Reduction of Large Killer Defects in EUV Mask Blanks

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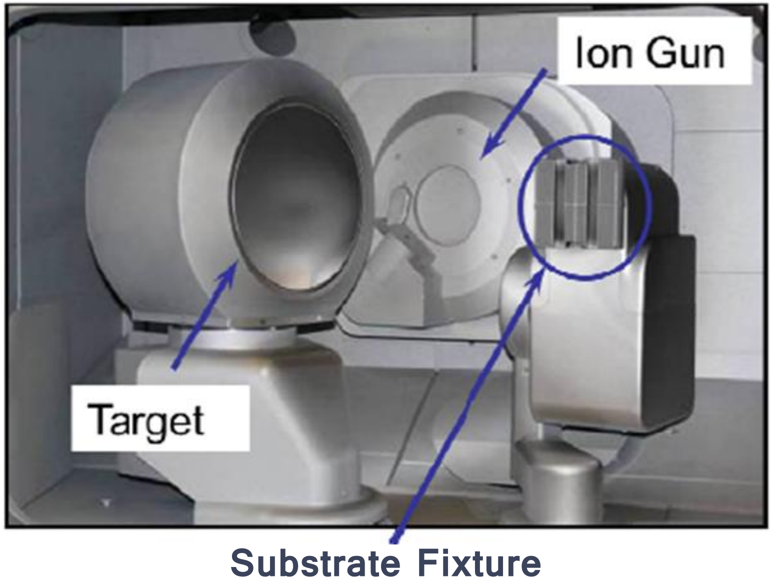
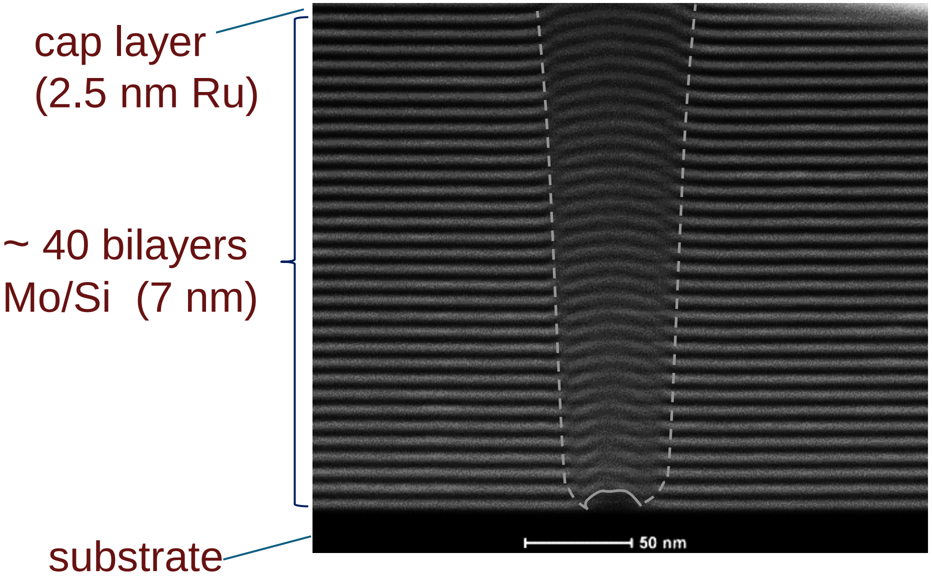
Agenda

- Background
  - Mask blank deposition and defects
  - Defect root causes / beam overspray issue
- Beam overspray reduction program
- Comparison of overspray reduction effects
- Process qualification of new ion optics at SEMATECH
- Summary and Conclusions
- Source Technology Improvement Path
- Acknowledgments

EUV Mask Blank Deposition and Defects

Veeco NEXUS™ LDD-IBD





Cross-section of EUV mask blank coating with particle defect

Ion Beam Low Defect Deposition System*

- Primary plasma confined to gridded ion source
- “Electrostatic shutter”

Particles added during deposition process are currently the major source of > 80 nm “Killer” mask blank defects.

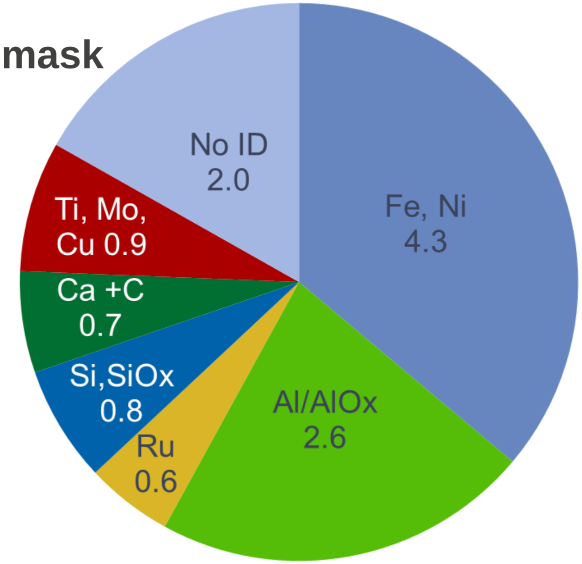
**U.S. Patents 5,982,101; 6,590,324, Veeco*

Defect Root Causes and Beam Overspray Hypothesis

Particle Composition

A. Antohe; et al, Proc SPIE 2015

 # Adders / mask >100nm



Most added defects are SS and **Al/AlOx**

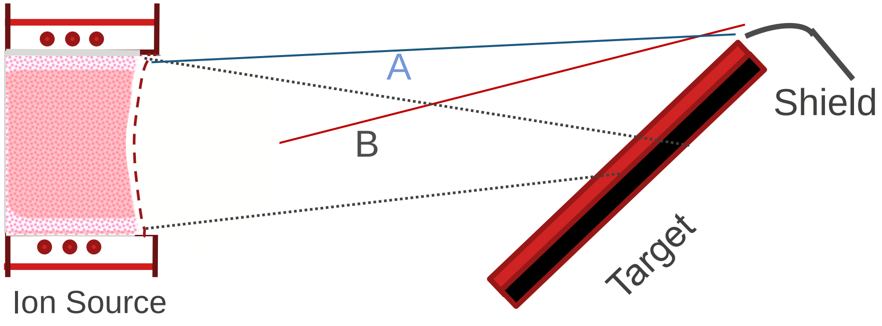
How do particles get embedded in film?

Potential Sources:

- Substrate Handling components
- Alumina grit-blasted SS shields

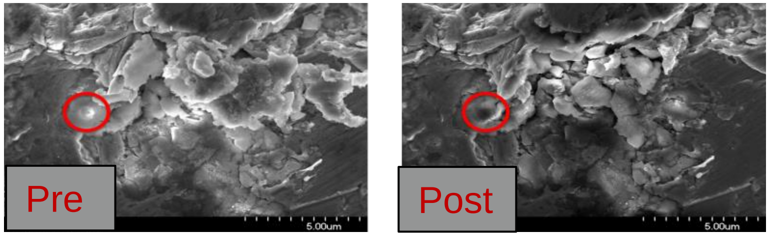
“Beam overspray” issue

V. Jindal; et al, Proc SPIE 8679, 2013



A- Divergence
(High tilt angles)

B: Gas scattering

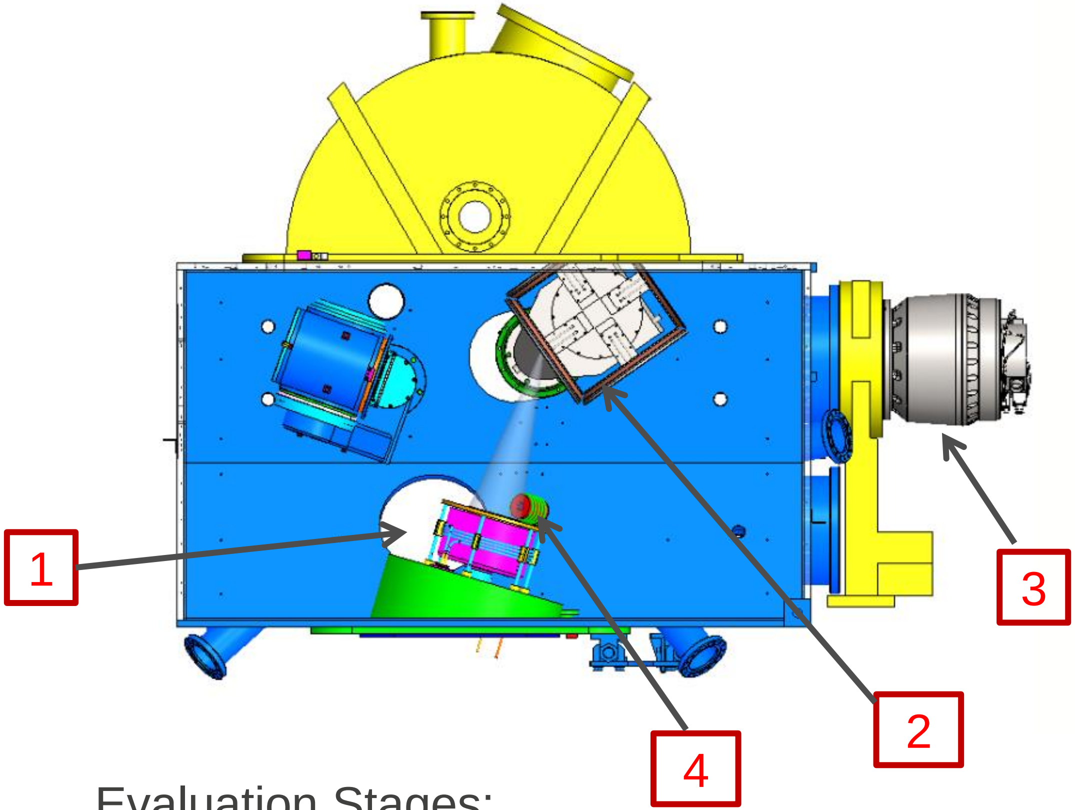


SEMs of Ion Beam Etched Shield Surface ,
A. Leitz, et al, presented at AVS 2013

Overspray etches surface,
undercutting and dislodging particles

H. Yu, et al, JVST A31, 021403 (2013)

Beam Overspray Reduction Program



	Potential Solutions
1	Redesigned ion optics (reduced beam divergence)
2	Larger target size
3	Increased pumping speed (lower pressure)
4	Enhanced beam neutralization

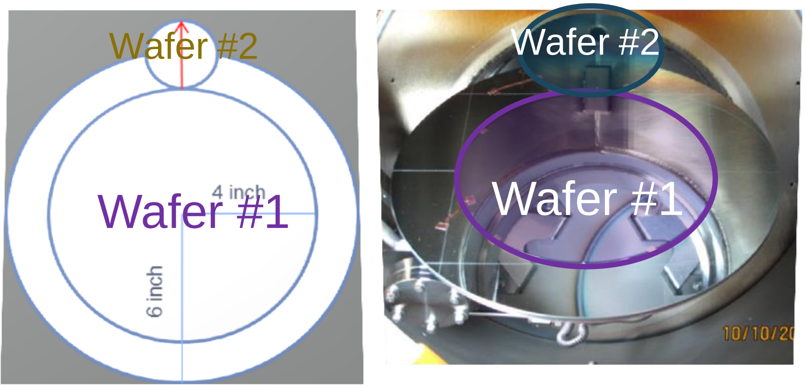
Evaluation Stages:

A. Preliminary beam overspray testing and design
B. Installation and form, fit, and function testing
C. Overspray comparison (validation of preliminary tests)
D. Process qualification and defect studies

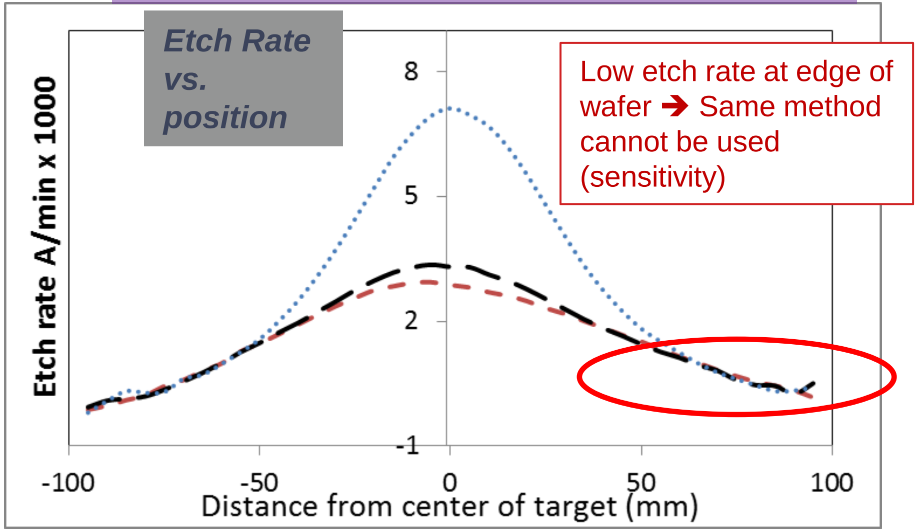
Beam Overspray Characterization Method

- ❑ Etch profiles measured at target center and edge using coated Si wafers mounted on target
- ❑ "Stitched profile" with thick Cr (~500Å) in center and thin Diamondlike Carbon (DLC, ~30Å) at edge
- ❑ Pre and post measurements of thickness changes by resistivity (Cr) and ellipsometry (DLC)

Wafer Layout For Etch Profile Measurement

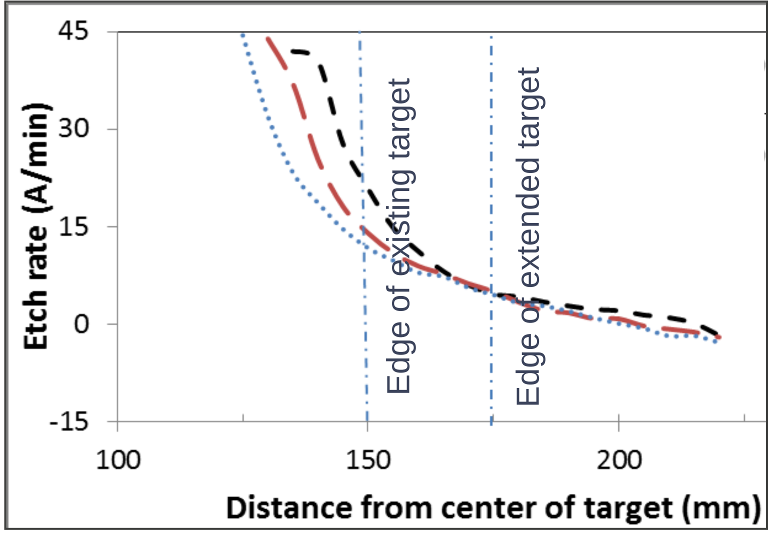


Wafer #1: Thick Cr Film – Center of Profile

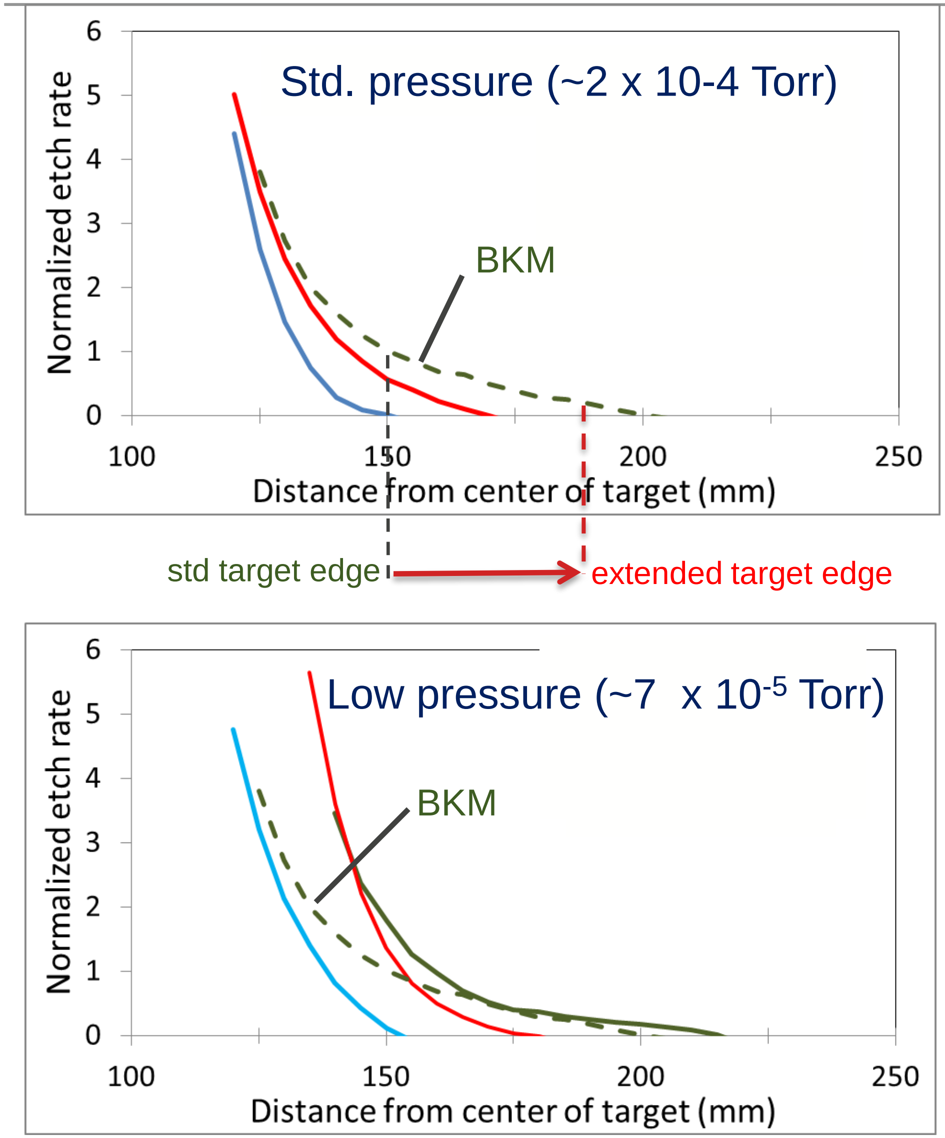


Low etch rate at edge of wafer ➔ Same method cannot be used (sensitivity)

Wafer #2: Thin DLC – Edge of Profile



Results of Overspray (OS) Tests



- - - Standard Ion Optics (Std Pressure)
— Standard Ion Optics (Low Pressure)

— New Ion Optics
— New Ion Optics + Enhanced Neutralization

Overspray Model: Particle Gen. Rate ~ I_{OS} (beam current off the target)
ER (etch rate) Profile => Beam I Profile
OSR (Ratio OS to BKM OS) = $I_{OS} / I_{OS\text{-}BKM}$

- ➢ **Lower Pressure** actually **increases OS** (higher beam divergence, overrides lower gas scattering)

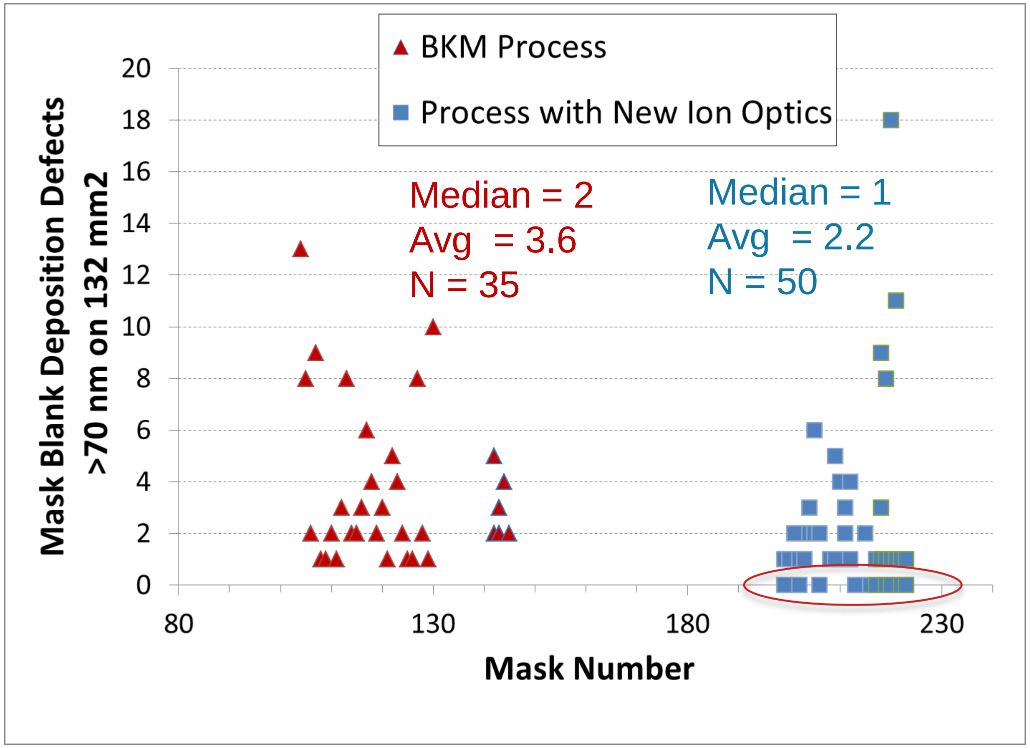
- ➢ **New Ion Optics with elliptical grid pattern: OSR ~0.2**

- ➢ **Target extension: OSR ~ 0.05**
- ➢ **+ New Ion Optics: OSR < 0.01**

- ➢ **Enhanced Neutralization + New Ion Optics: OSR < 0.01**

EUV Mask Blank Process Qualification at SEMATECH

- BKM Process from first stage of marathon, includes improvements in substrate handling and substrate management protocols
- New Ion Optics installed in latter stage



A reduction in defects, and achievement of a significant number of 0-defect masks, was observed in the latter stage of the evaluation

These results correlated with introduction of the new optics, as well as some other operational changes

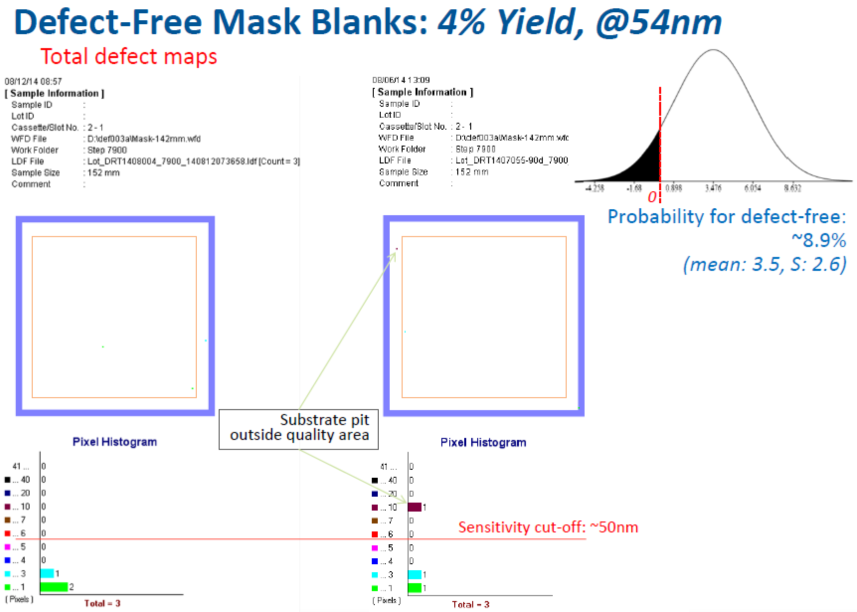
A, Antohe, et al, 2014 EUVL Symposium, A. Antohe; et al, Proc SPIE 2014;
F. Goodwin, et al, 2014 EUVL Symposium

EUV Mask Blank Process Qualification at SEMATECH*

Neutralization Mode	EUV Reflectivty	CW (nm)	CW Range (nm)
Std	65.8%	13.55	0.03
	65.8%	13.51	0.02
Enhanced	66.3%	13.56	0.03
	65.6%	13.56	0.02
Specification	>65%	13.5	<0.03

EUV properties of mask blanks fabricated with new ion optics met specification (with and without enhanced neutralization)

PARTICLE COMPOSITION		
Adders >100nm	Initial	Final
Fe, Ni	4.3	0.3
Al/AlOx	2.6	0.2
Ru	0.6	0.0
Si/SiOx	0.8	0.2
Ca+C	0.7	0.2
Mo / MoOx	0.0	0.3
Other: Ti, Mo, Ni, Cu	0.9	0.0
NO ID	2.0	1.4
# blanks analyzed	*35*	*43*



Defect-Free Mask Blanks: ***4% Yield, @54nm***

Total defect maps

08/12/14 08:57
[Sample Information]
Sample ID :
Lot ID :
Cassette/Slot No. : 2 - 1
WFD File : D:\def003a\Mask-142mm.wfd
Work Folder : Step 7900
LDF File : Lot_DRT1408004_7900_140812073658.ldf [Count= 3]
Sample Size : 152 mm
Comment :

08/06/14 13:09
[Sample Information]
Sample ID :
Lot ID :
Cassette/Slot No. : 2 - 1
WFD File : D:\def003a\Mask-142mm.wfd
Work Folder : Step 7900
LDF File : Lot_DRT1407055-90d_7900
Sample Size : 152 mm
Comment :

Substrate pit outside quality area

Probability for defect-free: ~8.9%
(mean: 3.5, S: 2.6)

Sensitivity cut-off: ~50nm

- ✓ First reported 0-defect masks @ >54 nm!
- ✓ Deposition-added yield ~30% @ >54 nm
- ✓ Deposition-added yield ~38% @ >100 nm

- ❖ Major reduction in Fe,Ni and Al /AlOx particles
- ❖ Includes improvements in substrate handling and management

*A. Antohe; et al, Proc SPIE 2015

Summary and Conclusions

- Overspray reduction >100X

  -larger target + improved ion optics with elliptical grid pattern

- New ion optics qualified for process
  - Correlated with first 0-defect masks in quantity, as well as first 0-defect masks @ 54 nm (improved optics only)
- Extended target + new ion optics proposed for larger overspray reduction
  - Would also enable lower gas pressure (for reduced gas scattering) with >100X overspray reduction
  - Target is fully functionally tested, not yet LDD qualified but low risk (relatively minor change)
- Components are commercially available

Source Technology Improvement Path

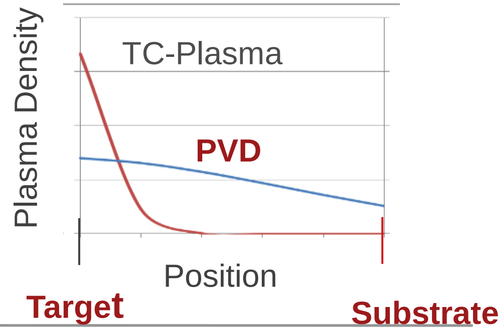
- Ion beam target overspray, target nodule formation, and particle entrainment in the ion beam, are potential ultimate limitations to particle reduction in IBD

- Alternate Source Deposition Technology – “Biased Target IBD”
  - Low ion energy minimally sputters shields
  - Normal incidence sputtering prevents nodules formation
  - Plasma generation area is not confined to target. Results in particles charging and entrainment of the particles in ion beam with subsequent formation of defects on the wafer surface

- Other deposition technologies, such as conventional PVD, have own drawbacks (e.g. poor plasma confinement, non-uniform target erosion)

- TCP (Target Confined Plasma) Sputtering technology, in progress, is a promising alternative (multi-lobe, or multi-cell magnetrons)
  - Plasma confined near target / uniform erosion
  - No ion beam – no overspray

- This is still long term development, not an immediate replacement for IBD



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Thank You!