Advanced process capabilities for electron beam based photomask repair in a production environment

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ABSTRACT

The cost and time associated with the production of photolithographic masks continues to grow, driven by the ever decreasing feature size, advanced mask technologies and complex resolution enhancing techniques. Thus employment of a high-resolution, comprehensive mask repair tool becomes a key element for a successful production line. The MeRiT® utilizes electron beam induced chemistry to repair both clear and opaque defects on a variety of masks and materials with the highest available resolution and edge placement precision. This paper describes the benefits of the electron beam induced technique as employed by the MeRiT® system for a production environment.

KEYWORDS: mask repair, repair tool, MeRiT®, electron beam, Carl Zeiss, PSM deposition

INTRODUCTION

The cost involved in the production of photolithographic masks makes up an increasingly larger portion of the semiconductor industry as the technology node decreases. The industry has currently reached the 45 nm node and the International Technology Roadmap for Semiconductors (ITRS) projects that the 32 nm node will be upon us within five years [1]. In order to resolve such small features, resolution enhancement techniques (RET) such as the use of phase shifting and optical proximity correction (OPC) must be employed. Phase shift masks (PSM) are commonly used in today's mask shop with high end shops looking ahead towards high-transmission and extreme ultra-violet (EUV). OPC involving the addition or modification of features such as scatterbars, hammerheads and serifs is another commonly used RET that becomes more aggressive and intricate the smaller features become. Furthermore, an increase in the number and intricacy of process steps, as well as the use of more cost intensive production tools and materials has also occurred. All of these technologies contribute to the increased complexity of photomask design and fabrication. The ability to repair photomask defects is more important than ever in order to increase yield, reduce costs and stay competitive in the semiconductor industry.

Although several photomask repair techniques exist, until now there has been no single tool that can repair all defect types. Focused ion beam (FIB), laser and atomic force microscopy (AFM) based repair tools are commonly used, however each technique has its limitations. Laser based tools do not have the resolution necessary for the 45 nm node and below and only have the capability for opaque defect repair. FIB repair tools suffer from exposure damage such as ion implantation resulting in optical transmission loss (referred to as staining) and unwanted physical sputtering. These effects eliminate the ability to perform repair inspection and deposit phase-shift matching material as well as make small opaque defect repair difficult due to riverbedding and the lack of material selectivity. AFM based techniques are time consuming in the case of large defects and create debris, often requiring multiple cleaning procedures during a single repair. Furthermore these techniques are limited by certain tight geometries and are restricted to opaque defect repair only. The need for a high-resolution, comprehensive mask repair tool is detrimental for today's competitive production environment.

The MeRiT® electron beam mask repair tool meets this need by utilizing electron beam induced chemistry to repair both clear and opaque defects on a variety of masks with the highest available resolution and edge placement precision [2]. The use of an electron beam eliminates radiation damage as there is no ion implantation or physical sputtering. No debris is created due to the purely chemical nature of the process, so no cleaning steps are required. Features of the MeRiT® such as the proprietary charge blocking method, laser interferometer, gas introduction system, pattern copy and recognition, and drift correction have previously been addressed. Furthermore, experimental results on the repair of some programmed defects such as opaque binary defects and clear PSM defects have also been reported [3].

This paper demonstrates the advantages of electron beam technology and presents recently developed features of the MeRiT® that seek to broaden its repair capabilities and further improve yield. Both clear and opaque PSM defects are repaired and subjected to AIMS® analysis in order to demonstrate the advantages of the electron beam technology for PSM repair. Incorporation of the above-lens energy and angle selective backscatter electron (EsB) detector for atomic number based endpointing is also introduced. Finally, in collaboration with the Advanced Mask Technology Center GmbH & Co (AMTC), several production plate defect repairs have been performed successfully to validate the performance of the MeRiT® in a true production environment.

MeRiT® CAPABILITIES AND BENEFITS

The advantages of the MeRiT® repair technology over other techniques lie in the use of a focused electron beam to induce chemical reactions between an adsorbed precursor and the photomask surface. Depending on the precursor chemistry and photomask material, this reaction results in the removal of volatile products in the beam irradiation area (etching) or the addition of non-volatile material (deposition). The industry proven, robust Carl-Zeiss Gemini® electron beam column [2] with its electrostatic and electromagnetic immersion lens, provide the outstanding performance at 1 keV (with a 50 pA specimen current and spot size under 3 nm) which is required to meet the stringent requirements for this application.

The use of an electron beam to induce the chemical reaction introduces no radiation damage such as physical sputtering or ion implantation. Since there is no physical sputtering component to the repair process, physical alteration only occurs in the area irradiated by the beam when the precursor is locally introduced. In the absence of precursor gases unlimited pre- and post-repair inspection is possible with minimal degradation of the optical properties and with better resolution than many CD-SEMs. The absence of ion implantation allows the deposition of pure materials that can match the phase shift and absorption properties of any advanced PSM. The ability for quartz etching has also been realized without the deleterious effects of staining.

Figure 1 shows an example of a broken line on a 193 nm 6% transmission MoSi mask that has been repaired with PSM deposition. SEM images of the defect are shown before the repair in a) and after the repair in b). AIMS® analysis data is included in c) to make evident how well the deposited material matches the original MoSi. Note how the transmission and the through focus behavior of the CD for both the deposited line as well as the neighboring spaces closely agrees with that of the MoSi.

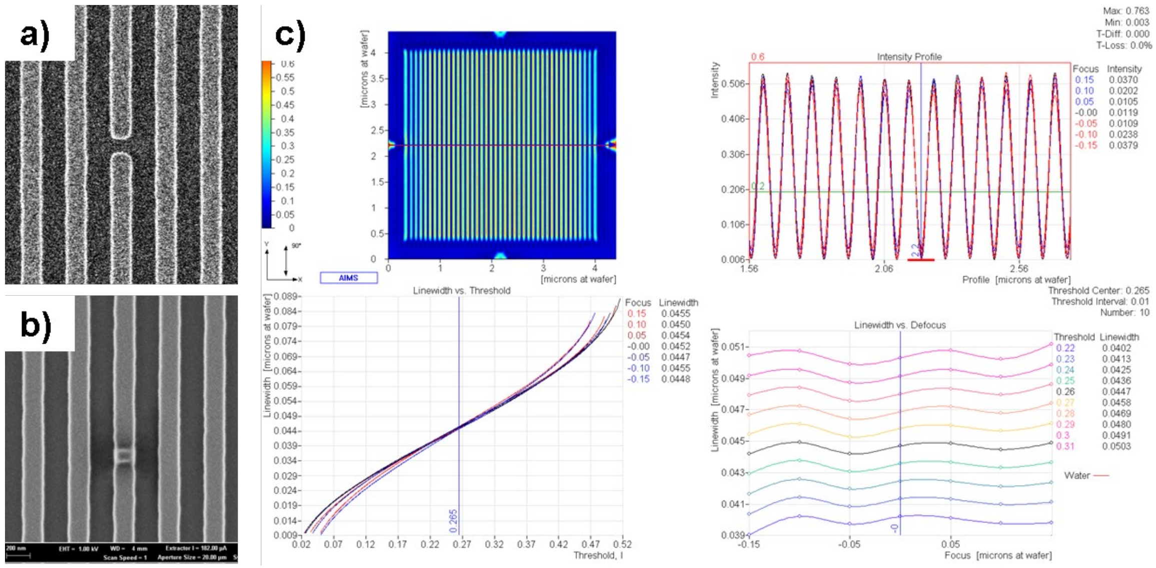

Figure 1 Example showing good phase and transmission matching of 193 PSM deposition process. A line break is shown a) before the deposition and b) after the deposition with AIMS data for the deposition shown in c). The AIMS data shows that the deposit matches the transmission and through focus behavior of the neighboring lines and spaces well.

The above AIMS® data has been quantified below in Table 1. The mask feature is a 1:1 line and space pattern with 360 nm pitch and the reference was taken from the same line approximately one micron above the repair area. The first column shows the intensity difference for the deposited line as well as for the clear spaces to the left and right in order to elucidate the effects of the deposit to the surrounding area. The last three columns show the difference in CD measured at the mask level in nanometers below focus (-0.15 um), at focus and through focus (+0.15 um).

	Intensity Difference	Below Focus CD (-0.15 um)	At Focus CD (0 um)	Through Focus CD (+0.15 um)
Left Space	+0.003	0 nm	+1 nm	-2 nm
Center Line	-0.002	+1 nm	+6 nm	0 nm
Right Space	+0.008	+6 nm	-6 nm	-4 nm

Table 1 Summarized results of the AIMS® data from Figure 1. The intensity and CD difference for the deposition versus a reference are tabulated for the deposited line as well as the neighboring spaces. The through focus CDs are included to give an indication of how well the phase is matched. All measurements were taken at the mask level for 180 nm lines.

In addition to the in-lens SE detector, the MeRiT® has an additional above-lens EsB detector for the collection of backscattered electrons (BSEs). The above-lens EsB detector allows the etching process to be stopped between materials due to the atomic number dependence of backscattered electrons. This means opaque defects of uneven height can be fully removed without unwanted etching into the underlying layers. Major benefits of the EsB detector over typical BSE detectors are the ability to detect material contrast in low voltage applications as well as in the nanometer range, both of which are important for our purposes. Furthermore, the detector sits above the lens which allows the possibility of working at very short working distances and the ability to simultaneously use the EsB and in-lens detectors.

An example of a programmed defect repair is demonstrated in Figure 2 to clarify the basic principle of the method. A single opaque bridge between two lines on a 193 nm 6% transmission MoSi mask is shown before the repair in a) and after the repair with endpointing in b). During the etching of the defect, the endpointing stops the etch process precisely at the MoSi/quartz interface, resulting in a smooth bottom.

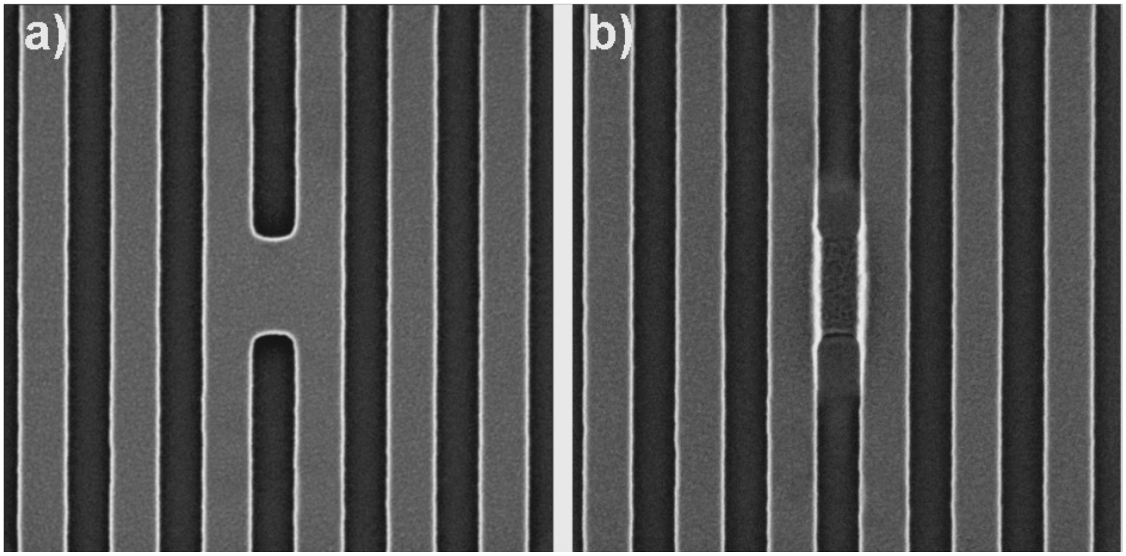

Figure 2 Example of a 193 nm 6% transmission MoSi line and space bridge defect. The image in a) shows the bridge before etching and the resulting repair after etching is shown in b).

Several significant benefits of the MeRiT® repair technology have been discussed including the elimination of radiation damage and debris allowing pre- and post-repair imaging and inspection as well as the ability to touch up previously repaired sites thus significantly improving repair yield. The unique PSM deposition capability enables the repair of clear defects that match the transmission and through focus behavior of MoSi. This deposition was demonstrated along with the corresponding AIMS® results. Finally, the removal of opaque defects using endpointing has been presented.

EXAMPLES OF PRODUCTION ENVIRONMENT REPAIRS

In order to validate the quality of repairs performed by the MeRiT® in a true production environment, the Advanced Mask Technology Center GmbH & Co located in Dresden, Germany, has provided images of actual defect repairs on product plates performed on site. The MeRiT® MG45 was the only repair tool used to repair these defects. All of the repairs shown below passed the specification for acceptable repair quality and were shipped to the customer.

Figure 3 shows a small opaque extension on a 193 nm 6% transmission MoSi line before being repaired in a). This extension was removed using the endpointing process and the post-repair image in b) shows that the extension was completely etched without any unwanted overetching into the quartz. It can also be seen that the line edge roughness and CD has been preserved.

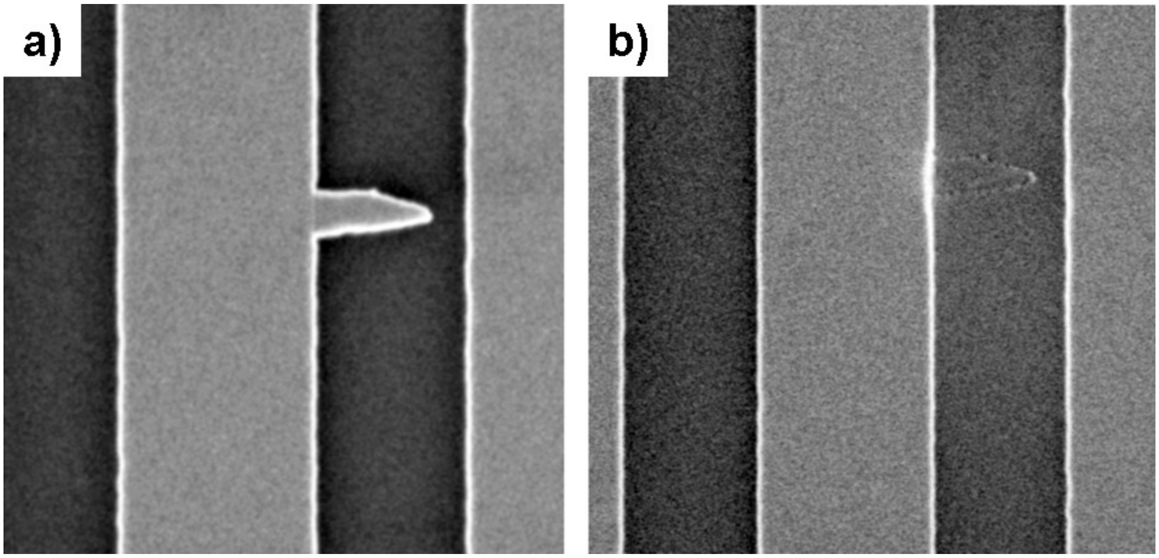

Figure 3 Images of an opaque 193 nm 6% transmission MoSi extension defect a) before repair and b) after etching using endpointing. Note the smooth remaining quartz left in the region of the defect.

Another opaque 193 nm 6% transmission MoSi defect is presented in Figure 4 below. This defect is much larger and more complex than the first as can be seen from the pre-repair image in a) showing that it consists of both a bridge between two lines as well as an extension in the neighboring space. The post repair image in b) again shows that the defect has been removed without overetching into the quartz. Both sides of the line remain smooth and straight conserving the CD along the line. The post repair image scan direction has been rotated 45 degrees in order to eliminate scanning artifacts in the region of interest.

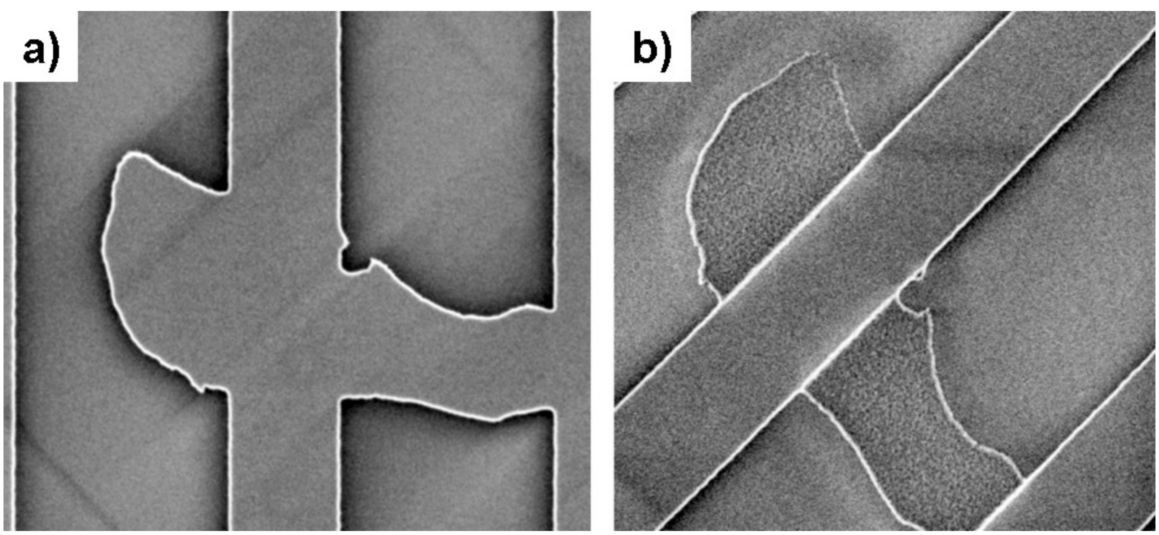

Figure 4 A large line/space defect consisting of a bridge and an extension shown before repair in a). The post repair image in b) shows removal of the entire defect while line width and edge roughness are preserved. The post repair image was rotated to reduce scanning artifacts.

The previous two examples demonstrate the successfulness of endpointing for full height defects, but the true benefit of this technology is the ability to also repair partial height defects no matter the thickness or topography with no additional work required for the operator. The images in Figure 5 were supplied by another customer site and show a partial height

248 nm 6% transmission MoSi opaque defect in a field of quartz. From the pre-repair image in a) it is evident that the defect is not a full height etch block and contains a great deal of topography. The post repair image in b) shows that the endpointing works very well for partial height defects, removing the entire defect while maintaining a smooth quartz surface with minimal surface roughness.

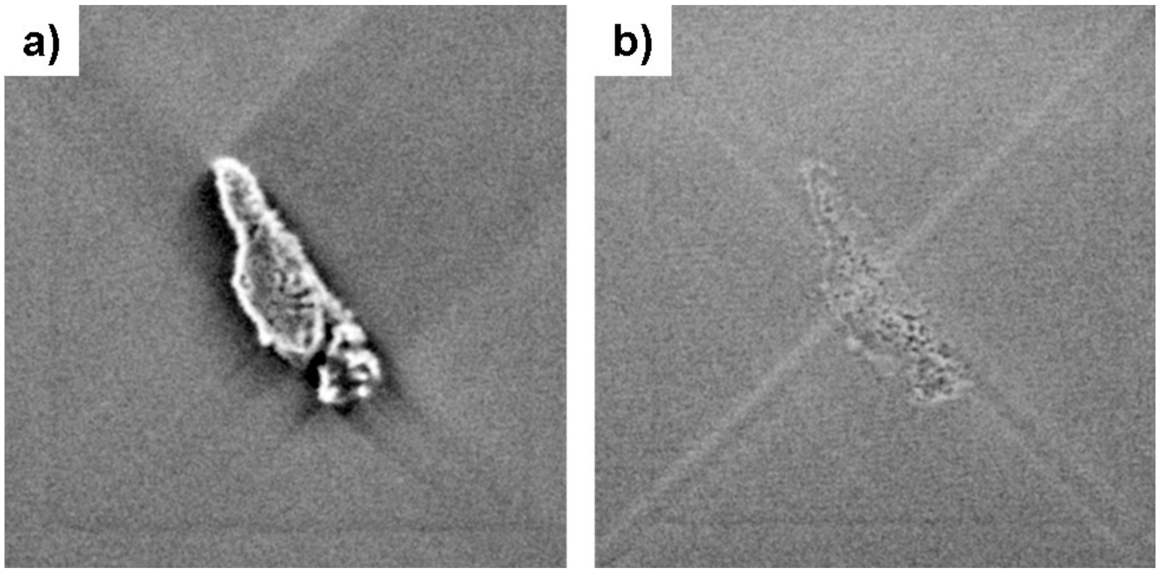

Figure 5 A partial height 248 nm 6% transmission MoSi defect approximately 500 nm by 800 nm in a field of quartz shown a) before repair and b) after repair. The process resulted in a very smooth repair area that was not discernable in AIMS®.

Several examples of production environment repairs performed by the MeRiT® have been presented to support the performance and validity of the endpointing technique. This method has been employed for successful repairs on a variety of PSM and binary mask types. It is important to point out that this ability in combination with the precision and minimal contamination to the surrounding area is not available with any other repair technology in production today.

CONCLUSION

The MeRiT® mask repair tool is the only available tool using electron beam induced chemistry technology for photomask repair. The use of an electron beam for mask repair eliminates the damage and other deleterious effects associated with other repair techniques and allows the operator virtually unlimited imaging as well as the ability to perform both opaque and clear defect repair on binary and phase-shifting masks. Furthermore, a single site can be repaired multiple times if necessary in the case of challenging defects or human error, thus increasing yield and contributing to the overall mask house productivity. Several examples of production defect repairs using endpointing from customer sites have been presented as well as the ability to deposit material that matches the transmission and through focus behavior of MoSi. This defines the MeRiT® as the first comprehensive mask repair tool capable of repairing all types of defects on a variety of photomasks.

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