e-beam induced EUV photomask repair – a perfect match

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1. ABSTRACT

Due to the updated ITRS roadmap EUV might enter the market as a productive solution for the 32 nm node[1]. Since the EUV-photomask is used as mirror and no longer as transitive device the severity of different defect types has changed significantly. Furthermore the EUV-photomask material stack is much more complex than the conventional 193nm photomask materials which expand the field of critical defect types even further. In this paper we will show, that “classical” 193 mask repair processes cannot be applied to EUV material. We will show the performance of a new repair process based on the novel ebeam repair tool MeRiT® HR 32. Furthermore this process will be applied on real EUV mask defects and the success of these repairs confirmed by wafer prints.

2. KEYWORDS

MeRiT MG 45, MeRiT HR 32, mask repair, defect repair, absorber defect, multilayer defect, electron beam repair, spontaneous etching, passivation

3. 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. EUV has been discussed to be key for next-generation production techniques for several years. Issues like the EUV source, EUV resists and mask-defects have kept engineers and researchers busy for some time now. Remarkable progress was achieved for the EUV sources, whereas defect free masks are still a major challenge. It can be expected, that the first EUV pilot lines will go online 2-3 years from now.

From a mask maker point of view mask defects are not a new topic but the requirements for EUV are much different than for 193 nm mask types. Since the EUV-photomask is used as a mirror and no longer as a transmission device the severity of different defect types has changed significantly. Furthermore the EUV-photomask material stack is much more complex than the conventional 193nm photomask materials which expand the field of defect types even further. For the transition phase from 193 nm to EUV it is extremely helpful to have a defect repair tool which can be used for the classical 193 nm and EUV technology.

Over the last years photomask defect repair by focused electron beam induced processing using the Zeiss MeRiT® MG 45 tool has become standard in practically all high end mask manufacturing processes. This technology employs a high resolution electron beam to induce a local chemical reaction on the mask surface. A suitable precursor gas is dispensed through a nozzle in close vicinity to the incident beam (Figure 1). Depending on the precursor chemistry, a reaction is induced by the electrons, leading to either a deposition caused by fragmentation of precursor molecules or to a reaction between the adsorbed molecules and the substrate material, resulting in volatile products and thus etching of the substrate material. The reaction is confined to the area exposed by the electron beam, so this technique allows high resolution nanostructuring.

The MeRiT® electron beam mask repair tool provides many benefits over other mask repair techniques. These benefits have been addressed in previous papers and include the lack of irradiation damage that arises with FIB based tools, including physical sputtering and ion implantation, as well as the ability to perform repairs without creating debris, as is the case with AFM based repair techniques[2,3,4]. The MeRiT® ebeam repair tool is the only repair tool that can perform both clear and opaque repair on a wide variety on masks[5].

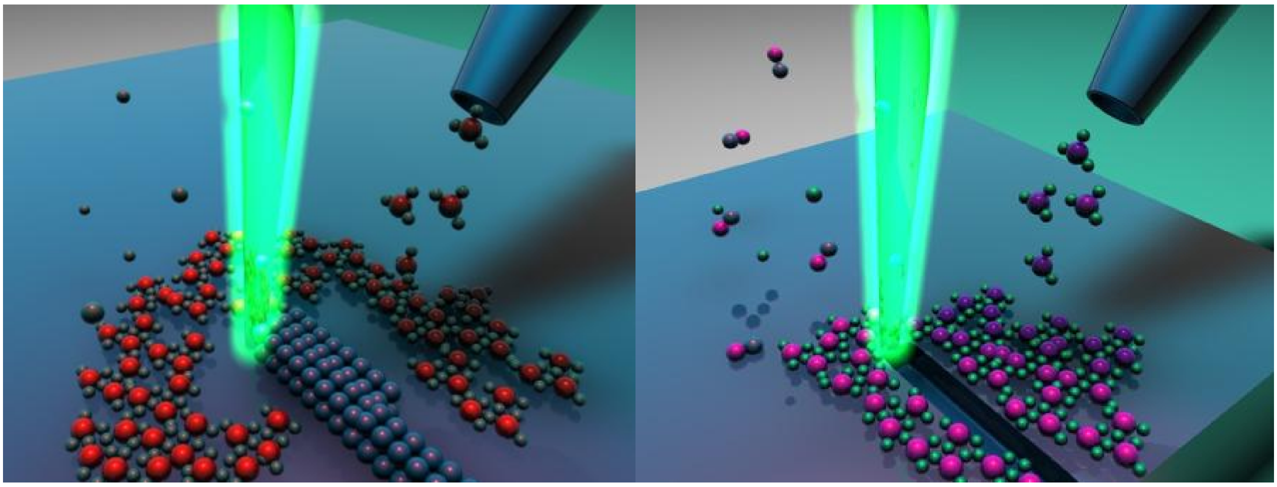

Figure 1: Basic principle for photomask repair: First the precursor molecules are adsorbed on the mask. The exposure with a focused electron beam can either start a reaction which immobilize the precursor (deposition) or reacts with the substrate to a volatile product (etching)

For the upcoming technology nodes the required accuracy for an ebeam based mask repair tool is quite high. Furthermore it can be expected that new mask materials will enter the market which might require new processes and new chemistry. To serve these needs a new tool has been developed called MeRiT® HR 32 (Figure 2). The MeRiT® HR 32 is a completely redesigned tool. Due to the reduced mechanical and electronic noise, reduced drift and a small beam diameter the tool can perform high resolution repairs. The new developed precursor management allows handling “exotic” materials and enables even very complex sequences.

Figure 2: To enable mask repair for the upcoming nodes a new ebeam based mask repair tool was developed called MeRiT® HR 32

4. Experimental

E-beam based mask repair is well established in any state of the art mask making technology for 193 nm photomasks. The first obvious test to apply 193 nm etches process on EUV material was not successful (figure 3). Once the absorber material is etched parasitic degradation is induced. This process continued over hours until the pattern fidelity is no longer sufficient.

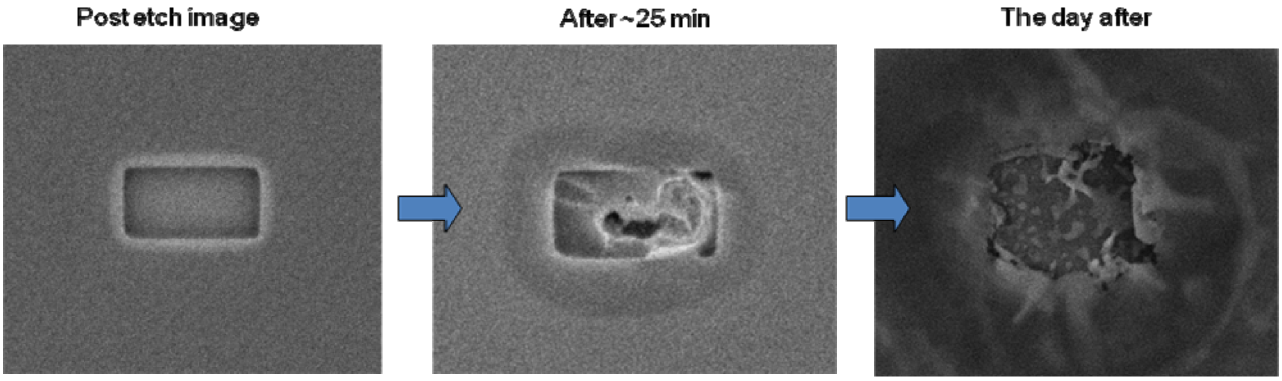

Figure 3: Basic 193 nm etch technology applied on EUV material shows strong and uncontrolled degradation of the absorber material

Investigation with a tilted SEM showed, that the absorber dissolves between the capping layer and the anti reflective layer forming a cavity as depicted in figure 4. It is obvious, that this kind of repair technology cannot be used for any productive process.

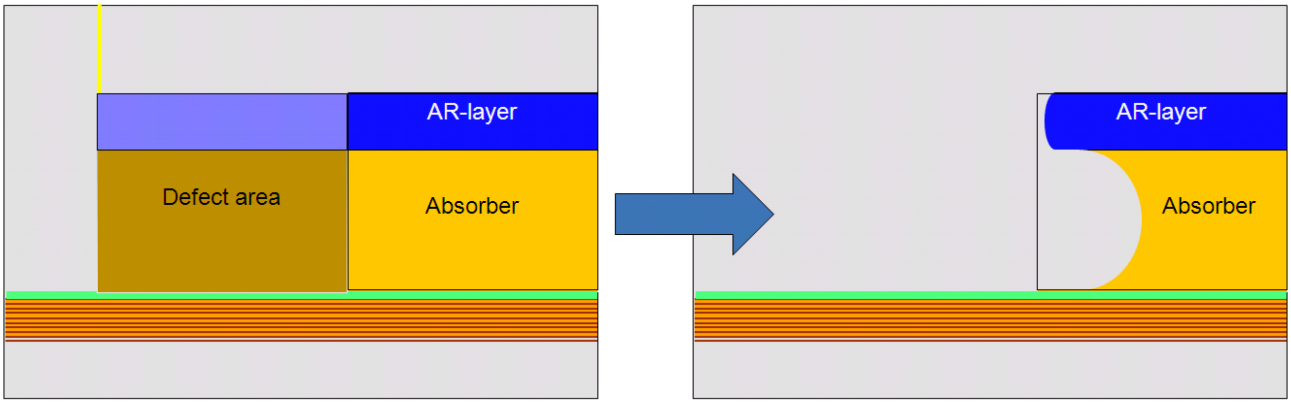

Figure 4: Basically all EUV absorber materials show parasitic degradation if etched with established etch chemistry for 193 nm photomasks.

There have been attempts to suppress spontaneous etching behavior by executing a two step process. First the defect is repaired then the surface is passivated**.** For passivation the repaired area is flooded with a passivation precursor and exposed by the electron beam again. This technology works does not work in a production environment. The reason is that the spontaneous etching modifies the sidewall on a minute timescale. For realistic repairs it is not unusual, that a repair takes longer than unwanted side effects need to affect the mask integrity. If the absorber degenerates faster than the repair itself it is impossible to perform a successful repair. Assuming very small and fast repairs still have the problem, that the most important area which needs passivation is the sidewall. In best case the ebeam comes parallel to the sidewall. So at the sidewall, where passivation is most critical the passivation process has the lowest efficiency. Last but not least the passivation layer can be effected by the etch process itself. In mask production it is likely that there is more than one defect on the mask. Even if a repair was performed successfully and the defect area was passivated successfully the repair of a second defect can destroy the passivation.

This is depicted in the upper part of figure 5. In this row a large contact hole was etched into the absorber and then passivated. This process was repeated 3 times at different position from left to right. It can be observed clearly, that the first contact hole has a big “aura” which is also visible in the middle contact hole. This “aura” is due to a growing cavity below the antireflective layer. This very basic experiment shows the limitation of the two step etch / passivation process.

To get to a process which is more applicable in a productive environment Carl Zeiss developed a new etch process which has no spontaneous etching. Therefore passivation with all the implications is no longer required. In the lower section of figure 5 the same etch sequence was performed with the new process. None of these etched contact holes shows an “aura”. Since the SEM image in was taken after all 6 contact holes have been etched it shows that the new process is soft enough not to damage the passivation of the first row.

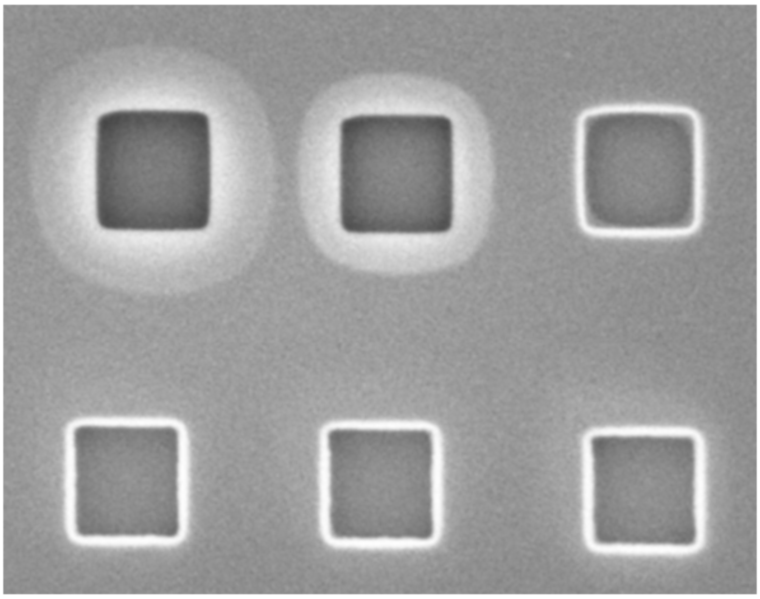

Figure 5: Two etch series have been performed. The SEM image was taken after all six boxes have been etched. The upper part was etched 1 by 1 and each hole was etched than passivated from left to right. A clear degradation can be observed. On the lower part the same experiment was repeated with the new etch chemistry. No absorber degradation could be observed in the lower part.

To quantify the process the etch selectivity was derived. Therefore a series was etched into the EUV mask material where the etch time was varied in a laboratory environment. The depth of the etched area was than measured using AFM (see figure 6). If can clearly be seen, how first the antireflective layer is etched then the absorber itself before the etch speed slows down on the Ru-capping layer. To derive the etch selectivity the different slopes are fitted assuming a linear behavior. The so derived etch selectivity is better than 75:1.

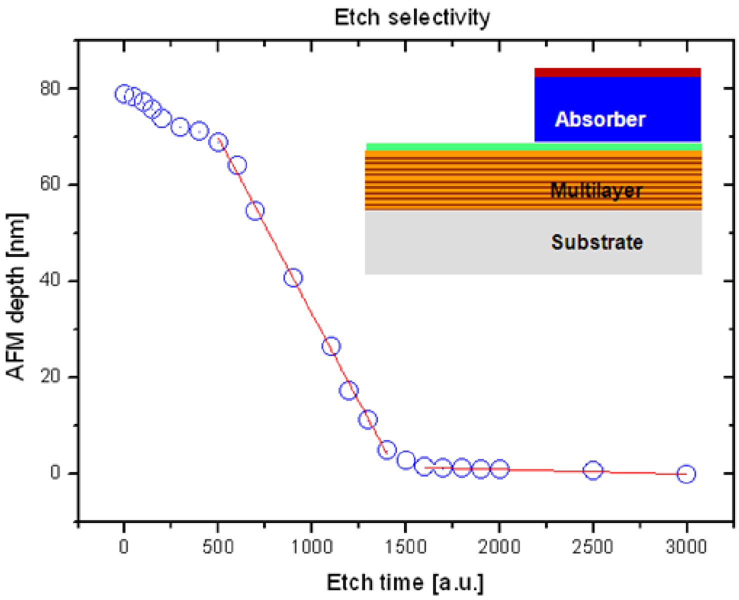

Figure 6: The etch selectivity is derived from the etch speed in the different layer. The red lines are linear fits of the etch speed in the absorber layer and on the Ruthenium capping layer. The etch selectivity is better than 75:1

An example for a successful EUV mask repair is depicted in figure 7. The upper left image shows a SEM image from a mask with a particle defect embedded in a sidewall line. From a repair point of view a particle defect is much more complicate than a standard absorber defect. This mask was printed and measured again on the wafer using SEM depicted in the lower left image. It can be clearly observed that the particle defect prints on the wafer. Then the mask was repaired and measured again with SEM. This is shown in the upper right image. The defect was removed almost completely. Furthermore no damage of the capping layer is visible. This so repaired mask was again printed on wafer and measured with SEM (lower right image). The wafer print confirmed that the defect was removed successfully. Furthermore no negative impact of the surrounding of the repair area could be observed.

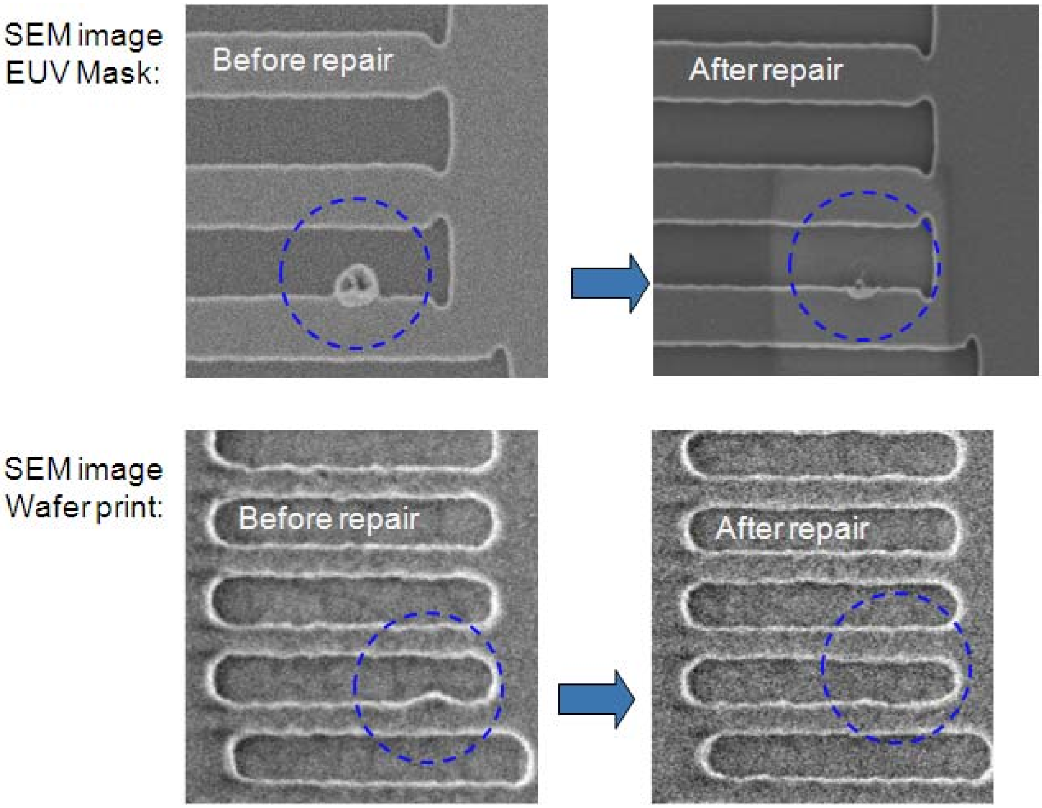

Figure 7: Example for a particle defect on a EUV mask. In the wafer print before repair shows that this defect is transferred to the wafer during the printing process. After repair the particle is removed and is no longer visible on the wafer print result

The second example shows a deposition[6] (Figure 8). The upper left picture shows an SEM image of an absorber defect. This defect looks not so critical but in AFM (upper middle picture) it can be seen, that the absorber is thinned. In the lower left image you see an SEM image of the area as printed on the wafer. It shows that this defect is transferred during the printing process. Reason might be that the absorber material is too thin to absorb the EUV light sufficiently. This defect was repaired using a deposition process (upper right image). After repair the corresponding wafer print shows that this defect is no longer transferred to the wafer. Again no negative interference of the repair process can be observed in the surrounding of the repaired area can be observed.

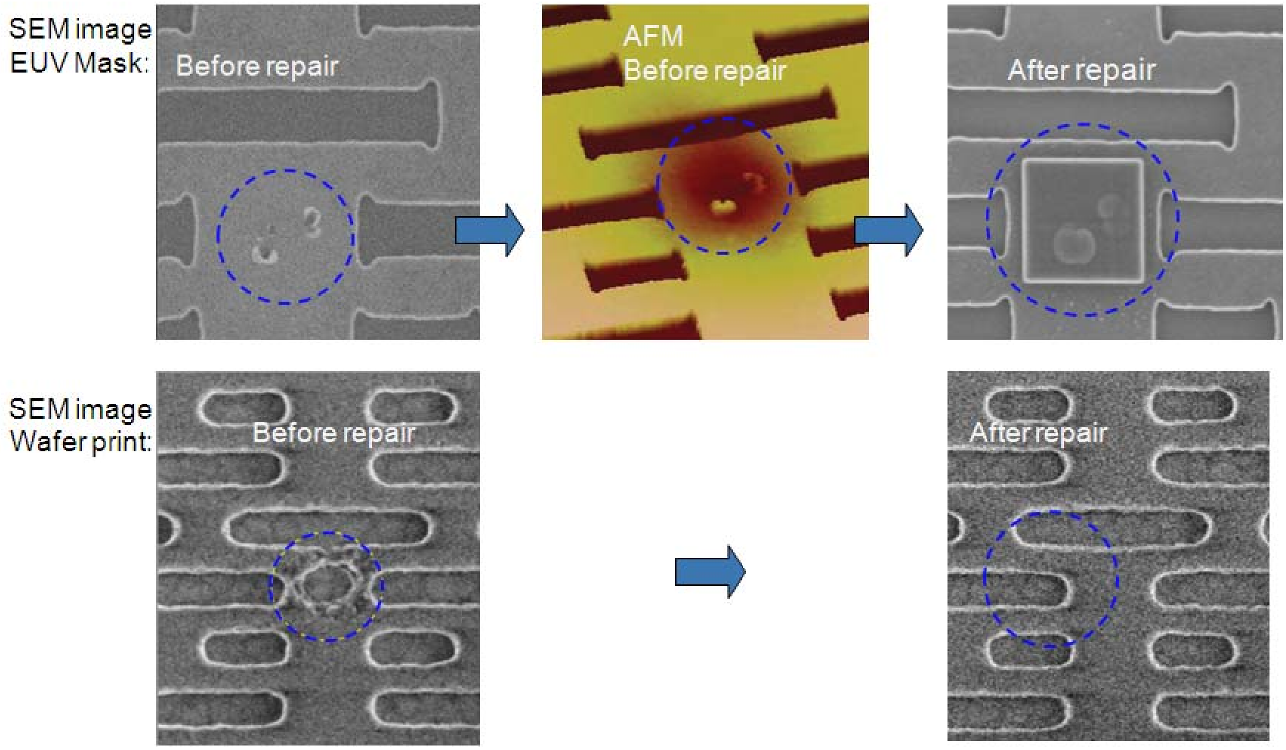

Figure 8: Example for deposition. Where the defect is almost invisible in SEM, AFM shows that the absorber is too thin which is confirmed in the wafer print. After deposition the defect is no longer transferred to the wafer.

5. CONCLUSION

The novel MeRiT® HR 32 mask repair tool has been specifically developed for electron beam induced photomask repair for 32nm and below for 193nm and EUV lithography. The significantly improved tool stabibilty together with a new gas management system allows the development of new repair processes especially for EUV masks.

It was shown, that the well established repair processes for 193 nm masks of the previous MeRiT® MR 45 tool generation cannot be applied to EUV mask material due to parasitic degradation. The new MeRiT® HR 32 allowed the development of new EUV repair process avoiding this effect. It was shown, that this process has a very broad process window. Furthermore this process can be controlled in a way that the capping layer between the absorber material and the reflective multilayer is not damaged. The ebeam based MeRiT® HR 32 mask repair tool enables accurate, stable and damage free repairs for 193 nm and EUV mask types, both . for the repair of clear and dark defects.

6. ACKNOWLEDGEMENT

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