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Optimization of PMMA 950KA2 resist patterns using Electron Beam Lithography

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Introduction

Resist 950 PMMA A2

From MICROCHEM

- PMMA(Polymethyl methacrylate) is a polymeric material that is most commonly used for direct ebeam writing.
- PMMA comes with 495,000 and 950,000 molecular weight resins in either chlorobenzene or anisole.
- 950 PMMA A2 is a positive tone resist formulated with solvent anisole.
- Pattern resolution-Down to 20nm
- Easy to remove(Soluble in Acetone)
- Development compatible in MIBK:IPA

Objective

To understand the optimum dose for lines of different dimensions.

Experimental details

Processing,

- Silicon sample was cleaned in Piranha solution(1:3),Sample is dipped in dilute HF
- Dehydration bake at 250°C for 10 minutes
- Spin coat 950 PMMA A2 at different rpm and respective thicknesses was measured using Ellipsometer. E-beam lithography exposures were done in a Raith eLiNE system.

Spin speed	Thickness in nm	Soft bake(Hotplate)
1000	146	180°C for 1min
2000	105	180°C for 1min
3000	95	180°C for 1min
4000	80	180°C for 1min
5000	76	180°C for 1min
6000	76	180°C for 1min

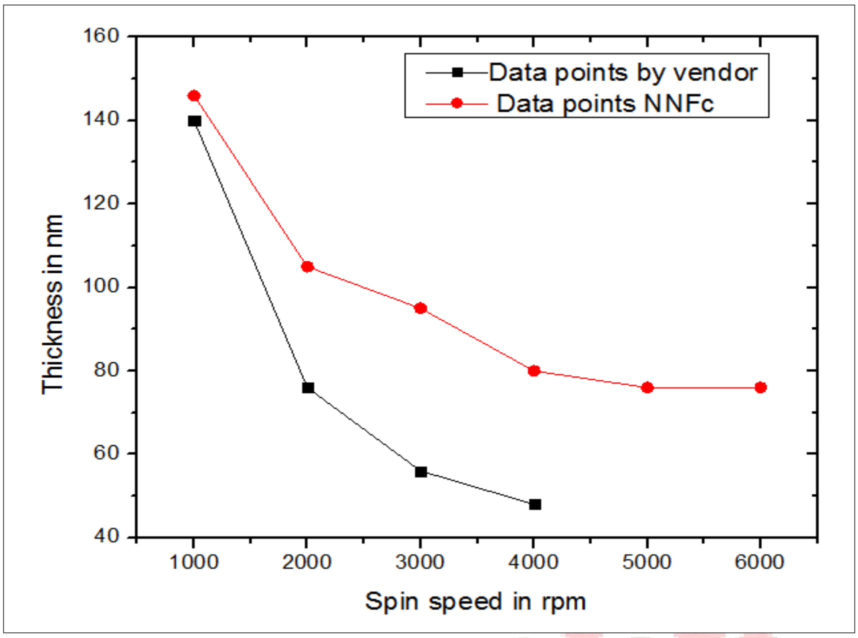

Figure 1: Spin speed versus Thickness plot for 950 PMMA A2

Results and discussion

Optimization of Area mode line patterns:

Area lines of different dimensions are patterned at 20kV EHT with a 20µm aperture. Lines of different dimensions (1:1),(1:2),(1:3),(1:4) are shown. To understand the optimum dose, the exposure dose window is varied from 140-272µC/cm². At lower electron doses, patterns are under exposed and as the dose increases the pattern dimension increases linearly. The potential to develop quality grating is mainly dependent on the optimum dose and interline distance. For 100/100 nm gratings, optimum exposure window is seen to be between 150-170µC/cm².The exposure dose window decreases when the grating pitch decreases.

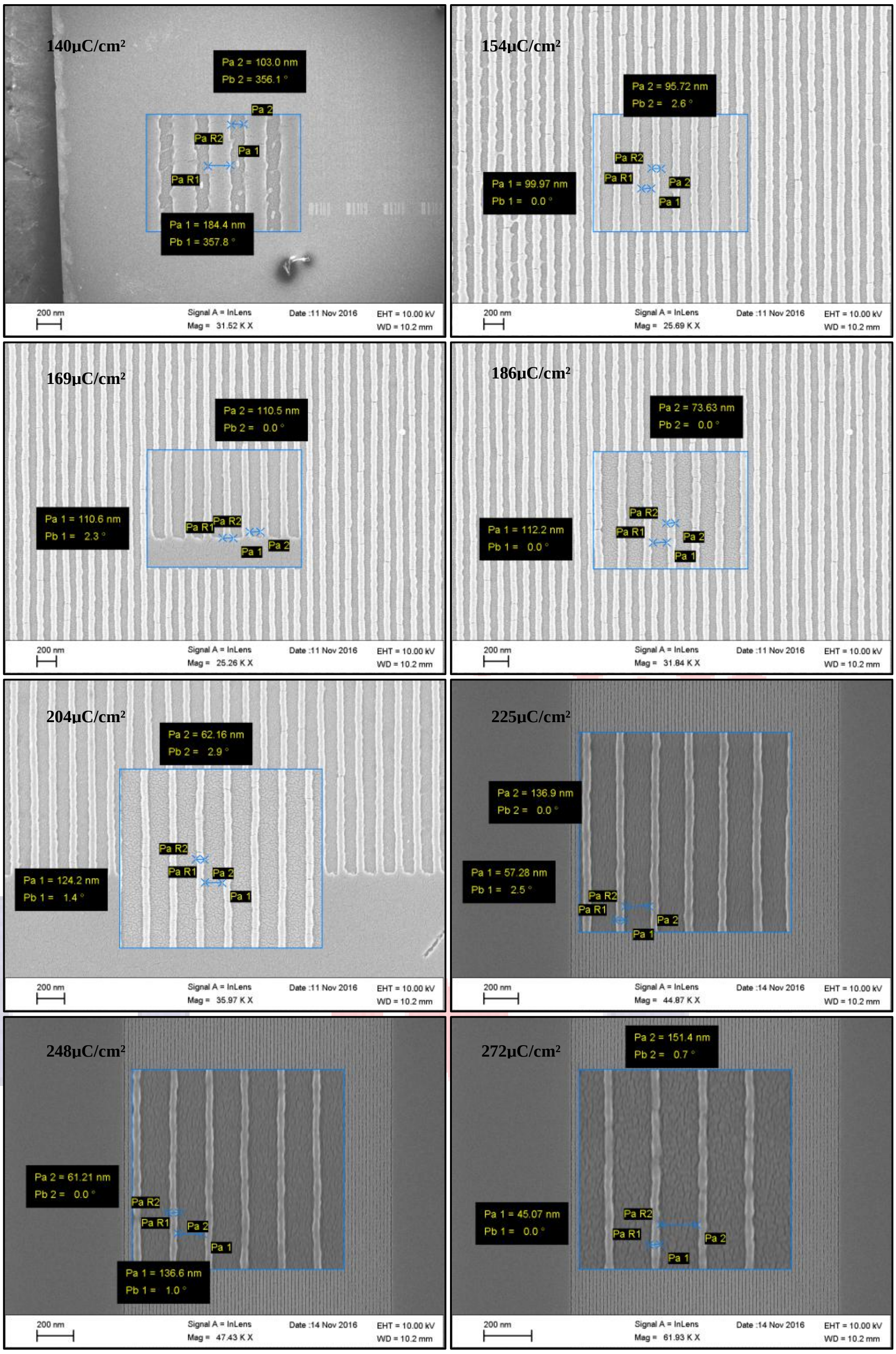

Figure 2: Dose variation for 100/100nm (Line width/line spacing)

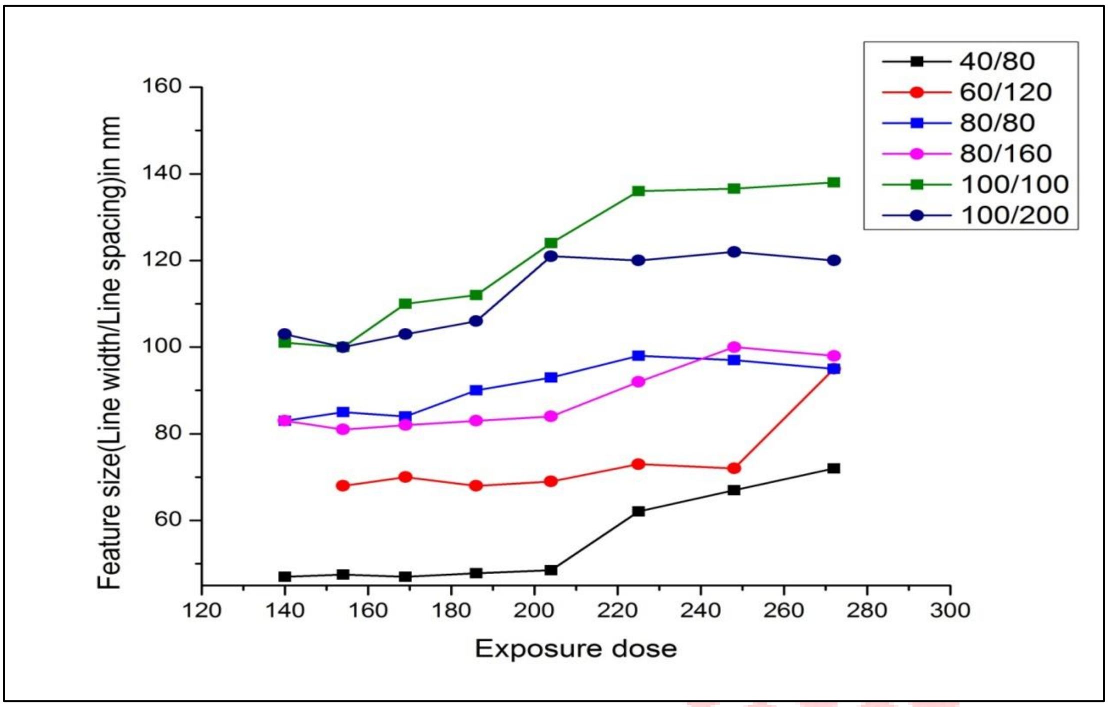

Figure 3: Exposure dose versus Feature size(Different line widths)

20/40nm **20/60nm** **20/80nm**

225μC/cm²

248μC/cm²

272μC/cm²

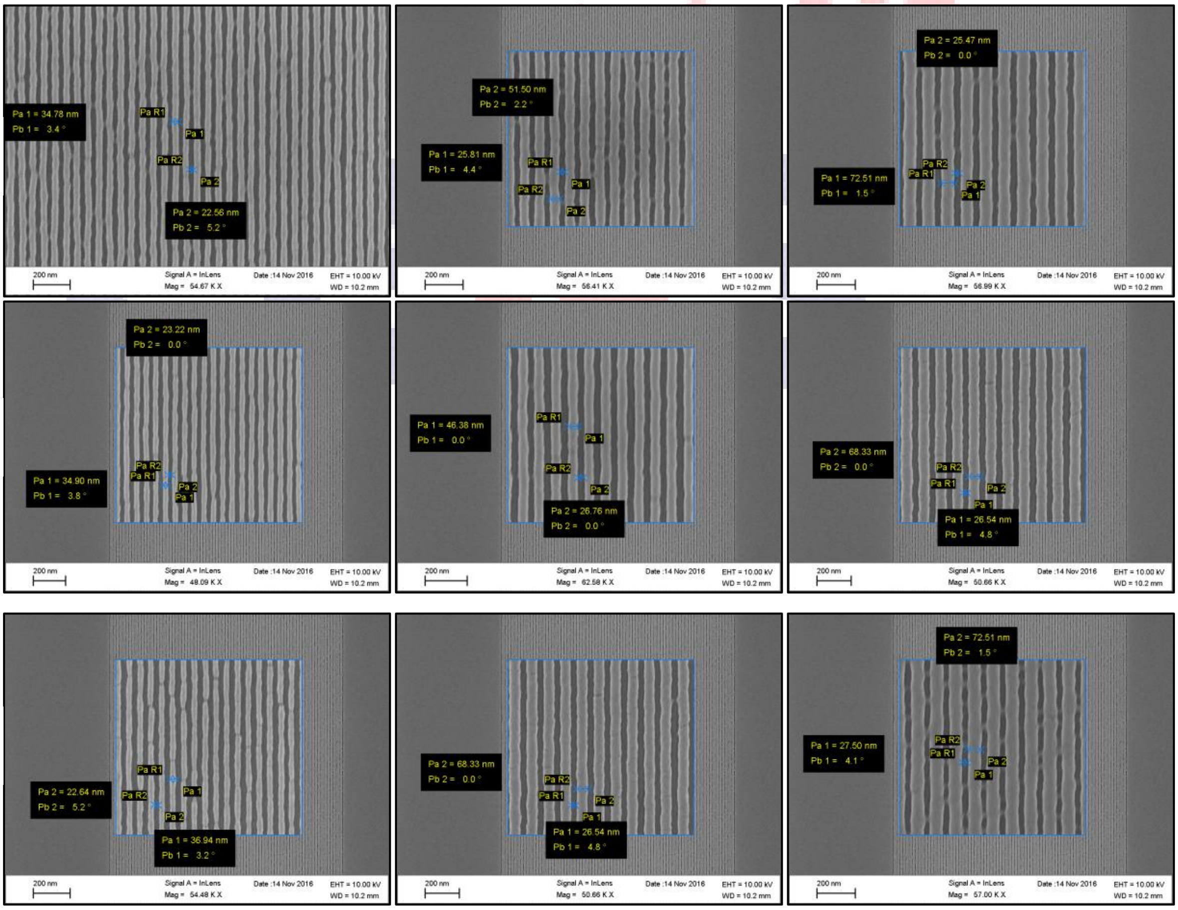

Figure 4: Dose variation for line dimensions in ratio (1:2), (1:3),(1:4)

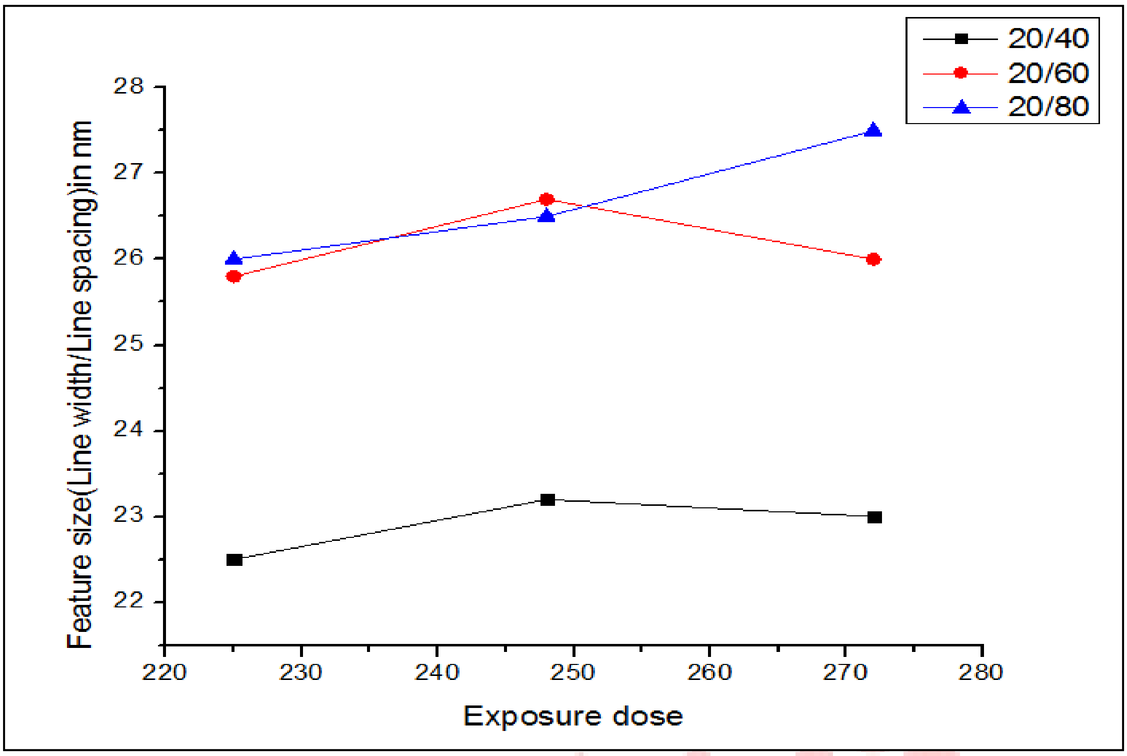

Figure 5: Exposure dose versus Feature size(Different spacing's)

From Figure 5, it can be observed that with increase in the grating pitch, dose window remains the same. At a dose of ~250µC/cm², gratings of width 20nm with different spacing show promising morphologies with a slight variation in the width which could be due to the proximity effect.

Pattern Description	Targeted Critical dimension and space(nm)	EHT, Aperture	Exposure Dose window
Area lines	100/200,100/100 80/160,80/80, 60/120,40/80	20kV, 20µm	150-170 µC/cm²
Area lines	20/40,20/60 20/80	20kV, 20µm	240-250 µC/cm²

Temperature Dependence Development:

The resist development generally occurs through the removal of relatively low-weight fragments from the exposed regions in case of PMMA resist. Decrease in the development temperature from room temperature down to 4-8^{o}C, helps increase the process yield.

A 70nm thick PMMA layer was coated on a Si substrate, single pixel lines with different spacing's 40nm, 60nm, 80nm, 100nm were patterned. Exposure dose was constantly maintained at 100 µC/cm^2 with EHT 20kV.Development was carried out at room temperature and down to 4-8^{o}C.a) In the first case, line widths of 20nm with a 40nm spacing were developed with rough edges, b) In the second case, line widths of 20nm with a 40nm spacing were developed with relatively smooth edges as seen in Figure 6.

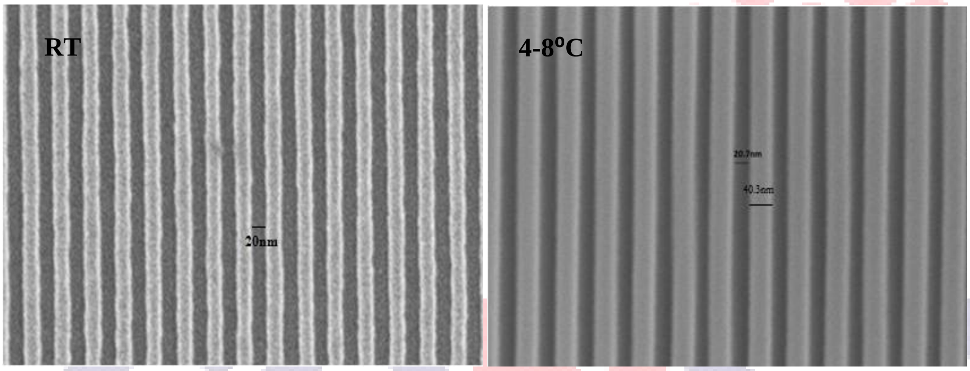

Figure 6: Comparison of room temperature with cold development

Obtaining a smoother edge in patterns of nanoscale dimensions involves optimization of several process conditions. One can conclude that minimum feature size significantly reduces with the decrease in the development temperature from room temperature down to 4-8^{o}C.

Comparison of exposures in different apertures:

Apertures are small holes through which the beam passes on its way down to the column. In our system, we have different apertures ranging from 120µm to 7.5 µm. Single pixel lines with different spacing's 40nm, 60nm, 80nm, 100nm were patterned. With EHT 20kV, writing was performed using different apertures 20 µm, 10 µm, and 7.5 µm.

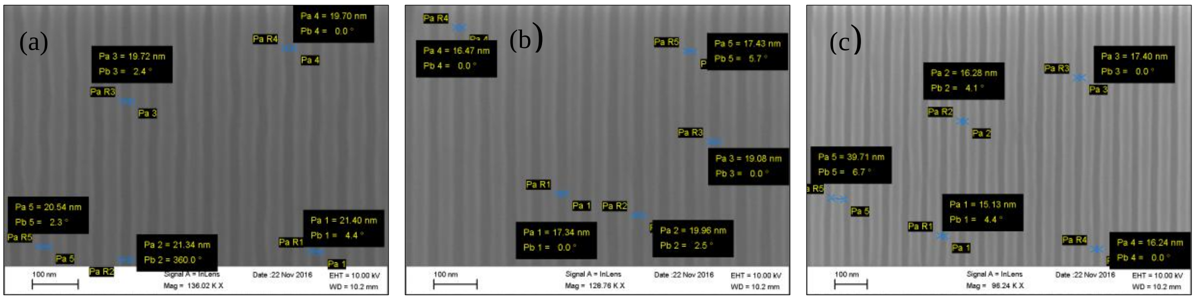

Figure 7: (a-c)Single pixel lines with a gap of 40nm exposed with different apertures 20µm,10µm,7.5µm

With the same process conditions, single pixel lines with 40nm spacing in different apertures 20 µm, 10 µm, and 7.5 µm were measured to be 19.7nm, 17.4nm, 15.1nm.

Conclusion

PMMA950kA2 resist optimizations are shown. Dose variations are studied to optimize the optimum dose for different dimensions of lines. Study of temperature dependence development infers that with cold development improves the pattern quality, removes PMMA residues and helps minimize the line edge roughness. Single pixel lines are patterned using different apertures and we can conclude that with a smaller aperture, the writing time is generally higher which results in much finer features.

References

- Sub-10 nm electron beam lithography using cold development of poly(methylmethacrylate), Wenchuang(Walter) Hu, Koshala Sarveswaran and Marya Lieberman, Gary.H.Berstein
- Effect of cold development on improvement in electron-beam nanopatterning resolution and line roughness, L.E.Ocola, A.Stein
- Fundamentals of Electron Beam Exposure and Development , Mohammad Ali Mohammad, Mustafa Muhammad, Steven K. Dew, and Maria Stepanova

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