A Solution to Reduce the Effect of Edge-placement Errors by Selective Etching and Alternating-material Self-aligned Multiple Patterning

Part 1. Edge-placement Yield Modeling and Optimization

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Complementary lithography is widely considered as a promising solution for continuous IC scaling down to 5-nm half pitch (HP). A satisfactory edge-placement-error (EPE) performance of the cut-hole patterning process is critical for its future success [1], regardless of what lithography technology will be adopted. In particular, the overlay errors and cut-hole critical dimension (CD) variations are the main contributing factors of the EPE budget in a self-aligned multiple patterning (SAMP) process.

In this paper, we propose a method to reduce the EPE effect by combining a novel alternating-material self-aligned multiple patterning (altSAMP) and selective etching processes. Unlike the conventional SAMP processes [2-4], the line arrays will be fabricated with an altSAMP technique using two different materials which allow highly selective etching processes to remove one material without attacking the other. As illustrated in Figure 1, a line array arranged in an alternating order A-B-A-B-... can be fabricated by an alternating-material self-aligned quadruple (altSAQP) or octuple (altSOAP) patterning process, while a line array arranged in a quasi-alternating order A-B-A-B-A-B-... can be fabricated by a self-aligned sextuple (SASAP) or triple (SATP) patterning process [2]. Ideally, the etching process to cut A-type (or B-type) targeted lines will not attack the exposed B-type (or A-type) non-targeted lines (made of a different material) even in the presence of severe EPE. Nevertheless, as shown in Figures 2 and 3, the actual material loss of B-type (or A-type) non-targeted lines depends on the etching selectivity (with respect to the targeted lines) and miscut amounts. To reduce the EPE effect, we decompose the holes over the lines made of material A into one mask and the holes over the lines made of material B into the other mask, as illustrated in Figure 4. Since the targeted-line density on each decomposed mask is half of the original array, each separate cut-hole patterning process can tolerate more edge-placement errors. To accurately estimate and optimize the related patterning yield, it is necessary to develop a physical model to quantify the corresponding cut-process yield loss. For this purpose, we reasonably assume the probability of a cut failure (POF) is a linear function of the material loss of non-targeted lines determined by the ratio of the etched area (e.g., $ht$) to the total cross-sectional area (e.g., $HT$) of a line (see Figure 2).

Figure 3 schematically shows that both the overlay errors and cut-hole CD variations affect the edge-placement accuracy. We assume the probability density functions of overlay errors and cut-hole CD variations obey the 1-D Gaussian distribution. Yield loss can be calculated as:

$$ L = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} POF(x, y) \cdot \frac{1}{2\pi\sigma_1\sigma_2} \exp \left(\frac{1}{2} \left( \frac{x^2}{\sigma_1^2} + \frac{y^2}{\sigma_2^2} \right) \right) dx dy $$

The cut yield is simply: $Y = 1 - L$. Here, $x$ and $y$ are the sample values of overlay error and cut-hole CD variation, respectively. $\mu$, $\sigma_1$, and $\sigma_2$ are the mean value and standard deviations of the related error distributions. POF($x, y$) is the probability of a cut failure as a function $x$ and $y$ [5]. Figure 5 shows the yield performance when cutting A-B and A-B-B types of line arrays for four different HPs, and a comparison with the yield performance when cutting line arrays made of one single material. Apparently, the proposed method significantly improves the process yield, especially when half pitch reaches sub-7nm. We shall discuss more details of the parametric optimization to improve yield performance in our manuscript.