Self-Powered Electron Lithography

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Electron beam exposure is the tool of choice for highest resolution lithography, but suffers from the low throughput during serial beam writing. We have designed and developed a low-cost Self-Powered Electron Lithography (SPEL) technique, which utilizes the spontaneously emitted energetic electrons from beta-emitting radioisotope thin-films. This approach enables massively parallel e-beam lithography, with almost no limit on concurrently exposed surface area. This method potentially eliminates the need for vacuum systems and the electron focusing column as needed in existing electron beam lithography systems. This will greatly simplify the overall lithographic system, and reduce cost of deep-sub nanometer lithography[1-2]. In SPEL, emitted electrons are spatially blocked using a nano-stenciled micromachined mask that is placed in proximity to an electron sensitive resist on silicon substrate (Figure 1). The electrons that are not blocked, impact and enter the photoresist, along with secondary electrons generated by primary electrons impacting the sidewalls of the stencil layer.

Using 3D Monte Carlo simulations, we show that the critical dimension in our system could be down to 20nm with 17keV electrons emitted from ^{63}Ni. Our 3D MC simulation considered both elastic scattering and inelastic scattering for the high energetic primary electrons as well as the cascade secondary electrons generated[3]. The 20nm limit is imposed by the secondary emission scattering. In order to prove SPEL concept, experiments were conducted using the safe, and low-activity (10mCi/cm^2) beta particle emitting ^{63}Ni thin film source with electrons emitted at average energy of 17keV. We exposed negative tone resist NEB31A, and a minimum gap between photoresist posts of 100nm was achieved. The secondary electrons generated by the mask are also useful for exposure. The laterally emitted electrons are stopped by mask layer. The mask material should have high stopping power to maximally absorb lateral electrons and also have good conductivity to eliminate the charging effect. Compared with currently used electron beam lithography (EBL) with serial raster scanning taking days to expose a wafer, our lithography system will enable parallel exposure of large patterns on arbitrarily large wafers in several minutes. Along with the modeling and experimental results, we will present a trade study of using different radioisotopes and effect on resolution and throughput.

1. T. Ito, S. Okazaki, *Nature* **406**, 1027 (2000).
2. R. F. Pease, S.Y. Chou, *Proceedings of the IEEE* **96**, 248 (2008).
3. Z. J. Ding, R. Shimizu, *Scanning* **18**, 92 (1996).

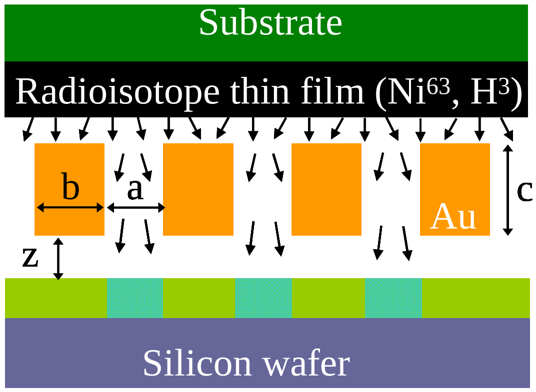

Fig 1: Schematic drawing for Self-powered Electron Lithography setup: *a* is the width of the line holes in nano-stenciled Au mask; *b* is the separation of the line holes; *c* is the thickness of the mask needed to fully block beta particles in non-hole region; *z* is the tunable proximity to contact.

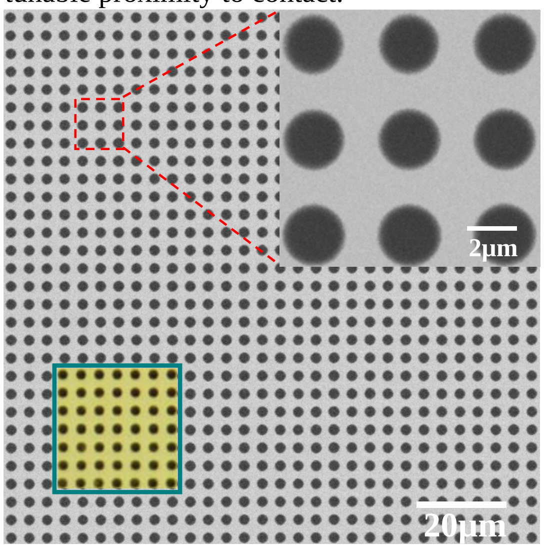

Fig 3: Scanning Electron Microscopy (SEM) image of the resist pattern. Proof-of-concept experimental demonstration for our Self-powered Electron Lithography system, using radioactive ^{63}Ni thin film source ($I=12pA/cm^2$) to expose the nano-stenciled Au mask (circle-hole-shape) that is placed proximity to negative e-beam resist NEB31A(120nm). Left-bottom-inset shows the optical image of the Au membrane mask (500nm in thickness).

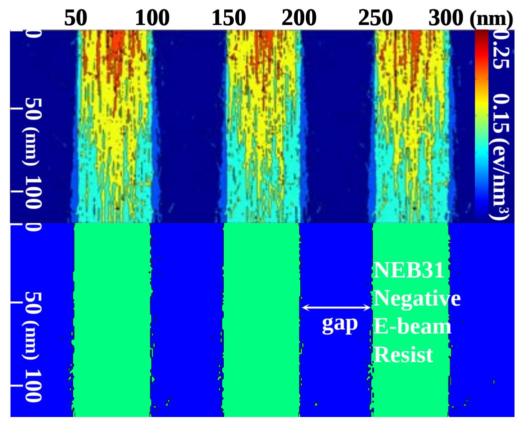

Fig 2: 3D Monte Carlo simulation of exposure and development processes, using ^{63}Ni thin film source to expose negative electron beam resist NEB31A, with Au mask, *a*=*b*=50nm, *c*=400nm, *z*=0nm (contact). 175,000 electrons in 350x150 nm^2 area were used. Top image is for exposure process, showing the cross section contour plot of the energy density absorbed by resist NEB31A; bottom image shows the resist profile using dose-based development model.

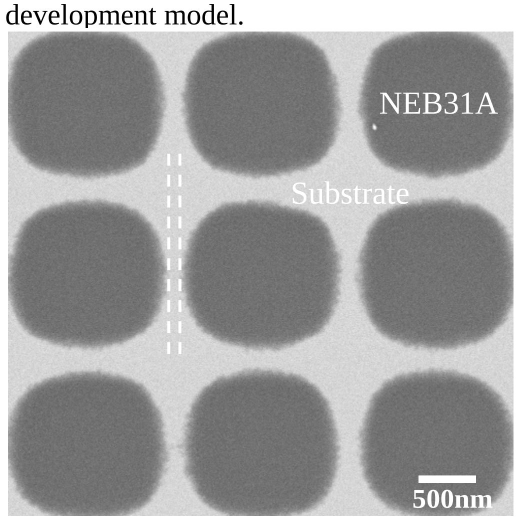

Fig 4: SEM image of NEB31A pattern, with ~100nm gap, using ^{63}Ni thin film source ($I=12pA/cm^2$), with Au-mask (quasi-square-hole-shape).