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激光直写中误差校正迭代方法的改进

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摘要:为了进一步校正激光直写中的邻近效应,对误差校正迭代方法进行了完善。用虚拟的高分辨力声光调制器对直写图案进行校正,然后将曝光量数据转换圆整为低分辨力声光调制器对应的曝光量数据,消除了低分辨力声光调制器校正直写图案时出现的退化现象;调制各误差区域重心最邻近光点的曝光量,以整体图案误差最小为判断标准进行串行寻优,解决了当被调制光点附近的图案正、负误差个数相等时无法进一步校正的问题。以无心方框图为例进行的仿真实验表明,使用低分辨力声光调制器时,改进的误差校正迭代方法能用于校正邻近效应,校正后图案误差相对原始误差减小了 91.78%;使用高分辨力声光调制器时,图案误差相对原始误差减小了 92.32%,继续应用本文方法校正后,图案误差相对原始误差可又减小 1%。

关 键 词:激光直写;邻近效应;误差校正迭代法

中图分类号:TN305.7 **文献标识码**:A

Improvement of iterative error-correction method in laser direct writing

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Abstract: In order to further correct the optical proximity effect in laser direct writing, the Iterative Error-Correction Method (IECM) proposed by Rajesh Menon is improved from two aspects. Firstly, one virtual acoustooptic modulator with high resolution is used to correct the direct writing pattern, and then the exposure data obtained are converted and rounded to that corresponding to the low resolution acoustooptic modulator to avoid the degradation during correction. Secondly, the exposure dose of writing spot that is the nearest to each error area barycenter is modulated by taking the minimum whole pattern error as a yardstick to achieve serial global optimization, which avoids a failure to correct the optical proximity effect when the number of positive errors is equal to that of negative errors. By taking the centerless block diagram as the test pattern, numerical simulation results indicate that the optical proximity effect of pattern with a low resolution acoustooptic modulator can be preferably corrected and the corrected pattern error value is decreased by 91.78% as compared with the initial error value. Furthermore, the optical proximity effect of pattern with a high resolution acoustooptic

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modulator can be further improved after being corrected by IECM, and the corrected pattern error value is further decreased by 1% based on 92.32% as compared with the initial error value.

Key words: laser direct writing; optical proximity effect; Iterative Error-Correction Method(IECM)

1 Introduction

Laser direct writing (LDW) has been applied widely to fabricating micro-optical elements[1-6] and photomasks[7-8] for its simplicity, flexibility and low cost as compared with projection lithography and electron beam direct writing technology. However, optical proximity effect (OPE) appears for the Gaussian distribution of writing beam, which can not be neglected for the demand of pattern resolution increased and need to be corrected.

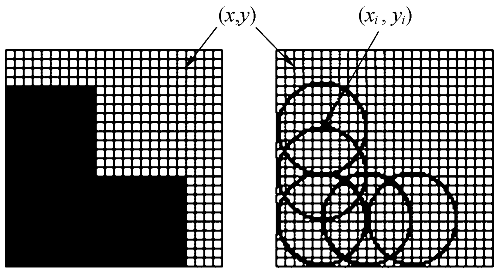
So far, to reduce the laser direct writing distortion, the following methods may be used: (1) reducing the spot size of the writing beam or improving its intensity distribution[9]; (2) modulating the exposure dose on the photoresist in direct writing process[10-11]; (3) using contrast enhancement polymer resist[11]. Comparatively, the exposure dose modulation has been general concerned due to its simplicity and the avoidance of the redesigning the optical system and using new polymer resist.

Much work has been done on optimal modulation exposure data, for example, a laser writing exposure data pre-compensation method[11] was used to correct the optical proximity effect by Institute of Optics and Electronics, Chinese Academy of Sciences, but not in detail; and in recent years, Rajesh Menon has proposed a practical method, Iterative Error-Correction Method[10], for which the dose quantization is automatically taken into consideration during the calculation, moreover, the convergence is very rapidly and better results can be obtained. However, on the one hand, for the direct writing system equipped with a low resolution acoustooptic modulator, the degradation phenomenon may appear during correction with Iterative Error-Correction Method. On the other hand, although the high resolution acoustooptic modulator can achieve good correction results, further correction can not be well done due to the equality of the number of positive errors and that of negative errors around modulated spots. Aiming at the first shortcoming, one virtual acoustooptic modulator with high resolution is used to correct the direct writing pattern, then the exposure data obtained are converted and rounded to that corresponding to the low resolution acoustooptic modulator. Aiming at the second shortcoming, Error Area Barycenter Nearest Spots Correction Method is presented, namely the exposure dose of each error area barycenter nearest spot is modulated while serial global optimization is performed with the minimum whole pattern error as a yardstick.

2 Defects of iterative error-correction method

According to Rajesh Menon's Iterative Error-Correction Method[10], some numerical simulation parameters have been defined as follows: in Fig. 1, the grid represents the discretization of space for calculation of the exposed pattern, i. e. the grid points are the sample points for the aerial image, denoted as (x, y). The desired binary pattern is depicted in gray superimposed on a grid of points, which composed of some writing spots overlapped, and (x_i, y_i) are the center coordinates of the positions of the exposed spots. In this schematic, the spot steps over a distance are equal to half of the spot-size for each exposure.

We choose the centerless block diagram as



(a) Desired binary pattern　(b) Focused spot is scanned to form a pattern

Fig. 1　Dot array LDW simulation calculation scheme

the desired binary pattern to be written as shown in Fig. 2. Simulation has been done according to Iterative Error-Correction Method and simula-

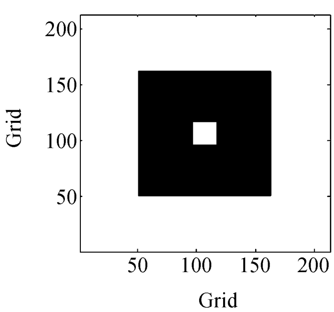


Fig. 2　Desired binary pattern

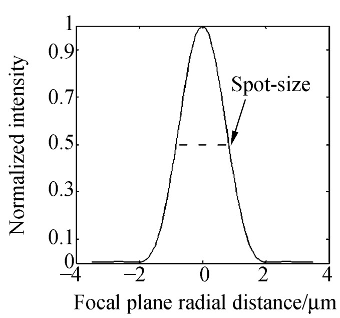
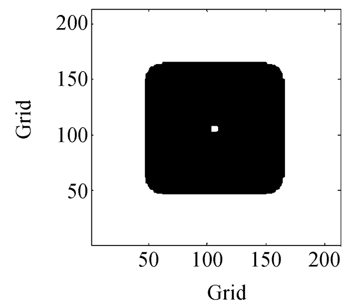
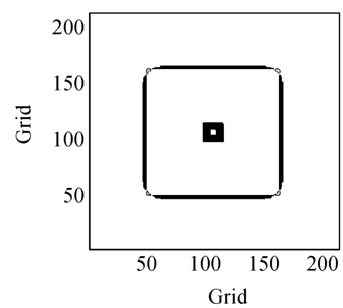


Fig. 3　Normalized intensity profile of writing spot

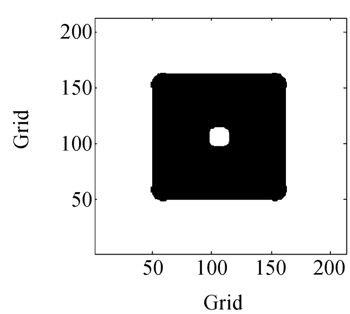
tion condition is as follows: (1) The intensity distribution of a writing spot on diffraction focal plane imaged by parallel laser beam normally incident upon the objective lens is calculated and normalized according to Scalar Diffraction Theory. The intensity profile of the focused spot is shown in Fig. 3, whose size is measured at the half-maximum point, meanwhile, a resist



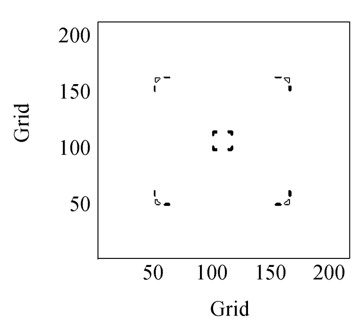
(a) Exposure pattern uncorrected



(b) Error pattern uncorrected



(c) Exposure pattern corrected



(d) Error pattern corrected

Fig. 4　Exposure patterns corrected and uncorrected threshold at half of the peak image intensity is assumed. (2) The sampling grid size is one-sixteenth the spot size. The initial exposure data of the desired binary pattern is 1, while the modulation scope of the exposure data is set to be 0～2, and therefore the soft is capable of bi-directional correction. The spot steps over a distance are equal to half of the spot-size for each exposure. (3) The error value of the pattern is defined as the sum of the absolute value of the difference between the desired pattern and the modulated pattern. The uncorrected exposure pattern and its error pattern are shown respectively as Fig. 4(a) and (b).

As shown in Fig. 4 (c), (d), numerical simulation discloses that good correction results can be obtained with the acoustooptic modulator with 7 bits of grayscaling (128 dose levels). However, as grayscaling bits decrease from 7 to 5, the degradation phenomenon comes forth as shown in Fig. 5, i. e. the error value of uncorrected pattern is 1 460, and that of corrected pattern further augments, and oscillates at last. Understandably, the lower the resolution of the acoustooptic modulator becomes, the higher the sensitivity of dose quantization will be. Consequently, for the same number of the errors, exposure data of writing spot will be over modulated, which leads to the degeneration of the pattern. In practice, because the resolution of acoustooptic modulator equipping direct writing system is certain and impossibly,infinetely high, it is very possible to come forth the degradation phenomenon and need to be resolved. In addition, that the number of positive errors and that of negative errors around modulated spot are equal results in that the modulation quantity counteracts and error value converges certain value, no longer reduced. In fact, the distance from the position of positive errors to that of modulated spot may be not equal to that from the position of negative errors to that of modulated spot, thus the influence degree of exposure dose variations on the positive errors and that on negative errors are different, which indicates that it is possible to further correct OPE.

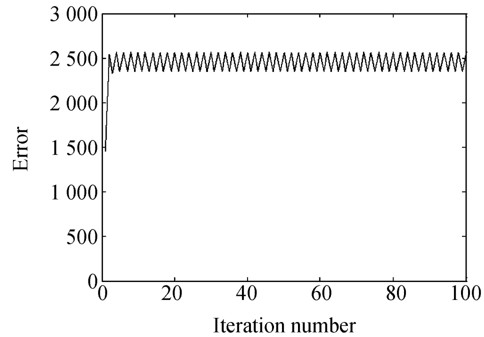


Fig. 5 Curve of pattern error value and number of iterations

3 Introduction to improved method

In order to make up the two defects of Iterative Error-Correction Method, a corresponding improved method is proposed. On the one hand, one virtual acoustooptic modulator with high resolution is used to correct the direct writing pattern, then the exposure data obtained is converted and rounded to that corresponding to the low resolution acoustooptic modulator, which is conductive to avoiding the degradation phenomenon during correction. On the other hand, the Error Area Barycenter Nearest Spots Correction Method is presented, namely the exposure dose of each error area barycenter nearest spots is modulated while serial global optimization is performed with the minimum whole pattern error as a yardstick, which solves the problem that the optical proximity effect can not be further corrected when the number of positive errors and that of negative errors become equal.

3.1 Method to avoid degradation phenomenon during correction

In order to avoid the degradation phenomenon during correction, an effective method is proposed as shown in Fig. 6, where n denotes the virtual acoustooptic modulator bits, $D(x_i, y_i)$ denotes the pattern exposure data after correction, DQ denotes dose quantization of the virtual acoustooptic modulator, DQ_0 denotes dose quantization of the acoustooptic modulator equipping direct writing system, start_error denotes the pattern initial error value, i. e. the sum of the absolute value of the difference between desired pattern and modulated pattern, and modulation scope of the exposure data is 0～2. The process involved are detailed below: firstly, the dose quantization of the acoustooptic modulator equipping direct writing system is calculated. Iterative Error-Correction Method is then used to correct the pattern distortion while the pattern error value is judged during the previous steps. If the current pattern error value is bigger than the pattern initial error value, the degradation is considered to come forth. Then the bits of acoustooptic modulator is added 1 and virtual dose quantization is calculated, again the above process is repeated until the pattern error value is smaller than the pattern initial error value. At last the modulated spot exposure data obtained with virtual high resolution acoustooptic modulator is converted to that corresponding to the low resolution acoustooptic modulator, and the converted method is detailed as follows: the dose quantization of acoustooptic modulator equipping direct writing system is divided by the modulated spot exposure data obtained with virtual high resolution acoustooptic modulator, then the quotient is rounded and is multiplied by the dose quantization of acoustooptic modulator equipping direct writing system, then the product is taken as the modulated spot exposure data corresponding to the low resolution acoustooptic modulator.

We still choose the centerless block diagram as the desired binary pattern to be written as shown in Fig. 2, and the degradation phenomenon comes forth with the bits of acoustooptic modulator to decrease to 5. According to Fig. 6, correction is done and, with the resolution continuously increasing, the curves about the pattern error value and the number of iterations are shown as Fig. 7. It can be seen that the degrada-

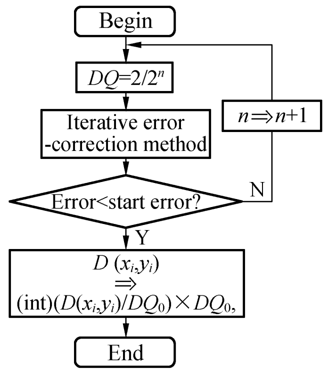
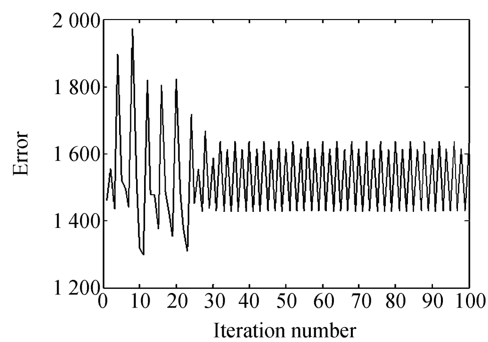
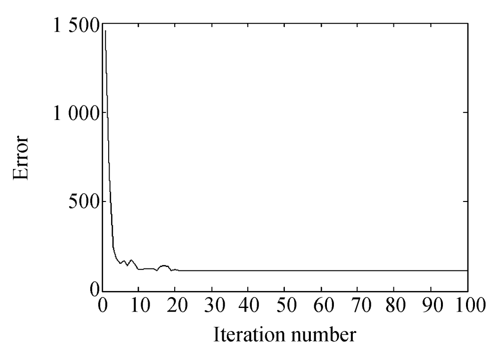


Fig. 6　Flow chart avoiding writing pattern degradation phenomenon



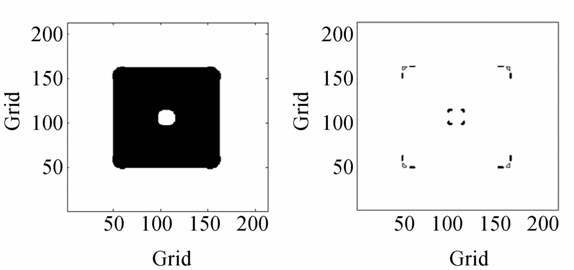
(a) 6 bit acoustooptic modulator



(b) 7 bit acoustooptic modulator

Fig. 7　Curves of pattern error value and number of iterations

tion phenomenon is avoided until the bits of acoustooptic modulator is 7, and the pattern error value is 112. Then the exposure data of writing spot are converted and rounded to that with 5 bits acoustooptic modulator, and the pattern error value is changed to 120 as shown in Fig. 8, decreased by 91.78% relative to the initial error, from which it can be seen that writing pattern is corrected obviously compared with Fig. 4 (b), meanwhile, better correction results with virtual high resolution acoustooptic modulator is kept. However, further increase in the bits of virtual acoustooptic modulator shows that the corrected pattern improves slightly. This is the case even after running the algorithm for a large number of iterations. Since the bigger the number of the acoustooptic modulator bits becomes, the more computational cost increases, the number of the virtual acoustooptic modulator bits is determined with just no degradation phenomenon in real application.



(a) Exposure pattern (b) Error pattern

Fig. 8 Writing pattern with exposure data converted and rounded after correction

3.2 Error Area Barycenter Nearest Spot Correction Method

Error Area Barycenter Nearest Spot Correction Method is depicted as shown in Fig. 9. The process involved is detailed below: firstly, Iterative Error-Correction Method is used to correct the pattern distortion, and if the degradation phenomenon doesn't come forth, each error area barycenter (x_g, y_g) is searched using image processing technique[12]. Subsequently, the position (x_i, y_i) of writing spot nearest to each error area barycenter is found, then, for the modulated writing spots, pattern error value is calculated through all available exposure data with the dose quantization as step size one by one. For each modulated writing spot, the exposure data with the minimum error of whole pattern is retained and the optimization proceeds to another modulated writing spot. The reason why each error area barycenter is chosen as the referenced error position is that errors in some error areas have the same benefit and the calculation cost can be decreased.

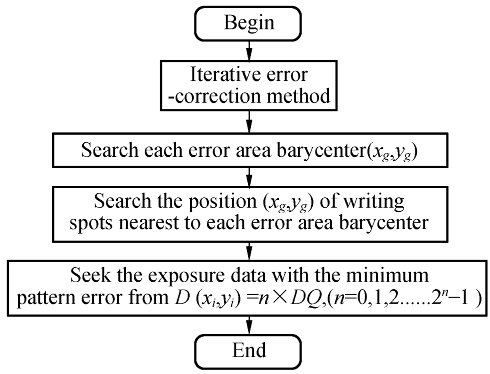
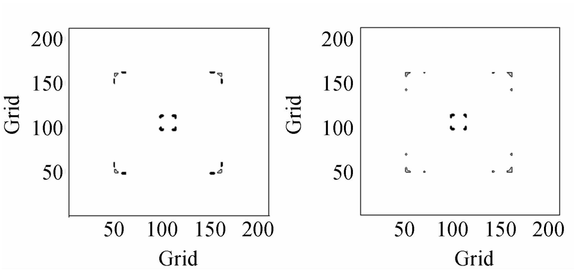


Fig. 9 Flow chart of Error Area Barycenter Nearest Spots Correction Method

The centerless block diagram is still chosen as the desired binary pattern to be written as shown in Fig. 2, and the bits of acoustooptic modulator is 7. Firstly, Iterative Error-Correction Method is used to correct the pattern distortion and the corrected pattern error value is 112 as shown in Fig. 10 (a), which is decreased by 92.32% relative to the initial error value. Error Area Barycenter Nearest Spots Correction Method is then used to continue to correct the pattern distortion and the pattern error value changes to 96 as shown in Fig. 10 (b), which is decreased by 1% relative to the initial error value and denotes the further correction on the pattern distortion.

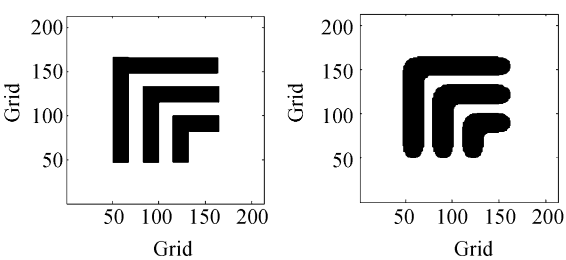
In order to further verify the effectiveness of Error Area Barycenter Nearest Spots Correction Method, nested-L pattern is chosen as the desired binary pattern to be written as shown in Fig. 11 (a), and the line width and space are equal to the spot size, respectively. The pattern before correction is shown in Fig. 11 (b), and the error value is 2 295. With the 8 bits acoustooptic modulator, Iterative Error-Correction Method is used to correct the pattern distortion



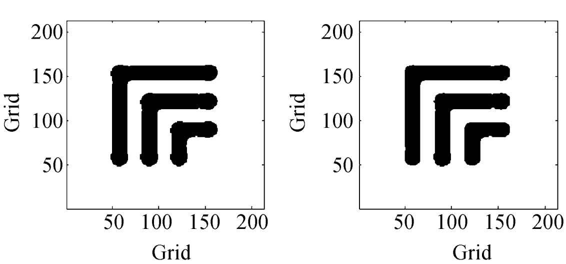
(a) Before correction　　(b) After correction

Fig. 10　Comparison of error pattern before and after correction by Error Area Barycenter Nearest Spots Correction Method

and after correction the pattern error value is 309 as shown in Fig. 11 (c). Then Error Area Barycenter Nearest Spots Correction Method is used to continue to correct the pattern distortion and the pattern error value changes to 237 as shown in Fig. 11 (d), which decreases pattern error value by 3% relative to the initial error value and denotes the further correction on the pattern distortion.



(a) Desired binary pattern　　(b) Exposure pattern before correction



(c) Exposure pattern after correction by Iterative Error-Correction Method　　(d) Exposure pattern after correction by Error Area Barycenter Nearest Spots Correction Method

Fig. 11　Correction of nested-L pattern

In the above simulation, not only the nearest writing spot can be considered for error correction but also the next nearest one as well. Simulation results demonstrate that the pattern is improved a little, not obviously.

4　Conclusions

It is known that Iterative Error-Correction Method is an effective correction method for the optical proximity effect in laser direct writing. However, it has two shortcomings: on the one hand, for the direct writing system equipped with a low resolution acoustooptic modulator, the degradation phenomenon may appear during correction with Iterative Error-Correction Method. On the other hand, although the high resolution acoustooptic modulator can achieve good correction results, further correction can not be well done due to the equality of the number of positive errors and that of negative errors around modulated spots.

Aiming at the first shortcoming, one virtual acoustooptic modulator with high resolution is used to correct the direct writing pattern, then the exposure data obtained are converted and rounded to that corresponding to the low resolution acoustooptic modulator. Numerical simulation results indicate that we have avoided that Iterative Error-Correction Method can not be used to correct the pattern distortion for the lower resolution acoustooptic modulator and have achieved good correction results.

Aiming at the second shortcoming, an Error Area Barycenter Nearest Spots Correction Method is presented, namely the exposure dose of each error area barycenter nearest spot is modulated while serial global optimization is performed with the minimum whole pattern error as a yardstick. Moreover, we choose each error area barycenter as the referenced error position to consider the same benefit of the errors in some error areas and lower calculation costs. Numerical simulation results indicate that optical proximity effect can be further corrected by using the Error Area Barycenter Nearest Spots Correction Method after correction by the Iterative Error-Correction Method.

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●**下期预告**

上海光源新型一维位置灵敏电离室研制

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研制了一台一维位置灵敏电离室。该电离室的收集电极由两块完全一样的相互独立并彼此绝缘的单元构成，每个单元有两路劈裂式极板，根据输出的电流信号可获得 X 光束的强度和位置。该电离室在上海光源(SSRF)生物大分子晶体学光束线上进行了实验测试。测试中采用了一个标准电离室作为强度测量对照。一维位置灵敏电离室被固定在一维电控滑台上，分别在水平和垂直方向上移动电控滑台逐步扫描测试光束的位置。测量时，光子能量为 8 keV，扫描范围为 10 mm，重复扫描 12 次。测试内容包括电离室的坪区、线性度、位置测量精度及光强测量。结果表明，该电离室的线性度较好，位置测量精度好于 20 μm，线性测量范围为 6 mm，其将安装在该光束线上用于对光束稳定性的监测。