EUV mask repair using a combination of focused-electron-beam-induced processing and vacuum AFM

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Extreme Ultra-Violet (EUV) photolithography is scheduled to be introduced for high-volume manufacturing at the 22 nm node starting 2013. In order to support this drastic wavelength shift used for lithography, defect-free reflective optics must be available in high yields. This concerns in particular EUV masks. The more complex nature of the optics (Bragg multilayer mirrors at 13.6 nm wavelength, operated under vacuum), and the increased complexity of manufacturing steps involved, increase the number of possible sources for defects. Small embedded particles, or deviations from smoothness as shallow as 3 nm, are already critical.[1] The semiconductor industry requires accurate tools to analyze, control, and tackle these new challenges.[2]

The state-of-the-art technology for mask repair at the critical nodes (from 65 nm in 2006 and 45 nm in 2008, down to the present 32 nm) involves gas-assisted nano-processing with focused electron beams. An industrial solution from Carl Zeiss SMS is the MeRiT mask repair tool platform, as already presented at this conference. Upgrading this technology from 193 nm immersion lithography to EUV patterning requires being able to rapidly locate and efficiently visualize the mask defects, before repairing them. Since shallow defects can be invisible by (SEM), a combination of optical and scanning probe methods is necessary.

A vacuum-compatible atomic force microscopy (AFM) measurement head was developed as upgrade for the MeRiT HR32 platform and integrated into the vacuum chamber next to the electron column. Using the interferometric stage, the mask can be accurately positioned under either the electron beam or the AFM head. The offset error between focused electron beam and AFM is below 200 nm. This allows for a rapid and accurate switching between 2-D and 3-D imaging as well as nano-processing using either the SEM or AFM mode. Successful imaging under vacuum conditions was demonstrated (see fig. 1). EUV-specific multilayer defects can thus be reviewed, located, and repaired in a single tool (see figure 2). The topography of the repair itself can then be checked

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[1] D. Van den Heuvel *et al*., „Natural EUV mask blank defects: evidence, timely detection, analysis and outlook“, Proceedings of BACUS / SPIE 2010, 7823-47.

[2] T. Liang *et al*., „Strategy and Feasibility of Defect-free Mask Fabrication to enable EUVL“, Proceedings of the Sematech - International symposium on EUV Lithography, Prague, 2009.

instantaneously by AFM. Future applications can be envisioned, including material analysis, nano-mechanical processing, or electrical probing.

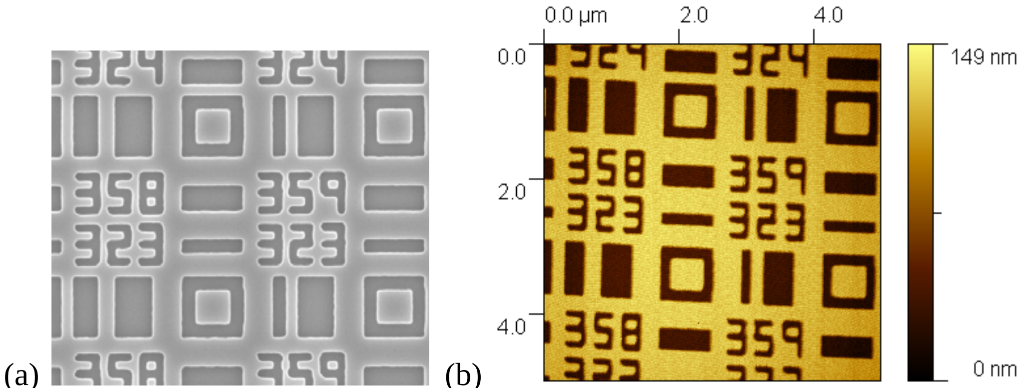
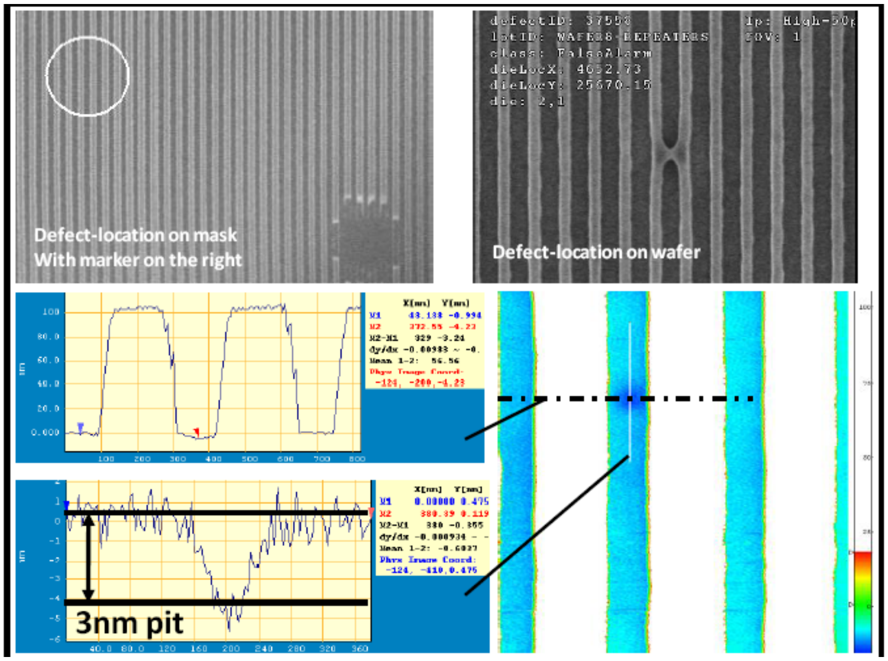


Figure 1: Switching between 2 imaging modes in a single tool:
(a) SEM image of a Si calibration probe.
(b) Vacuum AFM image of the same area, 1 µm/s. Offset control is ~100 nm.



```
defectID: 37558          Ip: High-50
lotID: WAFER8-REPEATERS  COV: 1
class: FalseAlarm
dieLocX: 4652.73
dieLocY: 25670.15
die: 2,1
```

```
         X[nm]    Y[nm]
M1       43.138 -0.994
M2       372.55 -4.23
M2-M1    329 -3.24
dy/dx -0.00983 ~ -0.
Mean 1-2:   56.56
Phys Image Coord:
 -124, -200,-4.23
```

```
         X[nm]    Y[nm]
M1       0.00000 0.475
M2       380.39 0.119
M2-M1    380 -0.355
dy/dx -0.000934 ~ -
Mean 1-2: -0.6027
Phys Image Coord:
 -124, -410,0.475
```

Figure 2: Identification of a EUV multilayer defect: a SEM-invisible EUV mask defect (top left) leads to a bridge on the wafer print (top right, resist image). AFM imaging (bottom) reveals a 3 nm deep, 100 nm wide pit in the multi-layer of the EUV mask. It is located within the 160 nm wide space. Having located the defect by AFM (with respect to a reference area) and quantified its topography, mask repair using the 3-dimensional data can be undertaken.