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Microelectronic Engineering 84 (2007) 1033–1036

MICROELECTRONIC ENGINEERING

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CD control of direct versus complementary exposure for shaped beam writers and its correlation to the local registration error

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Available online 2 February 2007

Abstract

When using electron beam direct write for patterning, resist selection (positive or negative) plays an important role. This is because writing time for shaped beam machines is proportional to the mean density of exposed shapes. There is an optimum with respect to writing time when using either the direct exposure or the complementary exposure with reversed resist tonality. Switching from positive to negative resist or vice versa has an impact on writing time. In this paper, we derive the fundamental differences on CD accuracy when using direct or complementary exposure, which is given by the local registration error. Additionally, a simple method is developed to measure this local registration error by simple CD SEM measurement of 1:1 line/space patterns.

Keywords: e-Beam direct write; Direct exposure; Complementary exposure; Resist; Registration error; CD; Variable shaped beam

1. Introduction

Electron beam (e-beam) lithography is known for its high resolution, but suffers from very low throughput. For shaped beam writers, the writing time depends on the data to be written [1,2], but the main contribution comes from the number of shapes to be written and the coverage of the layout. This is valid for mask writing as well as for e-beam direct write on the wafer (EBDW).

For EBDW, this is the reason why usually the gate level (or other wiring levels patterned by etching) is written into negative resist by exposing the gate area (direct exposure).

On the contrary, the same resist mask for the gate can be obtained by exposing the non-gate area into positive resist (image reversal of data and complementary exposure, see Fig. 1).

When resist sensitivities for positive and negative resist are similar, it is typically preferable to select negative resist for the gate exposure.

It is possible to compare the writing time for the direct versus the complementary exposure when a simulator for the complete writing process is available and, of course, if this simulation takes care of the sensitivities of the positive and the negative resist. By this, one can decide quite definitely whether it is preferable to use the direct or the complementary exposure.

However, if one takes into account the stability of the resist process, or the resolution of the resist, or its line edge roughness, the decision whether to use direct or complementary exposure is much more complex [3]. How to compare the individual advantages to the drawbacks? Are there other criteria than writing time and process stability? What are the ultimate criteria?

In this work the parameter "CD accuracy" has been considered, when comparing direct versus complementary exposure.

It turns out that the CD accuracy is different for direct and complementary exposure for shaped beam writers, and this difference is related to the local registration error of the shaped beam writer.

2. Direct versus complementary exposure

As shown in Fig. 2, the imaging process with a shaped beam writer for a line structure (controlled afterwards by

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0167-9317/$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.mee.2007.01.141

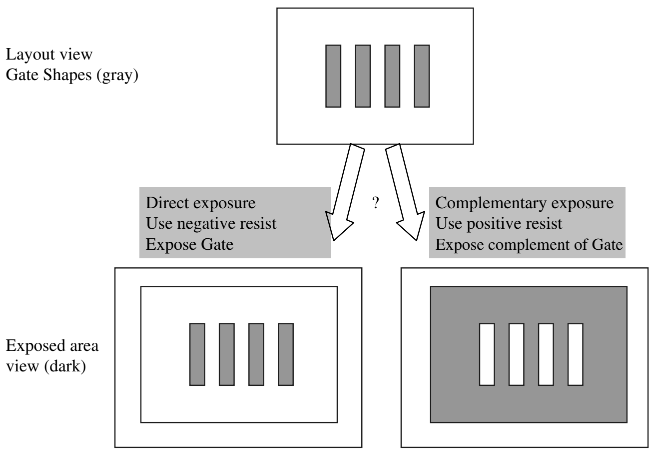

Fig. 1. Layout view and possible exposures: direct exposure (left) and complementary exposure (right).

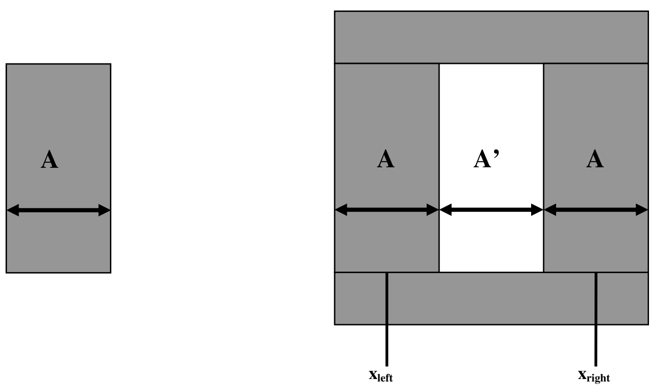

Fig. 2. Layout view and possible exposure modes: direct exposure (left) and complementary exposure (right). Dark regions correspond to exposed area.

CD measurement) is different for direct and complementary exposure. Let us think of this line as a gate, the CD determining the channel length.

For the direct exposure, where the image of a gate is formed with one shot, the accuracy of the imaging of the shaping aperture determines the resulting CD of A.

For the complementary exposure, the image A' is formed with at least two shots. The registration accuracy of the direct writer (accuracy of the deflection unit) becomes important in this case. According to Fig. 2, we can derive the following formula:

$$A' = (X_{\text{right}} - A/2) - (X_{\text{left}} - A/2) = (X_{\text{right}} - X_{\text{left}}) - A, \tag{1}$$

where A' is the resist image (CD) with complementary exposure and A is the image (CD) with direct exposure. After averaging multiple exposures and multiple measurements, the mean of CD is

$$\langle A' \rangle = \langle X_{\text{right}} - X_{\text{left}} \rangle - \langle A \rangle$$

and therefore

$$\langle X_{\text{right}} - X_{\text{left}} \rangle = 2\langle A \rangle, \tag{2}$$

when the writer is perfectly calibrated. Then,

$$\langle A' \rangle = \langle A \rangle. \tag{3}$$

This means there should be no difference between the CDs of direct and complementary exposure. However, the RMS deviations of A and A' with $s_x = \text{sqrt}(\langle(x - \langle x \rangle)2\rangle)$ give (assuming that deflection/registration control and the aperture imaging control are independent):

$$s_{A'}^2 = s_A^2 + 2 * s_x^2, \tag{4}$$

where s_x is the RMS deviation of the local deflection/registration and $s_{A'}$ is the RMS deviation of A'. The CD control for complementary exposure measured by $s_{A'}$ is worse than that of the direct exposure, s_A. Even considering the best calibration according to Eq. (2), there will be the difference as written in Eq. (4) since s_x cannot be zero. The factor of two of the registration error term in Eq. (4) is the consequence of the image formation process in the complementary exposure by two shots. It is important to note that Eq. (4) is valid even if $\langle A \rangle$ is not equal to $\langle X_{\text{right}} - X_{\text{left}} \rangle/2$ in Eq. (3), which means an imperfect calibration of the writer according to aperture imaging or using a wrong exposure dose. Now knowing the fundamental difference of direct versus complementary exposure, it is important to know the value for s_x for the writer used and for the different exposure conditions, i.e. stage speed (when using the write on the fly mode), and for the different orientations of the CD, since the registration/deflection may be different for horizontal and vertical directions or even for the 45° directions. This can be done using a tool dedicated for registration measurement. We propose and use a different approach by printing a 1:1 dense line/space pattern in resist and using simple CD measurement.

3. Determination of the local registration error

According to Eq. (4), the local registration error can be determined by measuring simultaneously the RMS error of the direct and the complementary exposure

$$s_x = \sqrt{(s_{A'}^2 - s_A^2)/2}. \tag{5}$$

The easiest way to do this is to print a simple 1:1 dense pattern and measure both the CD of the lines and the spaces, since they represent the direct and the complementary exposure in close neighbourhood, with very identical conditions of beam current, local resist thickness, sensitivity and so on.

Depending on the resist in use, the definition of direct and complementary exposure is different for positive and negative resists. Direct exposure can be done in one shot, that is a line with negative resist and a space with positive resist, see Table 1 and Fig. 3.

It is very important to note that the CD SEM may influence the RMS determination of s_A as well as $s_{A'}$. However, when doing the subtraction according to Eq. (5), the contribution of CD SEM on s_x determination will vanish. One