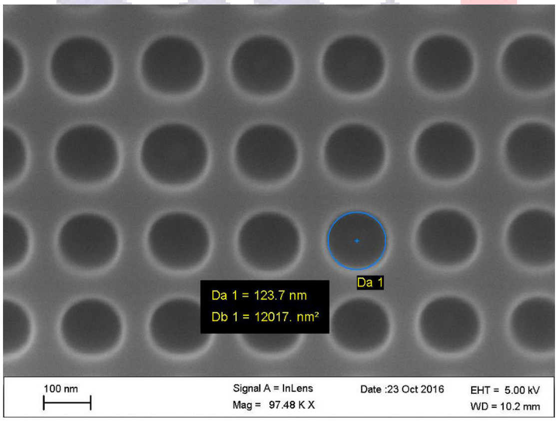
B) Cirles using single pixel dot exposure



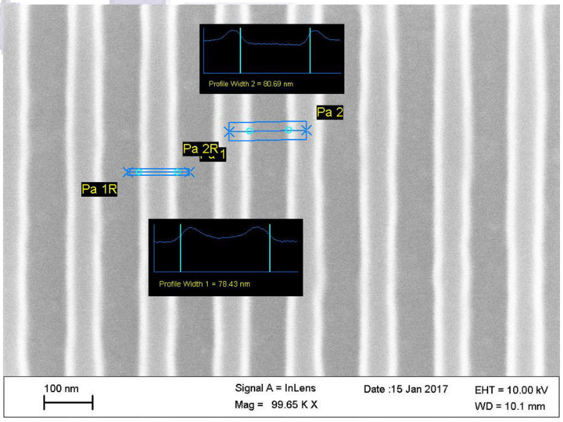
C) Cirles using single pixel dot exposure



D) Square patterns



E) Area mode circles



F) Area mode lines

Figure 8: Typical optimised e-beam lithography patterns

Area mode exposure circles will have smoother curves than the single pixel dot exposure circles. In area mode exposure, multiple beam incidence occurs on ER coated substrate to pattern/cover the feature as per the design. Each single ebeam spot causes some scattering around the spot, Consequently more resist area than the required feature can be defragmented . So that the feature size will be more than the actual design. This can be avoided by using higher EHT with lower aperture to achieve minimum features with smoother edges.

Pattern Description	**Targeted Critical dimension and space(nm)**	**Achieved Critical dimension and space(nm)**	**EHT, Aperture**	**Dose**
Hexagon structures	200/100	220/50	20kV, 10µm	150µC/cm^2
Circles	100/100	120/60	20kV, 10µm	200µC/cm^2
Squares	100/100	110/70	20kV, 10µm	250µC/cm^2
Circles by Single pixel dot design	10/500	13/500	20kV, 10µm	0.006pc
Circles by Single pixel dot design	100/100	100/100	20kV, 10µm	0.04pc
Area lines	80/80	80/80	30kV, 20µm	220µC/cm^2

Figure 9. E-Beam Exposure parameters for different patterns

Conclusion

In this document , we showed our recent optimization activities to achieve high resolution e-beam lithography patterns using PMMA950kA4 resist and studied the influence of EHT voltage and exposure dose on high resolution patterns. Parameters are optimized for critical dimensions like L/S:60nm/60nm and also for different kind of structures. We will continuously been improving the patterns quality such as line edge roughness control and proximity effect control.

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