New Three Dimensional Simulator for Electron Beam Lithography

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In order to model 3D effects appearing in fabricating ultra high density ICs using an electron beam lithography(EBL), a new 3D integrated simulator 3D-EBLS(3D Electron Beam Lithography Simulator) has been developed. 3D-EBLS can simulate EBL processing from sub-quarter to sub-half micron patterns under various exposure and development conditions and predict accurately proximity effects. A new algorithm for a topography simulation of the development process is presented.

3D-EBLS consists of 5 modules as shown in Fig. 1. The Monte Carlo(MC) module calculates an energy deposition within a resist exposed by an e-beam using MC simulation of electron scatterings including effects of secondary electrons and an exact boundary condition for a resist/substrate interface[1]. In the Proximity Function module, the energy deposition profiles are fitted with 4 Gaussian functions in order to create so-called " proximity functions" along the depth of the resist. Fig. 2 shows a good agreement between MC data and 4 Gaussian proximity functions. As shown in the figure, the energy deposition profile for the top layer of the resist is sharper and has a higher peak value than the result for the bottom layer. Then the proximity functions are convolved numerically with the exposure dose distributions in the Convolution module to calculate the absorbed energy densities within the resist.

A development rate of the resist $R(D)$ can be represented by a following empirical function of the absorbed energy density D

$$R(D) = R_0(B_m + D/D_0)^c. \qquad (1)$$

Here the parameters R_0, B_m, D_0, and c are extracted by fitting of experimental development rates with MC data. Once the development rates are determined from Eq.(1), a time evolution of the development of the resist is simulated in the Development module. Recently, several algorithms for the development process have been introduced, which are mainly new formalism of a ray-tracing method[2] and a modified diffusion equation model[3]. These methods generally solve a system of nonlinear partial differential equation and have been applied to the photolithography. In this paper, a simple modified ray-tracing algorithm based on an analytic formula is introduced. At $t=0$, rays are incident on the top surface of the resist. Then their tracing directions are determined by parameters a and b using simple analytic functions derived from the ray equation, as shown in Fig. 3. Here $R(t)$ is a velocity of the ray at time t, which is the development rate at the position along the trajectory. The ray advences in next dt time interval by an amount of $R(t+dt)\,dt$.

The simulation is performed using a rectangular electron beam exposure with 20keV energy and 1.0um edge width on a 0.55um resist/Si-substrate target and 3 min developing time. Fig. 4 shows the simulation result of a test pattern consisting of 10 primitive bars with 0.1-1.0um width and 2.0um length. The developed pattern has peaks caused by different energy deposition profile of top and bottom layer as shown in Fig. 2. The forms of the primitive bars show the strong proximity effect resulting from neighboring bars. A good agreement is seen between the simulation result and SEM photograph. The simulation result of a gate poly pattern with 0.3um width shows a rounding effect at corners where the primitive bars are contacted, as shown in dotted circle of Fig. 5. This phenomenon can be explained by the proximity effect. Fig. 6 shows the developed patterns of four 0.35um contact holes separated by 0.5um. The proximity effect also can be obserbed for the simulated profile of contact holes which are almost overlapped as shown in Fig. 6. These gate poly and contact hole patterns can be applied to the fabrication of 64M DRAM. 3D-EBLS can be applied to a quarter micron design rule of the 256M DRAM EBL process as well.

References

[1] K.Y. Lee *et al.*, J. Appl. Phys. **67**, pp 7560-7657(1990)
[2] E. Barouch *et al.*, J. Vac. Sci. Technol.**B 7**, pp 1766-1770(1989)
[3] M. Fujinaga *et al.*, IEEE Trans. Electron Devices **ED. 37**, pp 2183-2192(1990)

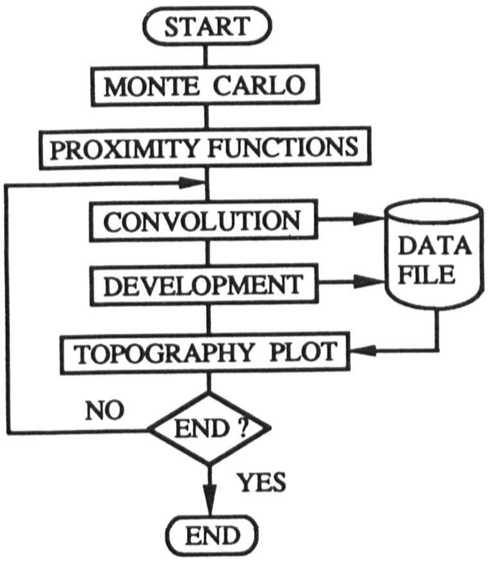


Fig. 1 Flow Diagram of 3D-EBLS.

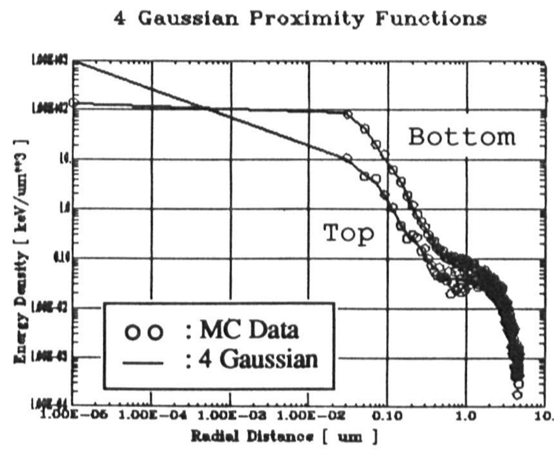
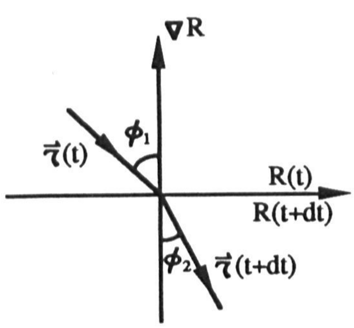


Fig. 2 Four Gaussian proximity functions agree well with MC data.



$$\vec{\tau}(t+dt) = a\,\vec{\tau}(t) + b\,\frac{\nabla R}{|\nabla R|}$$

$$\sin\phi_2 R(t) = \sin\phi_1 R(t+dt)$$

$\vec{\tau}$: unit directional vector

R(t)dt : tracing distance

Fig. 3 Ray Tracing Algorithm.

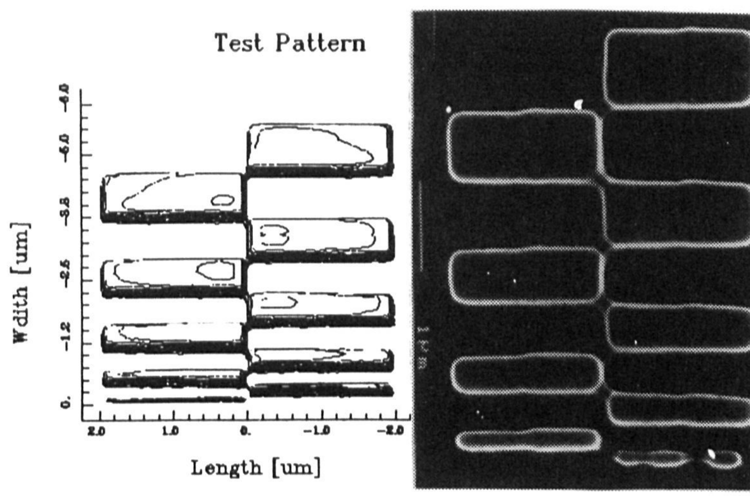


Fig. 4 (a) Simulation results of test pattern.
(b) SEM photograph.

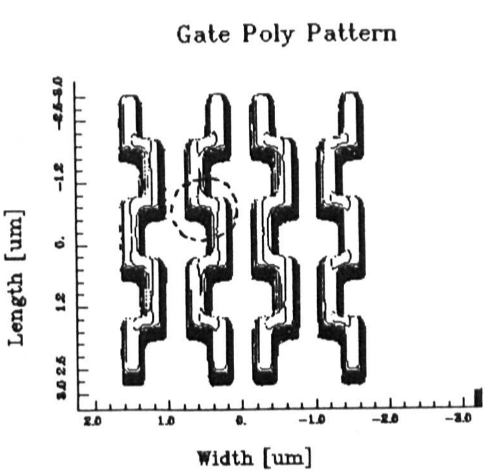


Fig. 5 Simulation result of gate poly of 0.3 um width.

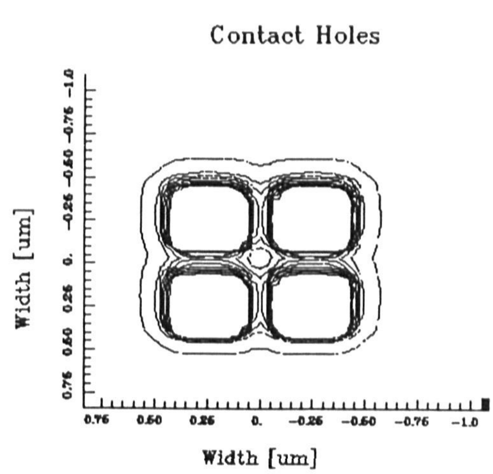


Fig. 6 Simulation result of four 0.35 um contact holes separated by 0.5 um.