Research and Development of Electron-Beam Lithography Using a Transmission Electron Microscope at 200 kV

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Abstract:

Conventional electron-beam lithography is done using a scanning electron microscope (SEM), with a resolution limit of ~ 10 nm [1]. However, there is continued need for higher resolution lithography.

The goal of this project is to investigate higher resolution electron-beam lithography using a scanning transmission electron microscope (STEM). In principle, the STEM has two main advantages: less scattering of incoming high energy electrons, and a smaller electron probe diameter. We have created 100 nm wide trenches in PMMA resist, which are promising early results. Reducing the exposure of the resist will likely give higher resolution.

Figure 1

Figure 1: Electrons exposing certain areas of resist, which development then eliminates.

Figure 2

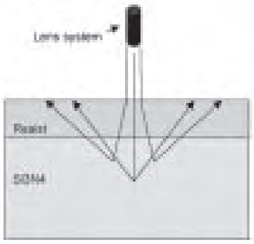

Figure 2: Electron beam is scattered, exposing larger area of resist.

Introduction:

Lithography is the creation of three dimensional structures on a substrate that allows for transfer of a pattern to that substrate. First, a "resist"—a material sensitive to light or electrons—is deposited on a substrate. Certain areas of the resist are "exposed" by light or electrons, making the area more susceptible to a subsequent chemical treatment, called "development". After development, the substrate has only certain places where it is still covered by resist. The substrate is etched or additional material is deposited (the remaining photoresist covers the area that is not meant to be etched or to have material deposited on it). Finally, the resist is stripped away, leaving the desired pattern in the substrate (see Fig.1).

There are two common lithography methods. The first, called photolithography, is shining UV light through a plate with the proper pattern engraved in it, exposing light-sensitive resist beneath in the same pattern. The limit of the smallest feature that can be produced (the resolution) depends linearly on the wavelength of light used. State of the art deep UV photolithography using light wavelengths of 193 nm has a resolution of ~ 50 nm [2]. However, for some applications, higher resolution is needed. Thus, the second common lithography method is electron-beam lithography.

Electron-beam lithography uses electrons instead of photons to expose a resist. Because electrons have a much smaller wavelength than the light used in photolithography, then electron-beam lithography has a much higher intrinsic resolution. There is also a difference in that the electron beam can be focused onto a substrate directly and controlled so it only exposes those areas which ought to be exposed, without needing a mask to block certain light from reaching certain areas. Conventional electron-beam lithography is done using an SEM. The SEM can give electrons energies up to about 30 KeV, and uses an electron probe with a diameter of a few nanometers. Due to scattering, however, the maximum resolution is about ~ 10 nm [1].

There are two main types of scattering—forward and back scattering. In forward scattering, the paths of the incoming electrons are deflected by the atoms' coulomb potential into a cone-like trajectory. In backscattering, the path is deflected by an angle greater than 90 degrees, and the electrons go back to expose a much larger area of the resist than the area of the incoming electron beam (see Figure 2). The lower the electron energy, the more likely backscattering is to occur. The SEM has relatively low beam energy; thus, backscattering is an important problem. If two lines are written too close together, then the backscatter will end up exposing all the area in between. The TEM electron beam has a much higher energy, substantially reducing the backscatter. Thus, the TEM or its cousin, the scanning TEM (STEM), should have an inherently higher resolution.

In the late 1980s, STEM was tried for electron-beam lithography [3]. Early experiments with the STEM succeeded in producing patterns with resolution of ~ 10 nm [3]. Few groups have worked on this since, despite the availability of new electron-beam resists. It was our purpose to further explore this idea by using a new resist, a high accelerating voltage in a STEM, and a thin sample.

Experimental Procedure:

We explored two different methods for writing with an STEM. The first was a lithography setup, where we spun coated an HMDS adhesion layer and then a layer of PMMA 495 C_3 positive electron-beam resist on a 100 nm thick silicon-nitride membrane, and then used a JEOL 2010 STEM with a Nabity pattern generator attached to expose the resist. We developed with MIBK 1:3 to clear away the exposed areas, and examined the patterns under the SEM. The idea behind using a silicon-nitride membrane is that this should reduce backscatter even more, thus potentially giving even cleaner, smaller lines.

The next method we tried was direct writing on a thin metal layer that was deposited on the 100 nm Si_3N_4 membrane. The 200 keV beam energy of our STEM should have been enough to ablate the metal. We demonstrated this in principle by ablating holes in a Si_3N_4 membrane without a metal layer. We then thermally evaporated 10Å of aluminum onto the Si_3N_4 membrane. However, the metal did not adhere well enough to form a uniform layer; instead, the aluminum aggregated into clumps on the membrane surface. For better adhesion, we tried thermally evaporating 20 nm of chromium onto the membrane surface. This still clumped (see Figure 4), making pattern writing impossible.

Results and Conclusions:

With our lithography setup, we have created some trenches in the PMMA resist (see Figure 3). We would like to achieve finer resolution than that demonstrated (about 100 nm is the smallest line width), but this is an important first step. One area that needs to be examined more is the current dose used in the writing. We used doses between 1 and 16.5 nC/cm. However, given that some of our lines blended together, much lower doses may need to be explored.

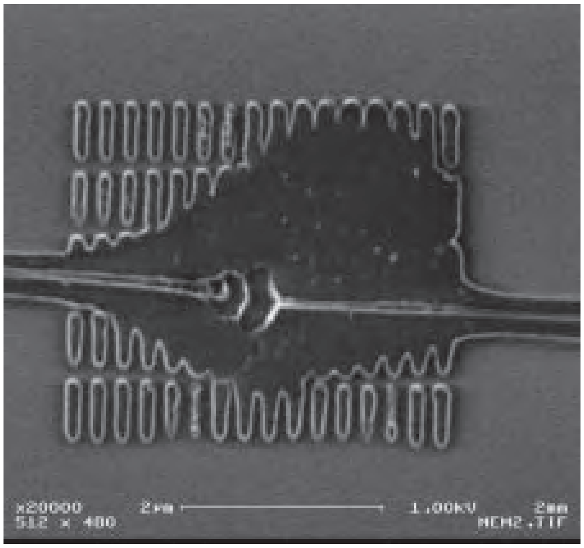

Figure 3: 100 nm trenches in PMMA resist on Si_3N_4 membrane.

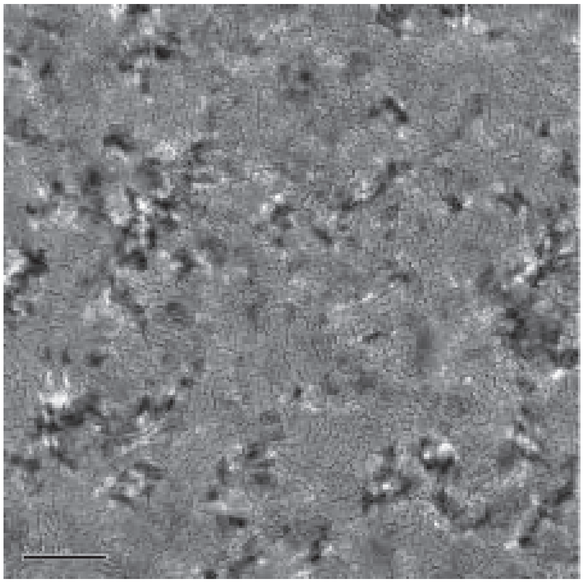

Figure 4: 20 nm chromium "clumps" on 100 nm Si_3N_4 membrane.

In our direct writing setup, we need to reduce the aggregation problem, and achieve a uniform layer. There are several possibilities to explore. Perhaps we are using the wrong metals, and that a different metal might thermally deposit in a much more uniform way. Perhaps we could sputter coat the metals on, instead of thermally evaporating them onto the Si3N4 membrane. This might give the metal atoms enough energy to stick in place on the membrane, rather than allowing some to aggregate.

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References:

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