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Optimization of EID Function for Proximity Effect in Electron Beam Lithography

(전자-빔 Lithography 근접효과에 대한 노출강도 분포의 최적화법)

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要 約

전자빔 노광에서 근접효과를 보상하는데 필요한 EID 함수를 간단히 구하는 방법을 제시하였다. 최적화 기법을 사용하여 EID함수의 파라메타를 구하였고 그 결과는 실험치와 잘 일치하였다.

Abstract

A simple method to derive EID function which is necessary to compensate for the proximity effect in electron-beam lithography is presented. Using optimization techniques, parameters of EID function is derived and well agreed with experimental value.

I. Introduction

The proximity effect appears to be a fundamental problem in electron-beam lithography, especially in micron or submicron patterning. This is, the contour of the patterns exposed with the electron beam has a swelling-out tendency due to the effect of the electron back-scattered inside the wafer material.

This phenomenon causes deterioration in resolvability of fine patterns, especially when they are closely located. This is called the proximity effect.[1] It is classified into two categories: interproximity effect (or the interconnection of adjacent patterns) and intraproximity effect (or the rounding of patterns).

To achieve accurate pattern contour, it is therefore necessary to apply some method of exposure adjustment to compensate for the proximity effect.[2] One correction method is the method to control exposure intensity of the patterns and the other is to modify the shape of pattern contour. In general, the first is widely used and Exposure Intensity Distribution·[EID] function plays a important role in this theory.

So that, this paper deals with the determination of the EID function experimentally and simple method of calculating exposure intensity.

II. Simple Calculation of Exposure Intensity

When an electron beam is incident at a point

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Q on the surface of wafer, an intensity distribution decreases with increase of radial distance as shown symbolically in Fig. 1.

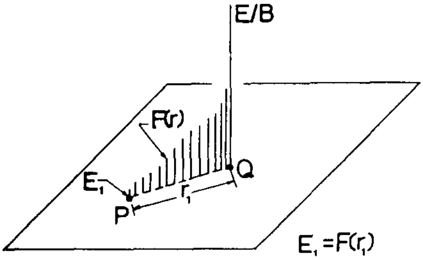

Fig. 1. Exposure E_1 received at point P due to beam incident at point Q.

The exposure intensity E received at a point P, radial distance r_1 away from point Q, is given by

$$E_1 = F(r_1)$$

where F(r) is the function describing the exposure intensity distribution.

Similarly, in the case where the electron-beam exposure is uniformly distributed over a given area A as shown in Fig. 2.

The most straight forward way to obtain the exposure received at an arbitrary point x is to integrate the exposure intensity distribution (EID) function.[1]

The amount of exposure intensity received at point x is expressed by

$$E(x) = \iint I(y)\Theta(y)F(\|x-y\|)d^2y \qquad (1)$$

where
F: EID function for unit exposure intensity
I(y): exposure intensity at pointy
$\Theta(y) = \begin{cases} 1, y \in A \\ 0, y \notin A \end{cases}$
A: exposed pattern

and $\|\quad\|$ denotes norm.

If value E(x) exceeds a given threshold value, point x will be etched. Thus if one can control I(y), it is possible to control whether point x is etched or not, and eventually to correct the proximity effect.

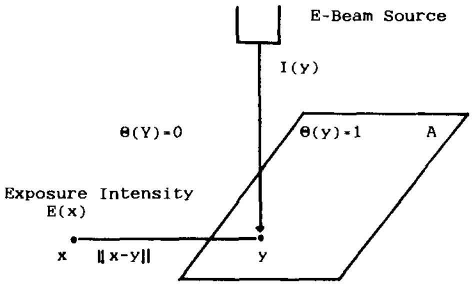

Fig. 2. Relation of between E-beam exposure position and exposure intensity.

III. EID Function

The radial exposure intensity distribution introduced by a point source of electron can be evaluated either analytically or experimentally. The analytical techniques applicable to this evaluation include the Monte Carlo technique[3,4] and other analytical models.[5]

But, analytical methods are complicated and since, in general, EID function depends on the experimental parameters such as beam voltage, film material, film thickness, substrate material, electron dose, PMMA (polymethyl methacrylate) thickness, electron gun and developing time, experimental technique is widely used.

EID can be closely approximated by the sum of two Gaussian distributions.

i) Gaussian distribution of incident primary beam; $C_1 \exp[-(r/\sigma_1)^2]$

ii) Gaussian distribution of backscattered electron; $C_2 \exp[-(r/\sigma_2)^2]$]

So, assume that the EID function is of the form

$$F(r)= C_1 \exp[-(r/\sigma_1)^2]+C_2 \exp[-(r/\sigma_2)^2 \qquad (2)$$

Here, C_1, C_2, σ_1, σ_2 treat as parameters which have some range in experimental. But, strictly speaking, since they are changed by various conditions, it is necessary to accurate this parameters.

Especially, EID curve is a fundamental element of exposure intensity and the accuracy of EID curve plays an important role in compensating for proximity effect. So, accurate parameters (C_1, C_2, σ_1, σ_2), relatively, are derived in this paper by using the optimization techniques based on the real experimental value.

IV. Optimization for EID Function

1. Least Square Fitting of EID Function

In determination of EID function accurately and simply, least square error approximation based on the real experimental value is used.

$$G(C_1,C_2,\sigma_1,\sigma_2)=\sum_{i=1}^{N} W_i\,(F(r_i)-f_i)^2 \qquad (3)$$

where N is the number of observations, f_i is the observed intensity at point r_i ($i=1,2,3,\ldots\ldots, N$), W_i is the given weight at point r_i and $F(r_i)$ is given by formula (2). Minimizing for (3), Davidon-Fletcher Powell method[6] and Rosenbrock method[7] are adopted as minimizing algorithm.

2. Minimization Algorithm for EID Function

a) Davidon-Fletcher Powell Algorithm

The iterative procedure of this method can be stated as follows;

Step 1; Start with an initial point X_1 and a n x n positive definite systemtric matrix H. Usually H is taken as the identity matrix I. Set iteration number as i=0.

Step 2; Compute the gradient of the function, $g(x_i)$, at the point x_i and set

$$S_i = -H_i \cdot g(x_i) \qquad (4)$$

Step 3; Find the optimal step length λ_i^* in the direction S_i and set

$$X_{i+1}=X_i + \lambda_i^* S_i \qquad (5)$$

Step 4; Test the new point X_{i+1} for optimality. If X_{i+1} is optimal, terminate the iterative process. Otherwise, update the H_{i+1} matrix

Step 5; Set the new iteration number i= i+1, and go to step 2.

The flow-chart illustrating the above procedure is given in Fig. 3.

b) Rosenbrock Algorithm

This method of rotating coordinates is based on direct search method given by H.H. Rosenbrock. This case does not require gradient of function such as Davidon Fletcher Powell method.

The method of rotating coordinates proceeds to minimize function as follows.

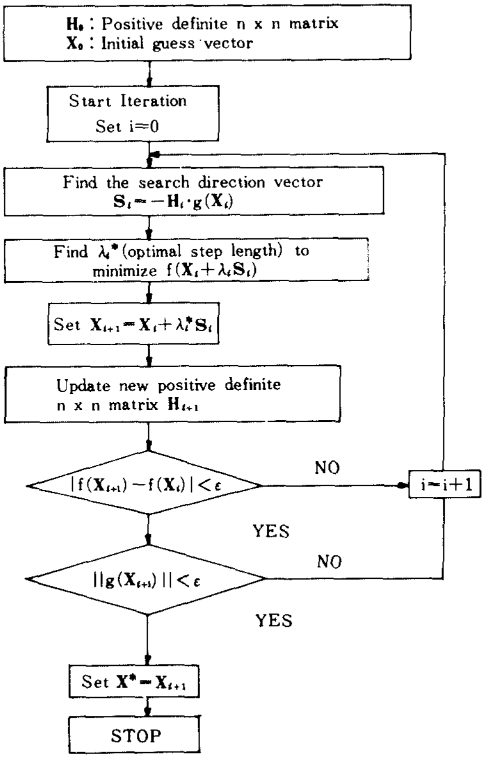

Fig. 3. Davidon fletcher-powell algorithm flow chart.

Step 1; A starting point and initial step size, Z_i ($i=1,2,\ldots, N$) are selected and the objective function evaluated.

Step 2; The first variable X_1 is stepped a distance Z_1 paralled to the axis, and the function evaluated. If the value of objective function decreased, the move is termed a success and Z_1 increased by a factor α, $\alpha \geqslant 1.0$. If the value of objective function increased, the move is termed a failure and Z_1 decreased by a factor β, $0<\beta\leqslant 1.0$ and the direction of movement reversed. (The values recommended by Rosenbrock are $\beta=½$ and $\alpha=3$)

Step 3; The next variable, X_i, is in turn stepped a distance Z_i paralled to the axis. The same acceleration or deceleration and reversal procedure is followed for all variables in consecutive repetitive sequence until a success (decrease in objective function) and failure (increase in objection function) has been encountered in all N directions.

Step 4; The axes are then rotated. Each rotation of the axes is termed a stage.

Step 5; Direction search is made in each of the X directions using the new coordinate axes:

$$\text{New } X_i^{(K)} = \text{Old } X_i^{(K)} + Z_j^{(K)} \cdot S_{i,j}^{(K)} \qquad (6)$$

Where i = variable index (i=1,2,3, N)
j = direction index
k = stage index
$S_{i,j}$ = direction vector component

Step 6; The procedure terminates when the convergence criterion is satisfied.

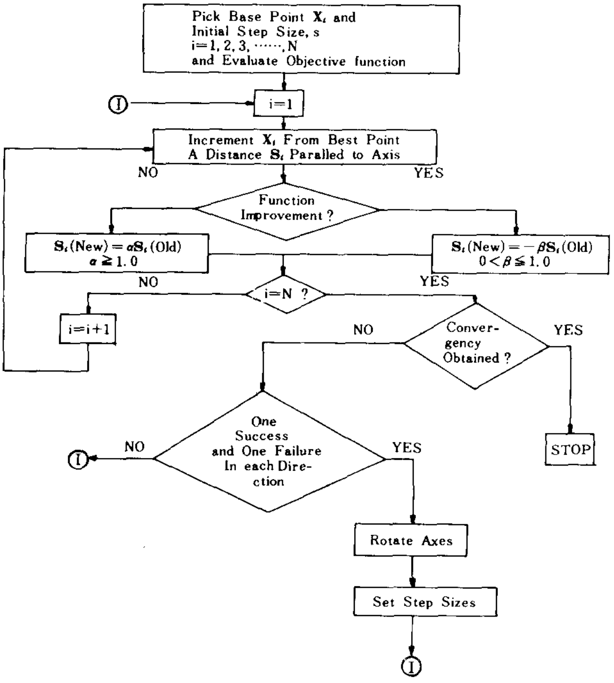

Fig. 4. Rosenbrock algorithm flow chart.

A flow chart illustrating the above procedure is given by in Fig. 4.

3. *Comparison with Experimental Results*

Theoretical EID function is compared to experimental value following three samples having the next conditions.

a) The first sample was covered with a 5000Å thick PMMA (polymethyl methacrylate) resist on an Si wafer and has 20Kv incident beam voltage. The exposed sample was developed with a 1:1 developer [MIBK: IPA (Isopropyl alcohol)] at room temperature for 60 sec and E-gun is LaB6 gun.

PMMA thickness	Beam Voltage	Electron gun	Developer	developing time
5000Å	20 Kv	LaB6	MIBK:IPA (1:1)	60 sec

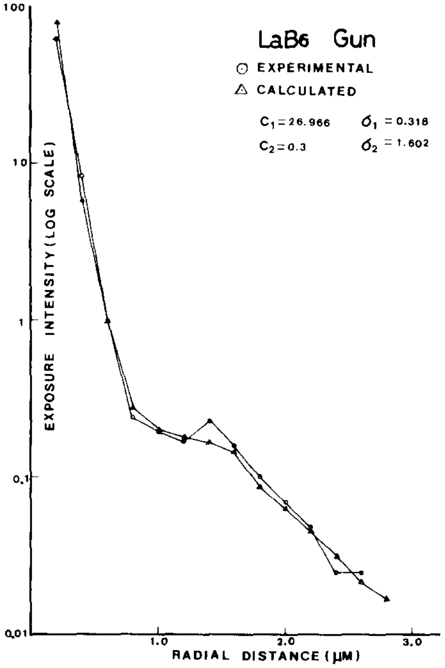

Fig. 5 Comparison of exposure intensity distribution about distance r between theoretical and experimental value.

By using exposure intensity distribution obtained experimentally about first sample and optimizing, then parameters value are

$C_1=26.966$ $\sigma_1=0.318$ $C_2=0.3$ $\sigma_2=1.602$

So, EID function F(r) in this case is

$$F(r)=26.966\mathrm{Exp}[-(r/0.318)^2]+0.3\mathrm{Exp}[-(r/1.602)^2]$$

Theoretical and experimental exposure intensity is following in Fig. 5.

b)

PMMA thickness	Beam Voltage	Electron gun	Developer	developing time
5000Å	20 Kv	LaB6	MIBK:KPA (1:1)	150 sec

parameters are

$C_1=1.499$ $\sigma_1=0.316$ $C_2=0.0143$ $\sigma_2=1.576$

So, EID function in this case is

$$F(r)=1.499\mathrm{Exp}[-(r/0.316)^2]+0.0143\mathrm{Exp}[-(r/1.576)^2]$$

Theoretical and experimental exposure intensity is following in Fig. 6.

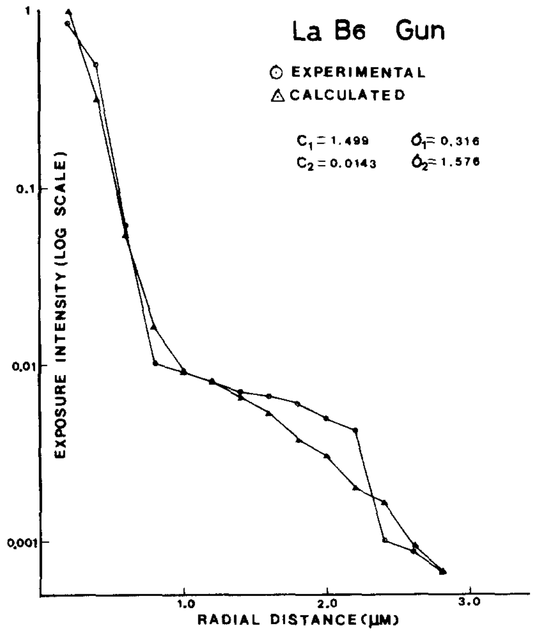

Fig. 6. Comparison of exposure intensity distribution about distances r between theoretical and experimental value.

PMMA thickness	Beam Voltage	Electron gun	Developer	Developing time
5000Å	20 Kv	FE(Field Emission)	MIBK:IPA (1:1)	120 sec

parameters are

$C_1=1.08$ $\sigma_1=0.243$ $C_2=0.011$ $\sigma_2=1.814$

So, EID function in this case is

$$F(r)=1.08\mathrm{Exp}[-(r/0.243)^2]+0.011\mathrm{Exp}[-(r/1.814)^2]$$

Theoretical and experimental exposure intensity is following in Fig. 7.

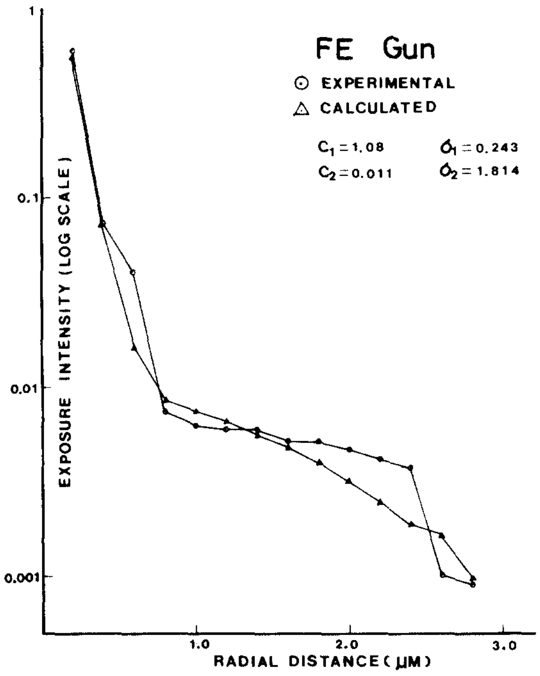

Fig. 7. Comparison of exposure intensity distribution about distances r between theoretical and experimental value.

V. Conclusion

The experimentally generated EID curve was found to approximate the sum of two Gaussian-distribution curves which considerably simplifies the computation.

Using optimization techniques, EID function parameters (C_1, C_2, σ_1, σ_2) for each sample were calculated. Also, this calculated EID curve and good agreement was achieved. From now on, calculated EID curve will apply to compensation algorithm (it is omitted in this paper) for proximity effect.

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