A First Principles Approach to Electron-Beam Lithography

Roger W. Pryor, Ph.D.[1]

1. Pryor Knowledge Systems, Inc., 4918 Malibu Drive, Bloomfield Hills, 48302-2253, USA

INTRODUCTION: The COMSOL Multiphysics® Simulation Software model employed herein is used to parametrically explore a single stage magnetic lens, as would typically be applied in the first stage of a high resolution direct-write multistage electron-beam lithography system.

The choice of exposure beam and the resist type selected are determined by the requirements of the follow-on processes being used and the resolution required. The highest microfeature resolution can be achieved by using electron-beam lithography processes. Figure 1 shows the result of using a negative resist process. Figure 2 shows the result of using a positive resist process.

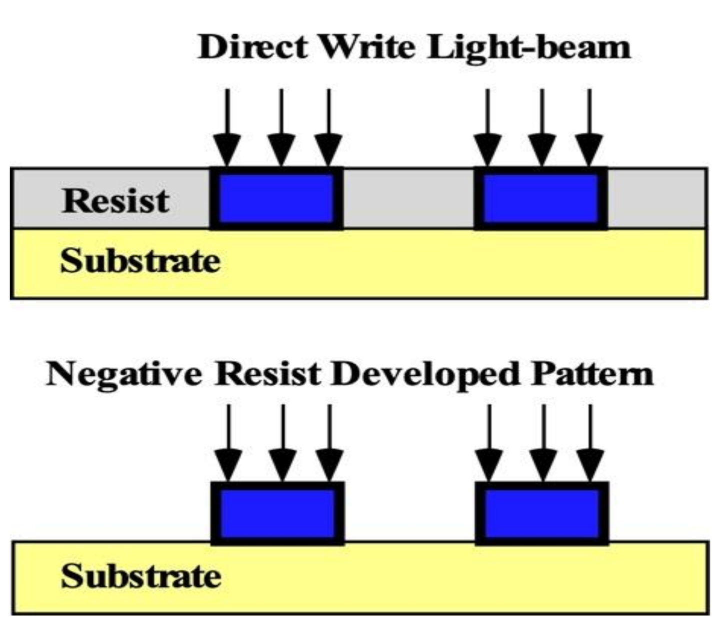

Figure 1. Direct Write Electron-beam Negative Resist

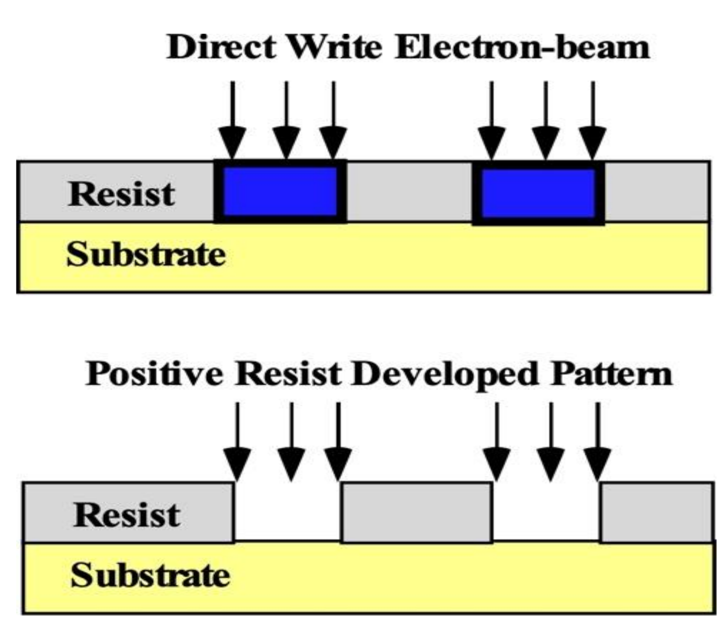

Figure 2. Direct Write Electron-beam Positive Resist

COMPUTATIONAL METHODS: The Magnetic Lens model used herein (COMSOL 10185) [1] employs the COMSOL Multiphysics® Module, the AC/DC Module, the Particle Tracing Module and the Charged Particle Tracing interface. The mathematical relationship of the focal length (the distance measured from the axial center of the lens to the axial center of the minimum beam diameter {focal point}) of the magnetic lens is given by:

$$f = K * \left(\frac{V}{i^2}\right)$$

Where: f = focal length

K = coil constant

V = electron accelerating Voltage

i = coil current

This model has been run for different parametric conditions of coil current and electron accelerating voltage. See the Results section that follows.

Results: The most critical portions of any direct-write system are the focusing elements. In the case of the electron-beam system, the first stage lensing element would be a simple magnetic lens. The active portion of the magnetic lens is the magnetic field generated by the current flowing in the circular coil, as shown in Figure 3 (a cross-sectional view).

This model, when built using the nominal parameters (0.32A & 0.5 keV), has a measured focal length of 5.75 mm. See Figure 3. When the model is built, using different parameters (0.32A & 1.0 keV), the observed focal length in the model increases to 11.65 mm as seen in Figure 4. Assuming that the units for this formula are as presented earlier: $f = K * \left(\frac{V}{i^2}\right)$

Inserting the nominal modeled results:

$$5.75 = K * \left(\frac{0.5}{(0.32)^2}\right)$$

Next, inserting the next set of modeled results:

$$11.65 = K' * \left(\frac{1.0}{(0.32)^2}\right)$$

$$\frac{\boldsymbol{K'}}{\boldsymbol{K}} = \frac{\mathbf{1}}{\mathbf{2}} * \frac{\mathbf{11.65}}{\mathbf{5.75}} = \mathbf{1.013}$$

Since K and K' are the same numerical geometrical constant derived from the construction of this simple circular multi-turn coil, then:

$$\boldsymbol{K} = \boldsymbol{K'} = \mathbf{5.75} * ((\mathbf{0.32})^2/\mathbf{0.5}) = \mathbf{1.1776} \pm \mathbf{1.3\%}$$

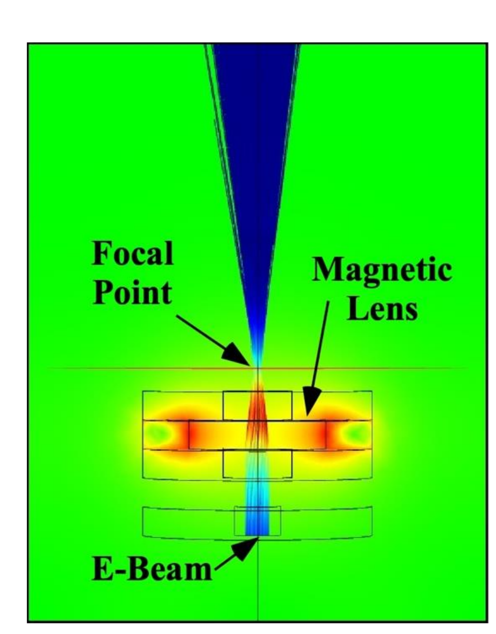

Figure 3. Magnetic Lens 0,32A 0.5keV

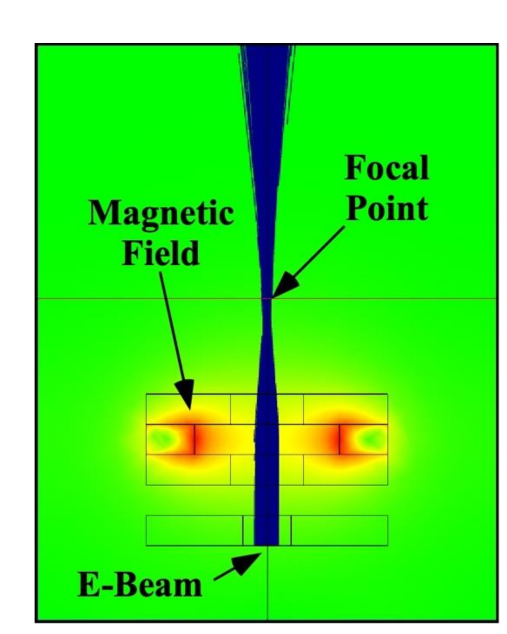

Figure 4. Magnetic Lens 0.32A 1.0keV

CONCLUSIONS: The COMSOL Model (10185) for a simple circular single coil magnetic E-Beam lens yields good results for a First Principles E-Beam calculation. The results were found to be within approximately 1.3%.

REFERENCES:

1. COMSOL Multiphysics Simulation Software, Application Library path: Particle_Tracing_Module/Charged_Particle_Tracing/magnetic_lens)

Excerpt from the Proceedings of the 2019 COMSOL Conference in Boston