EUV and non-EUV inspection of reticle defect repair sites

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The production of defect-free mask blanks for extreme ultraviolet (EUV) lithography is a central challenge that can only be met if mask inspection tools of unprecedented sensitivity can be created and qualified in time for volume production. Presently, it is an open question whether or not EUV inspection tools will ultimately be required. One area where EUV *at-wavelength* inspection, also called *actinic inspection*, has recently provided unique feedback is in the evaluation of EUV multilayer coating defect repair efforts.

It is well known that the resonant reflectivity of EUV multilayer coatings is highly sensitive to any disturbance of the coating surface or layer structure: including substrate bumps and pits which cause phase-defects, and absorbing particles or surface material which causes local reflectivity loss. Multilayer defect repair efforts seek to restore the local optical properties of the multilayer and minimize the impact of coating imperfections on printed patterns. The development of effective defect-repair techniques requires detailed feedback that, realistically, can only come from at-wavelength evaluation. Non-EUV inspection tools may be able to verify the restoration of the top surface quality, but they are insensitive to the multilayer properties that determine the EUV reflectivity. EUV printing can be an effective evaluation technique where available, but it is unlikely to provide accurate, quantitative feedback for open-field defect repairs.

In an effort to evaluate different multilayer defect repair methods and recipes, we have recently scanned defect repair sites on an EUV mask blank with the actinic mask inspection tool at Lawrence Berkeley National Laboratory using both actinic brightfield (BF) and darkfield (DF) dectection with sub-micron spatial resolution and sensitivity to reflectivity variations as small as 0.2%, as shown in Table 1. Interestingly, some repair sites that exhibit large BF reflectivity losses have very small DF scattering strengths. Furthermore, we did not observe a strong predictive correlation between DF scattering and BF reflectivity loss, as shown in Figure 1. This observation has important implications for the design of next-generation EUV mask inspection tools.

In the talk we will report the cross-calibration of the EUV measurements with AFM measurements and non-EUV commercial inspection tools.

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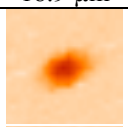
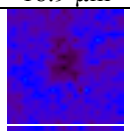
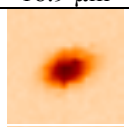
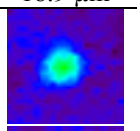
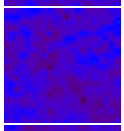
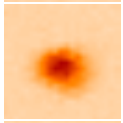
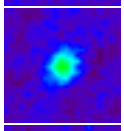
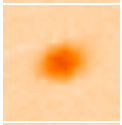
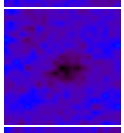
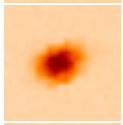
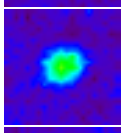
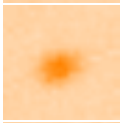
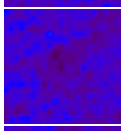
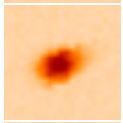
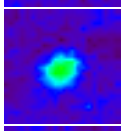
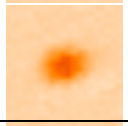
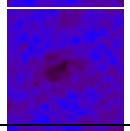
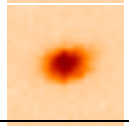
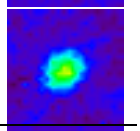
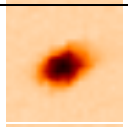
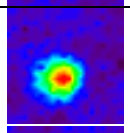
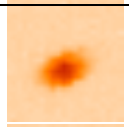
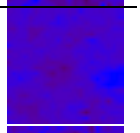
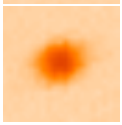
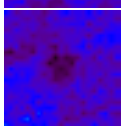
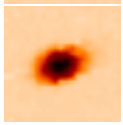
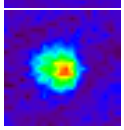
Table 1. EUV Inspection of fourteen defect-repair sites of three different types: A, B, and C. In brightfield (BF) the local reflectivity is measured with 1.0 µm spatial resolution and 0.2% relative uncertainty. The lowest relative reflectivity value and the reflectivity loss are shown. Darkfield (DF) measures the scattering strength relative to the clean-mirror background value. Negative numbers indicate regions that absorb but do not scatter strongly. The scanned images cover areas 18.9-µm wide. The BF and DF images are separately plotted on consistent color-scales.

Site	BF R ±0.2%	BF ΔR ±0.2%	DF signal	BF scan 18.9 µm	DF scan 18.9 µm	Site	BF R ±0.2%	BF ΔR ±0.2%	DF signal	BF scan 18.9 µm	DF scan 18.9 µm
A1	87.8%	–12.2%	–6.0			C1	79.1%	–20.9%	44.4		
A2	97.7%	–2.3%	–0.8			C2	85.6%	–14.4%	40.5		
A3	91.3%	–8.7%	–10.3			C3	82.0%	–18.0%	54.5		
A4	94.5%	–5.5%	–6.5			C4	83.4%	–16.6%	43.7		
A5	91.2%	–8.8%	–10.9			C5	82.5%	–17.5%	55.5		
B1	72.4%	–27.6%	68.4			B3	88.3%	–11.7%	–3.0		
B2	90.2%	–9.8%	–7.7			B4	70.1%	–29.9%	65.2		

Note: these figures are in color, and may not be represented clearly on a grayscale printout.

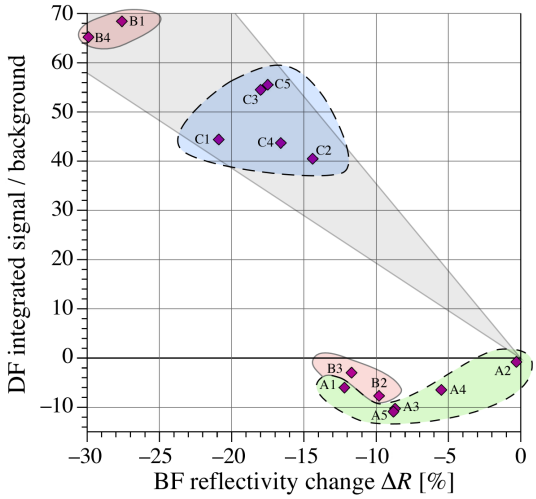


Figure 1. Correlation of EUV BF and DF measurements of the 14 defect-repair sites. Point labels correspond to the sites in Table 1 above. Some points (Type C and some of Type B) follow an approximate correlation between loss of reflectivity and increase in scattering. These points fall within the gray band. Other points (Type A and some of Type B) fall outside of the band, possibly indicating increased absorption.