Investigation of ma-N 2400 Series Photoresist as an Electron Beam Resist for Superconducting Nanoscale Devices

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Advancements in the nanoscale patterning of materials using electron beam lithography (EBL) have facilitated the development of a new family of superconducting devices based on thin-film nanowires. These devices are used in a wide variety of applications including photon detection, digital circuitry, and memory. The most prevalent choice of negative-tone electron beam resist is hydrogen silsesquioxane (HSQ), which offers advantages such as low line-edge roughness and ~ 5 nm resolution[1]. Despite these benefits, there are significant difficulties in using HSQ with superconducting materials. First, exposed HSQ cannot be easily removed without the use of a strong reagent such as hydrofluoric acid, which damages the quality of the superconducting film. This limitation is particularly hindering to multilayer fabrication, which often requires the resist to be removed between layers. Additionally, HSQ is notoriously sensitive to air exposure, and for best results must be patterned and developed immediately after spinning. Finally, HSQ often has difficulty adhering to superconducting materials such as niobium nitride, requiring a pretreatment step that can damage the film[2]. As a result, there is a need for investigating alternative negative tone electron-beam resists for patterning superconducting devices.

Here we study the use of ma-N 2400 series DUV photoresist as an electron beam resist for patterning superconducting nanoscale devices. While previous studies of ma-N have reported minimum feature sizes of 50 nm or more[3] [4], we are able to pattern repeated lines of widths down to 30 nm, and individual features with a minimum dimension of 20 nm. In comparison to HSQ, we find that exposed ma-N can be stripped with minimal damage to the superconducting film, making it a promising candidate for multilayer fabrication. We also study the resistance of ma-N to reactive ion etching in CF_4—a standard step in the superconducting fabrication process—and find that it has similar performance to that of HSQ, proving that ma-N is a suitable etch mask.

These results show that ma-N is a more flexible negative-tone electron beam resist for the patterning of superconducting films, and that it is capable of resolving geometries down to 20 nm. Future studies include measuring the line-edge roughness and evaluating the device performance of a superconducting structure patterned using ma-N.

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[2] E. Toomey, M. Colangelo, N. Abedzadeh, and K. K. Berggren, *J. Vac. Sci. Technol. B* (2018)
[3] B. Bilenberg *et al.*, *J. Vac. Sci. Technol. B* (2006)
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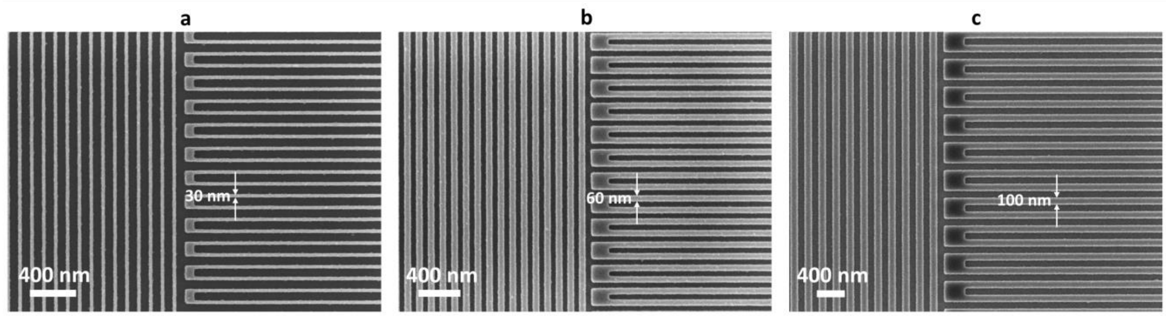

Figure 1: Resolution of ma-N 2401 patterned using 125kV Elionix (dose = 1000 µC/cm^2). (a) 30-nm lines with a 120 nm pitch. (b) 60-nm lines with a 120 nm pitch. (c) 100-nm lines with a 200 nm pitch. (Scanning electron micrograph settings: 3 kV, 4.2 mm WD).

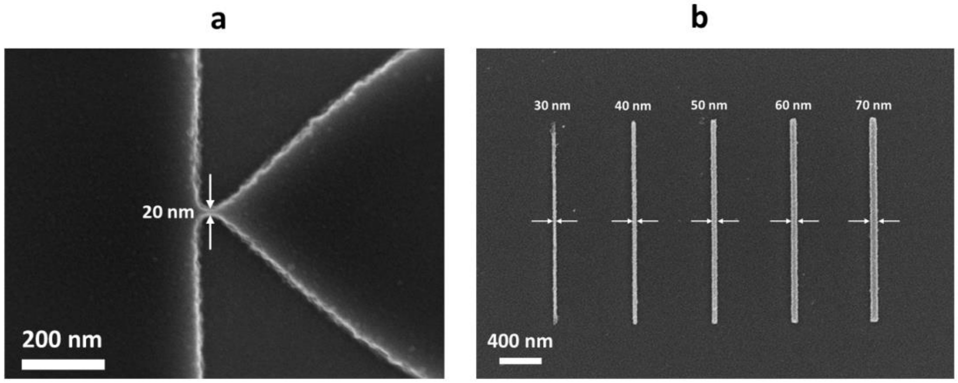

Figure 2: Resolution of isolated structures. (a) 20-nm single feature of a superconducting nanocryotron device, known as the nTron (dose = 900 µC/cm^2). (b) Lines of widths ranging from 30-70 nm patterned using 125kV Elionix (dose = 1000 µC/cm^2). (Scanning electron micrograph settings: 3 kV, 4.2 mm WD).

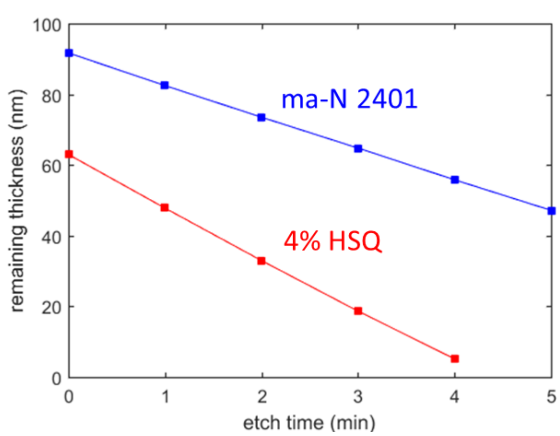

Figure 4: Etch rate in CF_4 of ma-N 2401 and 4% HSQ (both unexposed). The etch rate of ma-N 2401 was 8.9 nm/min, and the etch rate of 4% HSQ was 14.5 nm/min. Each resist was spun at 3krpm for 60 s. The substrate with ma-N was baked at 90 °C for 1 min prior to etching.