Fastwriting Ebeam for defining large arrays of nanoholes

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Fast-writing E-beam for defining large arrays of nano-holes

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Efficient nanoscale patterning of large areas is required for sub-wavelength optics. For example, 200 nm periodic structures are often too small to be made with standard UV- and DUV-equipment. Still, the final product must be made at an economic cost. Here we use a fast-writing strategy described in [1], where electron beam lithography (EBL) with a focused Gaussian beam is used to define shapes directly. The serial technique is optimized for speed and pattern fidelity to a maximum writing speed of around 30 min/cm^2 for 200 nm periods in 2D lattices. The overall costs in terms of machine time and feasibility are assessed for different topographies and dimensions.

Conventionally, EBL uses multiple exposures of slightly overlaying spots, see Fig. 1A. Instead, the fast-writing strategy uses the machine as a raster scan tool to write a large rectangle, using a beam step size larger than the spot size, see Fig. 1B. The JEOL JBX-9500FS is a prototype 100 keV EBL system. The beam is generated by a ZrO/W emitter and electron-beam scanning speeds up to 100 MHz are available. By optimizing the lens focusing system, a stable current of 30.5 nA can be provided with a sufficiently small beam diameter, two orders of magnitude higher than previous reported 0.33 nA [1].

Writing time tests of exposing 5 mm x 5 mm can be seen in Fig. 2 as function of dose. The effective current, that is the inverse slope in Fig. 2, is 28.0 nA, including time for calibration etc. Writing times are below 2 h/cm^2 and even a writing time of around 30 min/cm^2 for 40 μC/cm^2 can be achieved. EBL writing time has four components; shape time, beam time, stage time and calibration time. Shape time is negligible using the fast-writing strategy. Beam time relates to exposing the resist and is given by the TIDA-equation [2]. Stage time is related to moving the stage from site to site and depends on writing field size as seen in Fig. 2. Calibration is critical for focus, see [1], and efficient calibration routines in terms of stability and drift compensation become imperative with this method.

Figure 3 shows filling factor as function of dose based on SEM micrographs similar to Fig. 4 and Fig. 5. Devises were fabricated in silicon by exposure of ZEP-520A resist, development and reactive-ion etching. In Fig. 4 a SEM micrograph of structures with period 200 nm and dose 140 μC/cm^2 is seen. Another example is Fig. 5, showing out-of-focus "donut"-structures in a non-square lattice, illustrating rich possibilities for periodic patterning. An EBL writing time below two hours per cm^2 provides new possibilities where sub-wavelength structures can be used to provide functionality such as anti-reflective or plasmonic effects for large area applications in a cost-effective manner, similar to traditional parallel processing techniques.

[1] Gadegaard, N., et alt (2003). Arrays of nano-dots for cellular engineering. Microelectronic Engineering, 68, 162–168.

[2] Parker, N. W., Brodie, A. D., & McCoy, J. H. (2000). High-throughput NGL electron-beam direct-write lithography system. SPIE, Emerging lithographic technologies IV, 3997, 713–720. doi:10.1117/12.390042

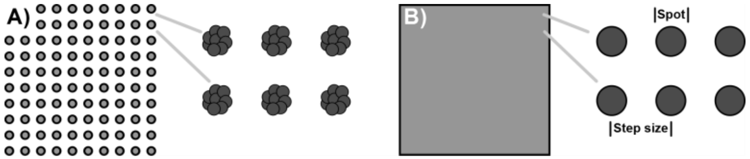

Figure 1: Illustration of the fast-writing exposure strategy. (A) The conventional method for pattern layout is to design an array of circular spots to form the final pattern. (B) Fast-writing patterns are formed directly by a single exposure with a given spot size spaced by the beam step size. Redrawn from [1].

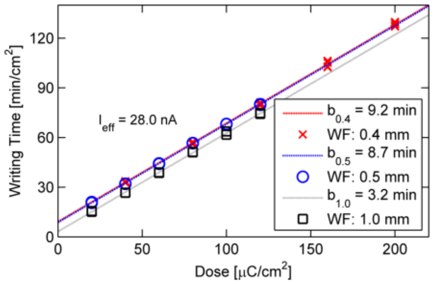

Figure 2: Measured writing time and linear fits as function of dose for different writing field side lengths with array periods in the range 150-250 nm. Y-axis *b* parameter. Exposure includes 5 min cyclic calibration. Initial machine calibration not included.

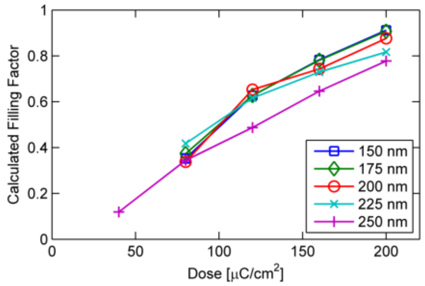

Figure 3: Filling factor as function of dose calculated by image analysis of SEM images similar to Fig. 4 and Fig. 5. Different periods are analyzed.

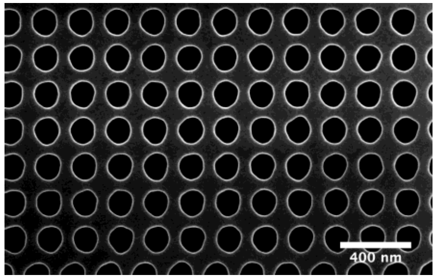

Figure 4: SEM micrograph of typical silicon structures with period 200 nm and dose 140 uC/cm^2.

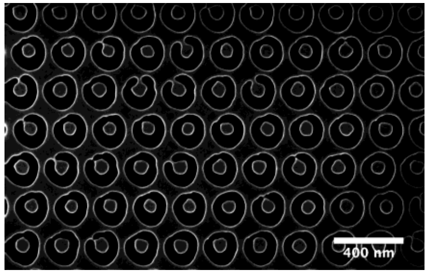

Figure 5: SEM micrograph of silicon structures illustrating non-square lattice and out-of-focus possibilities of structures with period 225 nm and dose 140 uC/cm^2.