EUV Lithography Development in the United States

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Stefan Wurm

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EUVL Development in the U.S.

Laboratories and Universities (26)

Air Force Research Laboratory
Argonne National Laboratory
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
MIT Lincoln Labs
National Institute of Standards and Technology
US Naval Research Laboratory
Sandia National Laboratories

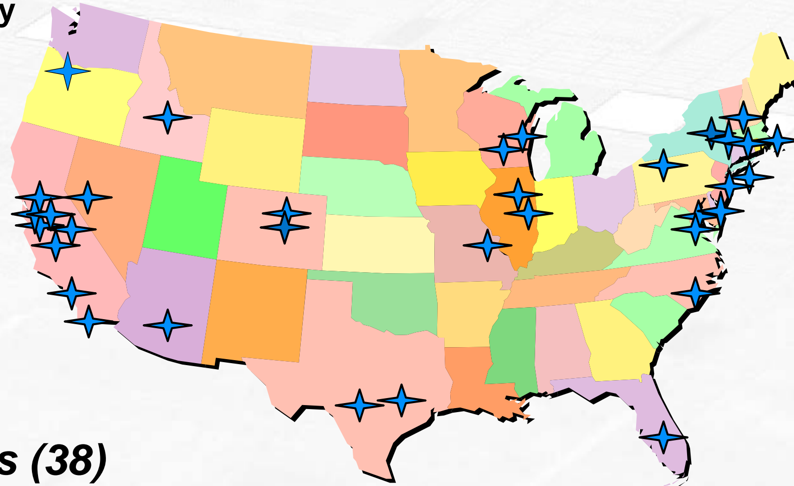
Colorado State University
Columbia University
Cornell University
Northeastern University
Rochester Institute of Technology
Rutgers, The State University of New Jersey
U. at Albany, SUNY
U. of California Berkeley
U. of Central Florida
U. of Colorado
U. of Illinois
U. of Maryland
U. of Minnesota
U. of Nevada
U. of North Carolina Charlotte
U. of Texas
U. of Wisconsin
Stanford University

IC Companies (5)

AMD
IBM
Qimonda
Intel
Micron

Consortia (7)

EUV LLC
DARPA
INVENT
NSF
SEMATECH
SEMI
SRC



Suppliers (38)

ADE
AERONEX
ASML
ASML Optics
Corning Inc.
Corning Tropel Corp.
Cymer
Dupont Photomask
Energetiq

Entegris
Etec
EUV Technology
FALA Technologies
Invax
Janos Tech.
JMAR
KLA-Tencor
Luxel
Ohara

Optimax
ORA
Osmic
Paragon Optics
Photronics
Plex LLC
Praxair
Prism Comp. Sci.
QED
Reflective X-Ray Optics
REO

Rohm and Haas
Schott-Lithotec
Starfire
Swales Aerospace
Thermacore
Tinsley
Veeco
Wave Optics

Accelerating the next technology revolution.

EUV Activity in the U.S.

Number of organizations

35
30
25
20
15
10
5
0

IC Manufacturer
Consortium
University / National Laboratory
Supplier

Source
Mask
Optic
Resist
Tool

Accelerating the next technology revolution.

U.S. Representation at the Symposium

Number of abstracts

18
16
14
12
10
8
6
4
2
0

IC Manufacturer
Consortia
University / National Laboratory
Supplier

Source
Mask
Optics
Resist
Tool

- R&D capabilities at national laboratories & universities are being extensively used

Universities & National Labs Focus

- Source
  - Scalability of source components (collector, debris mitigation, DPP electrode lifetime) for high power sources
  - Tabletop coherent EUV light sources
- Mask
  - Nanoscale cleaning/repair technologies
  - Transport/migration of nanoscale particles
- Optics
  - Fundamental understanding of processes limiting optics capping layer lifetime
  - Optics lifetime testing methods
- Resist
  - Chemically amplified resists meeting 32 nm hp requirements
  - New resist platforms for 22 nm hp

US EUV Exposure Capabilities

- The United States is the EUV photon factory that enables EUV resist development
- 3 Micro Exposure Tools (METs)
  - SEMATECH Albany MET: Standalone MET 8"/12" capable, high throughput
  - Intel MET: Similar capabilities to the Albany MET
  - SEMATECH Berkeley MET: Highest resolution MET enabled through programmable illumination, 4", synchrotron-based
  - EUV interference lithography tool at University of Wisconsin
- Alpha tool has been recently delivered to INVENT in Albany

U.S. EUV Mask Development Focus

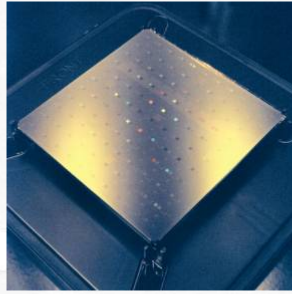
- SEMATECH's Mask Blank Development Center
  - Low added defect multilayer deposition technologies
  - Substrate defect smoothing technologies
  - Defect-free reticle handling
  - EUV mask substrates and blanks cleaning technologies
  - Actinic and visible light inspection technologies
  - Mask flatness
- Mask Makers and IC Manufacturers
  - Mask stack materials and architecture
  - Defect printing and aerial imaging for mask blank and patterned mask repair verification

U.S. EUV Mask Tool Suite

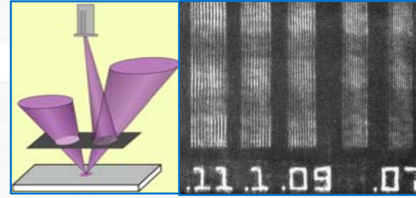
- World-class metrology and test equipment
  - World best visible light inspection tool
  - World-wide only actinic darkfield and brightfield inspection tool with scanning and microscope imaging mode
  - Unique hardware to drive evaluation and improvement of reticle handling infrastructure
- Multilayer deposition tool and defect analysis
  - World-wide unique tool that combines low defect deposition and defect smoothing in one tool
  - Compositional analysis of nanoscale particles on multilayers and substrates
- Mask blank cleans tool
  - World-wide unique cleans tool enabling development of localized cleaning technologies

SEMATECH's EUV Program

Advanced Cleaning & Metrology

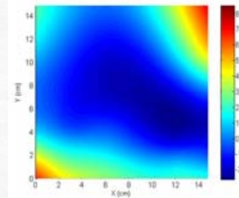


Defect-free Mask Blanks



Advanced Inspection

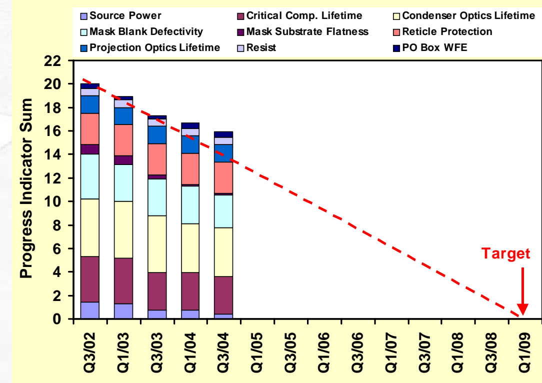
Reticle Imaging Microscope



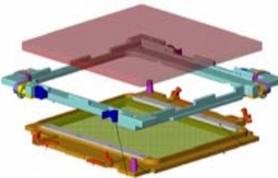
Mask Chucking

Year	2003 H1	2003 H2	2004 H1	2004 H2	2005 H1	2005 H2	2006 H1	2006 H2	2007 H1	2007 H2	Production 45nm
Parameter	Pre-alpha		Alpha		Beta		Beta		Beta		Gamma
Mask substrate											
Material	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM	LTEM
Mean CTE [±ppb/ deg K]	30	30	25	25	20	20	15	15	10	10	±5
CTE spatial variation [±ppb/ deg K TIR]	10	10	10	10	8	8	7	7	7	7	6
Front flatness in [um] P–V	0.6	0.6	0.5	0.4	0.3	0.25	0.2	0.1	0.075	0.05	0.03
Back flatness in [um] P–V	1	0.8	0.8	0.6	0.5	0.4	0.3	0.2	0.15	0.1	0.05
Surface finish											
MSFR in [nm] rms	< 2.0	< 2.0	< 1.5	< 1.0	< 1.0	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HSFR in [nm] rms	0.25	0.25	0.25	0.20	0.20	0.20	0.20	0.15	0.15	0.15	< 0.15
Local slope of front surface [mrad]	N.A.	N.A.	≤ 5.0	≤ 5.0	≤ 4.0	≤ 4.0	≤ 3.0	≤ 3.0	≤ 2.0	≤ 2.0	≤ 1.0
Total blank defects											
Total ML defect density [defects/cm^2]	2	1	0.8	0.6	0.4	0.2	0.12	0.08	0.03	0.01	0.003
Cut-off size: PSL equivalent in [nm]	150	150	120	120	90	90	60	60	40	40	25
Multilayer Performance											
Peak reflectivity [%]	> 60	> 60	> 62	> 62	> 63	> 64	> 65	> 65	> 66	> 66	> 67
Peak reflectivity uniformity abs in [%] P-V	0.80	0.80	0.70	0.60	0.60	0.55	0.55	0.50	0.50	0.50	0.50
Median central λ of reflectivity [nm]	13.40	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	TBD
Median central λ offset [nm]	±0.12	±0.1	±0.08	±0.08	±0.07	±0.07	±0.07	±0.07	±0.06	±0.06	≤ ± 0.06
Centroid reflected λ uniformity in [nm] P-V	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Mask Blank & Substrate Benchmarking



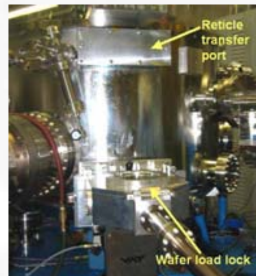
EUVL Readiness



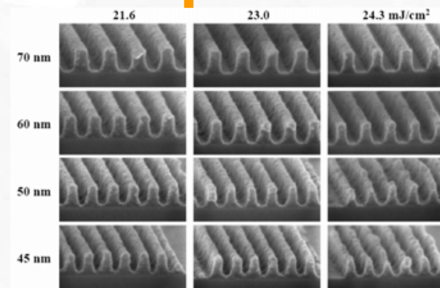
Reticle Handling

Optics Lifetime

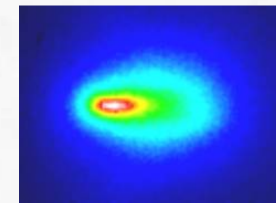
Albany MET



Berkeley MET



Resist Development



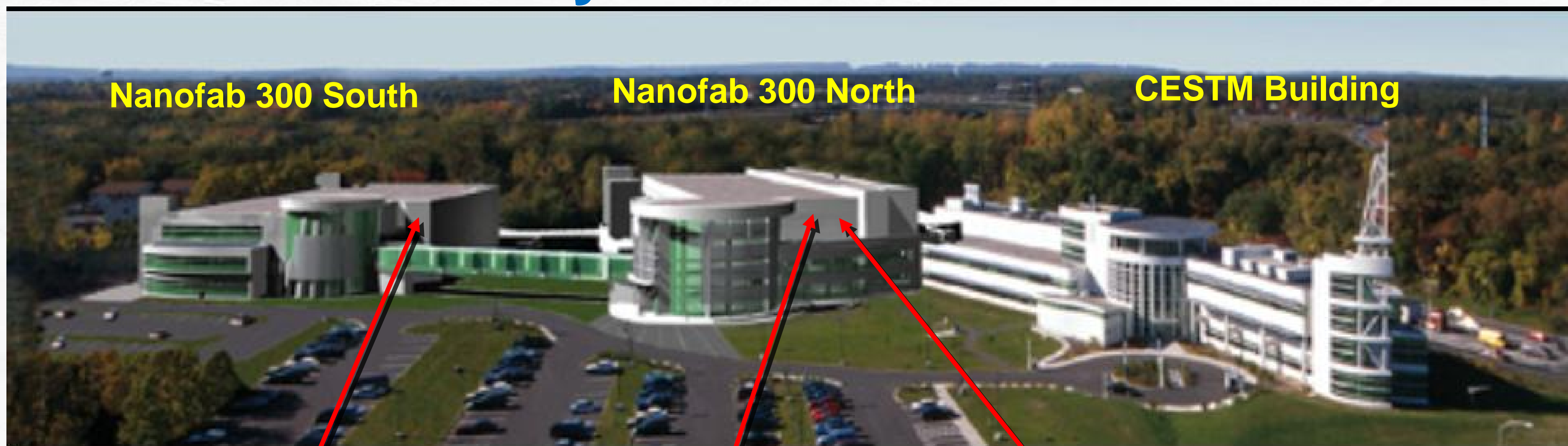
High Power Source

Accelerating the next technology revolution.

Albany Site EUV Litho Infrastructure

- A critical mass of EUV capabilities and expertise has been forming in Albany
- The combination of EUV hardware and know-how is unique among EUV centers

Albany NanoTech Facilities



SEMATECH EUV Mask Blank Development Center

INVENT EUV α tool

SEMATECH EUV Resist Test Center

Summary

- EUV lithography development in the U.S. is focused on the key supporting infrastructure.
- A full-field EUVL alpha exposure tool has been delivered to Albany Nanotech.
- A unique EUV infrastructure in the mask area is available in the U.S., most of it in Albany.
- The U.S. continues to provide most of the exposure capability to accelerate resist development.
- Key R&D capabilities in the source and optics area are provided to the world-wide EUV development effort by U.S. national laboratories and universities.