

PHOTOMASK

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Novel CD control of HTPSM by advanced process for sub-20 nm tech

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ABSTRACT

As the design rule of the semiconductor shrinks, the CD MTT (Critical Dimension Mean-to-Target) specification for photomask becomes tighter. So, more precise control of CD MTT is required. We have investigated the CD MTT control and applied it to the attenuated PSM (Phase Shift Mask) successfully for several years. We can control the CD MTT of MoSi pattern by measuring Cr/MoSi pattern to estimate MoSi pattern CD and additional etch to shrink MoSi pattern as reported in previous study. At first, the MoSi pattern CD can be estimated with the Cr/MoSi pattern CD because the CD gap between MoSi pattern and Cr/MoSi pattern is relatively constant. Additional MoSi etch is performed to shrink the MoSi pattern CD after then. The CD gap always exists and the variation of the CD gap is enough small to be not considered in conventional photomask production until now. However, the variation of the CD gap is not ignorable in case of sub-20 nm tech.

In this study, we investigated new method to measure MoSi pattern CD before Cr strip process to eliminate the CD gap between MoSi pattern and Cr/MoSi pattern. To eliminate the CD gap, we attempt three solutions – 1) Optimize etch process to perform perfect Cr/MoSi pattern profile without the CD gap, 2) Improve CD measurement accuracy by developing new SEM measuring mechanism, 3) Develop of new process to modify Cr/MoSi pattern profile to be measured without the CD gap. It was found that the CD gap can be eliminated and MoSi pattern CD can be measured perfectly. Finally, MoSi pattern CD control was improved because of CD gap elimination.

Introduction

We reported that we have investigated the CD MTT control and applied it to the attenuated PSM (Phase Shift Mask) successfully for several years. We can control the CD MTT of MoSi pattern by

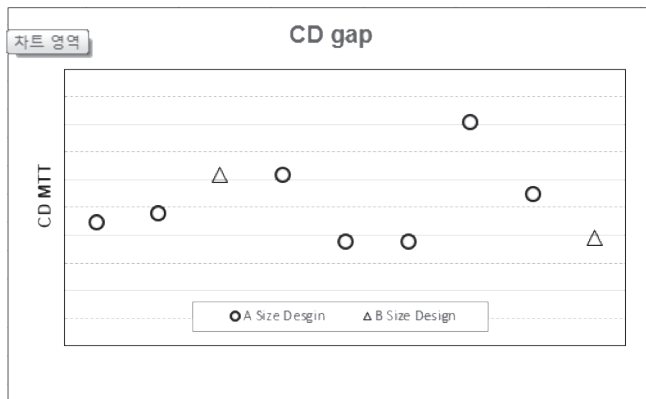


Figure 1. CD gap between Cr/MoSi pattern CD and MoSi pattern CD.

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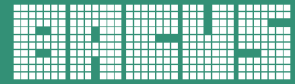
Time for a Changed Cooperation Model – Equipment Manufacturing for High-End Nodes

Jan Hendrik Peters, Carl Zeiss SMT GmbH

In the “good old days” equipment manufacturing was following a very traditional path. Engineering ingenuity in conjunction with the ITRS roadmap guidance and a close – almost intimate – knowledge of mask makers needs allowed equipment companies to develop tools that would fit the market needs for mask manufacturing. Many mask shops would jump to the new tool generations within a very short time, allowing equipment manufacturing companies to recuperate their development cost in a timely fashion and hence earn enough money to pre-finance research and development for the next generation.

The world, however, is moving on. Fewer mask shops are willing or capable of serving the top nodes with latest tools, the node timing gap between leaders and followers has increased and EUV tools are a game changer by themselves. At the latest BACUS 2015 Panel Session this topic was addressed by several speakers and people from the auditorium. Building equipment on own funds and then selling it to the market is no longer possible at the very bleeding edge of technology. EUV specific tools are the most pronounced examples for this development. Tool development time and related cost are exceeding by far any extrapolation from the classical tool set experience. Cooperation models like the EUV Mask Infrastructure Consortium (EMI) have been developed to bridge that gap. Here, a consortium of interested companies jointly supports the development of an EUV specific tool and the construction of a fully functional prototype with privileged access for research and development for mask making processes on this tool. Economically, such an approach is favorable for all participants including the equipment maker, if and only if, finally tools are being sold in due time and number. For EUV, the introduction for high volume manufacturing has been pushed out several times due to many different reasons, making it hard to reach economically solid grounds for the equipment manufacturing. This inherently will also have an impact on the support infrastructure once the tools are delivered and successfully operated in the field.

While this is pretty evident for EUV, I do see first signs of a similar development also in the regime of the more traditional 193nm mask specific high-end tools. Leading edge customers are requesting functionalities that will not be needed for a long time at other customer sites for their specific technology or manufacturing needs. Are we moving to an era of dedicated, specifically tailored machines as in other industries? This would have an impact on the current relationship between mask makers and equipment manufacturers. Consortium approaches, similar to the EMI activities, or full-finance models between customer and mask shop to support the development and market introduction of tools would become the normal way of interaction. Mask making has definitely moved out of the commodity corner towards an industry with very specific needs for dedicated tools and new models of cooperation with equipment makes. Let's shape this new era together.



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Figure 2. Structure of Mask before Cr strip.

measuring Cr/MoSi pattern to estimate MoSi pattern CD and additional etch to shrink MoSi pattern as reported in previous study. The MoSi pattern CD is needed to know accurately to control the MoSi pattern CD. We estimated the MoSi pattern CD with the Cr/MoSi pattern CD before 2nd Cr strip process because the CD gap between MoSi pattern and Cr/MoSi pattern is relatively constant. The CD gap have been ignorable until now, but the variation of the CD gap is not ignorable in case of sub-20 nm tech. The variation of the CD gap is larger than that of additional etch to shrink MoSi pattern. So, less CD gap is advantageous to estimate the MoSi pattern CD.

We investigated new method to measure MoSi pattern CD before Cr strip process to eliminate the CD gap between MoSi pattern and Cr/MoSi pattern. To achieve the purpose we attempt three solutions: optimization of etch process, Improvement of CD measurement and Development of new process to decrease the CD gap.

Experimental Details

Sample type and process condition

In this study, ArF 6% transmittance attenuated phase shift masks were used, which are coated with positive photo-resist. 50KeV VSB E-beam writer, puddle type developer and ICP type dry etcher were used to define patterns on mask surface. We measured CD with CD SEM and analyzed the pattern profile with TEM.

Comparison of variation between the CD gap and additional etch

We have investigated method to control the CD MTT of MoSi pattern by measuring Cr/MoSi pattern to estimate MoSi pattern CD and additional etch to shrink MoSi pattern. At first, the MoSi pattern CD can be estimated with the Cr/MoSi pattern CD because the CD gap between MoSi pattern and Cr/MoSi pattern is relatively constant. Additional MoSi etch is performed to shrink the MoSi pattern CD after then. There are two error factors to effect the CD MTT of MoSi pattern. It's the CD gap and additional MoSi etch because the two factors have variation. The variation of two factors always exists and the variation is enough small until now. The variation of additional MoSi etch is still ignorable, but the variation of the CD gap is not ignorable in case of sub-20 nm tech because the variation of CD gap is larger than that of additional MoSi etch. The variation of the CD gap is about 3 nm (Fig.1) but that of the additional MoSi etch is under sub nano meter.

Tighter CD MTT spec is needed to develop sub-20 nm tech, so ~3 nm is not ignorable variation value any more. The CD gap must be eliminated from their CD MTT control technology to meet tighter CD MTT spec.

Source of the CD gap

We studied the structure of mask to find out the source of the CD gap. We discover that the MoSi pattern CD is always smaller than that of Cr/MoSi pattern CD. It means the size of MoSi pattern is smaller than that of Cr pattern. We guessed the structure of mask

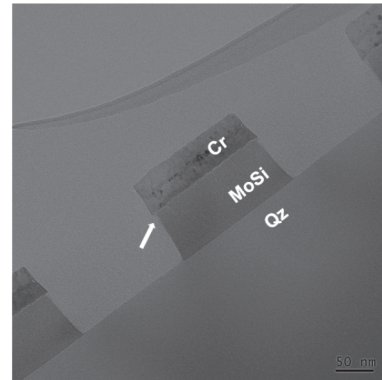


Figure 3. TEM image of Mask structure.

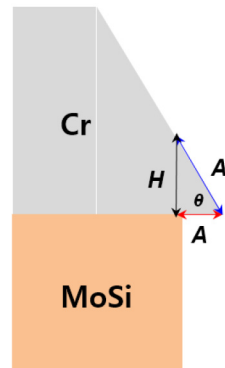


Figure 4. Schematic drawing of Cr/MoSi pattern edge.

with these results. (Fig. 2). And we verified the structure with TEM analysis. (Fig. 3)

We confirmed that the size of MoSi pattern is smaller than that of Cr pattern. As we confirmed at TEM image, the source of the CD gap is double profile of Cr/MoSi pattern structure. We attempt to measure the MoSi pattern CD through the double profile and modify the double profile with optimized etch process or adding new process.

Result and Discussion

Improvement of CD Measurement

We tried other method to eliminate the CD gap between the Cr/MoSi pattern and the MoSi pattern. Second method is measuring the MoSi pattern CD directly through the Cr patten. We tested the various condition of SEM like threshold, peak detection algorithm and pressure condition. Unfortunately, we could not measure the MoSi pattern CD directly. The reasons are guessed. We think that the result show the limit of SEM mechanism. Cr pattern has footing on the tip of the both side edges of pattern. The slope of the Cr pattern is not ideal so, Fig.4 demonstrate the magnified structure of Cr/MoSi pattern. The footing of Cr pattern have any angle, θ . The half CD gap, A is about 3 nm as shown fig. 1. The MoSi pattern CD can be measured if the electron beam of SEM can penetrate the Cr layer. The edge height, H is related to e-beam penetration as shown fig.4. Conventional SEM uses 1.0kV~1.5kV and the interaction depth is about 5 nm from surface so the edge height, H must be smaller than 5 nm. When the angle of edge is smaller

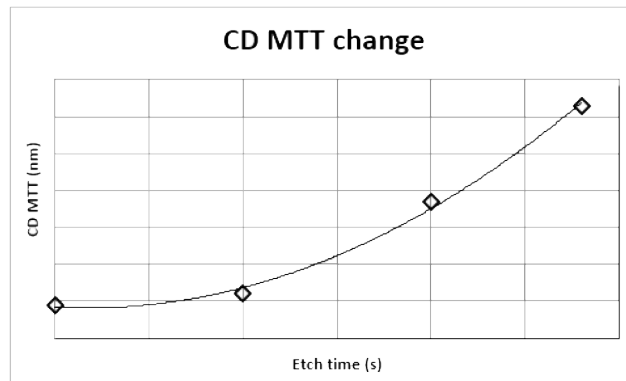


Figure 5. Cr shrink etch time –vs- CD MTT change.

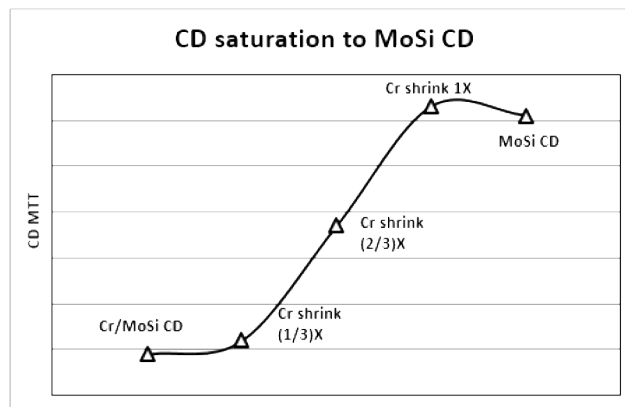


Figure 6. CD change trend and saturation to MoSi CD.

than 59° , the edge height, H is smaller than 5 nm and the MoSi pattern CD can be measured. The angle of all mask manufactured in our mask-shop is nearly 90° , so e-beam cannot penetrate the edge height and we cannot measure the MoSi pattern CD for conventional good photomask fundamentally.

$$\theta = \tan^{-1} \frac{H}{A} = \tan^{-1} \frac{5}{3.0} = 59^\circ \quad (\text{Eq.1})$$

CD gap decrease process

There is the other approach to detect the edges of MoSi pattern to measure MoSi pattern CD. It's that the real edges of MoSi pattern is peeled by new process. If the size of Cr pattern is shrunken the MoSi pattern CD can be measured. We can shrink the Cr pattern by additional Cr etch because the etch selectivity of Cr to MoSi by chlorine based plasma is larger than 1.0. But the Cr pattern shrink must be minimized as possible as because thin Cr layer cannot meet several photomask specs – O.D., transmittance and reflectivity of mask surface. So etch process condition that have high horizontal etch rate and low vertical etch rate. The additional series of patterning process like 2nd process is needed to protect Cr layer surface, too. The Cr layer that will be removed by 2nd process is under our concern.

The possibility of CD measurement was check first of all. We confirmed that the CD MTT can be changed as change of pattern

edge by Cr shrink etch. The relation equation is a quadric equation.

We found optimal Cr etch process condition including time. After then, we checked that the changed CD MTT is saturated to that of MoSi pattern. It was found that the MoSi pattern CD can be measured after optimal Cr shrink etch because the CD value is almost same the MoSi pattern CD after Cr strip (fig.6). The CD difference between the pseudo MoSi pattern CD (after Cr shrink) and the MoSi pattern CD is less than reliability of SEM.

We had interest in what happened in the pattern edge and double profile of Cr/MoSi structure. The changes of structure are analyzed with SEM and TEM. Figure 7 show the TEM image of Cr/MoSi structure after Cr shrink etch. The double profile structure of Cr/MoSi pattern was changed to 2 steps structure. It's shown that the shrunken Cr layer have size shrink to horizontal direction and vertical direction. The additional series of patterning process like 2nd process is needed to protect Cr layer surface of specific area what must be meet optical spec because of vertical Cr etch damage of Cr shrink etch.

CD SEM images were analyzed, too. The edge of pattern (white line in SEM image) is widened after Cr shrink etch as shown in fig.8 and fig.9. It shows the comparison of CD SEM images before and after Cr shrink etch. It is thought that the signal of edges of two steps are merged and the signal of edge grow strong. The edge of island pattern was wider than that of Line/Space pattern.

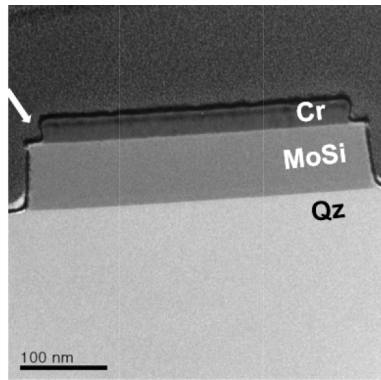
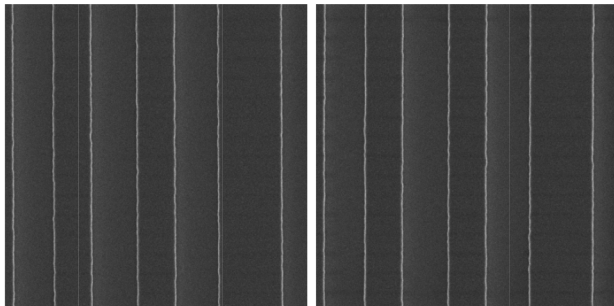


Figure 7. TEM image of Cr/MoSi after Cr shrink etch.

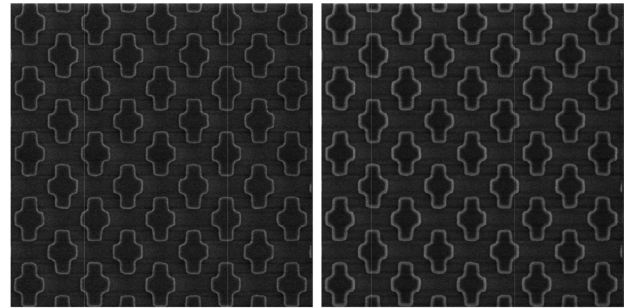


(a) before Cr shrink etch (b) after Cr shrink etch
Figure 8. CD SEM image of Line & Space pattern after Cr shrink etch.

It is thought that the island pattern is more damaged because this type have the exposed edges more. But CD MTT saturation is similar to each other.

Optimization of etch process

We attempted to optimize the profile of the Cr/MoSi pattern not to have double profile. The smaller size of MoSi pattern is thought caused by etch bias for MoSi etch process. Etch selectivity of MoSi to Cr is higher than 1 and plasma based on fluorine gas have a chemical etch characteristic. We optimized the etch process condition to minimize the etch bias. We approach the purpose with idea that maximize the vertical MoSi etch rate. Vertical MoSi etch rate is critical process factor because the etch rate determined phaseshift. It is difficult control phaseshift with high vertical MoSi etch rate. The new MoSi etch process is optimized to have high vertical etch rate, low phaseshift damage, low etch bias and no damage of Cr layer. We applied the new etch condition and found the decrease of the CD gap between Cr/MoSi pattern CD and MoSi pattern CD. It means that the double profile is improved. The reliability of CD gap was confirmed and the CD gap with new MoSi etch condition is enough smaller than reliability of CD SEM (Fig.10).



(a) before Cr shrink etch (b) after Cr shrink etch
Figure 9. CD SEM image of Island Pattern after Cr shrink etch.

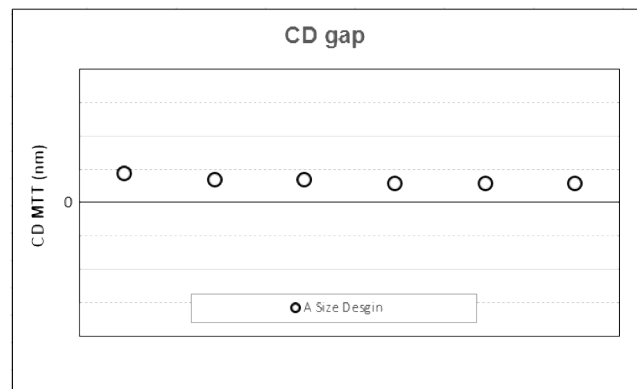


Figure 10. CD gap between Cr/MoSi pattern CD and MoSi pattern CD with new etch condition.

Summary

In this study, we investigated new method to measure MoSi pattern CD before Cr strip process to eliminate the CD gap between MoSi pattern and Cr/MoSi pattern. To eliminate the CD gap, we attempt three solutions- Improving CD measurement accuracy by developing new SEM measuring mechanism, Developing of new process to modify Cr/MoSi pattern profile to be measured without the CD gap and Optimizing etch process to perform perfect Cr/MoSi pattern profile without the CD gap. It was found that the CD gap can be eliminated and MoSi pattern CD can be measured perfectly. Finally, MoSi pattern CD control was improved because of CD gap elimination.

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Industry Briefs

■ Collaboration is the centerpiece to push the limits of lithography

Greg McIntyre, Director Advanced Patterning, imec, Solid State Technology, January 2016

The continuation of Moore's Law requires a combination of both physical and functional scaling, in a controlled and cost-effective way. Optical lithography tries to squeeze everything one can out of immersion lithography by both enhancing resolution and controlling variability. Resolution enhancement for immersion is being achieved through both an increasing degree of multiple patterning and by leveraging the properties of novel materials such as in directed self-assembly (DSA). In DSA, sub-resolution patterns are created by the micro-phase separation of specially engineered polymer chains called block copolymers, which are directed in specific orientations by lithographically generated guide patterns. Minimizing the impact of variability is done by developing techniques to measure, optimize and control the patterning process window and co-optimization of multiple unit process steps (litho, etch, deposition, etc.), with the variety of self-aligned integration schemes.

EUV lithography appears a necessity for the continuation of cost-effective physical scaling. The ramp in stable power of the light source is a prerequisite for EUV insertion. The ecosystem of EUV lithography, involves materials, masks, imaging fundamentals, and computational techniques. EUV resolution is currently material-limited, but work is needed on various aspects of the photomask, including inspection systems, printing performance, interactions between the light source, mask, lens, and photoresist, and computational techniques to optimize the pattern.

Collaboration is key to continue the path of lithography. Tool and material suppliers bring in not only state-of-the-art tools and materials, but also insights and experiences that help fuel developments and thus strengthen the core CMOS program.

■ Bubble-Pen Lithography Deftly Handles Nanoparticles

Photonics.com

AUSTIN, Texas, Jan. 18, 2016 — Bubble-pen lithography — which relies on microbubbles to inscribe, or write, nanoparticles onto a surface — has been demonstrated to efficiently handle nanoparticles used in micro- and nanomanufacturing. The ability to handle the tiny particles of gold, silicon and other materials could ease fabrication of biomedical sensors, optical computers, solar panels and other devices. Despite their potential, nanoparticles' small size makes them difficult to handle, and manipulation can affect their properties and functions. "The ability to control a single nanoparticle and fix it to a substrate without damaging it could open up great opportunities for the creation of new materials and devices," said University of Texas at Austin professor Yuebing Zheng. "The capability of arranging the particles will help to advance a class of new materials, known as metamaterials, with properties and functions that do not exist in current natural materials."

Using the bubble-pen device, the researchers focused a laser underneath a sheet of gold nanoscale islands to generate a hotspot that created a microbubble out of vaporized water. The bubble attracted and captured a nanoparticle through a combination of gas pressure, thermal and surface tension, surface adhesion and convection. The laser then steered the microbubble to move the nanoparticle on a site on the surface. When the laser was turned off, the microbubble disappeared, leaving the particle on the surface. If necessary, the researchers can expand or reduce the size of the microbubble by increasing or decreasing the laser beam's power.

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Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

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