**Motivation**
- Extreme ultraviolet lithography (EUV) is the leading candidate to replace DUV lithography for printing small features.
- One of the main roadblocks to the implementation of EUV lithography is buried defects in EUV masks.
- Simulating the effect of these defects is a difficult task.
- Rigorous simulations take many hours, or even days, to accurately simulate the reflected field.
- A faster option is needed.

**Goal of This Work**
- Exploit smoothing to develop a compact algebraic model to predict the reflected field from an EUV mask blank with a buried defect.
- Use this model to instantly predict the linewidth variation of the aerial image using a standard defect interaction formulation.

**The Problem**
There are many simulation options for EUV masks with buried defects currently available, but a faster and more accurate method is needed.

1. **Finite Difference Time Domain (FDTD)**
   - FDTD a rigorous electromagnetic simulation method. It requires a very high cell density to simulate EUV masks with buried defects and is therefore very slow.

2. **RADICAL (Rapid Absorber Defect Computation for Advanced Lithography)**
   - Uses a modified ray tracing method to accurately simulate the multilayer ~500x faster than FDTD.

3. **Single Surface Approximation (SSA)**
   - Considers only the path difference effects on phase due to the top surface of the multilayer. It is very fast, has been shown to be inaccurate.

**Speed of RADICAL**
- Time improvements from 3 minutes to 7 seconds.
- 3D pattern (lines) with a reduced footprint.
- Reduction in runtime from seconds to minutes.

**Smoothing Can Be Exploited by the New Model**
- **Goal of Smoothing**: Reduce printability of a buried defect in an EUV mask.
- **Smoothing Process**: Intentionally deposit extra silicon when making multilayer mirror, and then use ion beam sputter etching to etch back the silicon to the desired thickness.
- **Advantages**:
  - Reduces the printability of buried defects and transforms an arbitrary buried defect shape into a standard surface shape similar to a Gaussian.

**Constant Surface Defect Simulations**
**Smoothing model parameters adjusted to force a constant surface defect for varying buried defects**
- Reflected magnitude varies.
- Reflected phase is fairly constant.
- Printability depends mainly on surface geometry.

**Constant Buried Defect Simulations**
**Smoothing model parameters adjusted to force a different surface defect for a constant buried defect**
- Reflected magnitude varies.
- Reflected phase varies.
- Small surface defect changes result in large dip strength changes.

**Use Standard Defect Feature Interaction Method With New Model**
- **Standard equation** and new model.
- Integrate new EUV model.
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\[
\Delta L = \Delta L_{\text{MODEL}} + \Delta L_{\text{FDTD}} = 3.8nm
\]
- Results don't match FDTD simulation (slide 2).

**Modification to Single Surface Approximation (SSA)**
- SSA has been shown to be inaccurate in multiple publications.
- Plots above show that it underpredicts aerial image dip strength.
- The path difference due to the top surface of the multilayer does not represent the actual phase perturbation on the reflected field.
- The surface three bi-layers below the surface is more accurate.

**Future Goals**
- Study printability of defects as a function of covering by, and position relative to, absorber features.
- Add weighting based on position and covering to defect feature interaction model to accurately predict image perturbation for arbitrary surface defect heights and positions.
- Use this fast model to study buried defect compensation techniques.