Defect Repair for Extreme Ultraviolet Lithography (EUVL) Mask Blanks

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Introduction

Particles are a serious concern in the fabrication of reticles for EUVL because they nucleate perturbations in the reflective multilayer film that can print in the lithographic image. Besides continuous improvement of the cleanliness of the deposition process, several alternative defect mitigation schemes have been put forward such as smoothing or planarization of topological substrate perturbations using an ion-assisted Mo/Si deposition process, or strategies for repairing multilayer defects.

In this presentation, we discuss recent experimental progress made on the development of two complementary defect repair strategies: amplitude and phase defect repair.

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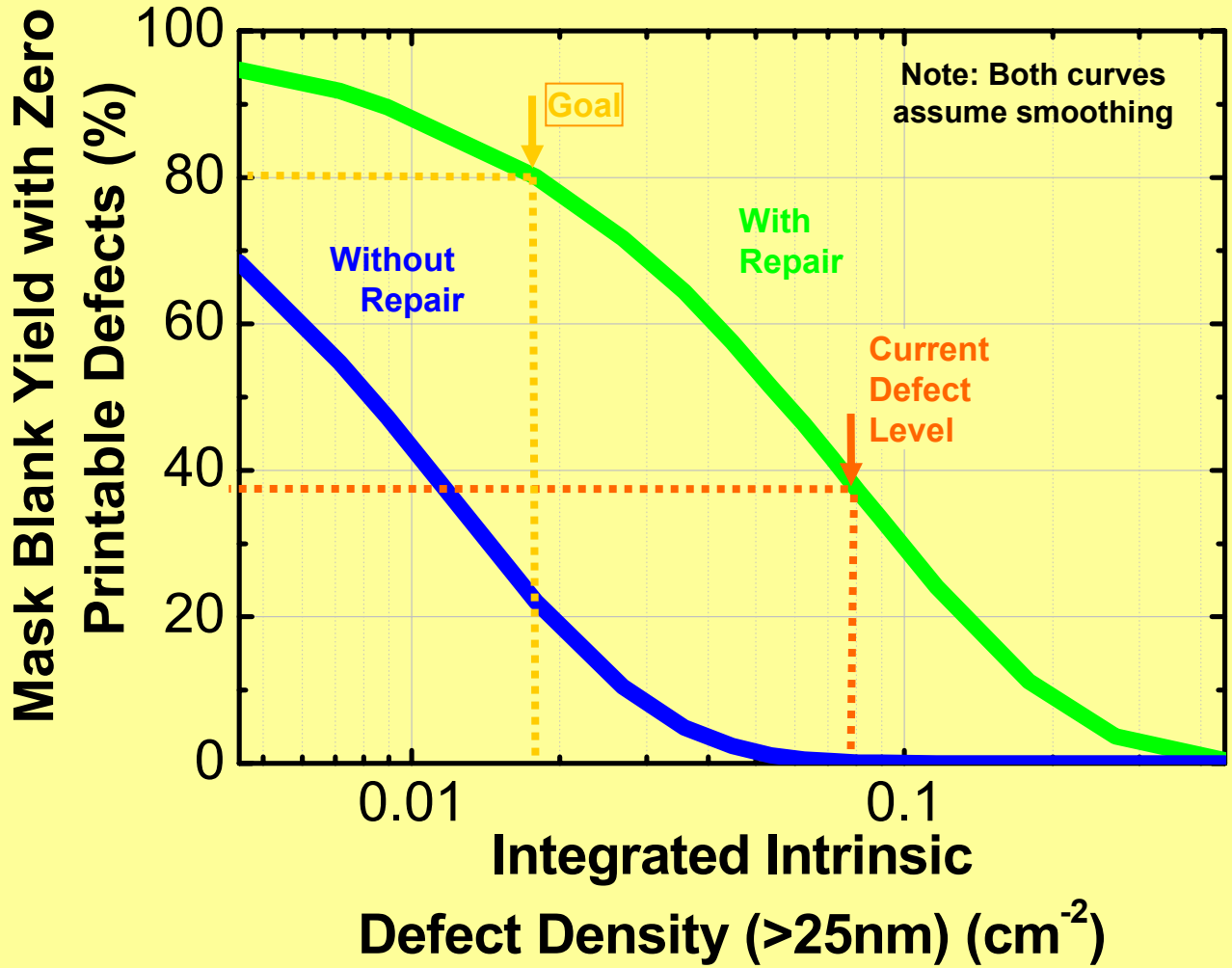
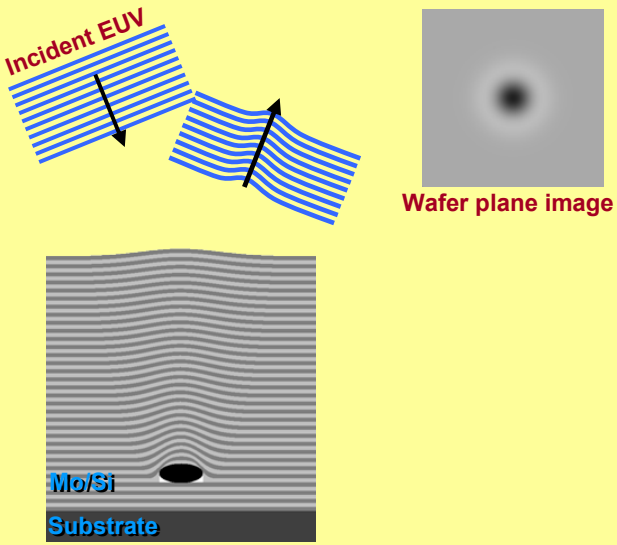
Mask Blank Defect Repair and a Low-Defect-Deposition Process are Necessary to Achieve Commercially Viable Yield of EUVL Mask Blanks

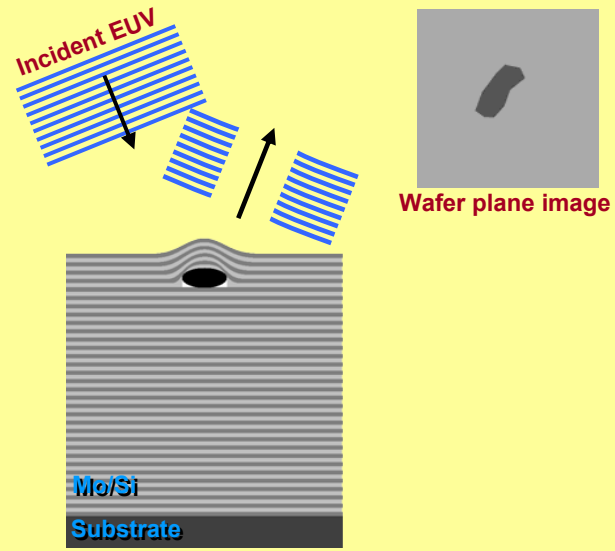


Review: Classify Defects to Select Optimum Repair Technique

"Phase defects"

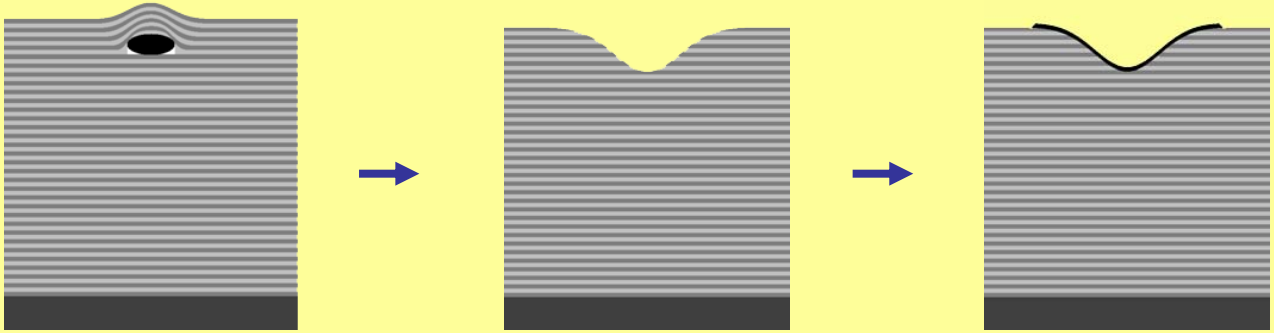


"Amplitude defects"



- **Both kind of defects can lead to severe unwanted CD changes**
- **Our goal is to develop repair strategies to minimize this CD variation**
  - **<u>Phase defects</u>: Buried defects can be repaired by shrinking the multilayer through local heating (e-beam preferred)**
  - **<u>Amplitude defects</u>: Surface defects can be removed using FIB, and repair zone is capped with a passivation layer**

Review: Amplitude Defect Repair Reduces CD Variation



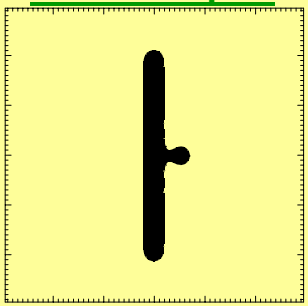
Amplitude defect

Remove damaged top layers locally with a FIB

Capping layer protects exposed materials

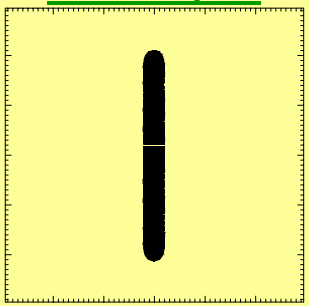
Aerial Image Calculations

Before Repair



Amplitude defect in proximity to isolated line: large ΔCD

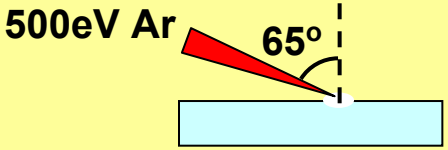
After Repair



Residual variation in reflectivity within repaired area: small ΔCD

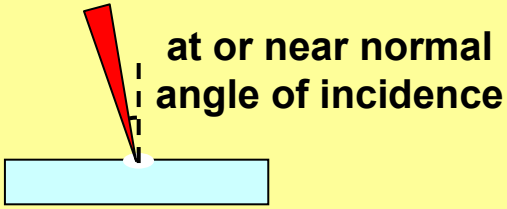
We Determined How Ion Energy and Angle of Incidence Affect Reflectance Variation Over Repair Zone

Experiments so far were done in Auger System



Parameters chosen to minimize impact of milling on reflectance variation

Configuration of typical commercial FIB Tool

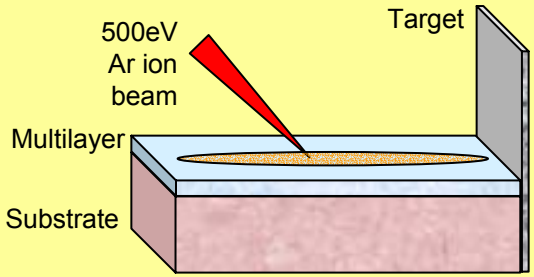


Typically operation conditions:
- **Ion energies > 500 eV**
- **Ga ions**

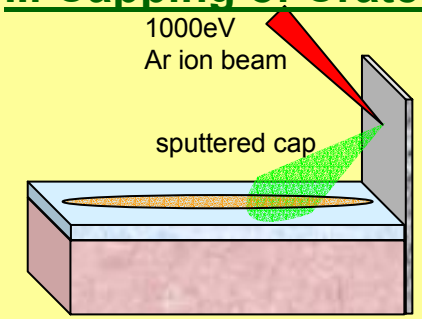
- Ga ions (commonly used in FIB tools) cannot be used since they stain of the multilayer. In future experiments, alternative ion sources need to be investigated (e.g. Si or Ar FIB's)
- We are using this information to determine if existing FIB systems are applicable to amplitude repair

Experimental Setup to Determine Reflectance Variation As a Function of Angle, Energy, and Repair Zone Depth

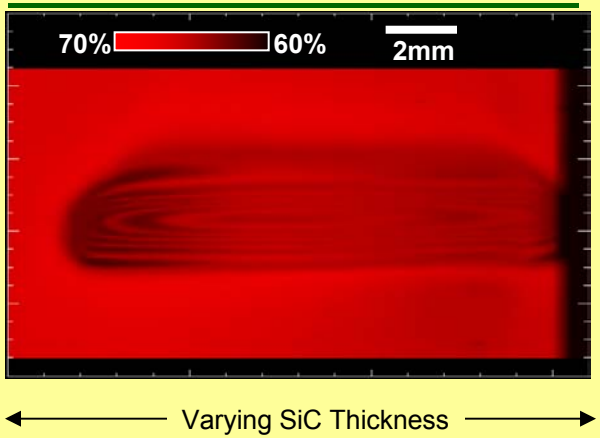
I. Milling of Crater



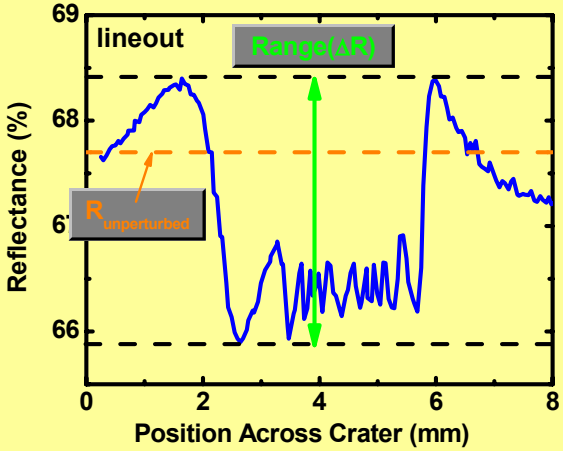
II. Capping of Crater



III. Measure Reflectance Map At ALS BL 6.3.2 and 11.3.2

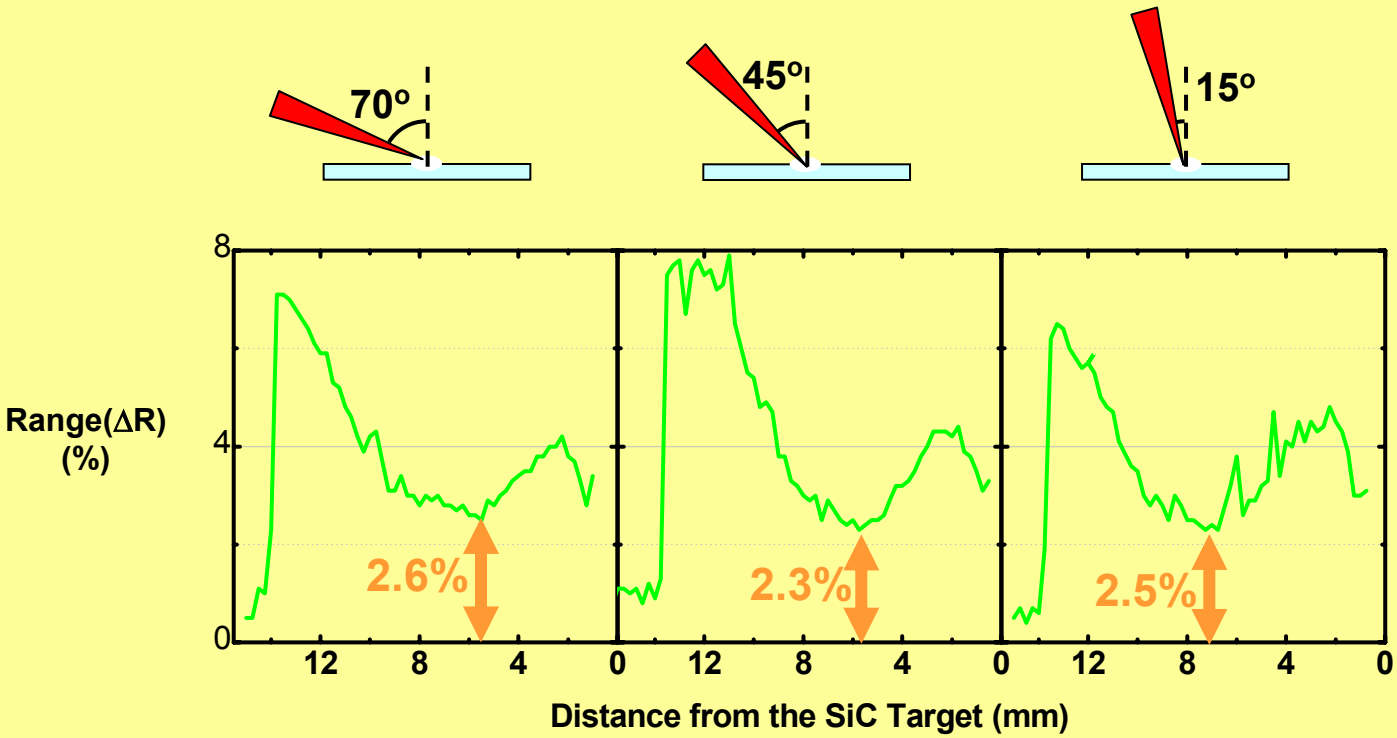


IV. Take Minimum of Range(ΔR) to Benchmark Repair Process



Varying The Ion Beam Angle of Incidence Has Minimal Effect on Reflectance

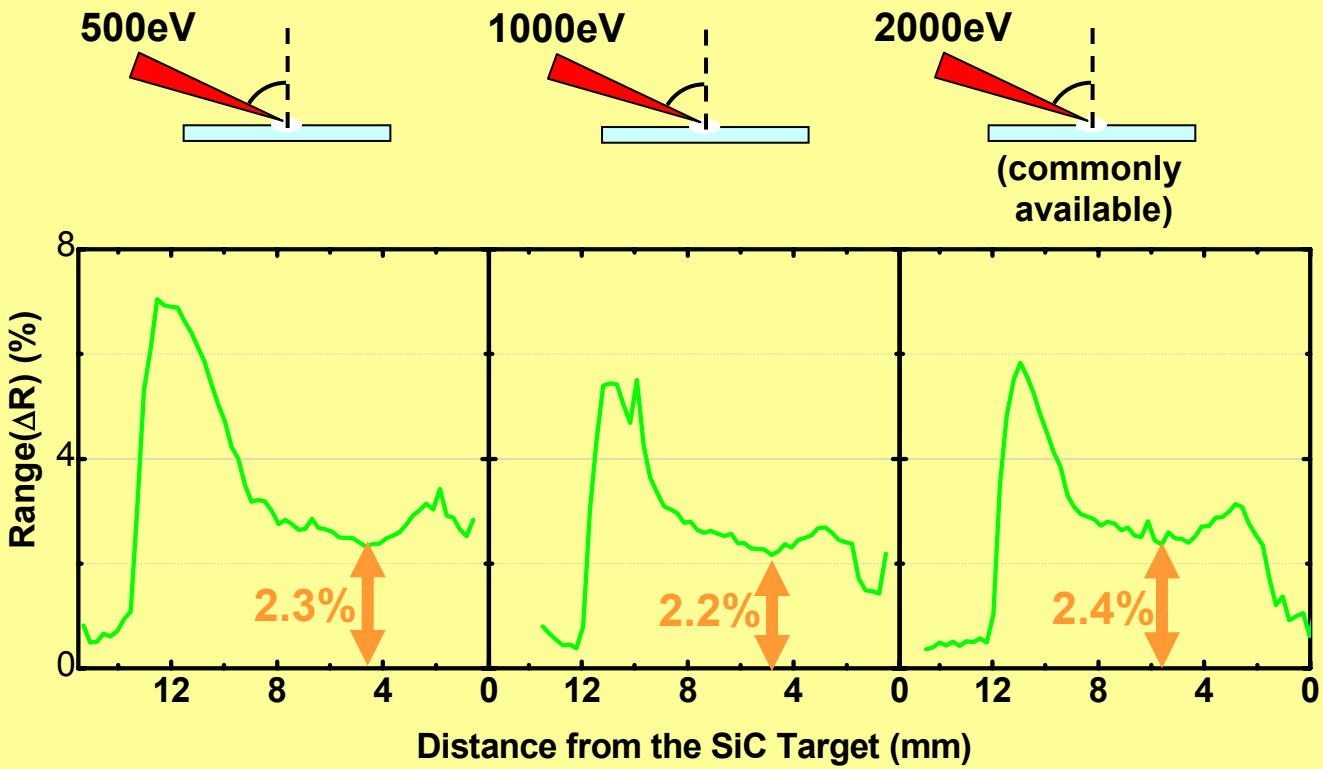
Geometries of Commercial FIB Tools are Compatible with Amplitude Repair



(mm-sized craters. Ar ion beam milling energy was 500 eV)

Varying The Ion Beam Energy Has Minimal Effect on Reflectance

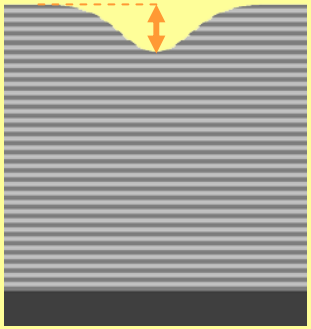
Ion Beam Energy of Commercial FIB Tools are Compatible with Amplitude Repair



(mm-sized craters. Ar ion beam angle of incidence was 65°)

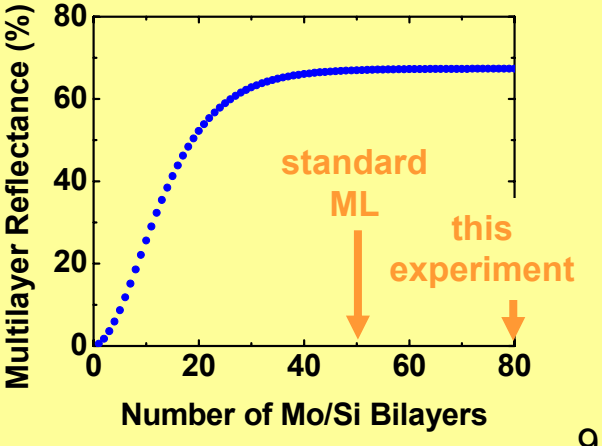
For Amplitude Repair, Reflectance Variation Depends on Depth of Repair Zone

- Amplitude repair has larger effect on yield improvement if deeper craters can be milled

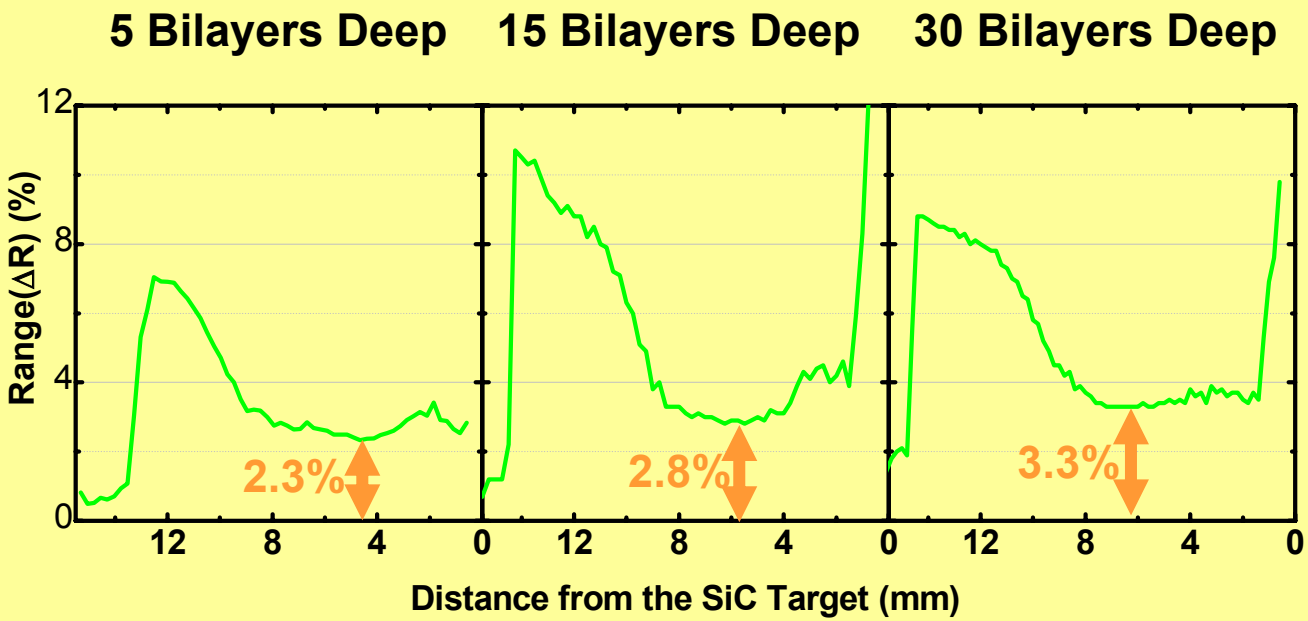


- Crater depth affects reflectance variation: Reduction of number of BL + Damage due to prolonged milling

- In this quarter, we investigated the effect of prolonged milling on repair



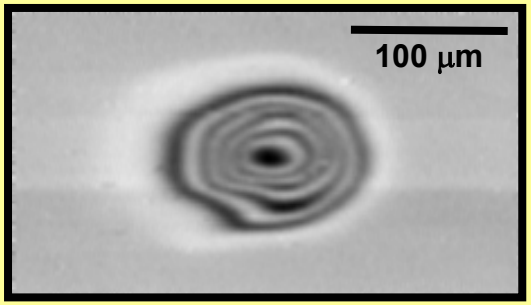
Prolonged Milling Increases Reflectance Variation Over Repair Zone

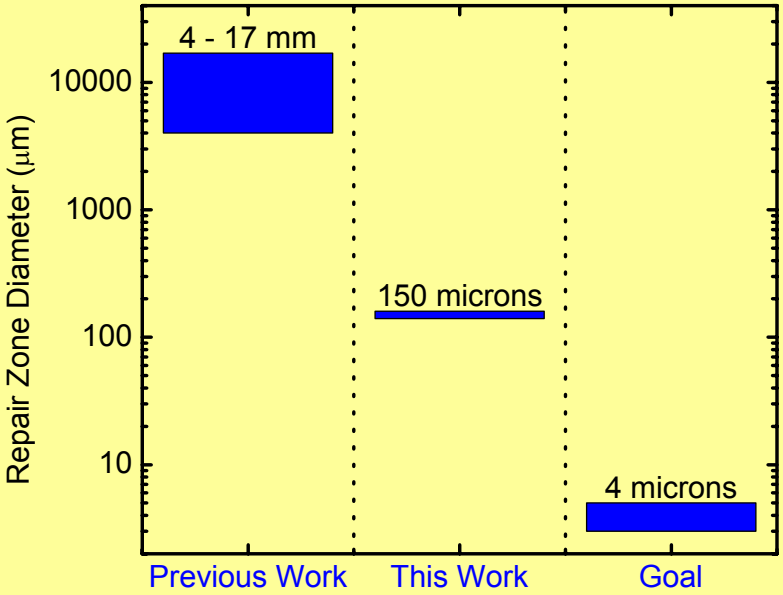


- This reflectance variation should not be due to layer removal. It is probably due to changes within the multilayer caused by milling deep craters using the current process

- For thinner multilayers (< 80BL), the increase in reflectance variation will be larger

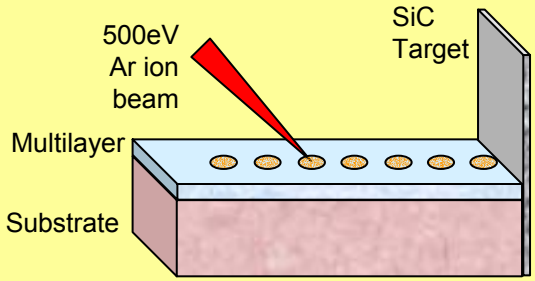
We Reduced the Repair Zone Diameter by 30X [From Several mm's to ~150 μm] through Refinement of Milling Technique



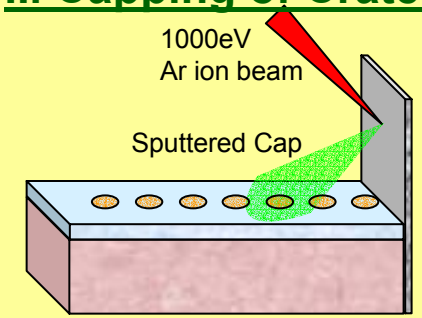


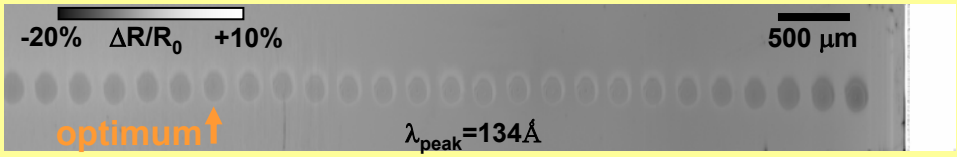
We Determined Reflectance Variation Over 150 μm Repair Zone

I. Milling of Crater



II. Capping of Crater





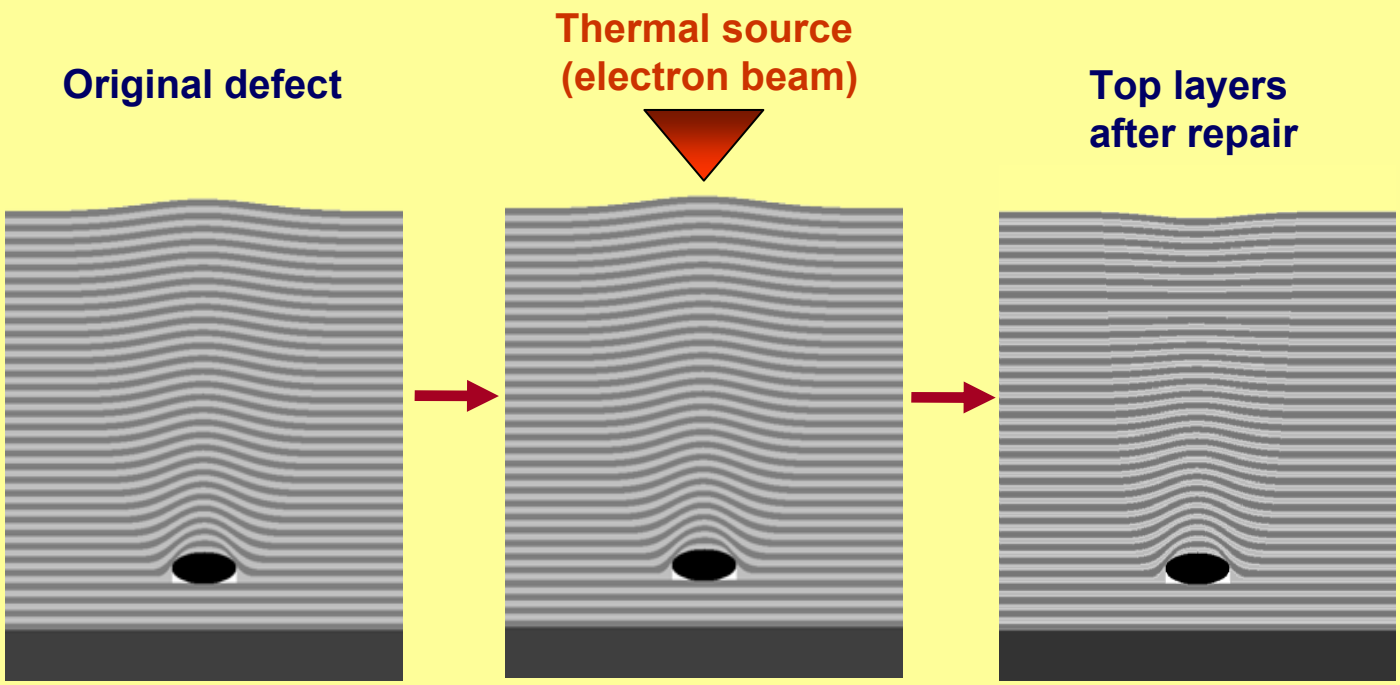
(Map reflectance drop measured at Actinic BL 11.3.2 at ALS)

- Cap thickness changes with distance from sputter target
- Reflectance variation over repair zone depends on cap layer thickness
- We measured a 3% reflectance variation over repair zone for optimum SiC cap thickness

This is similar to results on mm-sized craters, suggesting scalability

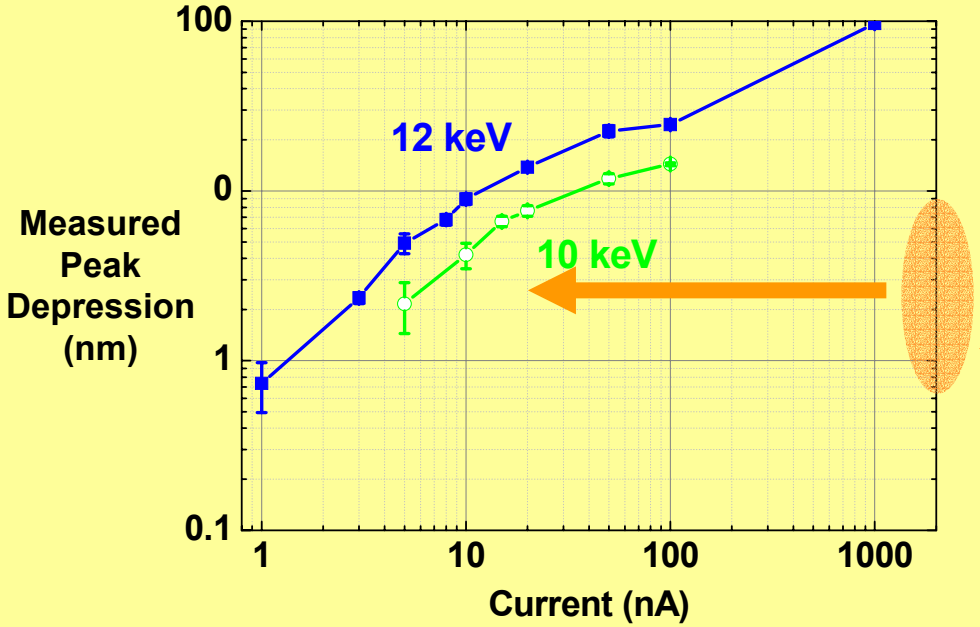
Overview of Phase Defect Repair Technique

Thermally-Induced Layer Contraction to Repair Phase Defects



- Heating-induced multilayer contraction due to silicide formation could,
  for example, flatten a 3 nm bump if each of the top 30 bilayers contracts by 0.1nm

Recent Tests Show That Electron Current Requirement for Phase Defect Repair is Lower Than Expected



Induced nm-deep and 2.5μm-wide depressions using a JEOL Microprobe

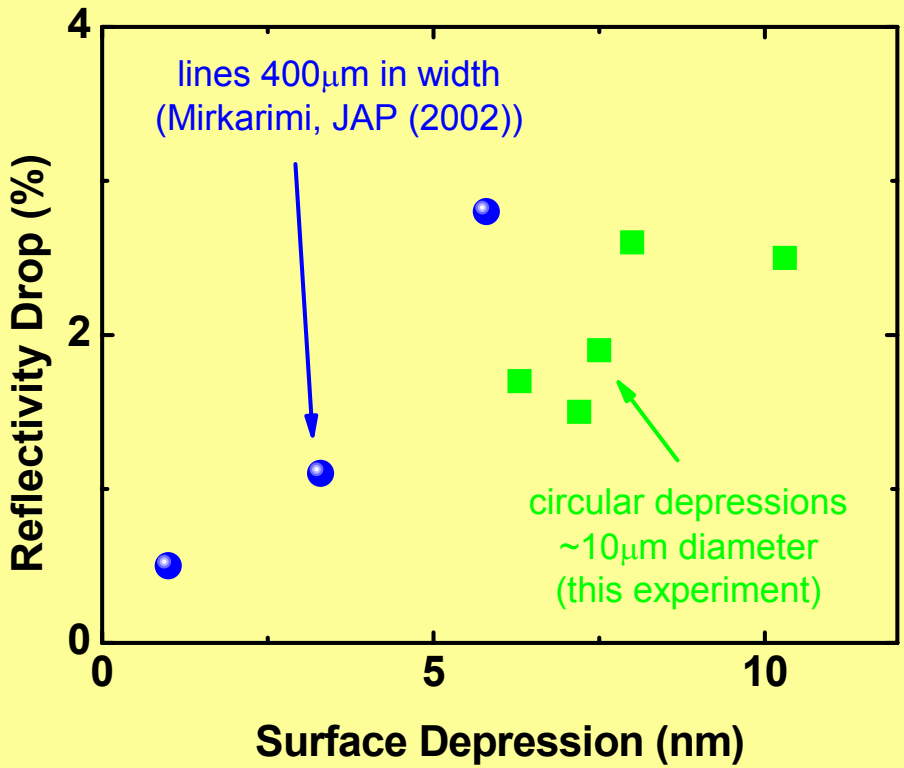
Expected parameter range

- The electron current requirement of 5 – 50 nA is significantly lower than expected from previous modeling (several μA)
- Current requirements for depressions of smaller diameters (e.g. ~100nm) is expected to be equal or even less

Existing commercial tool sets can form the basis for the development of phase defect repair technique

Recent Results Show That Reflectance Drop of Small Circular Depressions is Same or Lower than for Wide Lines

- We measured reflectance drop over μm-sized surface depression at ALS Actinic BL 11.3.2 and compared it with literature values of reflectance drop of 400μm-wide lines measured at ALS BL 6.3.2



Summary

We have made progress in three areas of defect repair:

1. **Our modeling has shown that commercially viable yield of mask blanks can be achieved if defect repair is used in conjunction with an ion-assisted smoothing process.**

2. **For the amplitude repair technique, we reduced the lateral footprint of the repair zone from several mm to ~ 150 μm. We determined that the reflectance variation over the repair zone is only weakly affected by ion beam milling energy and ion angle of incidence, suggesting that the configurations of existing commercial FIB systems are compatible with an amplitude repair tool.**

3. **For the phase defect repair technique, we demonstrated that the electron current requirement is only 5 – 50 nA or less, which is significantly lower than expected from previous modeling (several mA). This suggests that existing commercial tool sets could form the basis for the development of phase defect repair technique.**