Chemical Processes for Micro- and Nanofabrication
www.lithoguru.com/scientist/CHE323

# Bonus Lecture 1: Introduction to Mask Making, Part 1

Chris Mack
*www.lithoguru.com*

© 2016 by Chris Mack

## Mask Making - Outline

- Part 1
  - What is a photomask?
  - Mask making steps
- Part 2
  - Writing masks with electrons
- Part 3
  - Inspection, repair, and metrology
  - Challenges for EUV masks

© 2016


## Lithography Sequence

Illumination
Stepper or Scanner
Mask
Objective Lens
Wafer
Coat
Prebake
Expose
PEB
Develop
Metrology

Track and Stepper/Scanner combined into a "photocell"

© Chris Mack


## The Photomask

- A photomask (also called a reticle, or just mask) contains what you want to print on the wafer as opaque patterns on a transparent substrate

This mask contains patterns for 6 chips

Source: toppan.co.jp

- 6" square fused silica (quartz) substrate, ¼" thick is industry standard
- Opaque regions are typically made of chrome or molybdenum silicide (MoSi)
- Patterns on the photomask are defined by the chip design data
- Typical mask is 4X bigger than the wafer patterns and contains one or more chips
- 180-nm node devices need about 25 masks, 32-nm node devices need about 50 masks, and 16-nm node devices need about 75 masks

© Chris Mack


## Mask Making Steps

- Mask Blank Purchased
  - Substrate with absorber films and resist
- Data Preparation
  - Data files arrive in GDS II or OASIS format
  - Fracturing (convert design file to primitive features used by the mask writing tool)
  - Add test structures, alignment marks, barcodes, etc.
- Mask Writing (expose resist)
  - Electron-beam writer (highest resolution and precision)
  - Laser writer (lower resolution and precision)

Source: hoya.co.jp

© 2016


## Mask Making Steps (2)

- Mask Processing/Patterning
  - Develop the resist (liquid developer), positive or negative tone
  - Etch (wet/acid or dry/plasma etch)
  - Resist strip
- Metrology
  - Critical dimensions (after develop, after etch)
  - Pattern registration and overlay

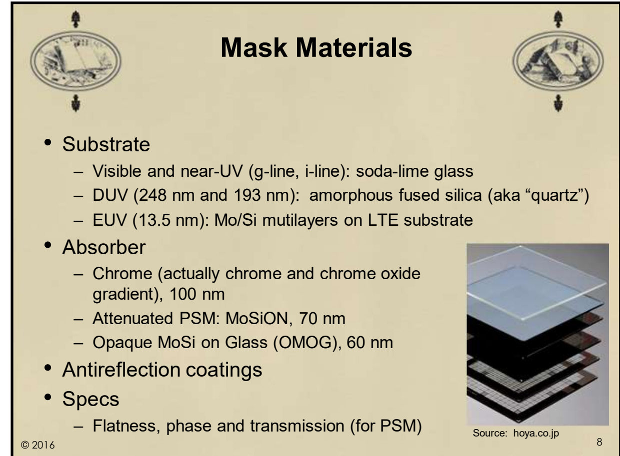
© 2016


© 2014 by Chris Mack, Lithographic Optimization

## Mask Making Steps (3)

- Defect Inspection
  - 100% coverage, die-to-die or die-to-database
- Defect Repair
  - Printable defects are repaired by adding or removing absorber material
  - Focused ion/e-beam repair or nanomachining with AFM
  - Repair verification using AIMS tool, second inspection
- Pellicle Application
  - Clean mask, apply pellicle
  - Final inspection

© 2016

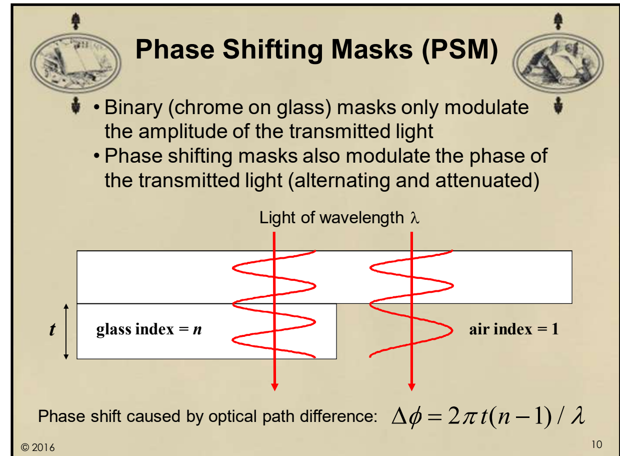



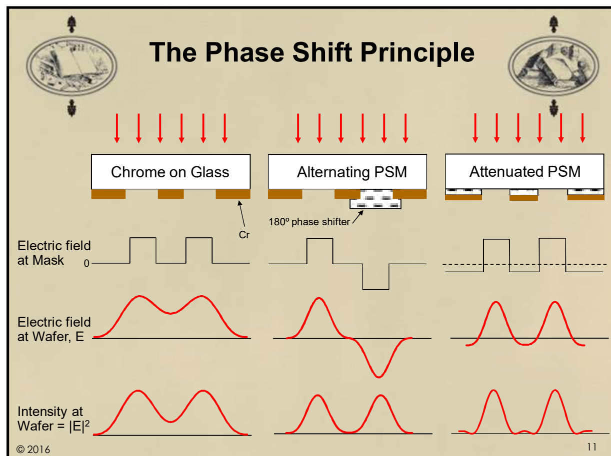

## Reduction Ratio Trade-Offs

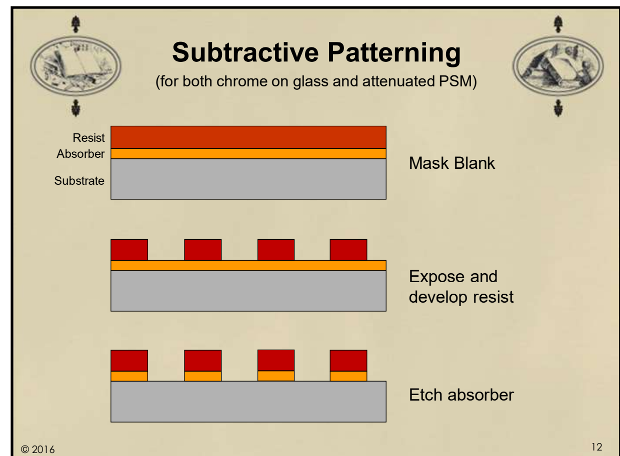
4X Reduction Ratio is the standard today

| | Lower Reduction Ratio | Higher Reduction Ratio |
|---|---|---|
| Defects | Smaller defects can print | Smaller defects do not print |
| Mask Making | Harder to make small mask features | Easier to make large mask features |
| Lens Optics | Easier to design and manufacture | Harder to design and manufacture |
| Mask Uniformity | Smaller mask means better uniformity | Larger mask means worse uniformity |

© 2016


© 2014 by Chris Mack, Lithographic Optimization

## Alt-PSM Requires a Second Lithography Step

Resist 2

Coat with resist 2

Align, expose, and develop second pattern

Etch second pattern into quartz substrate

© 2016


## Phase and Intensity Imbalance

Relative Intensity

1.4 1.2 1.0 0.8 0.6 0.4 0.2 0

-300 -200 -100 0 100 200 300

x (nm)

EMF Simulations Aerial Image

© 2016


## Imbalance Solutions

Dual Trench

Undercut

Bias

(or some combination of the above)

© 2016


## Masks – the Big Ideas

- Mask making is its own difficult lithography challenge, only without mass production
  - Every mask is "one off"
  - Every mask must be 100% defect free
- There are many trade-offs to optimizing reduction ratio
  - 4X is probably good enough, and the standard in the industry
- Phase shifting masks can improve image performance
  - Attenuated PSM uses a similar mask making process to chrome on glass, but alternating PSM is much more complicated
  - Off-axis illumination + attenuated PSM is common
  - Alternating PSM is only rarely used

© 2016


© 2014 by Chris Mack, Lithographic Optimization