Electron beam lithography, the first fifty years, and prospects for the future

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A focused electron beam is the smallest, finest practical writing pencil known, with the ability to create pattern features down to a few nanometers in size. As such, electron beam lithography (EBL) is firmly established as a workhorse technology for patterning in a large variety of applications on the scale of dimensions from a few to a few hundred nanometers. An e-beam writer generates its own patterns, in contrast to mainstream, high volume optical lithography, which relies on a pre-existing, patterned reticle. This capability enables short cycle time for new designs, while eliminating the reticle cost.

EBL grew naturally out of scanning electron microscopy, which had achieved a fair degree of maturity by the late 1950s. Lithography with charged particle beams was first proposed in 1958 by D. A. Buck and K. R. Shoulders[1] as a possible means of fabricating practical electronic devices with minimum feature sizes in the range of 100 nm, thus enabling the possibility of placing a large number of working devices on a single substrate. The use of a charged particle beam for patterning was also proposed by R. P. Feynman[2] in 1959 as a possible means of reducing printed feature size by a factor of up to 25,000, thus enabling dense storage of large amounts of information. The first actual demonstration of e-beam writing was by G. Möllenstedt and R. Speidel[3] in 1960, in which printed line widths of about 60 nm were shown. The enormous promise of EBL was quickly appreciated by many groups, and the state of the art improved rapidly through the 1960s and 1970s. EBL was used to practical advantage in a large variety of applications spanning research, development, and manufacturing. EBL systems became commercially available in the 1970s, and are widely used today.

The historical Achilles Heel of EBL has been its slow speed. The reason for this is two-fold. First, the writing is typically serial in nature, with a probe-like beam scanning the complex pattern in a sequential manner. This is in contrast to mainstream optical lithography, in which a complex pattern is transferred in a single scan. Second, mutual Coulomb scattering of the beam electrons places an upper limit on the useful writing current for a given resolution. Owing to these two factors, EBL remains at least three orders of magnitude slower than optical lithography, in terms of pattern area swept out per unit time. It is possible to substantially improve the writing speed of EBL, by designing systems with high pixel parallelism, and low Coulomb scattering, however. With the cost of mainstream, high volume optical lithography escalating rapidly, there is renewed interest in addressing the largely practical throughput limitations of EBL. A successful effort would make the superior resolution of electron beams available in high volume manufacturing at reasonable cost. In the present study, we present a critical review and evaluation of the status and future prospects of these efforts.

[1] D. A. Buck, K. R. Shoulders, Proc. Eastern Joint Computer Conference, American Inst. of Electrical Engineers, Philadelphia, PA, December 3-5, 1958.
[2] R. P. Feynman, Annual meeting of the American Physical Society, California Institute of Technology, December 29, 1959.
[3] G. Möllenstedt, R. Speidel, Physikalsche Blätter, 16, 192-198 (1960).

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