Process variation-aware 3-dimensional proximity effect correction for electron beam direct writing at 45 nm node and beyond

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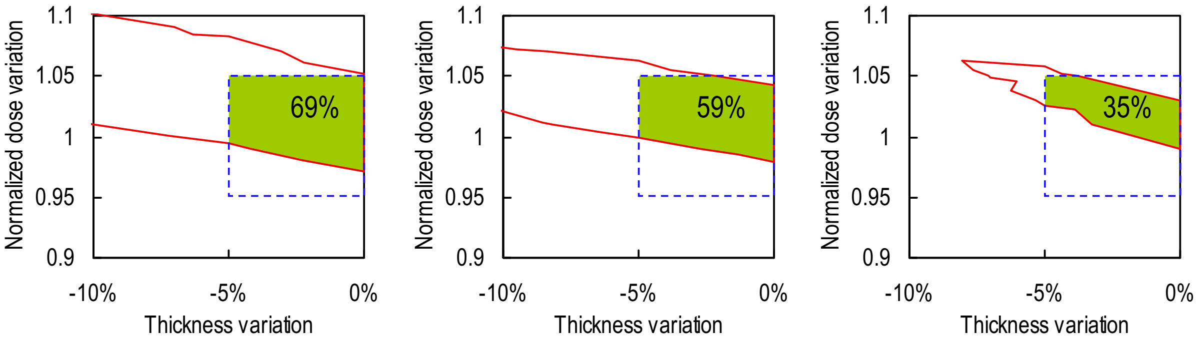
The printability and process window of the finer lithographic patterns for electron beam direct writing (EBDW) toward 45 nm and below are reduced due to process variations and difficulties in the correction of proximity effects caused by the multilayer structure that includes heavy-metal materials. A proximity effect correction (PEC) method based on the simplified electron energy flux (SEEF) model has been proposed [1]. Copper interconnect, however, introduces thickness variation problem caused by Chemical Mechanical Polishing (CMP) during planarization. This problem depends on pattern variation and may lead to the critical dimension (CD) variation. Moreover, CD variations caused by process variations, such as dose and thickness variations, will affect the final product yield.

We evaluated the dependence of CD variations on the dose and thickness variations using the Monte Carlo (MC) simulation. We assumed that the multilayer structure is composed of a dielectric layer to be fabricated, five pairs of wiring layer and via interlayer dielectric, and the silicon substrate. An acceleration voltage is 50 kV and an acid diffusion range is 40 nm. Figure 1 shows the coverage for a process window with dose variation in range from –5% to 5% and thickness variation of five wiring layers in range from –5% to 0% when lines-and-spaces (L/S) patterns with linewidth in range from 70 nm to 130 nm and density in range from 0% to 50% are delineated. Two criteria are assumed: (1) Linewidth deviation is within range from –5% to 5% and (2) difference of linewidth between patterns on various densities is less than 5%. As shown in Fig. 1, allowable pairs of dose and thickness variations exist on a band, which becomes narrower and shorter as technology progresses. The coverage for the process window was 69% at 90 nm node, 59% at 65 nm node, and 35% at 45 nm node, respectively. Therefore, a process variation-aware PEC for multilayer structure is in great demand for EBDW at 45 nm node.

We propose a variation-aware PEC method, which is enhanced the correction concept of the PEC in which the pattern shape modification for the forward scattering and the dose correction for the backscattering are separately applied [2]. The proposed main concept is that the differences of CDs on the process variations are minimized and equalized for all patterns. Figure 2 shows a schematic diagram of the correction concept of our PEC method. Firstly, patterns in the layout are categorized according to their feature sizes. Secondly, a representative pattern is selected from each group and its shape is modified so that the CD variations are minimized for the process variations. By this step, the maximum variation of CDs caused by the process variations is eliminated. Thirdly, other pattern shapes are modified so that the CD variations are approximately equal to those of the representative pattern to reduce the CD variations between sparse pattern and dense pattern. Finally, a correction dose for each pattern is calculated according to the backscattering energy that is calculated by the SEEF model.

Figure 3 shows the relationship between the dose normalized by the correction dose and the simulated linewidths for L/S patterns with linewidth of 70 nm and density in range from 0% to 50% when the PEC in which the dose variation is taken into account is applied. It is found that the same curves for all densities are achieved and the difference of linewidth between patterns on various densities is reduced to approximately 0 for the dose variations. Figure 4 shows the effect of the proposed PEC method for the dose and thickness variations using MC simulations. The same substrate structures used in Fig.1 were used and L/S patterns with linewidth of 100 nm and 70 nm and density in range from 0% to 50% were delineated after the correction shown in Fig. 3 is applied. The coverage for the process window was improved from 59% (Fig. 1 (b)) to 81% at 65 nm node and from 35% (Fig. 1 (c)) to 45% at 45 nm node. The effectiveness of our proposed PEC was confirmed. In this paper, the coverage for the process window, allowable condition of process variations, and variation-aware PEC at 45 nm node are discussed in detail.

[1] K. Ogino *et al*., Jpn. J. Appl. Phys. **43**, 3762 (2004)
[2] K. Takahashi *et al*., J. Vac. Sci. Technol **B18**, 3150 (2000)



(a) 90 nm node (130 nm L/S) (b) 65 nm node (100 nm L/S) (c) 45 nm node (70 nm L/S)

Figure 1. Allowable condition of dose and thickness variations to satisfy two criteria : (1)Linewidth deviation is within range from –5% to 5% and (2) difference of linewidth between patterns on various densities is less than 5%. 8-µm-square L/S patterns with density in range from 0% to 50% and linewidth of (a) 130 nm at 90 nm node, (b) 100 nm at 65 nm node and (c) 70 nm at 45 nm node are delineated on the multilayer structure which is composed of a 500-nm-thick dielectric layer to be fabricated, five pairs of 250-nm-thick wiring layer and a 250-nm-thick via-ILD, and the Si substrate. Dashed box indicates a required process window.

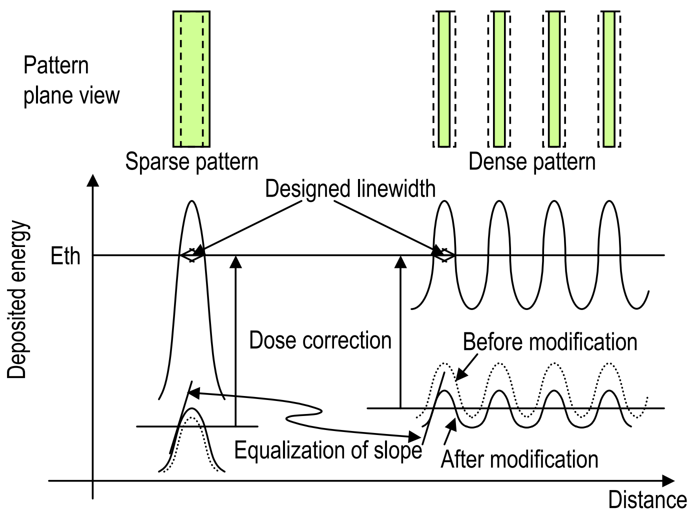


Figure 2. Schematic diagram of the correction concept.

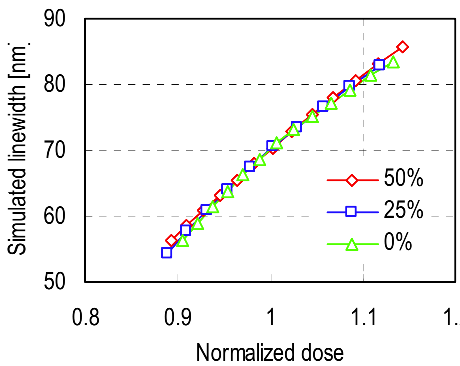
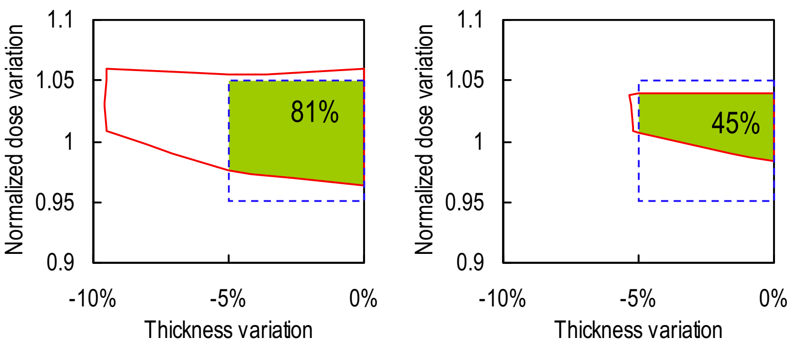


Figure 3. Relationship between the dose and the simulated linewidths for L/S patterns with linewidth of 70 nm and density in range from 0% to 50% after the correction. The dose is normalized by the correction dose. The modified linewidths for 50% L/S, 25% L/S and isolated line were 30 nm, 70 nm and 100 nm, respectively.



(a) 65 nm node (100 nm L/S) (b) 45 nm node (70 nm L/S)

Figure 4. Process window coverage for the 8-µm-square L/S patterns with linewidth of (a) 100 nm at 65 nm node and (b) 70 nm at 40 nm node and density in range from 0% to 50% after the correction shown in Fig. 3 is applied. The same substrate structures used in Fig. 1 were used.