Intelligent mask Inspection Systems for Next Generation Lithography

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San Jose, California
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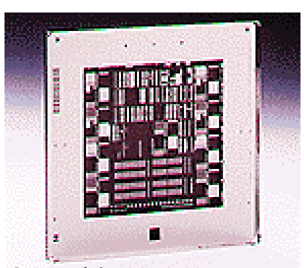
Defect Free Reticles are Critical to Achieving High Device Yields



Courtesy of Photronics

- Killer defects cause yield bust
- Linewidth defects lower IC performance
- Defects narrow the process window

Defect inspection is a key step in defect elimination

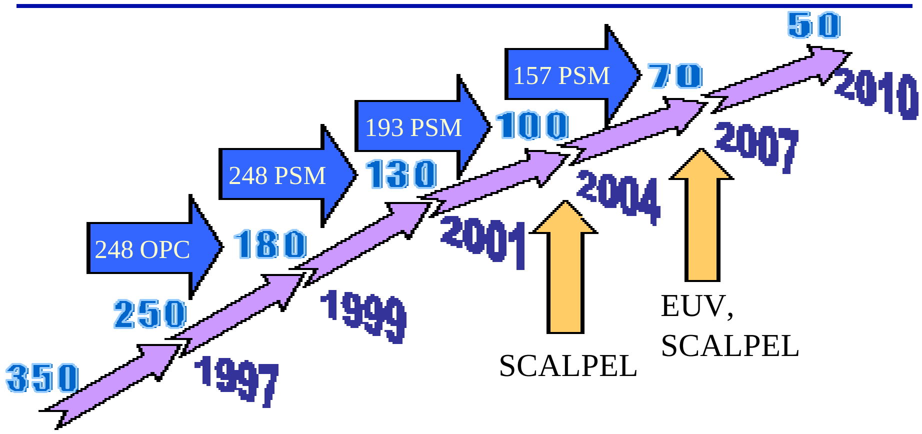
Next Generation Lithography Presents Unique Challenges for Mask Inspection


Courtesy of Lucent Technologies


Courtesy of EUV LLC

- Feature size shrink
  - primary features
  - defects
- New defect types
  - substrate and blank defects
  - patterning defects
- New materials
  - transmission is not an option
  - contrast is lower
- New exposure sources
  - which defects print?
  - are all defects visible?

When Does the Industry Need NGL?



The ATP Project Will Retire the Technical Risks and Accelerate the Introduction of New technology

The Intelligent Mask Inspection Project is a joint effort of these organizations:

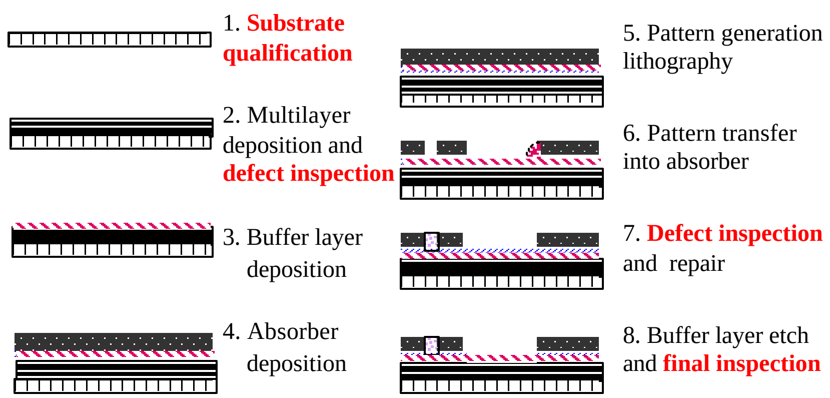
KLA-Tencor
- Build and test a research tool for inspecting NGL masks
- Develop tools for printability simulation and conduct printability experiments
- Develop methods and tools for EUV substrate and blank inspection

Lucent Technologies
- Provide SCALPEL mask models and samples

EUVL
- Provide EUV mask modeling, substrates, blanks and patterned masks

DuPont Photomasks, Inc.
- Develop process for patterning and repairing SCALPEL masks

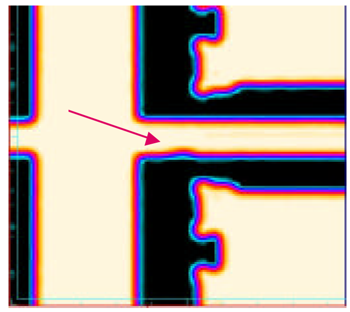
How Is a EUV Mask Fabricated and When Do We **Inspect** It?



Courtesy of EUV LLC

What Are The Driving Patterned Mask Inspection Requirements?

- Pattern defect detection sensitivity
  - Shape defects near edge
  - Pinholes
  - Linewidth errors
- Throughput (inspection time)



100nm shape defect on edge

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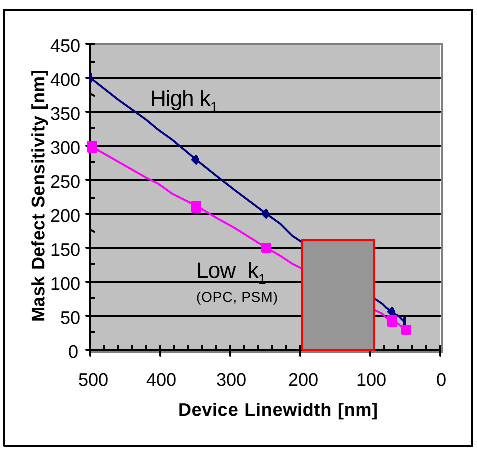
Sensitivity Requirements Vary by Mask Type and Lithography Mode



- Advanced lithography (optical proximity correction and phase shift masks) amplifies the defect printability
- Mask defect sensitivity requirements for NGL scale like conventional masks
- NGL requirement is 80nm to 60nm sensitivity for first generation tools
- Scaling rule is for shape defects, 4x masks

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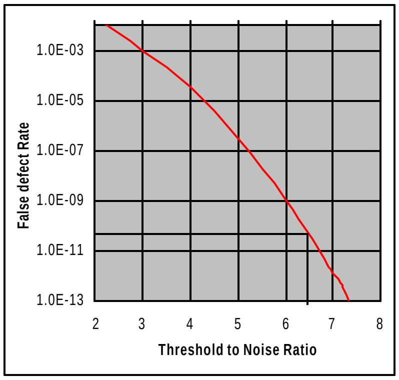
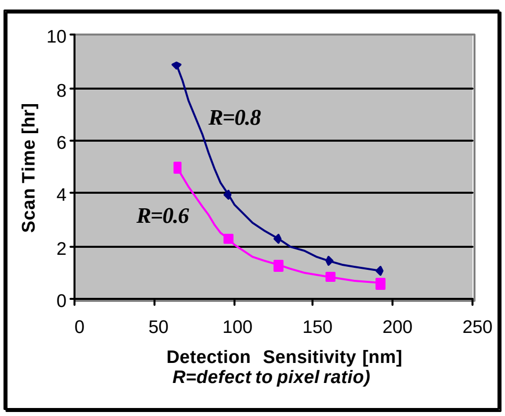
The System Design is Driven by The Required Low False Defect Rate



- Required threshold to noise ratio is about 6.5 (150nm pixel size and less than 10 false defects per inspection)
- Required signal to noise ratio is about 10 for 99% detection probability
- The SNR scales as the square of the linear defect size (for most defects)

Increased Sensitivity Comes at the Expense of Inspection Time



- Calculation based on current generation product:
  - 50 Mpixel/sec scanning and processing
- 100cm^2 inspected area

Reducing the defect to pixel ratio

has high leverage on inspection time!

Advances in Technology Are Needed to Meet The Emerging Requirements

Extending the capabilities of the current generation of optical inspection tools can be accomplished by:

- **Higher resolution imaging**
- **Lower noise**
- **Better detection and disposition algorithms**
- **Faster processing**

The alternative, non-optical inspection (e-beam, EUV, other), requires significantly more technology development

Inspection of Unpatterned EUV Masks Faces Additional Challenges

- Shallow defects on the substrate or on the coated blank modulate the wavefront phase, causing printing defects:
  - Cylindrical pit or hillock: 3.4 nm high x 80 nm diameter
  - Scratch: 3.4 nm high x 15 nm wide
  - Step: 1 nm high
- Can optical inspection meet the needs, or is at-wavelength inspection required?
  - Correlate optical and 13-nm blank inspections
  - Determine evolution or mechanism of formation of reflectivity defects
  - Model EUV defect properties in the visible/UV range
  - Determine what defects we missed optically
  - Determine if they are critical defects

Thorough Inspection Requires Both Bright Field and Dark Field Detection

- Bright-field technology is more adept at finding planar (phase) defects
  - Small pixel size, low throughput
- Dark-field technology provides superior sensitivity for particulate defects
  - Larger pixel size, higher throughput

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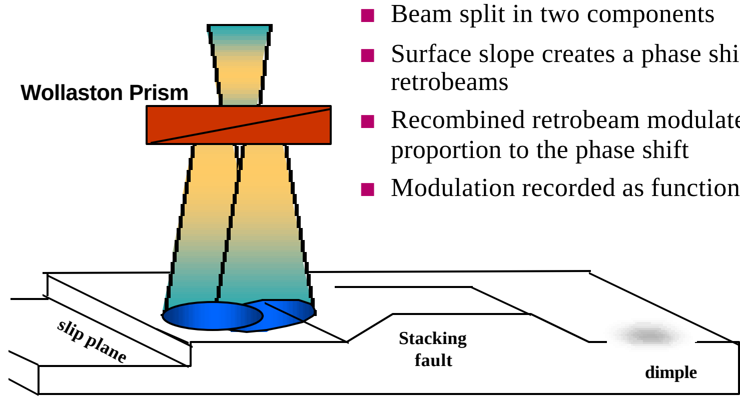
Nomarski Differential Interference Contrast (DIC) Detection Provides High Sensitivity on Planar Defects



- Beam split in two components
- Surface slope creates a phase shift between retrobeams
- Recombined retrobeam modulated in proportion to the phase shift
- Modulation recorded as function of (x,y)

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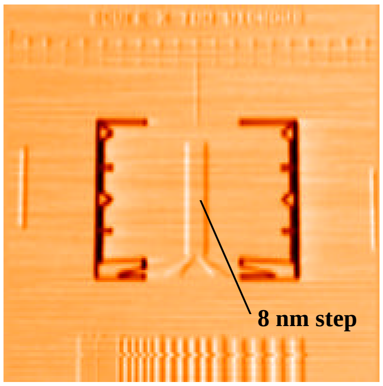
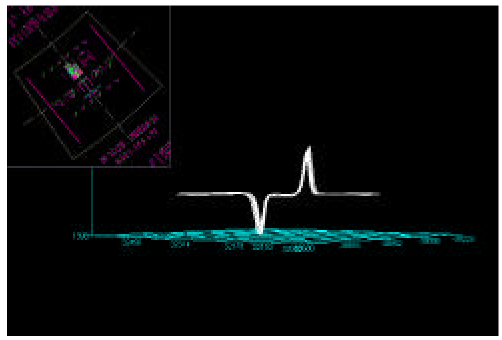
A 8 nm Step Height Standard Can Be Measured With the KLA-Tencor SP1 Nomarski DIC Channel





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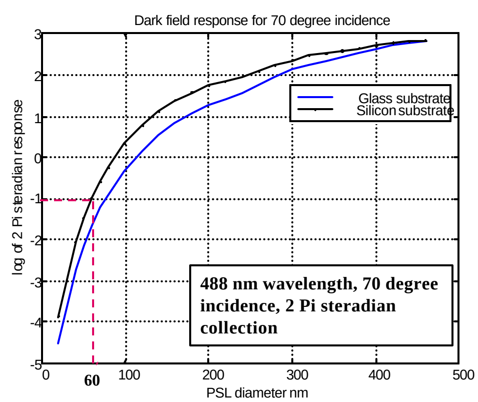
Current Dark-Field Inspection System Sensitivity Will Not Meet the Needs of EUV Inspection



- KLA-Tencor SP1 inspection tool has 60nm sensitivity on silicon
- Sensitivity is reduced on glass substrate

PSL: Polystyrene reference spheres

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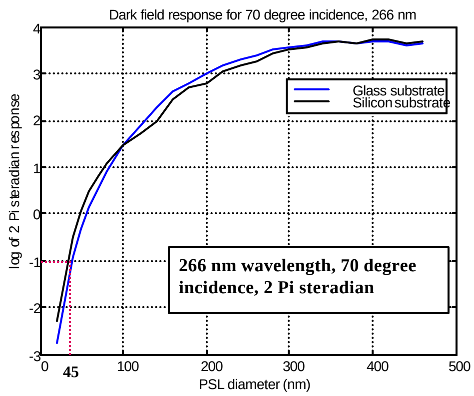
Dark-Field Inspection in the UV Has the Potential of Meeting the Required Sensitivity



- Sensitivity increases in the UV for both silicon and glass substrates
- Sensitivity of 45nm is obtained with signal level similar to the visible light system

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The Project Develops the Technology in Three Phases

- Phase I (year 1)
  - Build a research tool for NGL reticle inspection
  - Develop software model for NGL-steppers (aerial image)
  - Investigate EUV blank and substrate inspection
- Phase II (year 2)
  - Carry out inspectability/printability studies on the research tool
  - Correlate defects found on the wafer with those on the reticle
  - Establish the feasibility of Optical Inspection of NGL reticles
- Phase III (year 3)
  - Optimize and design a production prototype

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The ATP Project is Well Into the First Phase

- The team launched the technical work in mid-June, 1999
- We are modifying a KLA-Tencor UV inspection system to include:
  - High NA optics
  - High throughput image computer
  - Special handling of SCALPEL and EUV masks
  - Special contamination control
- Algorithm development work is focusing on increasing sensitivity and defect discrimination
- We have designed test masks for the printability and sensitivity studies
- We continue to collect data on blank and substrate inspection

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SCALPEL Mask Defect Inspection

SCALPEL Mask Team at Lucent Technologies

– Anthony Novembre, Technical Manager

- Chris Biddick
- Myrtle Blakey
- Gregory Bogart
- Carlos Caminos
- Reggie Farrow
- Robert Followan
- Joe Griffith
- Leslie Hopkins
- Rich Kasica
- Chester Knurek
- Jessica Li
- J. Alexander Liddle, TMGR
- Leo Ocola
- Paul Orphanos
- Milton Peobody
- Len Rutberg
- Tom Saunders
- Stuart Stanton
- Michael Stohl
- Kristine Teffeau
- Kurt Werder

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Outline

- SCALPEL Mask Introduction
- SCALPEL Mask Commercialization Program
- Optical Inspection of SCALPEL Masks
- Modeling of Defect Printability
- Preliminary Defect Printability Results
- Lucent Contribution to NIST-ATP for Inspection of NGL Masks

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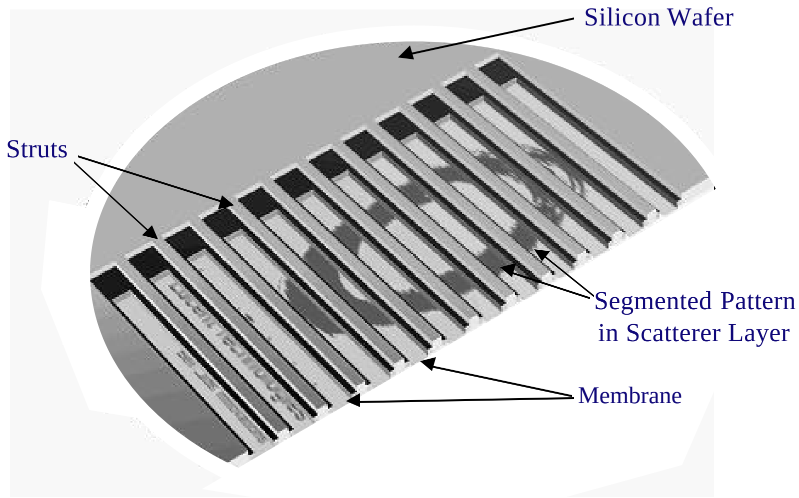
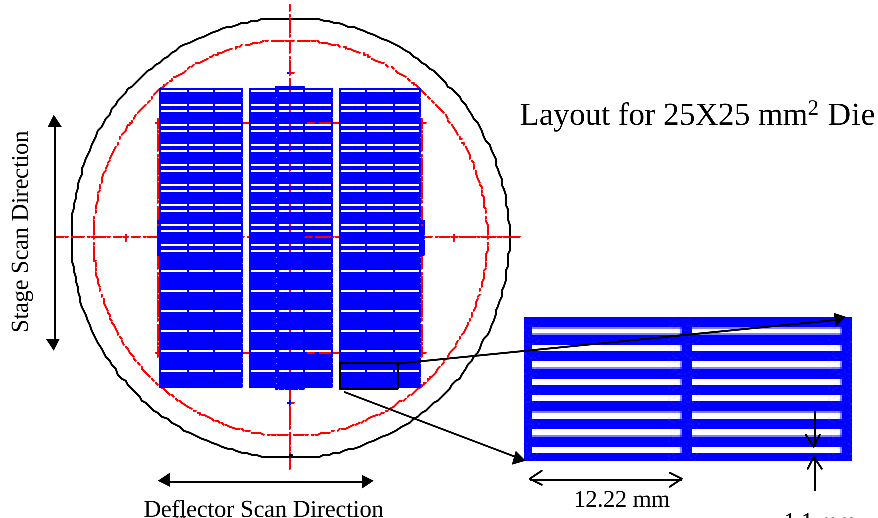
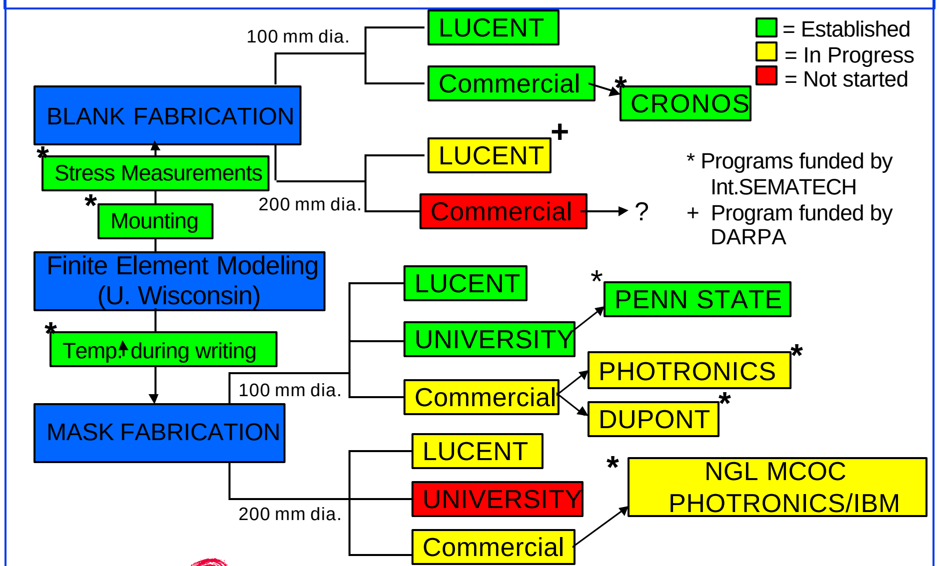
SCALPEL Mask Schematic



200 mm SCALPEL Mask



SCALPEL MASK PROGRAM



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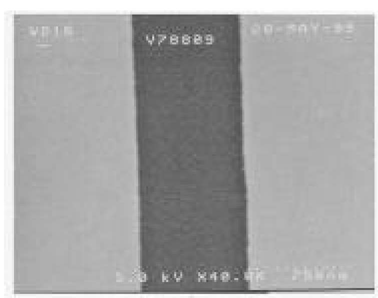
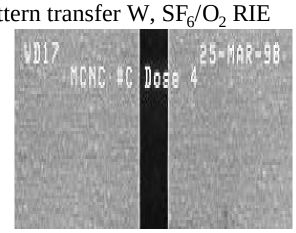
INITIAL DEMONSTRATION OF SCALPEL MASK PROCESSING CAPABILITY AT A MERCHANT (PHOTRONICS) MASK SHOP



***Coded 0.72 mm isolated trench in W/Cr scatterer layer**

Processing (Photronics)
- E-beam write MEBES 4500, 10kV, 7 mC/cm²
- Resist Develop, ZEP-7000, STEAG spray/ spin
- Pattern transfer Cr, CR-7S APT spray/spin

Processing (Lucent)
- Pattern transfer W, SF_6/O_2 RIE



* 0.18 mm at wafer

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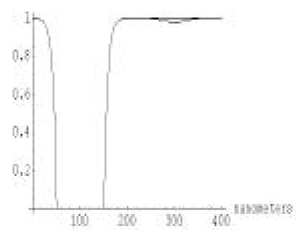
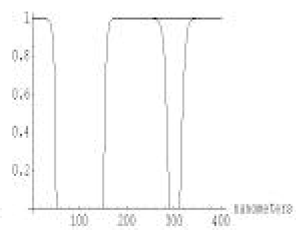
	248	365	488	

Defect Printability Examples

Case of W = 50nm, Xd=200nm, bright, Cdef = 1.





Blur=80nm
Unresolved

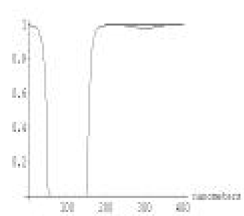
Dip=3-4%

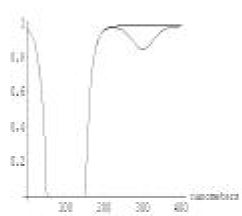
Blur=40nm
Resolved

Dip=100%

Change Gamma from 10 to 5

- **Defects Print "Stronger"**





Blur = 80nm FWHM
100 nm line
W = 50 nm
Cdef = 1

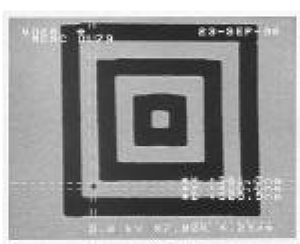
- **Gamma = 10 → 5**
- **Some CD Sensitivities to Defect Change, Some Don't!**
- **(lots of dependencies and permutations).**
- **BAD things (defect on or near edge) generally same or worse as resist contrast falls.**

Example - If the largest tolerable CD error from the defect is 1% (worst case), then:

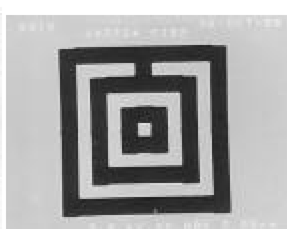
- **Tolerable full (Cdef = 1) pattern defects must be *far* from critical objects (Xd >> 100 nm @ wafer).**
- **Pattern *edge* defects (Cdef = 1) must be < CD/8.**
- **Defect repair on or near edge should be *nearly perfect* (e.g. Cdef = 0.05 post-repair @ CD/2).**
  - **Initial Focused Ion Beam Experiments Promising**
- **Even *low contrast* (Cdef ~ .25) contaminants no good if correlated to an edge (Xd < 100nm @ wafer)**
- **Even small CD/8 pinholes near CD object must be repaired; *they're very bright.***
- ***The Inspection improvements From This NIST-ATP Program are needed.***

PROGRAMMED DEFECT DENSITY MASK

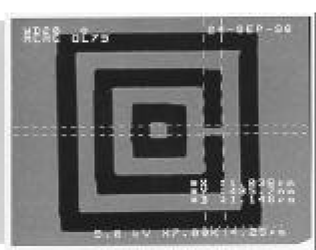
MCNC Manufactured Mask Blank (OL79)
E-Beam Write: JEOL JBX 6000FS, 50kV, 60nm spot size
Processing: STEAG Resist Developed, Post Developed Bake
PlasmaTherm RIE Dry Pattern Transfer



Pinhole (clear) defect



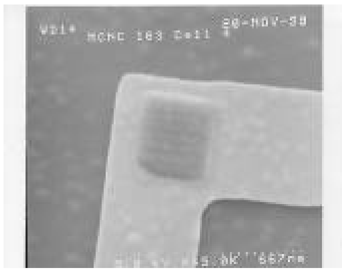
Gap (clear) defect



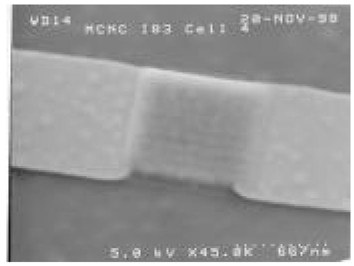
Bridge (opaque) defect

SEM MICROGRAPHS OF REPAIRED SCALPEL MASK DEFECTS

Repair tool : Micrion 8000
Chemistry: Carbon composite



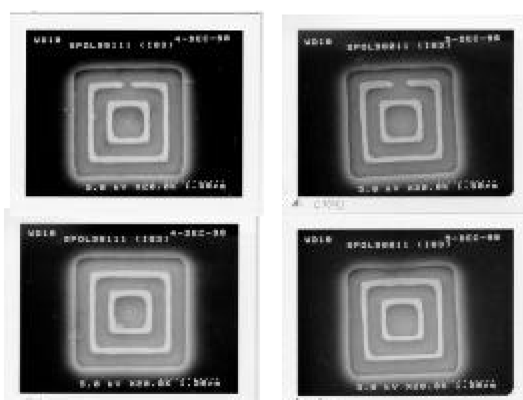
Defect = 0.70 mm pinhole



Defect = 0.70 mm break

PRELIMINARY DEFECT AND DEFECT REPAIR PRINTABILITY RESULTS USING SCALPEL PROOF-OF-LITHOGRPAHY TOOL

Mask: MCNC 150 nm SiN , 27.5 nm W, 6 nm Cr Program defect: 0.70 mm
Wafer process: ARCH1 CA + resist, 0.32 mm thick



Wafer print of clear (break) program defect
& FIB repaired (C composite) defect

Lucent Contribution to NIST-ATP for Inspection of NGL Masks

- Provide SCALPEL Masks
- Measuring the Optical Properties of Masks
- Provide Models for Defect Printability
- Experimental Verification of Defect Printability Using a SCALPEL Exposure Tool
- Consulting on the Design of Fixtures to Mount SCALPEL Masks for Inspection
- Protocol For Handling Masks

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