SOCS Based Post-Layout Optimization for Multiple Patterns with Light Interference Prediction

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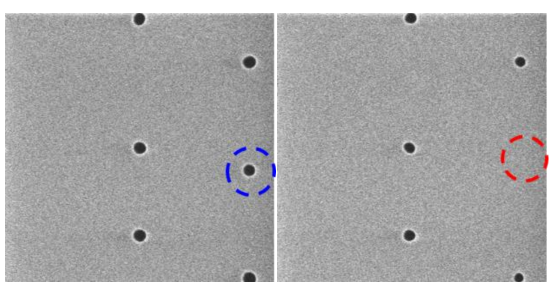
ABSTRACT

As technology node shrinks down, hotspots, i.e. patterning failures on wafer after etching process, become an inevitable problem. The main cause of such hotspots is low contrast of aerial image. There are several methods that can improve aerial image contrast such as SRAF insertion and OPC. However, it is difficult to fix all hotspots by applying only SRAF and OPC in advanced technology node. This paper proposes a new post-layout optimization method, before SRAF and OPC, based on SOCS kernel for improving aerial image contrast and reducing hotspots. Experimental results show average 4nm PV-band improvement, as a result of contrast improvement.

Keywords: lithography, SOCS kernel, hotspot, light interference, image contrast

1. INTRODUCTION

As technology node goes down, fine features are still exposed on ArF immersion lithography due to the delay of development of next generation lithography tools. The overall trend of image contrast of patterns in a layout decreases because of the limitation of wave length and numerical aperture (NA) of the lithography tools despite of the several resolution enhancement techniques. Lower contrast patterns are likely to result in hotspots at process corner condition. Pictures in Figure 1 show an example of such hotspots. Figure 1(a) shows a SEM image at process nominal condition, and Figure 1(b) shows a SEM image at process corner condition. A hole in the blue dashed circle in the Figure 1(a) disappears at process corner condition as shown in the Figure 1(b). In order to reduce hotspots, it is important to improve image contrast of patterns. Although there are some methods to prevent hotspots, such as SRAF insertion and OPC, those are insufficient for contrast improvement to cover all pattern variation. In this paper, we propose a new post-layout optimization method in which relative positions among patterns are optimized while evaluating light interference based on SOCS kernel.



(a) (b)

Fig. 1 Unopen hotspot.

2. THEORY

Essentially, the primary factor of improving image contrast is optimization of relative positions among patterns. Figure 2 shows relationship between relative distance of two holes and the intensity difference from baseline intensity. The baseline

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is defined as the intensity when the two holes are separated by an infinite distance. The upper direction means constructive light interference, which increase intensity of the holes. The lower direction means destructive light interference, which decrease intensity of the holes. As shown in Figure 2, the two holes have little impact on each other when they are separated by 500nm. In contrast, the light interference between the two holes are the best, when they are separated by 200nm. However, when they are separated by 150nm, the light interference between the two holes deteriorate. Thus we can understand that relative distance optimization is very important.

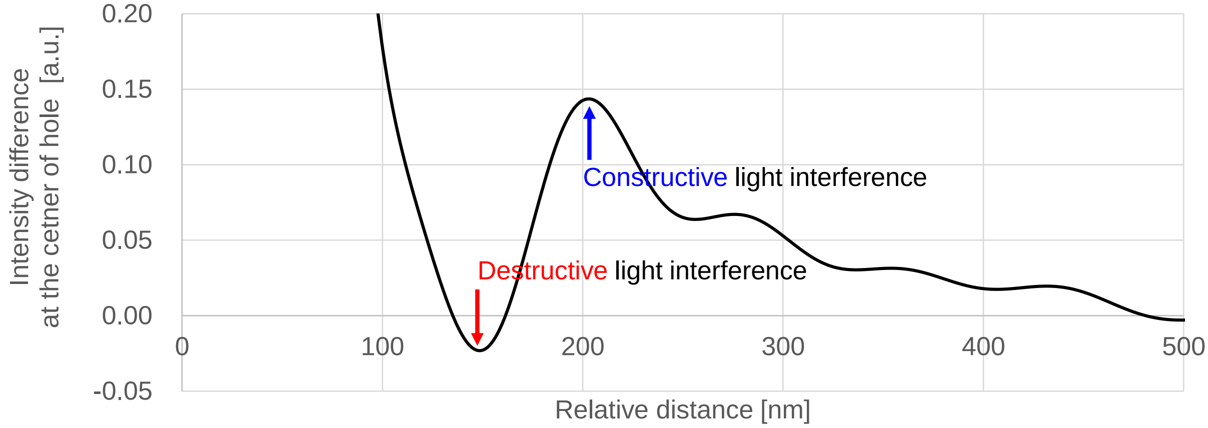

Fig.2 Intensity difference from baseline

2.1 **Layout optimization for real devices**

Although it is important to optimize the relative distances among holes in real devices, there are two issues to do it. One is restriction of movable area of holes. The movable area is usually defined by relations of upper and lower layers as shown in Figure 3. Therefore we cannot move holes freely. The other is that there are too many two-pair combination of relative distances which should be considered to be optimized. Figure 4 shows the number of two pair combination. If there are many holes, the number of two pair combination explode. It is impossible to optimize the relative distances of many holes manually. Therefore, an efficient method to optimize relative distances for many holes is required.

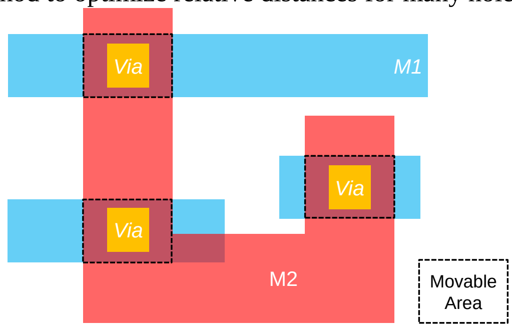

Fig.3 Movable area

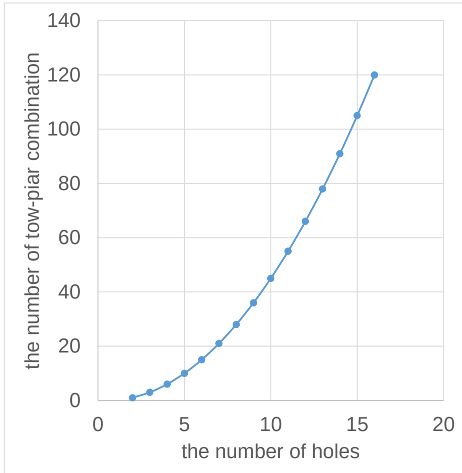

Fig.4 the number of two pair combination

2.2 Previous work

To optimize the relative distances of holes, light intensity map (LIM) approach has been proposed.[4] LIM shows difference between intensity of an isolated hole and intensity of the hole when there is another hole nearby. The position of the nearby hole is changed and the intensity difference is evaluated at each position. This relation between the intensity difference and the positions is stored as a map. Figure 5 shows layout optimization flow with LIM. In Figure 5, a cross-section of the map is expressed as *lim*(x). Firstly, we will place one hole as the step 0. As the next step, LIM function *lim*(x) is superimposed on the hole placed at the step 0. In the step 2, another hole is placed at the maximum point indicated by the LIM function within movable area. LIM function is sequentially superimposed on the newly placed hole and all superimposed LIM functions are accumulated in the step3. Then, another hole is placed at the maximum point indicated by the accumulated LIM function as executed in the step2. These steps are repeated for all hole patterns sequentially. This method can improve contrast to some extent. However, optimization may not be enough due to the sequential algorithm.

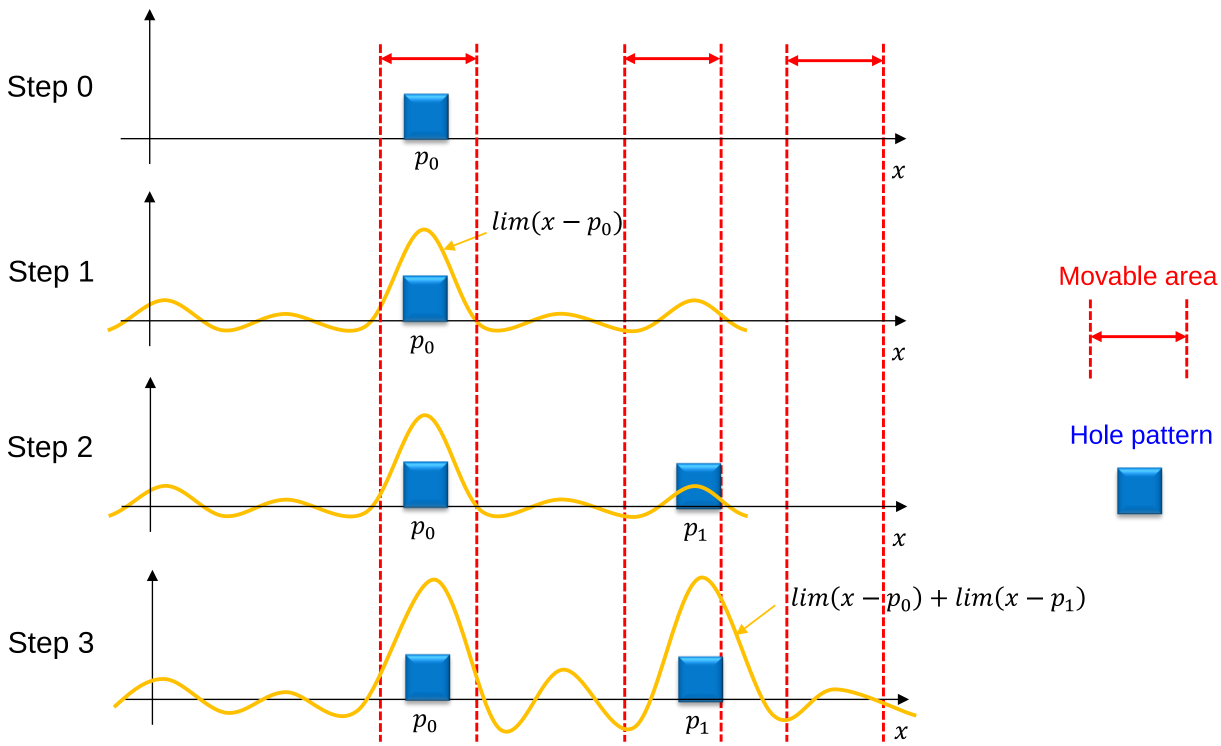

Fig.5 Previous work

3. SOCS BASED LAYOUT OPTIMIZATION

3.1 Concept of the proposed method

Figure 6 shows the overall flow of our method. Firstly, holes are placed in the center of the movable area. Moving direction of each hole is determined to get constructive light interference. The detail of its algorithm is explained in the next subsection. Then each hole is simultaneously moved for the determined directions. When all holes do not move, the flow is judged as converged. Otherwise, this process is repeated.

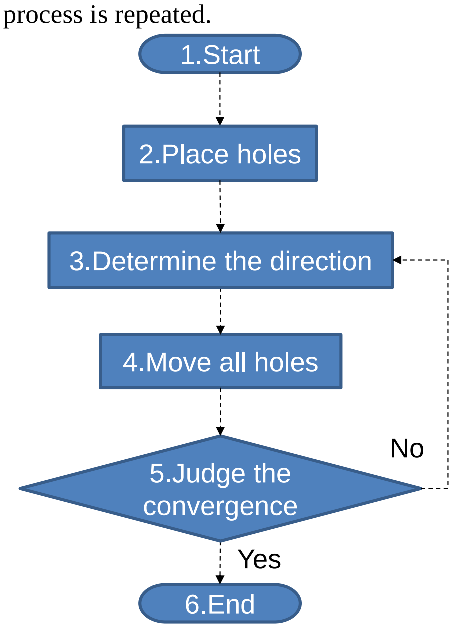

Fig.6 Flow of our method.

3.2 Light interference prediction using SOCS kernel

In this subsection, we explain how to determine the constructive light interference direction for each hole. The algorithm to determine the direction is explained by using three holes as shown in Figure 7. Our method is based on SOCS kernel and is similar to a "coherence map" [3] which is used to generate sub-resolution assist feature (SRAF). Due to inherent coherence of SOCS kernel, it is possible to individually evaluate light interference based on relative distance between every two holes in a layout. Light intensity $I(x)$ is described as convolution operations between SOCS kernel $\phi_k(x)$ and mask function $M(x)$.

$$I(x) = \sum_k \lambda_k |(\phi_k \otimes M)(x)|^2 \cong \lambda_1 |(\phi_1 \otimes M)(x)|^2 \quad (1)$$

In Figure 7, hole 1, hole 2 and hole 3 are described as rectangle function, and 1D-SOCS kernel is described as waved profile in orange. According to the equation (1), intensity value at each hole can be calculated by summation of shadow areas as shown in Figure 8. In the case of (a), if the both hole 2 and hole 3 are moved to the left side, the intensity of the hole 1 increases because the overlapped area (shadow area) between SOCS kernel and the hole 2 and the overlapped area between SOCS kernel and the hole 3 are increased. In the case of (b), SOCS kernel is put on the hole 2 in the same way. To increase the intensity of the hole 2, both the hole 1 and the hole 3 should move to the right direction because the overlapped area between SOCS kernel and the hole1 and the overlapped area between SOCS kernel and the hole3 are increased. In the case of (c), constructive light interference direction is evaluated for the hole3. The better position of the hole 1 is right direction and the better position of the hole 2 is left direction. Summarizing the three cases, the hole 1 should move to the right direction for the hole 3. Also, the right direction is better for the hole 2. Clearly, the final direction of the hole1 is right. Also, the final direction of the hole 2 is left, because the better directions for the hole 1 and the hole 3 are both left. In contrast, the final direction for the hole 3 is difficult to determine. Because the directions to increase the hole 3 intensity are opposite for the hole 1 and the hole 2. To solve this inconsistency, we use gradient vector of the SOCS kernel at center position of the holes, described as $\nabla\phi$ in Figure 7. The final direction $\boldsymbol{D_i}$ is described as the following equation (2).

$$\boldsymbol{D_i} = \sum_{j=1,\, i \neq j}^{N} \nabla\phi_k\big(x - p_j\big)\big|_{x=p_i} = \nabla\phi_k(x - p_2)|_{x=p_1} + \nabla\phi_k(x - p_3)|_{x=p_1} \quad (2)$$

Figure 8 shows aerial image of 9 holes before and after layout optimization based on the proposed method. This example has no moving constraints to show the benefit of our algorithm. From the Figure 8, we can see that the intensity gets better after layout optimization as the results of light interference improvement.

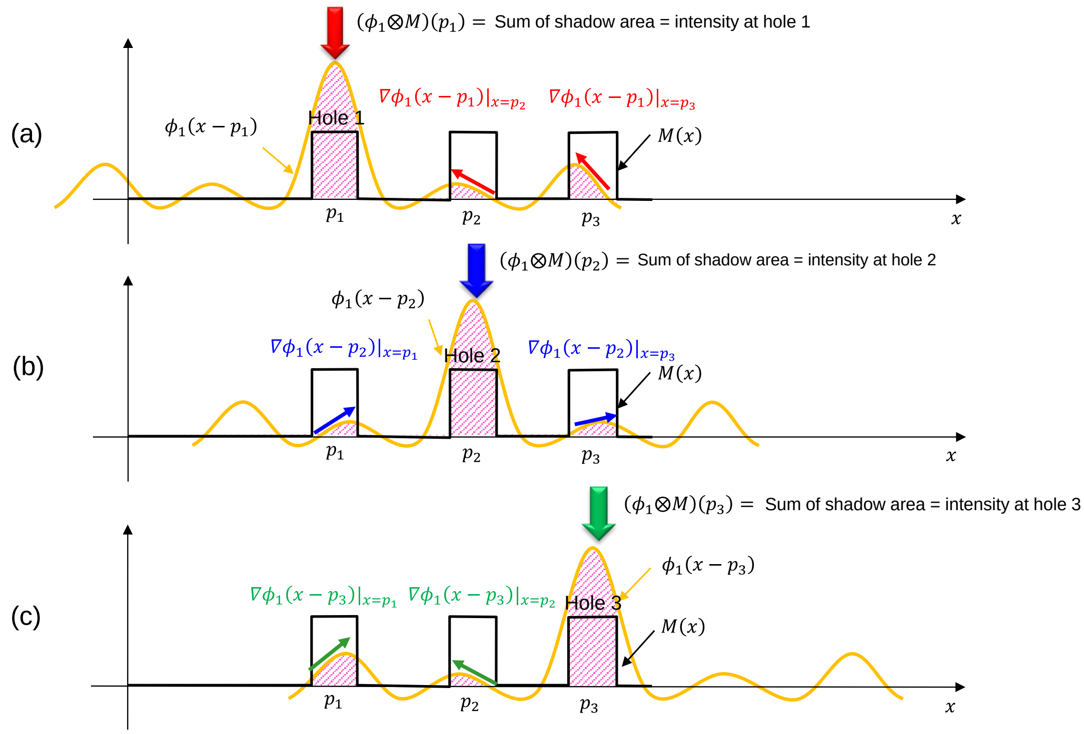

Fig.7 Algorithm to determine directions to increase intensity of hole patterns

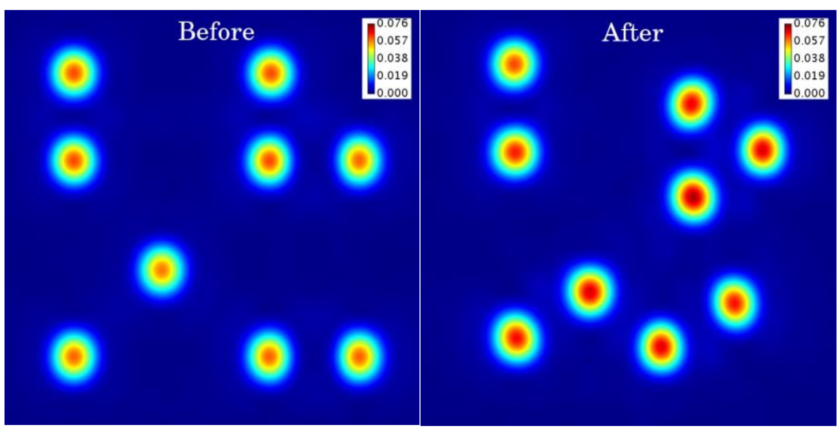

Fig.8 Intensity difference between before and after layout optimization

4. EXPERIMENTS

The proposed method is implemented in C++ on a Linux machine. The following optical conditions are used for this simulation; wavelength λ = 193nm, NA = 1.35, dipole illumination, and 2.4μm optical diameter. Test layout consists of 71 nm square hole patterns. We compare our method with LIM (See section 2.2). In this comparison, we prepared LIM whose dimension is 2400 x 2400 mesh (1nm grid).

4.1 **Experimental results**

Averaged PV band area is used as metric for this evaluation as shown in Figure 9. PV band is difference between maximum contour line and minimum contour line calculated by lithography simulation. Averaged PV band is average of PV band for all holes. Smaller value of the averaged PV band means better because it means smaller deviation due to the process deviation, such as defocus and over or under dose. Figure 10 shows comparison among averaged PV band for initial layout, optimized layout with the LIM method and optimized layout with our method. We can see that 3.3 % reduction for averaged PV band is achieved by using our method compared with the initial layout. It equals to 4 nm PV-band improvement. The result is better than the averaged PV band with the LIM method. This result shows that significant PV-band improvement can be realized with our proposed layout optimization.

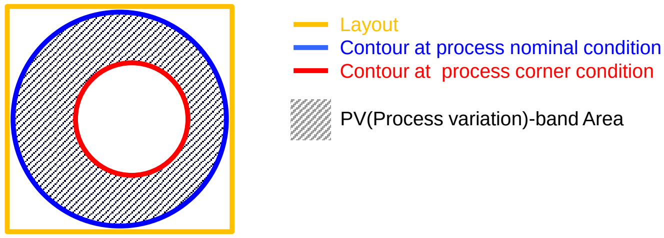

Fig.9 Evaluation metric

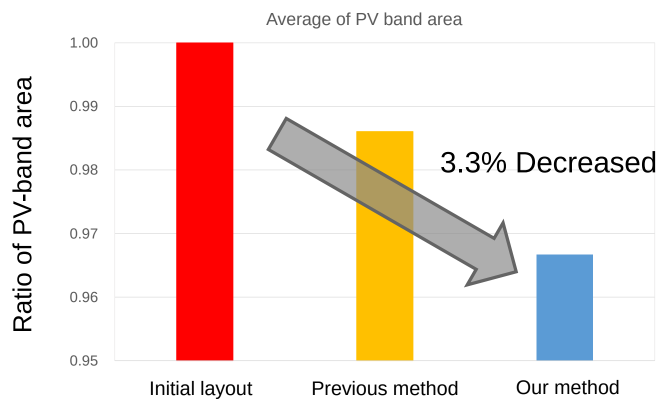

Fig.10 Comparison results with initial layout and LIM.

5. CONCLUSION

Layout optimization at design stage is essential to fix lithography hotspots in advanced technology node. In this paper we have proposed a SOCS based post-layout optimization method using a theory of inherent coherence of SOCS kernel. Light interference of every two holes in a layout is evaluated and the direction to improve intensity is determined using gradient vector of the kernel function. We have confirmed the effectiveness of our method with simulation for 71 nm square hole patterns The result shows averaged PV band area improvement by 3.3% which is corresponding to 4nm PV band improvement.

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