Lithography process for KrF in the sub-0.11 μm node*

Zhao Yuhang(赵宇航)[1], Zhu Jun(朱骏)[2], Tong Jiarong(童家榕)[1], and Zeng Xuan(曾璇)[1,†]

(1 State Key Laboratory of ASIC & System, Department of Microelectronics, Fudan University, Shanghai 201203, China)

(2 Shanghai IC Research and Development Center, Shanghai 201203, China)

Abstract: Currently, 200 mm wafer foundry companies are beginning to explore production feasibility under ground rules smaller than 0.11 μm while maintain the cost advantages of KrF exposure tool systems. The k1 factor under 0.11 μm at 248 nm illumination will be below 0.35, which means the process complexity is comparable with 65 nm at 193 nm illumination. In this paper, we present our initial study in the CD process window, mask error factor and CD through pitch performance at the 0.09 μm ground rule for three critical layers—gate poly, metal and contact. The wafer data in the process window and optical proximity will be analyzed. Based on the result, it is shown that the KrF tool is fully capable of sub 0.11 μm node mass production.

Key words: k1 factor; KrF photo resist; lithography

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1. Introduction

Consumer demand is driving semiconductor technical design rules and silicon wafer size even closer to the physical limitations of smaller chip size and higher integrated density for making more powerful ICs and reducing the average chip cost. In order to meet the requirement for continuing shrinking of groundrules, how to improve the pattern transfer fidelity is one of the key issues. In all of them, photo lithography resolution is always the first priority.

In our normal understanding, photo lithography resolution is related to many factors such as exposure wavelength, NA (numerical aperture) of the project lens, illumination method, mask related technology, and chemical characteristics. But of first order impact is the exposure wavelength. For sub-0.11 μm groudrules, the mainstream of the foundry will use ArF for the critical layers for better resolution and CD (critical dimension) control. However, the general KrF process cannot meet the sub-0.11 μm technology node requirement due to too low k1 and difficulty of process control[1, 2].

Cost reduction is a never-ending theme. There are huge relative material cost differences between the KrF and ArF processes, detailed in Fig. 1. This is why the KrF process for the sub-0.11 μm node is becoming more attractive. Thanks to the exposure tool and photoresist vendors' efforts, advanced exposure tools and high resolution KrF resists are available to meet the requirement of the sub-0.11 μm technology node. This will help us to realize similar performance with the KrF process in this technology node and reduce the cost[3].

In this paper, we present our results for critical layers—gate poly, metal-1 and contact—at the sub-0.11 μm technology node. The process window, CD through pitch and MEEF are checked. The results show that the KrF process with high NA exposure tool is acceptable to meet the sub-0.11 μm technology node requirement. During the evaluation and experiments, we do not use a scattering bar to enhance the isolated features process window. If even a more aggressive RET technology is used, the overlap process window is better.

2. Experiment

We studied the poly, metal-1 and contact layers in the photo process. The target feature design rules follow the generic sub-0.11 μm logical process and the metal layer pitch shrinks to 0.24 μm to meet the memory process requirement. A KrF excimer laser scanner was used as an exposure tool

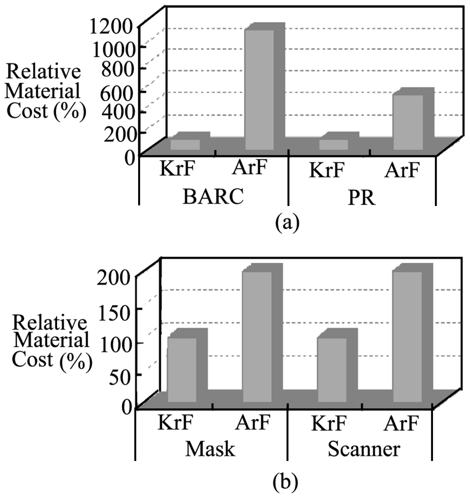

Fig. 1. If KrF lithography process manufactures 90 nm technology devices the cost of fabrication can reduce. (a) Cost for BARC and PR; (b) Cost for mask and scanner.

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† Corresponding author. Email: xzeng@fudan.edu.cn

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Table 1. DOF comparison between high NA/strong OAI and low NA/middle OAI.

	Dense	ISO
High NA / Strong OAI	0.41@8% EL	0.22@7% EL
Low NA / Middle OAI	0.33@8% EL	0.22@7% EL

with maximum NA 0.82, maximum out sigma 0.88 and maximum annular ratio 0.75. For minimum 0.24 μm pitch and maximum 0.82 NA, masks were fabricated using a PSM (phase shift mask). Two kinds of KrF chemically amplified positive resist (one for gate and metal, the other for contact hole) were used.

MEEF (mask error enhanced factor), DOF (depth of focus) and CD proximity effects were used as process criteria. MEEF is defined as the linear fitting curve for ADI CD versus Mask CD from target CD – 0.01 μm to target CD + 0.01 μm (lx). DOF is defined as the focal range with +/– 10% CD variation without resist thickness loss. The optical proximity effect is calculated as the CD difference for lines with pitch change from 0.22 to 1.2 μm under the best exposure conditions.

For the poly layer, in order to improve the process control capability, LWR (line width roughness) is evaluated as additional check item. LWR is defined as the stand deviation of line CD variation through the line.

3. Results and discussion

3.1. Poly layer

The gate poly layer is used to define the device channel length. It is very sensitive to CD variation both on dense features and isolated features. Due to exposure wavelength differences, the KrF process image contrast in dense features is worse than that in ArF. High NA and OAI (off-axis illumination) technology is required. But it is a trade-off: too aggressive NA and OAI will incur an isolated features process window. In order to balance between the image contrast for dense features and process window for isolated features, there are two options for evaluation. One is high NA and strong OAI and the other is low NA and middle OAI.

3.1.1. Process window

Displayed in Table 1 and Fig. 2 are the process windows of dense and isolated features for high NA/strong OAI and low NA/middle OAI. The result shows that high NA and strong OAI can achieve better performance of dense features and comparable performance of isolated features. For the non-scattering bar process, 0.22 μm DOF at 7% EL for isolated features is acceptable.

We checked the dense and isolated features CD and image through-focus performance at the best dose conditions. The result is shown in Fig. 3. The through-focus CD shift is comparable for both processes. But there is a small difference in profile. For LWR, the high NA/strong OAI process is better with a smoother profile. It confirms the result from the other side by LWR value in Fig. 4.

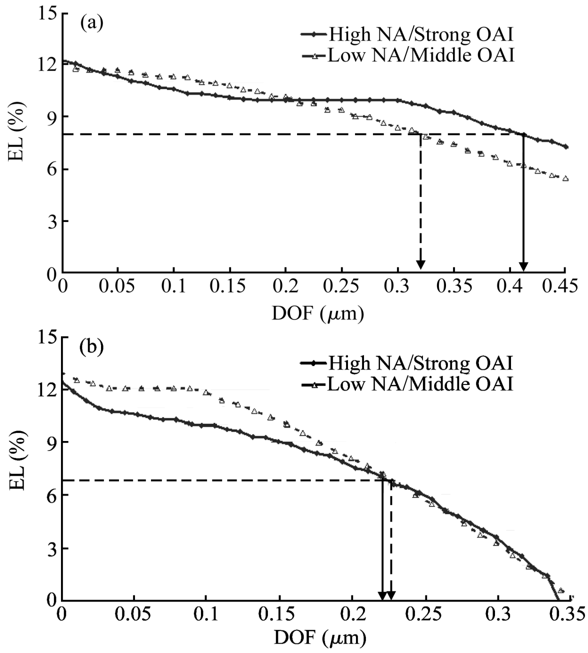

Fig. 2. (a) Dense features DOF comparison between high NA/strong OAI and low NA/middle OAI; (b) Isolated features DOF comparison between high NA/strong OAI and low NA/middle OAI.

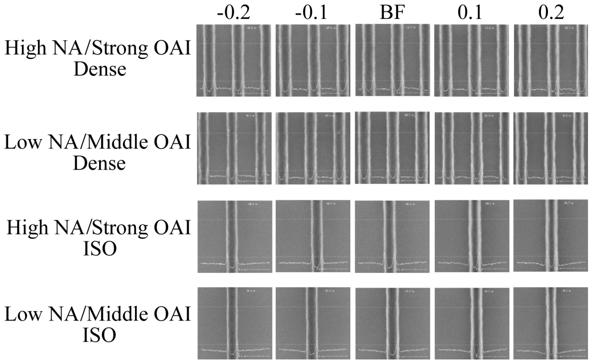

Fig. 3. Top view image comparison between high NA/strong OAI and low NA/middle OAI depending on focus variation at the poly layer.

3.1.2. MEEF

We checked the MEEF for dense features. Figure 5 shows the experimental ADI CD results for main features with line width from 0.10 to 0.12 μm. From the figure a high NA/strong OAI MEEF (2.08) is much better than that of low NA/middle OAI (2.78). It is consistent with our normal understanding that high NA and strong OAI could improve the MEEF.

For a smaller MEEF with high NA and strong OAI, we can control the CD uniformity and LWR more easily from the photo process side. In future process improvement, we will fine tune the other conditions to improve the MEEF.

3.1.3. CD proximity

The optical proximity effect is compared with CD variation with pitch. In Fig. 6, it is almost the same in dense pitch area for both processes. The main difference is that in the semi-

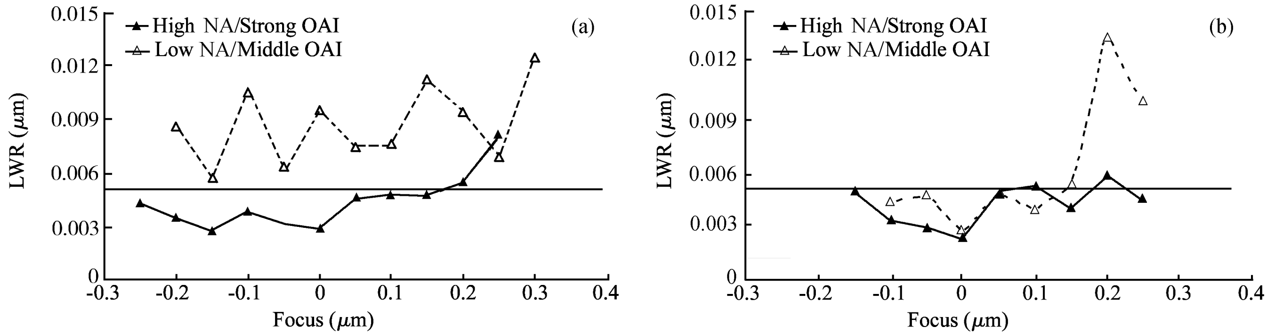

Fig. 4. (a) Dense features LWR through-focus performance comparison between high NA/strong OAI and low NA/middle OAI depending on poly layer; (b) Isolated features LWR through-focus performance comparison between high NA/strong OAI and low NA/middle OAI depending on focus variation at the poly layer.

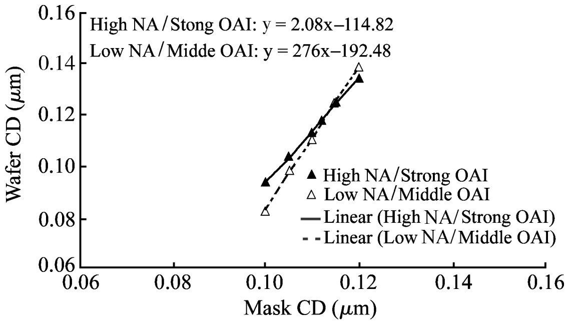

Fig. 5. MEEF comparison between high NA/strong OAI and low NA/middle OAI.

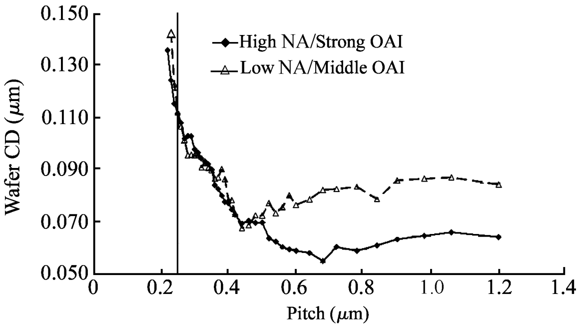

Fig. 6. CD proximity comparison between high NA/strong OAI and low NA/middle OAI.

dense pitch area the high NA/strong OAI will make the dip about 0.02 μm worse than low NA/middle OAI. But it will not gate the process. A 50 nm ISO-Dense bias is acceptable for the photo process and OPC process. At the same time, semi-ISO and isolated features can be improved with a scattering bar if necessary.

We checked the through-pitch LWR performance during the process window analysis. Here, we use 6 nm as the control spec, which is the generic process requirement. The result is shown in Fig. 7. Based on the data, most of the LWR can be well controlled for high NA/strong OAI and critical features can fluctuate within 5 nm. This is consistent with our result in Section 3.1.1.

With the illumination condition optimization, we get the acceptable overlap process window, MEEF, CD proximity and LWR etc. If other factors such as mask bias, bake temperature and resist evaluation can be optimized, the result will improve[4]. At the same time, a scattering bar is available to improve the isolated features performance if necessary[5].

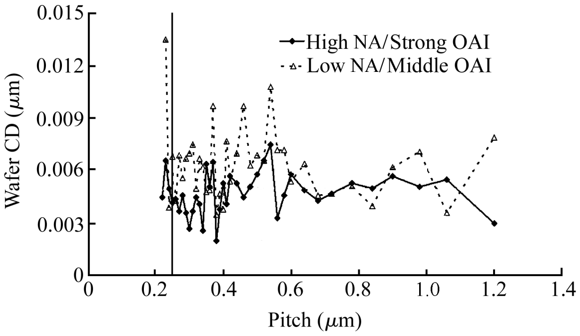

Fig. 7. LWR through pitch comparison between high NA/strong OAI and low NA/middle OAI.

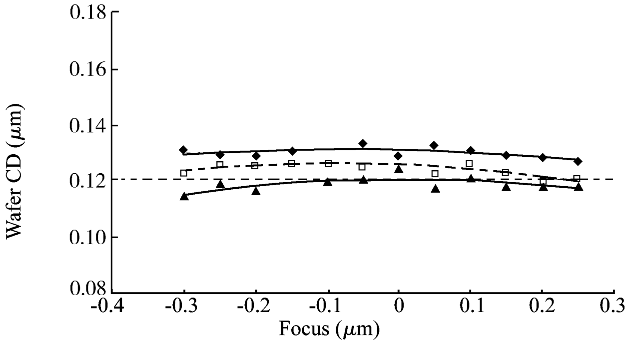

Fig. 8. Process window.

3.2. Metal layer

Unlike the poly layer, the metal layer is designed to interconnect among different devices. The feature of this layer is high integrated density and no bridging/shorting. The metal layer will be focused on a tighter pitch than an isolated line. It emphasizes improvement of the photo process resolution. That is why high NA and strong OAI are the best choice for this layer.

The process window of dense features is shown in Fig. 8. The process window is large enough. The DOF will be 0.55 μm at 8% EL. The top view image depending on focus variation is shown in Fig. 9.

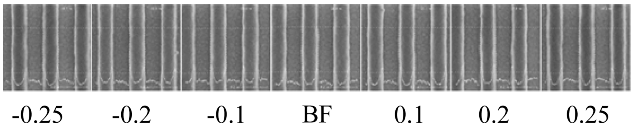

Fig. 9. Top view image depending on focus variation at the metal layer.

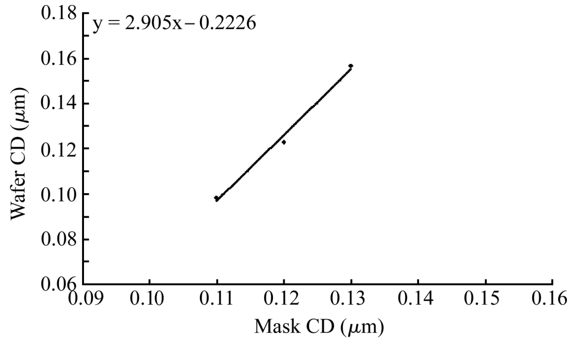

Fig. 10. MEEF.

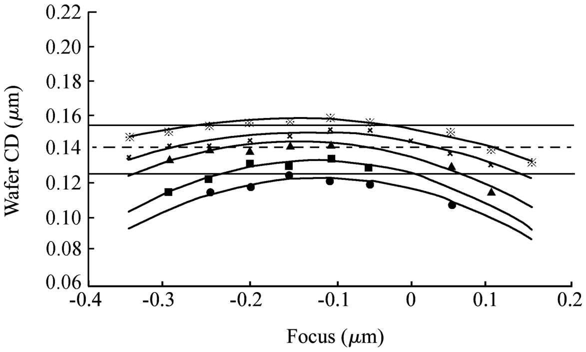

Fig. 11. Process window.

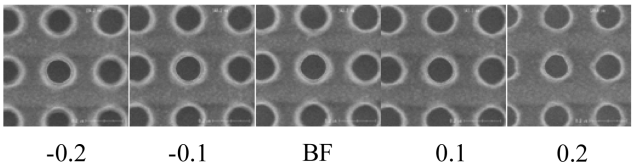

Fig. 12. Top view image depending on focus variation at the contact layer.

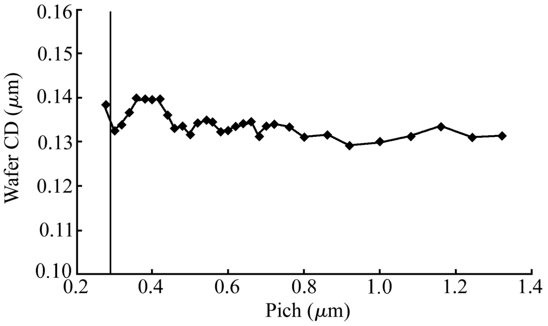

Fig. 13. CD proximity.

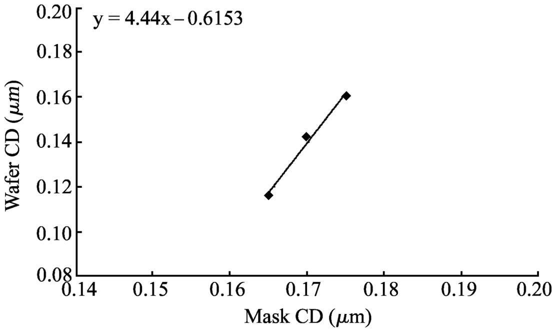

Fig. 14. MEEF.

The MEEF check result is shown in Fig. 10. Because the resist thickness cannot be decreased due to etch process requirements and the ARC layer SiON is not optimized, the MEEF performance is not better, as we required. It can be improved continuously. From these results, the KrF process is acceptable for a metal layer with pitch extended to 0.24 μm. If the ARC layer can be optimized and resist thickness decreased, the result will be better than we achieved.

3.3. Contact layer

As a next step, we studied the hole layer KrF process capability. In general, it is very challenging for the hole layer if k1 is low. The layer OPC is also very challenging if the CD proximity range is too large. In this case, a high NA conventional setting is popular for the generic logical process. We want to achieve an acceptable process window and well controlled CD proximity.

The process window of dense features is shown in Fig. 11. The process window is acceptable. The DOF will be 0.26 μm at 10% EL. The top view image depending on focus variation is shown in Fig. 12.

From Fig. 13, we can control the CD proximity within 10 nm without OPC. It is very amenable to the OPC process.

The MEEF check result is shown in Fig. 14. The number is not good (4.5) since we have to balance the isolated hole process window and CD proximity. From the results and the process requirements, the KrF process is acceptable for the contact layer although the MEEF performance is not as good as we required.

4. Conclusion

We have performed a study of KrF process capability in critical layers of the sub-0.11 μm technology node. Based on the data, we trust that KrF lithography can support enough process control capability for this generation, instead of the ArF process, to reduce the cost, even with some outstanding issues. Incidentally, as is known, the LWR of KrF lithography is better than that of ArF, which would be very helpful for CD and profile control. In general, by using advanced high NA KrF scanners, optimizing the process and improving the process margin in mass production, KrF lithography could fully meet the critical layer requirement of the sub-0.11 μm technology node.

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