What are the Challenges for Creating a Positive Tone Metal-Organic Resist?

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In the past, we have studied metal-organic resists for electron beam, ion beam and extreme ultra violet lithography[1]. We have reported extreme dry etch selectivities along with high resolution. In all cases, these resists have been negative tone. Metal-organic positive tone resists have not been fully demonstrated. The problem of producing a metal-organic positive tone resists is that exposing the resist reduces the metal organic resist into either a metal, metal oxide or a metal sulphide and this inherently reduces the thickness of the resist in the immediate exposure area and this allows the resist to appear to be positive tone when they are not. During our presentation, we will show that the exposed resist is a derivative of the unexposed resist and it is this that makes it extremely difficult to produce an *all* metal organic resist in the positive tone regime. This presentation describes a suitable method for producing a positive tone metal organic nanocomposite resist. We will show the balancing process of incorporating the metal organic material (see Figure 1a) into a polymer (see Figure 1b) host to create a nanocomposite resist. Through the use of our ‘Excalibur’ Monte Carlo simulation we will show our design process to produce a positive tone metal organic resist and demonstrate it. In the resist design, we will show the interaction of the organic ligand chemistry to the electron beam and determine their effects on the resolution, sensitivity and on its dry etch properties. From our simulations, we have discovered that Poly(1-naphthyl methacrylate) (PNMA, see Figure 1b) has excellent patterning resolution and silicon dry etch properties. To appreciate the effects of the metal-organic on the PNMA resist we must first understand the performance of the PNMA resist so that we may use the results as a bench mark. The PNMA resist was exposed with a resolution of 50 nm half-pitch (Figure 2a). The etch rate of the resist was determined to be 0.5 nm/second, while the silicon etch rate was 1.93 nm/second, yielding a selectivity of 3.8:1 (see Figure 2b). Figure 2c shows the successful pattern transfer after the resist has been removed. The PNMA nanocomposite resist was exposed with a resolution of 50 nm half-pitch (Figure 2d). Figure 2e shows that the etch rate of the nanocomposite resist was 0.08 nm/second, while the silicon etch rate was 2.06 nm/second, yielding a selectivity of 25:1. Figure 2f shows the successful pattern transfer after the nanocomposite resist has been removed.

[1] S. M. Lewis et al., *J. Micro/Nanopatterning, Materials and Metrology,* Vol. 21, 041404, (2022).

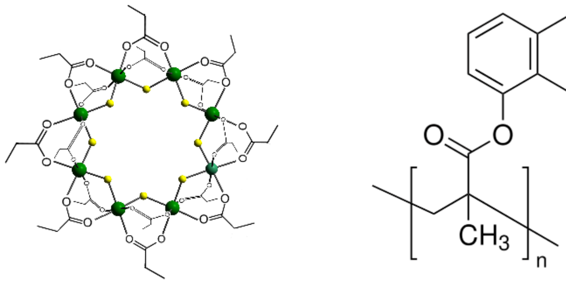
(a) (b)

Figure 1: (a) *$Cr_8F_8(propionate)_{16}$*: The structure of the molecules in a crystal, in ball-and-stick representation. Cr atoms are green, Ni atom is green with blue band and F atoms are yellow. H atoms are omitted for clarity. (b) The molecular structure of Poly(1-naphthyl methacrylate) (PNMA).

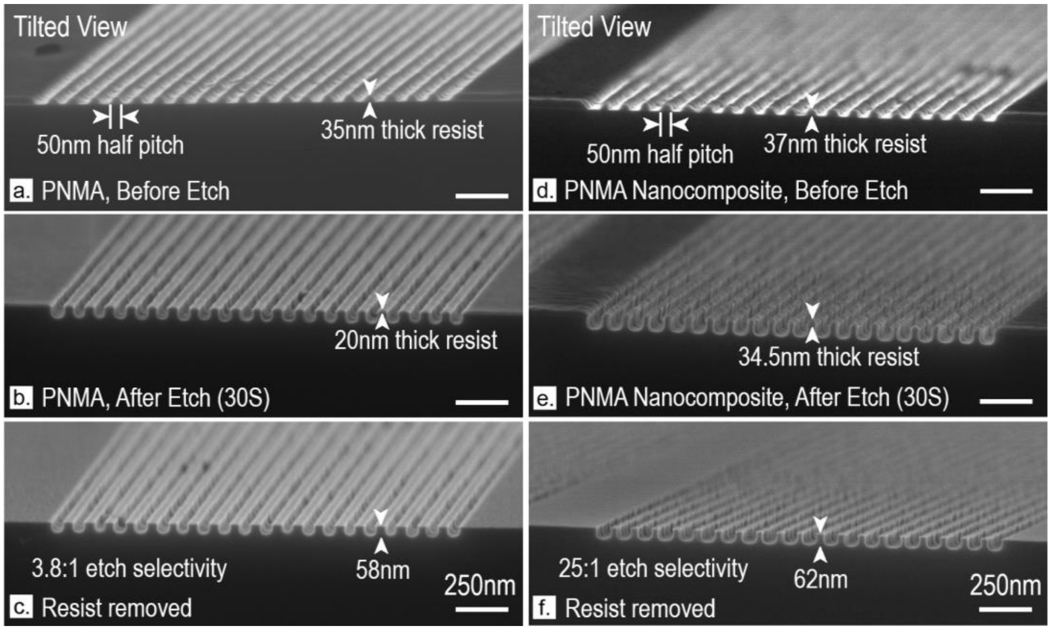

Figure 2: (a) Patterned PNMA resist before the dry etching process; (b) Resist after a 30 second pBosch dry etch process; (c) Fins with a 50 nm width after oxygen plasma removal of the resist. (d) Patterned PNMA nanocomposite resist before the dry etching process; (e) Resist after a 30 second pBosch dry etch process; (f) Fins with a 50 nm width after oxygen plasma removal of the resist. The exposure parameters were 100 kV acceleration voltage, 1 nA beam current, and 5 nm step size. The developer was Amyl Acetate : IPA where the ratio was 4:1 for 30 Seconds followed by an IPA rinse for 15 Seconds. The parameters of the dry etch process were as follows: a mixture of SF_6 and C_4F_8 gases with flow rates of 22 and 35 sccm, respectively, was admitted to the chamber and controlled to a pressure of 10 mTorr; the substrate holder temperature was set to 15 °C; 4 Torr of Helium back side pressure was maintained to provide good thermal conductance between the substrate holder and the sample; the RIE forward power was 20 W, and the ICP forward power was 1200 W.