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Important Works About Rules in Rules-Based Optical Proximity Correction

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Abstract: Considering the efficiency and veracity of rules-based optical proximity correction (OPC), the importance of rules in rules-based OPC is pointed out. And how to select, to construct and to apply more concise and practical rules-base is disscussed. Based on those ideas, four primary rules are suggested. Some data resulted in rules-base are shown in table. The patterns on wafer are clearly improved by applying these rules to correct mask. OPCL, the automatic construction of the rules-base is an important part of the whole rules-based OPC system.

Key words: optical lithography; optical proximity correction; rules-base

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1 Introduction

Recently along with the advances in semiconductor manufacturing technology, the critical dimensions (CD) have become shorter than the wavelength used for optical lithography. Thus, when layout patterns on a mask are transcribed to a wafer, more noticeable deformations are introduced by optical proximity effects (OPE). OPE refers to the effect of the interference and diffraction of exposure light through proximity layout patterns.

Because the deformations become more serious and begin to affect the chip performances and yield, some methods must be taken in order to get the desirable images on the wafer. It is impractical to update the optical lithography machines with high cost causes. So at present, the most commonly used methodology is optical proximity correction (OPC), which aims at modifying the layout patterns on the mask in advance to compensate for the deformations[1,2].

Presently there are two prime kinds of methods for OPC: rules-based[3,4] and model-based[5,6]. Model-based OPC builds a simulation tool in advance and the correction is done by iteratively simulating the transcribed image on the wafer. On the contrary, rules-based OPC builds a rules-base in advance and the correction is carried out by evaluating layout patterns, looking up the rules-base. Apparently, rules-based approach is much faster and more practical for full chip correction. So we use this method in our OPC system.

Several companies have developed their OPC systems using the rules-based method and put forward respective rules. Ryuji *et al*.[3] proposed a fast line-width correction system; Otto *et al*.[4] suggested three rules which are 1D,

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1.5D and 2D. However, there is limit in some rules and the parameters in some rules are not proper. In order to make the rules-base robust and adaptable to a wide range of cases, we carefully select and construct the rules for our OPC system, which are the main contribution of this paper.

The rest of the paper is organized as follows. In Section 2, we describe the OPC system and point out the importance of rules. In Section 3, we respectively discuss how to select, to construct and to apply the rules-base in detail. And Section 4 shows some experimental results. We give our conclusions in Section 5.

2 Rules-based OPC system description

The rules-based OPC system will be very complex and enormous. Figure 1 shows the system's frame. In rules-based approach since the corrections to layout are determined by looking up the rules-base, the rules-base's format and content will greatly affect the efficiency and precision of the OPC process. Therefore, the rules are essential to the whole system.

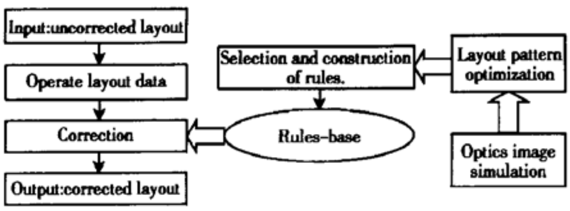

Fig. 1 Frame diagram of the rules-based OPC system

According to the geometric information of layout patterns, the rules are commonly divided into several types. Each type of rule should have a set of crucial parameters to describe the geometric information of the target pattern and its environment. And the corrections are usually some small patterns added to or removed from the original layout patterns. So each rule type will also have several parameters to describe the corrections. Different type of rule has different geometric information parameters and different correction parameters. Thus the correction can be expressed as

$$C_{\rm I} = f(L, I, P_{\rm I})$$

$$C_{\rm I} = \{C_{\rm I1}, C_{\rm I2}, \cdots, C_{{\rm I}n}\}$$

$$L = \{\lambda, {\rm NA}, {\rm defocus}, \sigma, {\rm CD}\}$$

$$I \in \{{\rm edge}, {\rm corner}, {\rm lineend}, \cdots\}$$

$$P_{\rm I} = \{P_{\rm I1}, P_{\rm I2}, \cdots, P_{{\rm I}m}\}$$

where $C_{\rm I}$ is the set of correction parameters, L the set of optical lithography parameters, I the type of the rule, $P_{\rm I}$ the set of geometric information parameters.

Our work is based on an optical image simulating and pattern-optimizing tool called OPCM[7], which takes layout as input and corresponding correction as output. Due to the size of limited input pattern and the unbearable time/space consumed by OPCM, it can not be applied directly to a full chip mask but is suitable for the construction of the rules.

3 Works about rules

3.1 Selection of rules

3.1.1 Fundamentals of selection

A larger rules-base usually means more precision and adaptability for the correction system. However, this also indicates more computation effort. Thus we must control the rules-base in proper size.

At first, rules-based OPC performs correction according to the OPC rules-base determined in advance. So the rules-base should represent the instances in layout as more as possible. Secondly, more detailed and complicated rule types will describe layout more accurately. However, the optimization process (OPCM) and the construction of rules-base will be more complicated. So with the scale of circuits becoming larger and larger, the rule types should be controlled as few as possible while maintaining high precision. Finally, the geometric information parameters of each rule are also direct factor influencing on the complexity of the rules-base operation. So proper parameters should be chosen to ensure the precision of correction with little additional burden on the system.

3.1.2 Process of selection

Considering the above fundamentals, we compared and tested many different patterns and combinations in some layouts. Finally come up with four primary rule types, which are called line-width, corner, line-end and hole.

According to some layout patterns and the rules suggested in other papers, we can determine several parameters for each rule to describe the patterns more accurately, but the number seems too much. For instance, supposing there are 6 parameters in some rule and each parameter has 10 different values, then there will be 10^6 items in this rule table. The construction and search of this rule table will obviously be time-consuming. So we try to choose comparatively important parameters and control the number for less than 3.

Here we define a variable DEF as the foundation. DEF is equal to the percentage of the deformation area between the patterns on layout and their images on wafer to the area of the patterns on layout. We can calculate three curves for every parameter through simulating. Curve 1 represents the relationship between the parameter and DEF before optimization, curve 2 represents the situation after optimization if this parameter is considered, and curve 3 represents the situation after optimization if this parameter is unconsidered. That the deformation of the underlying curve is small, means the patterns on the wafer are more coherent with their images on the mask. If curve 2 is similar to curve 3, it means the parameter has little influence on the correction and that parameter will be ignored. Otherwise, that parameter will be one parameter in our rule.

For example, let us see the line-width rule. We first define seven parameters just like the general 1.5D edge rule suggested in Ref. [4], shown in Fig. 2. We calculate curves for every parameter, for instance, the three curves of L_0, L_1 and G_0 are shown in Fig. 3. It shows parameter L_1 has little influence on correction, so it can be ignored, while L_1 and G_0 will be reserved in our line-width rule.

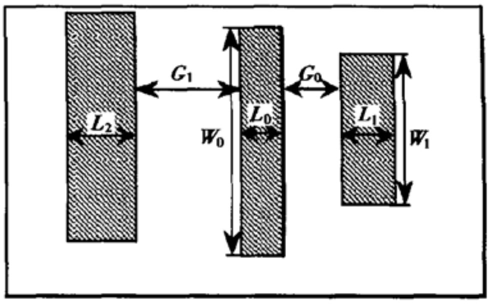

Fig. 2 1.5D rule pattern

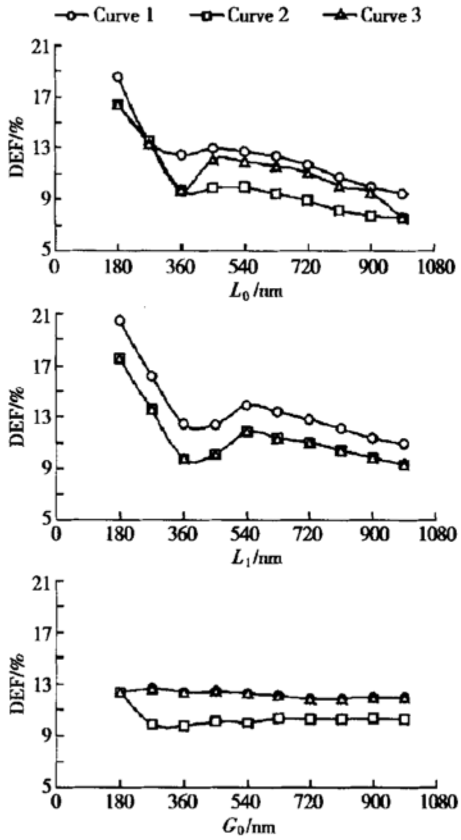

Fig. 3 Three curves of parameters L_0, L_1 and G_0 in 1.5D rule Optical lithography parameters: λ = 248nm, NA = 0.5, defocus = 0, σ = 0.5, minimum line width = 0.18μm

Furthermore, the patterns can be incised to obtain the same length of lines so a uniform length parameter can be used instead of two. Finally we confirm three parameters

(L_1, G_0, W). The simplicity of our line-width rule is quite obvious. Similar reduction process can be applied to other rules. Because the effect of optical conditions is consistent on the mask, so the different optical conditions can not change the trend and relation of curves.

3.1.3 Selection result

Figure 4 shows the four rules with respective parameters. These rules can cover a majority of instances in layouts.

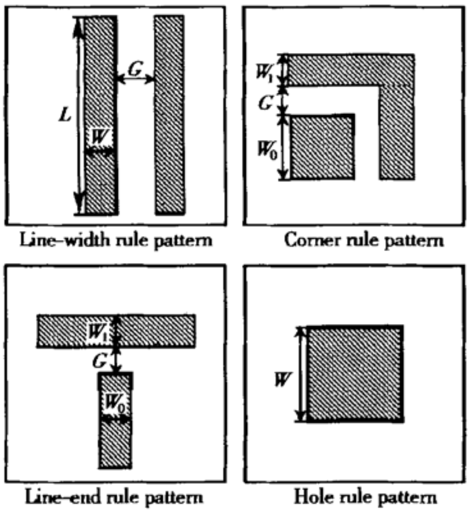

Fig.4 Four rules pattern The bold real line is the correction target and other patterns are its environment.

3.2 Construction of rules

3.2.1 Fundamentals of construction

In order to improve the efficiency of OPC process, we need build an apropos rules-base. Thus we must control some factors when constructing.

At first, each type of rule represents a class of instance. The changes of the rule' s geometric information parameters stand for a series of patterns belonging to the same sort of instance. Though more items in rules-base are favorable for looking up, the complexity issues make us only store important items in the rules-base. Secondly, the variation step and the variation range of parameters in rules-base will directly determine the number of items in table. So we must determine suitable values for them in order to get good performance of the OPC system.

3.2.2 Process of construction

The automatic construction of the rules-base called OPCL is an important part of the rules-based OPC system. Figure 5 is the flow chart of OPCL.

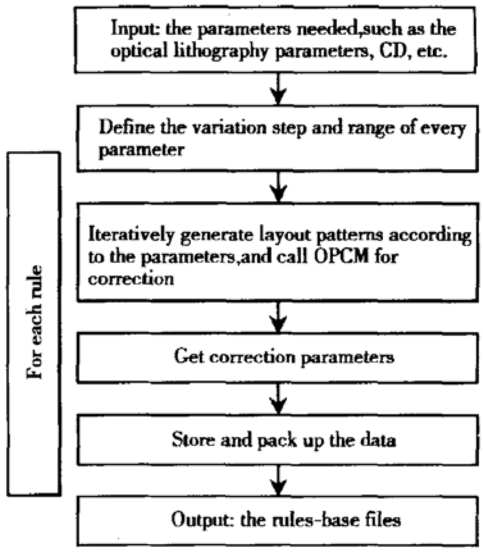

Fig.5 Flow chart of construction

3.2.3 Special management of construction

It is well known that most of the IC designs are on the base of integer. In other words, the dimensions of all layout patterns are integral times of a definite value called delta (the minimum line width is usually twice of delta). So we can define the variation step of every parameter by delta. Thus the rules-base will include enough items comparing with the layout patterns.

Since OPE comes mainly from the diffraction and interference of exposure light between nearby patterns within a definite distance, we can confine the range of influence of every parameter.

Moreover, because the variation step of parameters is fixed, only the correction results are saved in rules-base and other information are saved in a descriptive file while the specific values of parameters are unrecorded in rules-base. Furthermore the rule items stored in rules-base are organized according to the preferential importance of parameters. Thus improved efficiency of looking up can be achieved.

3.3 Application of rules-base

When correcting a given layout pattern, the actual parameters of the target as well as its environment and the pattern type are used as a key to search the rules-base. If an exact match is found, the correction can be returned directly. But while such exact match does not exist, the linear interpolation method will be used to get the correction. Finally the correction will be added to that original layout pattern.

4 Experimental results

We have implemented above ideas in C program on Sun Enterprise E450 and have built a rational rules-base for our OPC system. Table 1 and Table 2 show a part of the rules-base. By applying these rules, we can get optimized layout. Figure 6 shows a small part of mask and its image on the wafer before and after correction.

Table 1 A part line-width rule table

W	G	L	Edge offset
0.18	0.18	0.72	0.00
0.18	0.27	0.72	0.09
0.18	0.36	0.72	0.05
0.18	0.45	0.72	0.03
0.18	0.54	0.72	0.1

Table 2 A part corner rule table

W_0	W_1	G	Serif width	Serif overlap
0.18	0.18	0.18	0.09	0.015
0.27	0.18	0.18	0.075	0.006
0.36	0.18	0.18	0.084	0.006
0.45	0.18	0.18	0.072	0.01
0.54	0.18	0.18	0.072	0.01

Remark: The unit used in above table is μm. The conditions of optical lithography as follows: wavelength= 248nm; numerical aperture= 0.5; defocus= 0.0; partial coherence factor= 0.7; minimum line width= 0.18μm. The correction (edge offset) in Table 1 represents the offset of the target edge. The correction (serif width and serif overlap) in Table 2 represents the value and position of the serif added to the target corner.

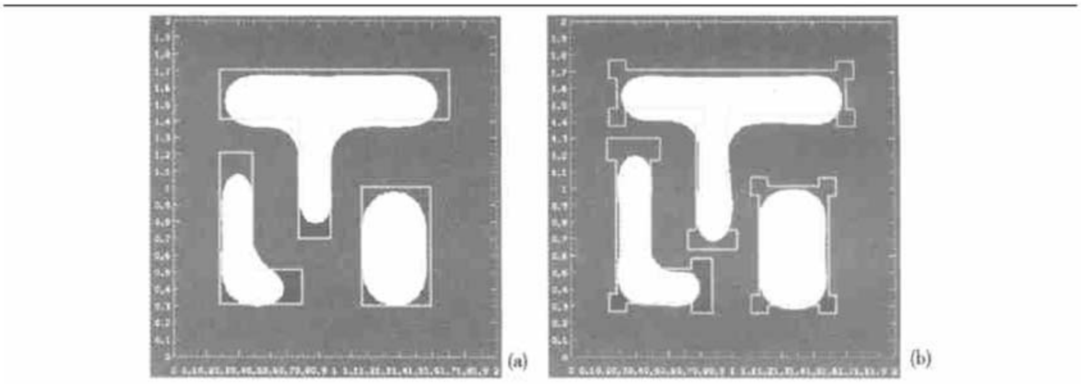

Fig. 6 A small part of mask and its image on the wafer (a) Before correction; (b) After correction

5 Conclusion

In this paper, we introduced the OPC method which is necessary for semiconductor manufacturing. We also analyzed the character of the rules in rules-based OPC system and presented our concise and practical rules. Based on the analysis of real layouts and our rules, we built our robust rules-base, which was the foundation of the rules-based OPC system.

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基于规则的光学邻近矫正中规则的相关处理

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摘要: 讨论了如何选择适当的规则, 如何建立简洁实用的规则库, 如何应用规则库. 提出了四种主要的光学邻近矫正规则, 在实验结果中列举了规则库中的部分数据. 利用规则矫正后的版图光刻得到的硅片图形有了明显的改善. 规则库的自动建立部分(OPCL) 是基于规则的光学邻近矫正系统的重要组成部分.

关键词: 光刻; 光学邻近矫正; 规则库

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