Seam Defects Caused By Clear Field Mask Chrome Dimensions

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Abstract

Seams are an anomaly that occurs when the chrome border of a clear-field mask is smaller than stepping distance during exposure. Both positive tone and image reversal resist processes are susceptible to this phenomenon. However, the result is different in both cases. On the surface, it may seem benign, but could have an impact on yield and cause issues with unconventional masking layers, specifically those that require field stitching. The stepping distance and the chrome border size play a large role in the seam formation. This paper documents an understanding of the issue and the ways to both fix the problem and mitigate its impact on current processes.

INTRODUCTION

Photolithography is the hub of any semiconductor manufacturing process from simple 5 masking layer LEDs to complicated 20+ layer CMOS devices. The photo area sees these wafers numerous times whether the need is for a temporary layer for etch protect or metal lift-off to permanent coating of polyimides and SOGs. The most expensive tool in this area is the exposure tool. Whether it is an I-line stepper, DUV step and scan or the latest in immersion or EUV systems, these tools are the work horses in the processing of any type of device. There are 2 interactive components that are typically taken for granted; the chrome border on the mask and the stepping accuracy of the exposure tool. SPC data is taken and PM activities verify that the tool is performing as it should. But what about the clear field chrome opening? How is it measured and controlled? And what kind of impact could it have if the size was not as expected?

PROBLEM

The best way to understand any issue is to gather as much information around the problem as possible. In this case, visual data was extremely important. Since the issue is at the microscopic level, microscope and SEM inspections were done to characterize the defects for both positive tone and image reversal modes. Optically, the defects looked very similar. It wasn't until SEM inspections were performed that the true nature of the defect was revealed.

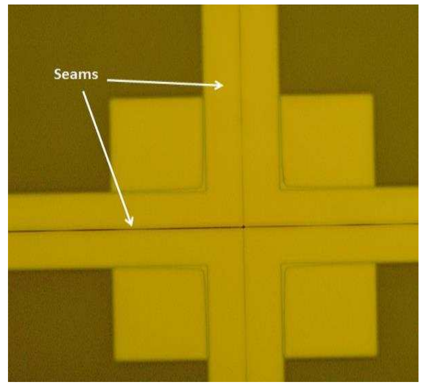

Fig.1 Optical image of an Image Reverse seam

Seams are small lines located at the edges of the exposure fields (Fig. 1). For the image reversal process, a shallow trench is formed in this region along the field borders. However, in the field corners, the trench depth reaches the substrate (Fig. 2). During metal deposition and lift-off, small metal poles or spikes could remain on the surface in these areas. These defects probably do not survive the lift-off process, however they could pop off and redeposit onto the wafer or impact future layer processing if they remain.

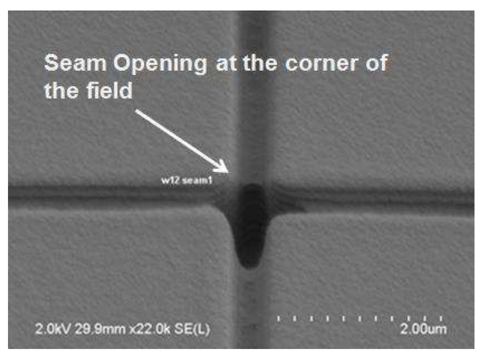

Fig.2 SEM image of an Image Reversal resist seam

In the positive tone mode, a small thin resist line remains along the field edges (Fig. 3). The effects of a seam in this mode could be worse. During etch steps, where positive resist is more widely used, a small unetched material barrier would remain. Again, this would be located in the streets but easily visible during optical inspection, flagging the lot/wafer for additional defect review and slowing its progress.

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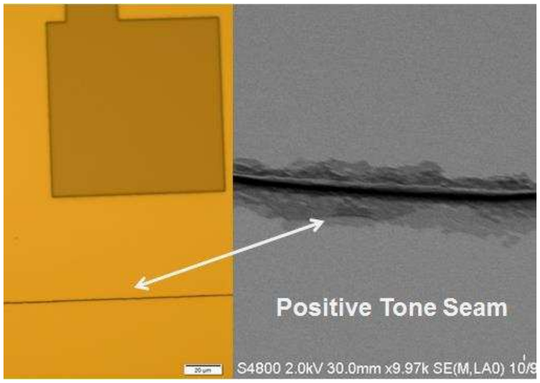

Fig.3 Optical and SEM image of a Positive Tone resist seam

In conventional device processing, seams are not a problem due to its location, in the street. However, in other devices, like MEMs, antenna and wave guide processing where field stitching is necessary, these seams can cause problems. Some metals in these processes are deposited as a blanket film then patterned and etched. Seams in the resist would block the etch and result in bridging of these features rendering the device useless. In areas that are not stitched, these metal stringers would have the potential to separate from the wafer surface, redeposit elsewhere on the wafer and short other devices, again rendering them non-functional and reducing yield.

BRAINSTORMING AND EXPERIMENTATION

Since there was a strong understanding of the problem, a brainstorming activity took place to identify possible root causes. Once the list was complete, the top 5 were selected to evaluate: (1) stepper blade location, (2) stepping distance, (3) magnification, (4) exposure, and (5) mask chrome border size. Experiments were developed around these items and tested to either validate or exonerate these potential root causes.

Before testing could begin, the defect needed to be replicated. This was done by processing wafers with a dose matrix and the reticles from known problematic (seam generating) layers. A significant under-dose of the resist showed distinct seams (Fig. 4). This gave a test bed to develop and test solutions to further understand and resolve the issue.

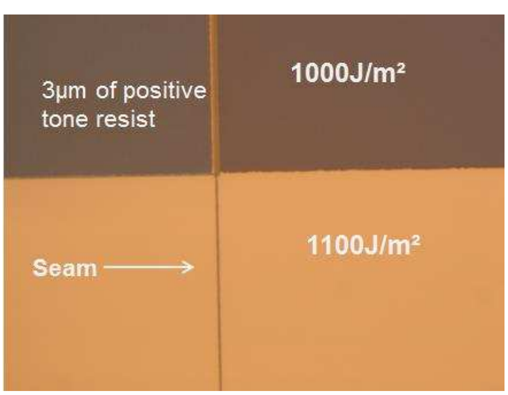

Fig.4 Optical image of a replicated seam in 3µm Positive Tone resist.

1. Stepper Blade Location

The blades are positioned a measureable distance from the edge of the chrome border so that the on-wafer field edge is defined by the mask chrome edge (clear field only). Screening experiments have shown that when a blade encroaches into the clear-field region of the mask, the diffracted light from the exposure results in a poorly defined edge in the resist (Fig. 5). So for this reason, the blade location is not causing the issue.

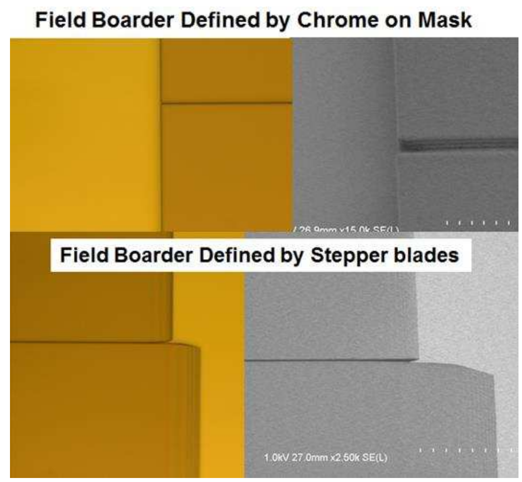

Fig.5 Optical and SEM images of Mask Chrome and stepper blade defined field border

2. Stepping Distance

Steppers are very precise in their stepping distance accuracy. To validate this, a Canon stepping distance monitor was processed with no offset then again with a 0.2µm offset. As Fig.6 shows, the control wafer sits at 0 on the vernier alignment targets, whereas the wafer with a forced stepping distance of 0.2µm shows the same error shift on the overlay verniers. The stepper is performing as it should. Then a wafer was processed with a shorter stepping distance using a known seam generating causing field to field overlap. Under these conditions, the seam was eliminated. This was the first indication that the mask field size may be part of the problem.

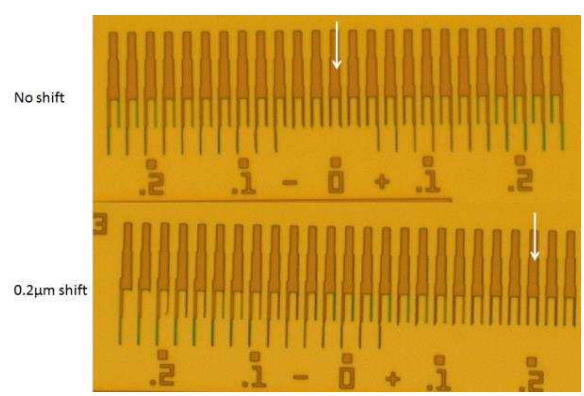

Fig.6 Optical image of overlay verniers with and without a stepping shift

3. Magnification

Based on the stepping distance results, the field size could also be modified by pushing the magnification parameter in the stepper to its limits, ~30ppm. This effectively made the field smaller and the result was seam formation at the field edges. However, since the entire field was shrunk, the alignment within the device shifted to an unacceptable level (Fig. 7). Increasing the magnification would have eliminated the seam, but a similar but directionally opposite alignment issue will occur across the field becoming worse at the field edges.

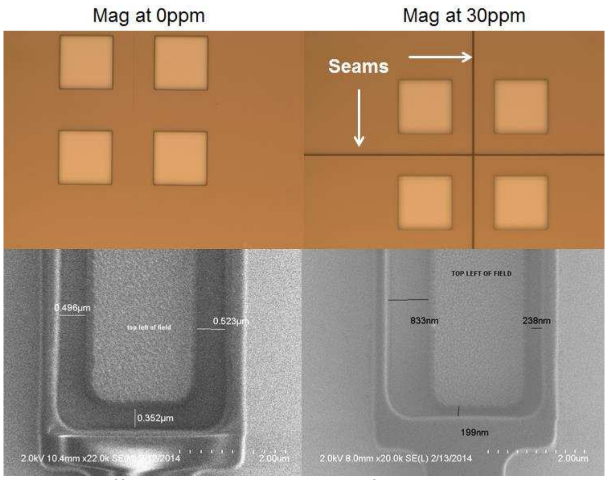

Fig. 7 Mag effects on Seam generation and feature alignment results

4. Exposure

One parameter that did eliminate/minimize the seam was dose. By increasing the dose by ~200J/m² (depending on resist thickness), the seams for both positive and image reversal processes were minimized and in most cases eliminated (Fig.8).

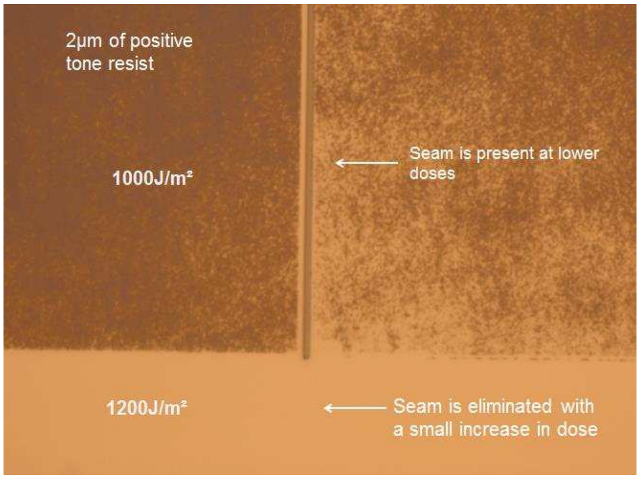

Fig.8 Optical image of exposure impacts on the seam

5. Chrome Border size

There was now substantial evidence to suggest that the leading root cause was related to the size of the chrome boarder. If the chrome border is smaller than the expected field size and the stepping distance matches the field dimensions, there will be no field-to-field overlap resulting in unexposed areas between steps. There will be light diffraction that will expose some regions of the resist but the intensity will not be enough to cause a significant reaction (Fig.9 and Fig.10).

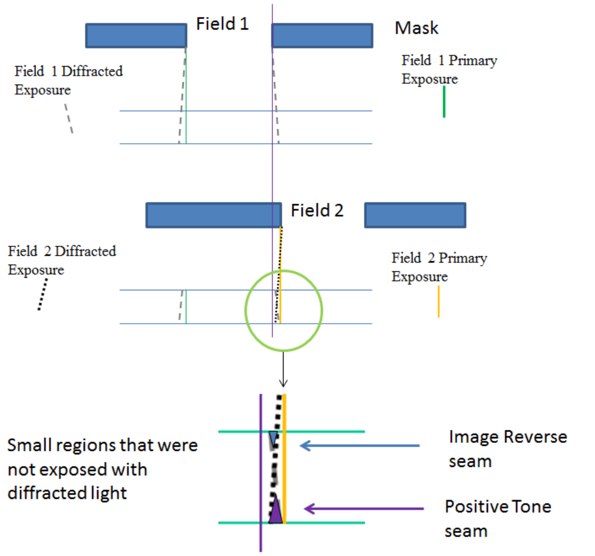

Fig. 9 Diffraction of light between 2 adjacent exposure fields

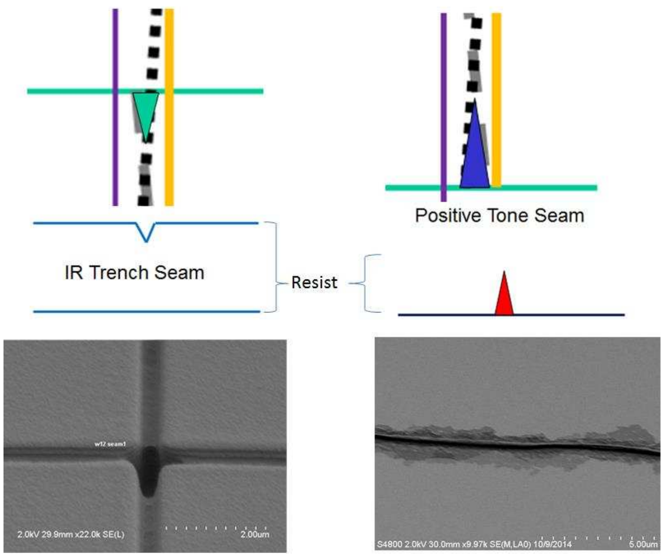

Fig. 10 Results of diffracted light on IR and Positive Tone Seam generation

From the results of these experiments, the **root cause** of the seam formation has been verified as the result of the size of the bright-field chrome border being smaller than the field to field stepping distance.

VALIDATION

To validate this theory, the actual measurement of the chrome to chrome opening of a bright-field mask must be known. With the help of the mask vendor, four (4) bright-field openings were measured on 1 reticle. They were able to give ~0.1µm of accuracy. The measured chrome opening on the mask (50mm x 50mm as designed) was 50.0007mm (50000.7µm or 0.7µm larger than required). Under a 5x reduction projection stepper, the on-wafer field size was 10.00014mm (10000.14µm or 0.14µm larger than the 10mm expected size)

With the field size dimensions known (10.000014mm), a dose matrix was run, keeping the stepping distance constant at 10mm. The region between the stepping fields received 2x the exposure dose (field-to-field overlap), clearing the resist along the field boarders (Fig. 12).

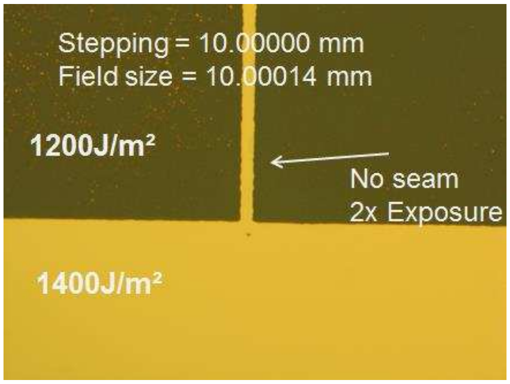

Fig. 12 Effect of field size, stepping distance and exposure on Seams in 3µm PR

The stepping distance was then increased from 10mm to 10.000025mm (0.11µm larger than the chrome boarder dimensions) to simulate a smaller field size with respect to the chrome boarder opening. A dose matrix was run and the results confirmed the theory. The seam was present in the under-dosed fields and eliminated in the higher-dose fields (Fig. 13).

Fig. 13 Effect of field size, stepping distance and exposure on Seams in 2µm PR

This validation exercise proved the root cause of seam formation (or lack thereof) is due to the dimensions of the clear-field chrome border on the mask. Previous experimentation also identified several contributing factors that can amplify or minimize the generation of seams.

Conclusions

Several different parameters were identified that contribute to the formation of seams: resist thickness, stepping distance variation, low dose, and magnification. However, the root cause of the seams is due to the size of the chrome border of the clear-field mask being too small in relation to the desired field size and stepping distance.

For current masks in house, increasing the dose (the main contributing factor to seam formation) by 200J/m² + (depending on resist thickness and substrate material) will eliminate the seam for both processing modes (IR and Positive Tone). However, some additional optimization will be needed for layers with sensitive critical dimension.

Stepping distance changes also eliminated the seam, however, it is not practical to implement. This parameter would need to be changed across all layers of the device at the start of the process. Wafers in line will not be able to use the new settings and could result in additional reworks for misalignment.

Finally, to address the root cause, all new masks will be ordered with a slightly larger chrome border size (at least 0.5µm) for clear-field layers to ensure field to field overlap occurs, preventing seam formation on all processes including those that require lower doses.

Acknowledgements

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Acronyms

PR: Photo Resist
IR: Image Reversal
CMOS: Complementary Metal–Oxide–Semiconductor
LED: Light Emitting Diodes
DUV: Deep Ultra Violet
EUV: Extreme Ultra Violet
SOG: Spin on Glass