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A New Method to Retrieve Proximity Effect Parameters in Electron-Beam Lithography *

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Abstract: A new method for determining proximity parameters α, β, and η in electron-beam lithography is introduced on the assumption that the point exposure spread function is composed of two Gaussians. A single line is used as test pattern to determine proximity effect parameters and the normalization approach is adopted in experimental data transaction in order to eliminate the need of measuring exposure clearing dose of the resist. Furthermore, the parameters acquired by this method are successfully used for proximity effect correction in electron-beam lithography on the same experimental conditions.

Key words: electron-beam lithography; proximity effect; electron-beam proximity correction

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1 Introduction

Electron-beam lithography has been widely used in advanced nano-device fabrication and research for its high resolution. However, the most serious problem that prevents electron-beam lithography acquiring higher resolution is proximity effect, which caused by the electron scattering in the resist film and the substrate. The resolution of electron-beam lithography can be further improved by means of proximity effect correction.

For precise correction of the proximity effect it is critical to determine the proximity parameters of the deposited energy distribution very accurately. One possible approach is to estimate the parameters with Monte Carlo simulation. But this method needs commercial softwares, which are all expensive. In addition, the proximity parameters are functions not only of resist and substrate compositions, resist film thickness, and incident electron energy, but also of developing conditions. So, empirically determined parameters are useful. More important, it is easy to achieve these parameters for a given process conditions by this method[1,2].

The point exposure spread function is usually assumed to follow a double Gaussian, as proposed by Chang[3],

$$f(r) = \frac{1}{\pi(1+\eta)}\left[\frac{1}{\alpha^2}e^{-(r/\alpha)^2} + \frac{\eta}{\beta^2}e^{-(r/\beta)^2}\right] \quad (1)$$

The first Gaussian, the α term, is intended to account for the forward scattering and the finite beam distribution, and the second, β term, describes the Gaussian distribution of the backscattered exposure. The term η is then the ratio of energy of the backscattered exposure to exposure due to the forward scattering. This model has been extensively used, and many different experiment methods

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have been proposed to determine α, β, and η[4~7]. However, these methods need either complex test patterns or complicated data transaction.

The purpose of this paper is to present a fast turnaround technique for obtaining proximity parameters with good precision. The single-line test pattern is used to determine the proximity effect parameters α, β, and η. In addition, this method need not measure the threshold clearing dose D_0 of the resist that is used in experiment previously.

2 Method description

For an incident charge dose distribution $D(r)$ a deposited energy distribution in the resist is obtained by convolving it with the point exposure spread function $f(r)$,

$$E(r) = k\int D(r')f(r-r')\,\mathrm{d}^2 r'$$

The charge to energy conversion factor k can be considered as a constant for any particular beam energy and resist material. For a point exposure with a charge Q_i,

$$D_i(r) = Q_i\delta(r),$$

We obtain $E_i(r) = kQ_i f(r)$.

For a large area exposure $D(r) = D_0$, we obtain $E(r) = kD_0$.

Many identical line exposures of a thin layer of high contrast resist are performed with an identical beam but different amounts of charge Q_i. On development, the resist dissolves to radius r_i, where $E_i(r_i)$ is equal to the energy E_0 dissipated at the threshold clearing dose of the resist, D_0, in μC/cm^2. The normalized exposure response at radius r_i is

$$f(r_i) = D_0/Q_i \qquad (2)$$

We use a single line as the test pattern, whose width and length are 25nm and 25μm respectively. In order to reduce the error due to both measuring tools and observers, every pattern contains four identical lines which should be measured individually and the final value is the mean of four measuring values. The pattern is exposed at different exposure dose D_i respectively. After exposure and development, scanning electron microscopy (SEM) is used to measure the width of the lines W_i and the half of the measuring value is r_i. So we can attain a set of data $\{r_1, r_2, \cdots, r_n\}$ corresponding to the other set of data $\{D_1, D_2, \cdots, D_n\}$. In this experiment, 550nm thick SAL601 resist is coated on Si substrate. Exposures for this work are carried out in the high resolution vector scan system JEOL 5000LS at 50kV accelerating voltage. Figure 1 shows the test patterns after exposure and development. Figure 2 shows the crude experiment data. According to Eq. (2), these two sets of data can be used to acquire the expression of $f(r)$ through curve fitting.

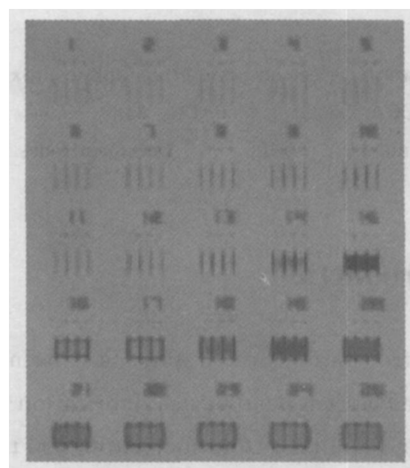

Fig. 1 Optical microscope photo of the line test pattern after exposure and development The exposure dose increases form left to right and from top to bottom.

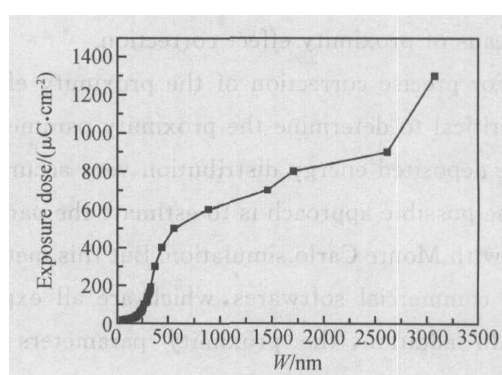

Fig. 2 Crude data of experiment

3 Determination of α, β, and η

The crude data can not be directly used for curve fitting. According to Eq. (2), we need to measure D_0 firstly. Although D_0 can be measured by exposing large areas of resist, it is time-consuming work. For a high contrast resist the exposure clearing dose D_0 can be considered a constant for a certain condition and special process. Therefore we can normalize the experiment data in order to avoid measuring D_0. Figure 3 illustrates the process flow of experimental data.

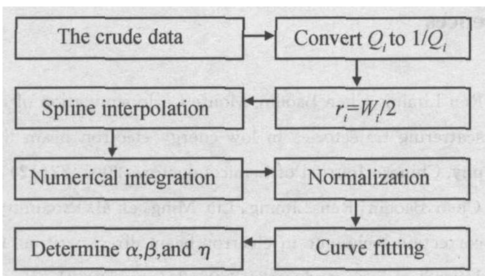

Fig. 3 Processing flow of the experimental data

After the experimental data are normalized, the value of α, β, and η can be determined simultaneously through fitting the curve by means of least-square curve fitting method. Usually there are several sets of values that can fit the curve, but only one set of value that is correct and the others can be excluded by general knowledge about the electron scattering, that is α is smaller than β[8]. Figure 4 shows the data after processing and the curve fitting. In this experiment, α, β, and η is 0.10092, 1.24034, and 4.70317, respectively.

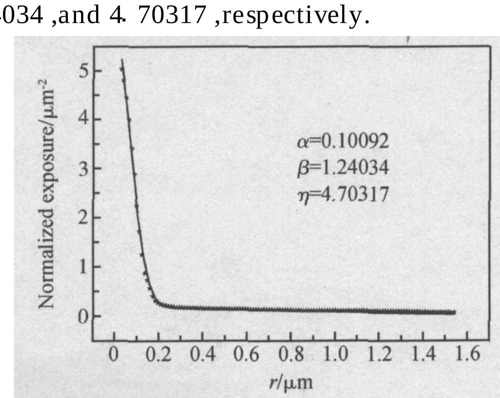

Fig. 4 Data after process and the proximity parameters α, β, and η are determined by curve fitting

4 Proximity effect correction experiment

The proximity effect correction can be performed after the parameters α, β, and η are determined. In this paper, CAPROX, software of Sigma-c Inc, is used to perform proximity effect correction. It uses double Gaussian model to perform proximity effect correction and therefore needs input the values of α, β, and η as Fig. 5 illustrates. Using the parameters determined in Sec. 3, we can perform proximity effect correction on the same experimental conditions. As Fig. 6(a) shows, the wider patterns are well developed while thin lines can not be printed due to the proximity effect. After correction, thin lines are developed as well as wider patterns as Fig. 6(b) illustrates. The width of the thinnest line is about 70nm.

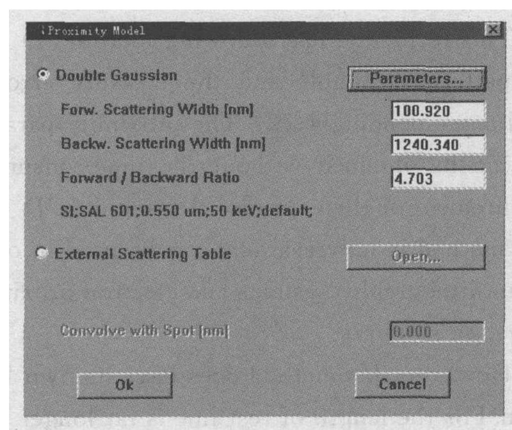

Fig. 5 Dialog box of CAPROX, which needs input the value of the proximity effect parameters α, β, and η

5 Conclusion

An efficient empirical method to obtain proximity parameters has been proposed. This is realized by a simple single-line pattern and the method of data transition. We have studied this method for a negative resist named SAL 601 on Si substrate. Based on the parameters obtained, the proximity correction for test patterns is made with correction software CAPROX.

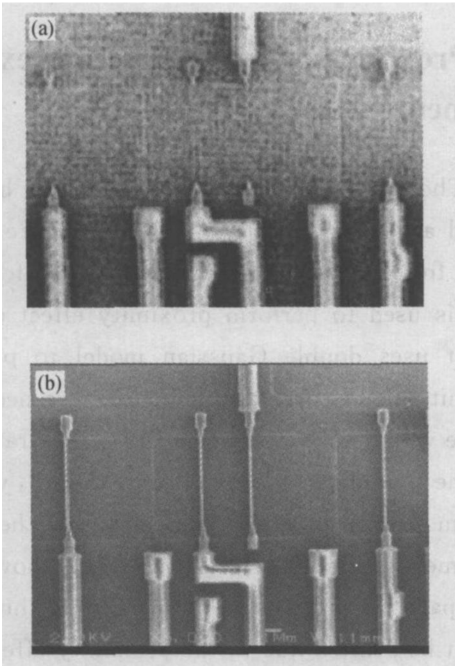

Fig. 6 SEM photos of the pattern before versus after proximity correction (a) Before correction; (b) After correction

This technique has following merits: (1) The test pattern is simple and the measure error is small correspondingly; (2) The proximity parameters can be obtained without the time-consuming measurement of the exposure clearing dose D_0; (3) This method is universal and can be used in other e-beam lithography systems and electron proximity correction software.

However, this method does have its own limitation. For the length of test line is far longer than its width, so we assume that the energy deposition is constant, which is correct for line patterns but not true for arbitrary shape patterns. In despite of its limitation, this method has great value in electron beam lithography because line pattern is an important kind of pattern in nano-fabrication. In addition, we look forward to solving this problem by either changing the test pattern or the data transaction method as early as possible.

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一种提取电子束光刻中电子散射参数的新方法*

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摘要：在电子散射能量沉积为双高斯分布的前提下，提出了一种提取电子束光刻中电子散射参数 α,β和 η的新方法. 该方法使用单线条作为测试图形. 为了避免测定光刻胶的显影阈值，在实验数据处理中使用归一化方法. 此外，用此方法提取的电子散射参数被成功地用于相同实验条件下的电子束临近效应校正.

关键词：电子束光刻；临近效应；电子束临近效应校正

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