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Electron Beam Lithography: A Superior Enabler for Nanoscale Fabrication

Abstract: Maskless pattern generation in combination with all but limitless resolution made probe-forming electron beam systems attractive tools in the semiconductor fabrication process. However, serial exposure of pattern elements with a scanning beam is a slow process and throughput has been the key challenge in electron beam lithography from the beginning. To meet this challenge the technology evolution led to imaging concepts with increasing exposure efficiency through ever larger number of pixels projected in parallel (see Fig.1).

Pixels/shot Full Chip Projection ? 10¹¹ 10¹⁰ **EPL** 10⁹ 10⁸ ML₂ 10⁷ PREVAIL EB Stepper REBL 10⁶ PML2 10⁵ Probe MAPPER Shaped Beam **Forming** 10⁴ Character/Cell 10³ Variable Fixed 10^{2} Gaussian Beam 10¹ 10° Single Pixel MASK MAKING 1960 1970 1980 1990 2000 2010

Fig 1: Electron Beam Lithography Evolution

The evolution started in the early 1960s with the SEM-type *Gaussian beam* systems writing one pixel at a time directly on wafers. These single pixel pattern generators became tools for mask making and, until recently, remained the technology of choice since throughput demands are lower than for direct write.

During the 1970s IBM pioneered the concept of **shaped beams** und led the industry in the development and application of high throughput e-beam direct write (EBDW) systems. By the 1980s more than 30 of these EL-3 shaped beam systems had been installed worldwide in IBM's fab-lines producing millions of bipolar logic chips for the company's mainframe computers. EBDW provided unique flexibility in part number management and cycle time reduction and proved extremely cost effective. But shaped beams did not keep pace with Moore's law. A new technology was needed.

By the early 1990s it was recognized that a quantum leap in pixel parallelism was needed and efforts to develop *massively paralle*l pixel projection were started. Electron projection lithography (*EPL*) - a mask based imaging technique emulating optical steppers - was pursued by Bell Labs with SCALPEL and by IBM in partnership with Nikon with the development of an e-beam stepper based on PREVAIL. In 2003 Nikon shipped the first NCR-EB1A e-beam stepper to Selete . It exposed pattern segments containing 10 million pixels in a single shot representing the first successful demonstration of massively parallel pixel projection. However, by then the interest of the industry had shifted back to *maskless* lithography (*ML2*).

Development efforts in the US and Europe are currently pursuing ML2 based on the concept of a 'programmable mask' forming and individually controlling a plurality of parallel electron beams. The following projects have in common the approach of physically separating beam electrons into individual beamlets to reduce stochastic Coulomb interactions and permitting higher beam currents and consequently higher throughput:

- MAPPER
- PML2
- REBL
- MSB

This presentation reviews the e-beam lithography evolution, highlighting the early successes of the technology as well as key limitations. It will provide a status report of the listed projects currently pursued with a discussion of their respective prospects and challenges.

Biography: Dr. Pfeiffer received his Ph.D. from the Technical University of Berlin, Germany in 1967 and joint the IBM Corporation the following year. During his 34 year career with the company he established a world class team and played a leading role in the development of IBM's state-of-the-art e-beam lithography systems. He is recognized for building the industry's first shaped beam lithography system. His work provided the technological base for IBM's five generations of high throughput EL exposure tools. Dr. Pfeiffer invented Character Projection and pioneered PREVAIL, an e-beam projection lithography (EPL) approach. His activities in electron optics, electron beam physics and electron beam lithography are recorded in more than 130 publications and 27 issued patents. He has received numerous IBM awards for his Inventions and for Outstanding Innovation, and was a member of the IBM Academy of Technology. He retired in 2002 as an IBM Fellow – IBM's highest technical honor designated for distinguished technical achievement. Since then he has been and still is consulting in the areas of electron optics for lithography, inspection and test.