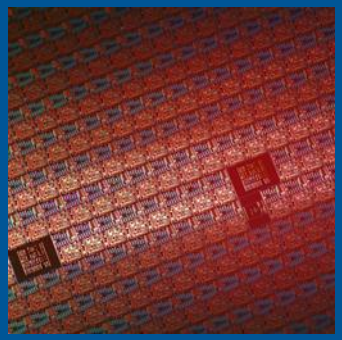
SEMATECH

Accelerating the next technology revolution

High-NA EUV Challenges and Promise

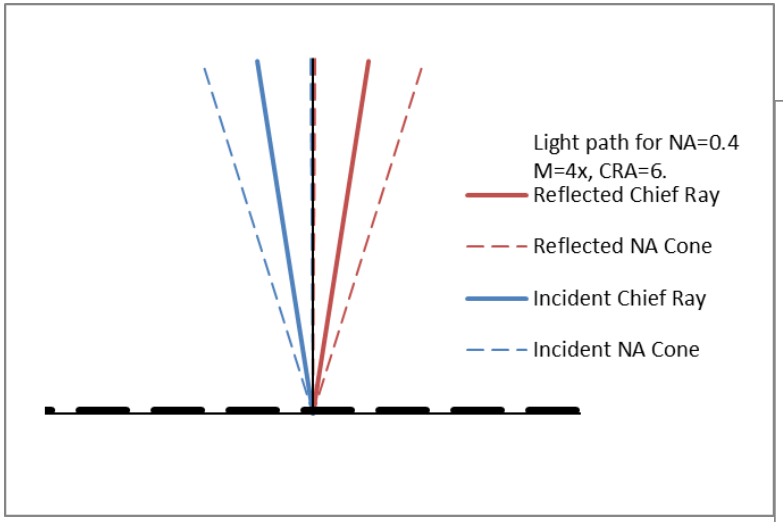


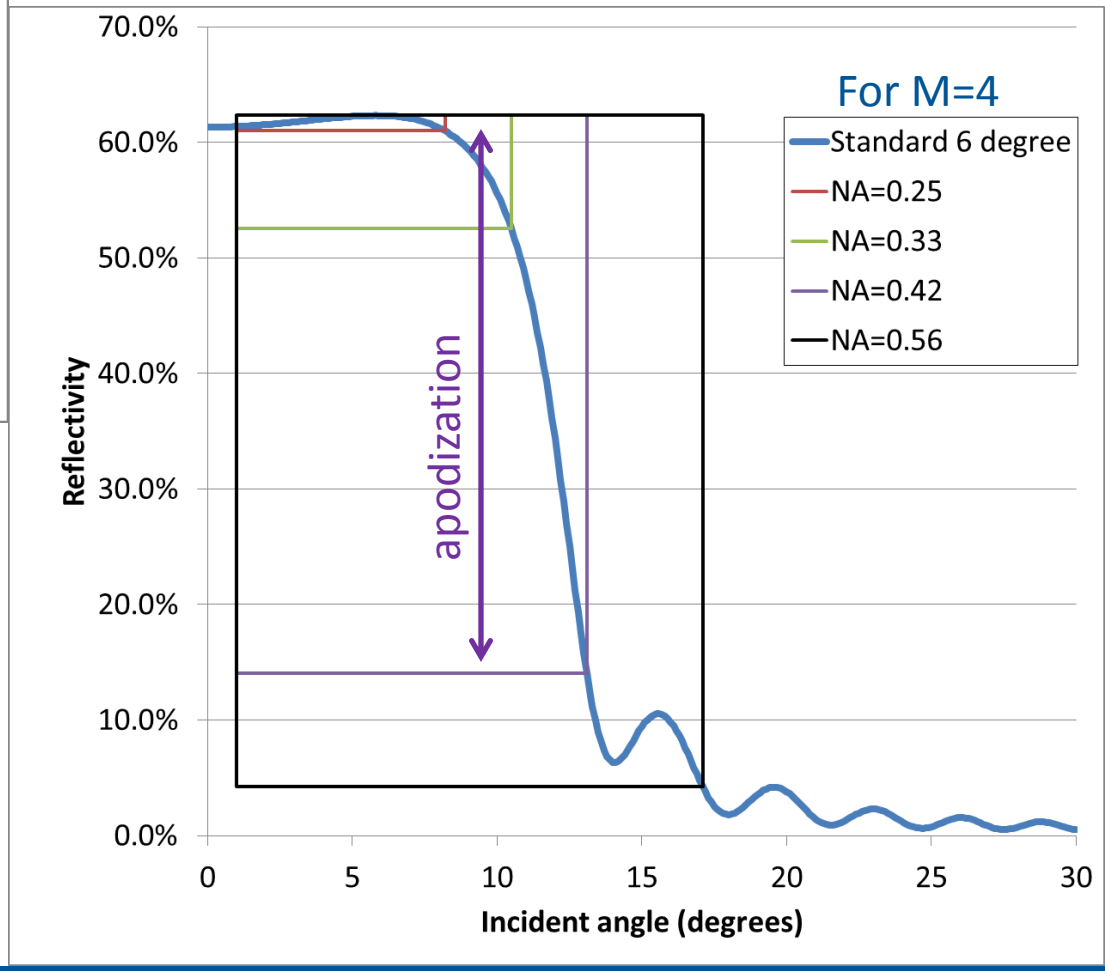
Patrick Kearney
EUV masks

Outline

- Limits to higher NA EUV
  - Multilayer bandpass may limit NA at the mask
  - Geometry limits force higher magnification or chief ray angle at higher NA
  - Imaging quality may limit the chief ray angle
- Roadmap
- Key decisions required

Can the current multilayer design support higher NA?

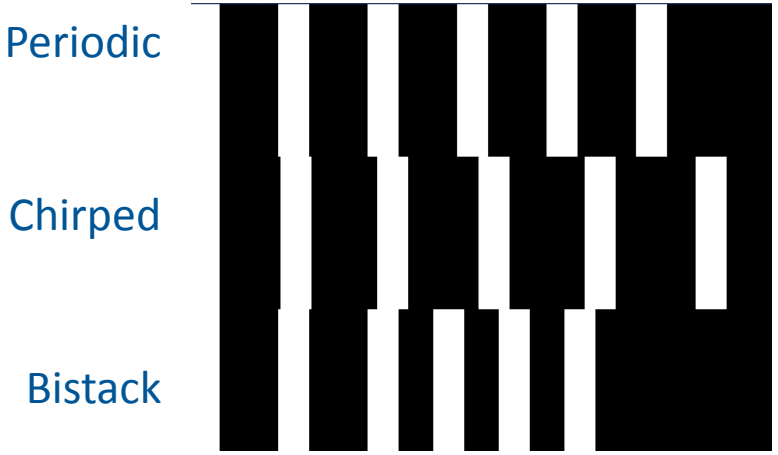


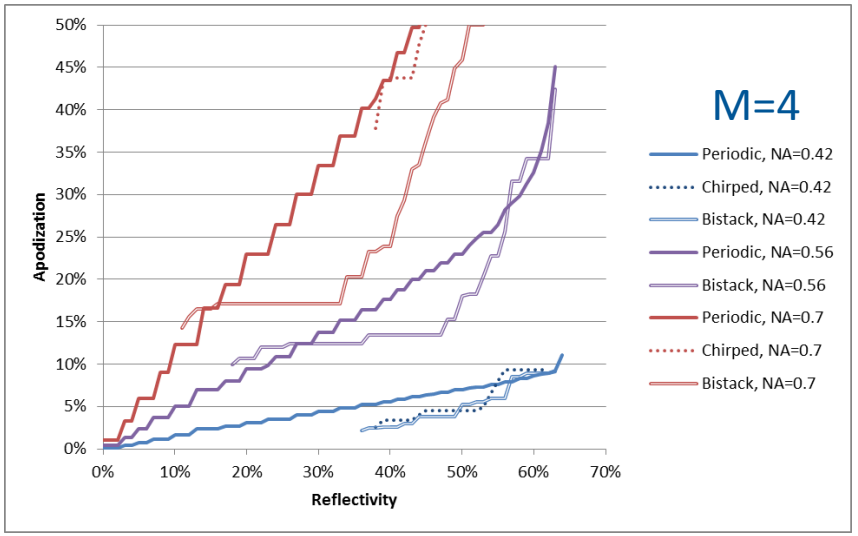


Current ML design can't support NA above ~0.33 at M=4.

A preliminary look at general periodic and aperiodic mask multilayers

- Simulate for three simple ML modifications
  - General periodic-vary N, dSi,dMo
  - Chirped-Linear dSi and dMo ramp
  - Bistacks-Vary periods and N for upper coating
- These simple modifications can improve apodization over current multilayer if we trade off reflectivity.
- What apodization can we tolerate?





Paths to higher NA - Chief ray angle or magnification

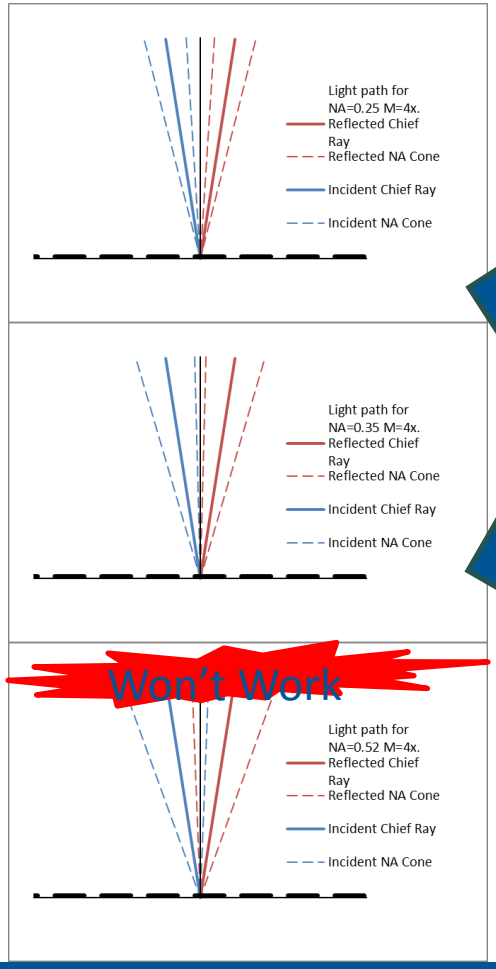
Increasing NA without changing M(4x) or the chief ray angle(6°) is limited to NA~0.42, just from the light cones.

NA

.25

.35

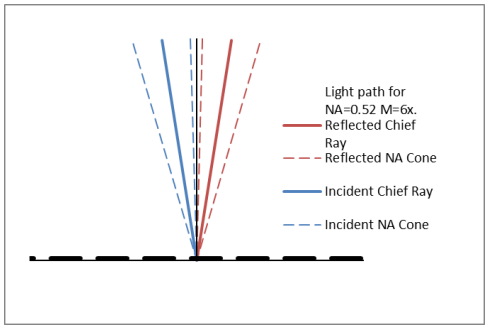
.52



Higher M

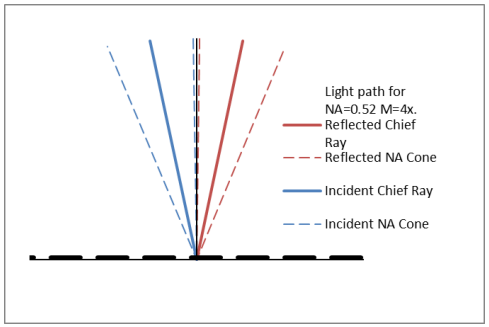
Higher Chief Ray Angle

NA=0.52, M=6x, CRA=6°



- Better imaging
- Easier ML design
- Critical defects larger
- Smaller die or larger mask

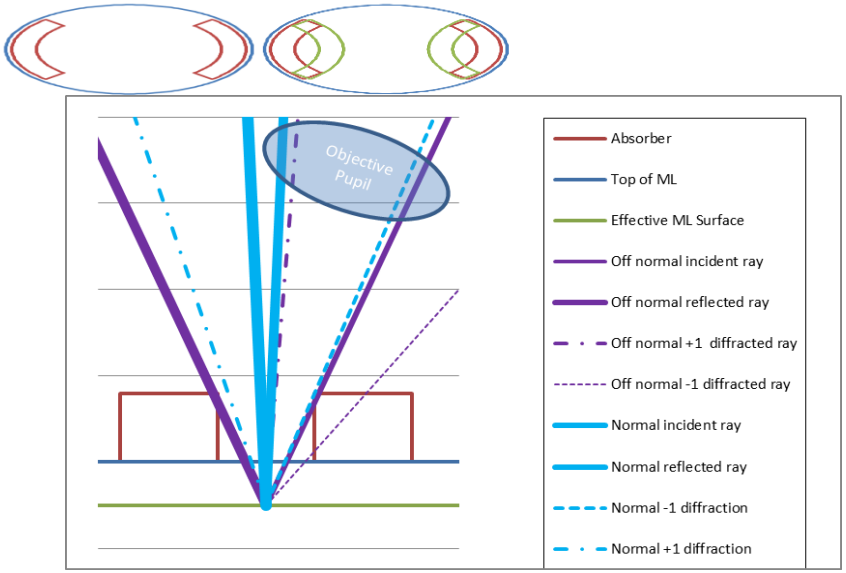
NA=0.52, M=4x, CRA=8°



- Optical design easier?
- Un-measurable in current reflectometer infrastructure
- Harder ML design

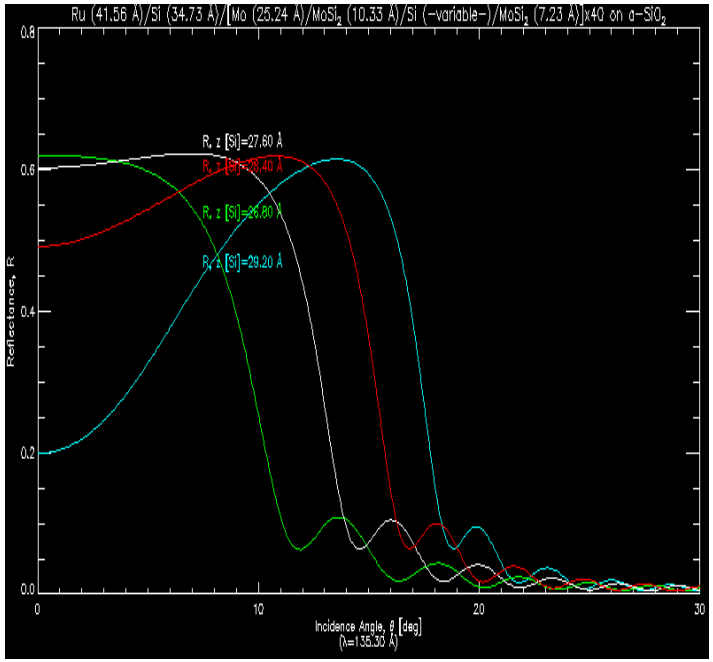
Imaging quality may limit chief ray angle to ≤7°

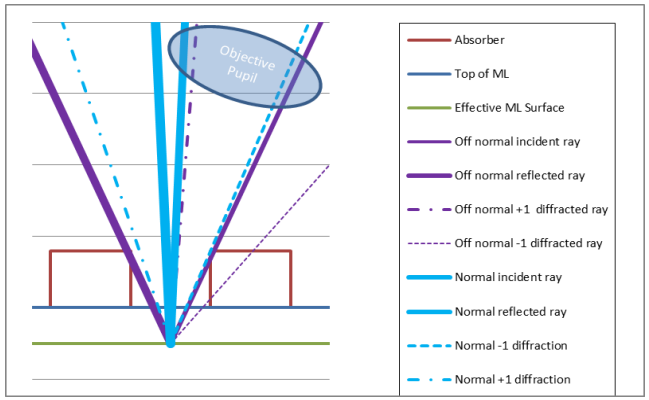
- Zeiss/IMEC made the case at the 2012 EUVL symposium that imaging quality limits the chief ray angle to ≤7°.
  - "Impact of Mask Stack on High NA EUV Imaging," Philipsen, et.al. EUVL Symposium 2012.
  - "3D Reticle Effects for High-NA EUV Lithography," Neumann, et. al. EUVL Symposium 2012.
- The highest NA that can be supported at M=4 and a chief ray angle of 7° is 0.48.
  - At higher chief ray angles and NAs, light incident from and reflected or diffracted to the off normal pole is absorbed strongly by the absorber pattern.
  - This leads to large intensity mismatches between the beams and poor imaging.



Designing the mask for high-NA imaging

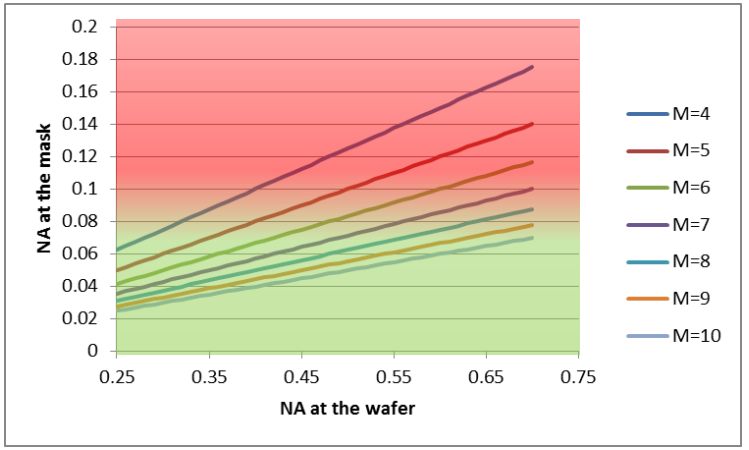
- Light from off normal portion of pupil will be absorbed more by the pattern
- Compensate for this by increasing off normal multilayer reflectivity with respect to normal incidence reflectivity to try and match intensities for maximum contrast
- Optimum mask design may be dependent on the illumination settings
- Optimum multilayer design will depend on absorber design
- This may challenge the current mask supplier business model
  - Different mask for each illumination condition
  - Different mask for each absorber stack



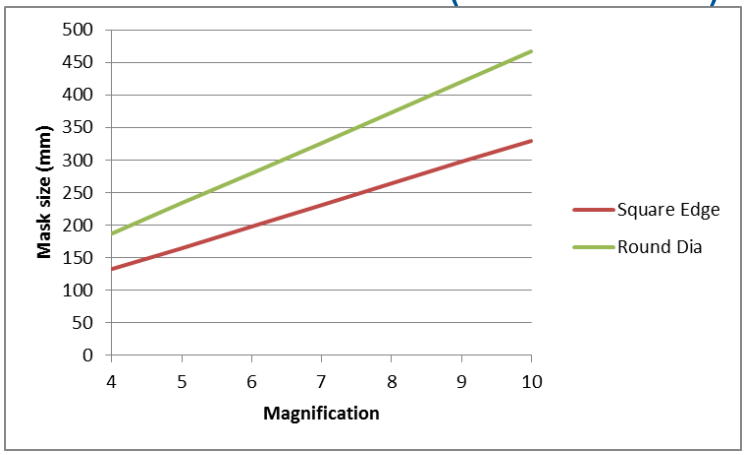


Increasing magnification
Smaller field or larger mask

- For reasonable imaging need M~7-8×, lets assume we go with 8×
- If industry can live with a 16mm wafer field, the current substrate form factor will suffice
- Otherwise we need a bigger mask ~300mm square



Minimum mask size (no overhead)



Roadmap

- Out to NA~0.42
  - (0.4*13.5/0.42=13nm)
  - Tweak ML design
  - Design ML/absorber for illumination.
  - Keep M=4 and 6” mask.
- NA=0.42-0.7
  - (0.4*13.5/0.7=8nm)
  - Increase magnification (~8×).
  - Increase mask size (~300mm)
- Beyond that:
  - BEUV (6.x nm)
  - or EUVDP

Key decisions required

- Do we bother increasing the chief ray angle?
  - CRA=6->NA=0.42, CRA=7->NA=0.48.
- How do we limit the number of mask multilayer/absorber designs the mask suppliers must support?
  - Standardize?
  - Increase magnification sooner?
- What magnification to use?
  - 8× should get us to NA=0.7.
  - Should we ramp M from 4 to 8 or just jump to 8?
- What mask size/format to use?
  - Can we live with a smaller wafer field?
  - When to change mask size?
  - Ramp mask size or just jump to largest mask?