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A—5—7 Sub-micron Pattern Control Technology for Variable-Shaped EB Lithography

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In the laboratory, a conventional Gaussian round EB system can be used to make features as small as 25 nm in resist pattern with a multilevel resist structure.[1] For the development of advanced LSIs, a variable-shaped EB system is needed because production throughput requirements can be satisfied by using it. However, variable-shaped EB lithography have been applied to 1 μm minimum pattern dimension LSIs, such as the 512 K bit ROM[2] and 256 K bit RAM[3] with a conventional single layer resist structure. This paper, therefore, describes a new viewpoint and novel approaches to the problems encountered in the sub-micron pattern control technology that needs both the variable-shaped EB system and multilayer resist process. These problems are shaped beam stitching error, beam heating and beam defocus as a function of beam size and resist pattern deformation caused by beam stitching error as a function of resist thickness.

The temperature rise in a multilayer target is a function of incident electron dose, beam energy, beam size and the buffer layer thickness. Resist pattern error is the direct proportion of buffer layer thickness and design width L_D. Error in width (L_S-L_D) increases to 1.6 μm for the 10 μm design width and 4 μm thick buffer layer, as shown in Fig. 1. A large part of incident EB energy is converted into thermal energy in the 4 μm-thick and lower-thermal-conductivity buffer layer, but penetrates into the higher-thermal-conductivity silicon substrate for thin buffer layer thickness. For scan line exposure parameters, beam energy, electron dose and PMMA resist film thickness are 20 keV, 0.4 A/cm^2, 2.0×10^{-4} C/cm^2 and 500 nm, respectively.

An attempt was made to calculate the transient temperature rise in heating resist film on glass. A stationary uniform cylinder source is supposed for simplicity. Figure 2 shows the temperture rise as a function of heat supply radius with different exposure time. The exposure time for PMMA corresponds to 500 μsec with 0.4 A/cm^2 beam current density. The temperature rise is more than 200°C, which is not a negligible value.

The beam size dependent problems are resolved to develop new algorithms for judicious partitioning (or subdivision) of lithographic patterns. For examples, if the pattern defined by three rectangular shapes, as shown in Fig. 3(a), is to be written by the variable-shaped EB machine, it can be partitioned into the pattern shown in Fig. 3(b). While the regions with the large rectangles are subdivided into 12.5 μm x 12.5 μm maximum beam shapes, the 0.6 μm line and the boundary of the large rectangles are subdivided into 0.6 μm x 2.0 μm shapes and 4.0 μm x 4.0 μm shapes, respectively. Figure 4 shows the lithographic pattern that results after the present partitioning exposure of 0.5 μm-thick PMMA resist on a 4.0 μm-thick buffer layer coated by thin metal to reduce charge-up effect.

There is a severer restriction in resist thickness for the shaped EB lithography than the conventional fine Gaussian beam lithography. The shaped EB stitching error effect on line morphology indicates that the partially-weak-crosslinked-resist is subject to deformation. This kind of deformation is a buckling mode for a slender resist pattern with large aspect ratio under compression with the adhesion constraint at the resist-substrate interface. Figures 5 and 6 show negative EB resist CMS patterns with 1.8 μm thickness in the single layer resist structure and with 0.4 μm thickness in the multilayer resist structure, respectively. The multilayer resist structure achieves increased quality in the pattern featurs.

In conclusion, an optimizing variable-shaped EB lithography has been made by considering the limitation of beam size, buffer layer thickness, EB resist thickness and EB resist sensitivity.

References
(1) L.D. Jackel et al., Appl. Phys. Lett. vol. 39, p.268, Aug. 1981.
(2) K. Suzuki et al., Proc. Custom Integrated Circuits Conf. late papers p.8, May 1980. (3) T. Mano et al., ISSCC Dig. Tech. Papers, p.234, Feb., 1980.

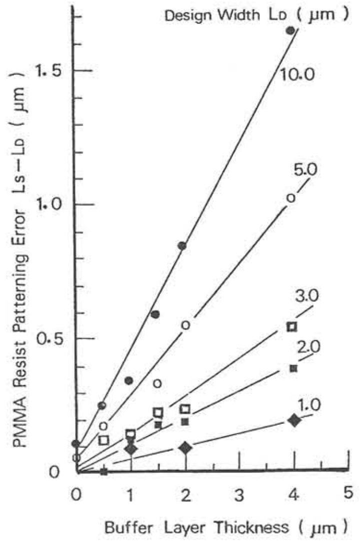

Fig.1 Buffer layer thickness dependence of PMMA resist pattern error in width (L_S-L_D) with different design line width L_D.

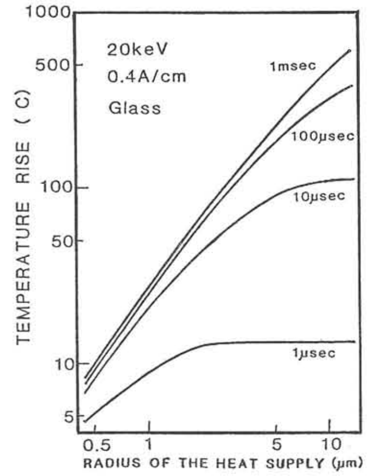

Fig.2 Temperature rise as a function of heat supply radius.

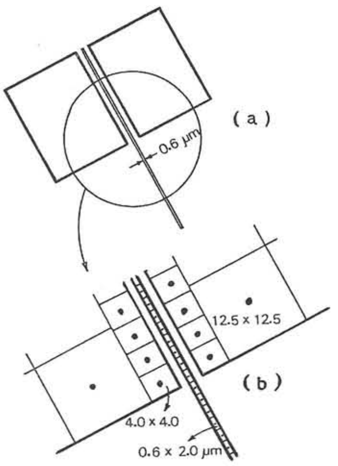

Fig.3 (a) A pattern consisting of three rectangles.
(b) Partitioned pattern that is obtained using the algorithm described in this paper.

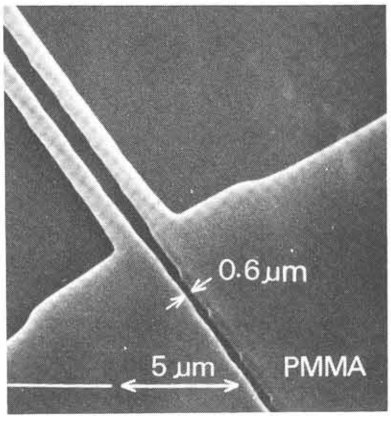

Fig.4 Lithographic pattern that results after the present partitioning exposure.

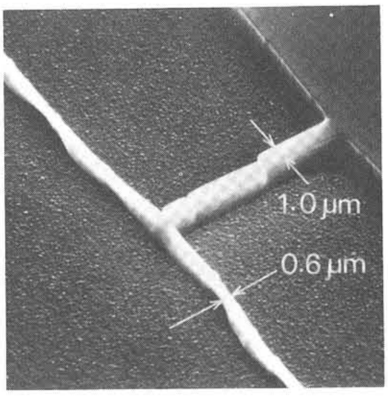

Fig.5 CMS resist pattern in the single layer resist structure.

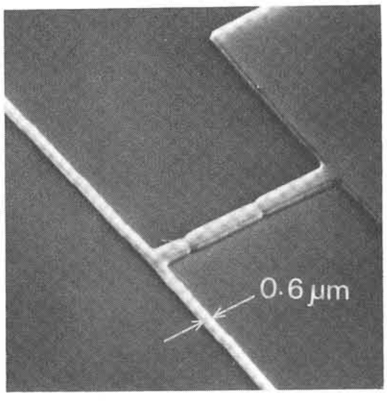

Fig.6 CMS resist pattern in the multilayer resist structure.