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International EUV Initiative (IEUVI) Overview; Challenges and Collaborative Efforts

(7/1/2006) Future Fab Intl. Volume 21

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For several years now, both technical and commercialization challenges for extreme ultraviolet lithography (EUVL) have been much reported. By 2000, a handful of EUVL R&D efforts had been established at various locations in Europe, Japan and the United States; by late 2002, several solid efforts to enable key infrastructure worldwide were under way. However, there was no entity that addressed the coordination of EUVL infrastructural issues among the different geographic regions. In autumn 2003, the International EUV Initiative (IEUVI)[1] was launched to further the coordination of collaborative efforts among leading EUVL R&D consortia and to address infrastructural issues for commercialization. It built on an earlier coordination effort between Japan's only EUVL R&D entity ASET[2] and the U.S. organization EUV LLC[3] by expanding membership to CEA/LETI[4] of France, SEMATECH[5] of the U.S. and several others who joined as members since then. The IEUVI coordinates R&D activities by identifying opportunities for inter-regional benchmarking and collaboration. It primarily addresses EUVL infrastructural issues, as a result of collecting technical inputs from its Technical Working Groups (TWGs), and identifies possible showstoppers for commercialization. The initiative meets three times annually. Activities are posted at http://www.ieuvi.org.

Introduction

For several years now, both technical and commercialization challenges for extreme ultraviolet lithography (EUVL) have been much reported. By 2000, a handful of EUVL R&D efforts had been established at various locations in Europe, Japan and the United States; by late 2002, several solid efforts to enable key infrastructure worldwide were under way. However, there was no entity that addressed the coordination of EUVL infrastructural issues among the different geographic regions. In autumn 2003, the International EUV Initiative (IEUVI)[1] was launched to further the coordination of collaborative efforts among leading EUVL R&D consortia and to address infrastructural issues for commercialization. It built on an earlier coordination effort between Japan's only EUVL R&D entity ASET[2] and the U.S. organization EUV LLC[3] by expanding membership to CEA/LETI[4] of France, SEMATECH[5] of the U.S. and several others who joined as members since then. The IEUVI coordinates R&D activities by identifying opportunities for inter-regional benchmarking and collaboration. It primarily addresses EUVL infrastructural issues, as a result of collecting technical inputs from its Technical Working Groups (TWGs), and identifies possible showstoppers for commercialization. The initiative meets three times annually. Activities are posted at http://www.ieuvi.org.

The IEUVI board is chaired by Paolo Gargini of Intel Corporation. Currently active board members are CEA/LETI of France, IMEC[6] of Belgium, MEDEA+[7] of Europe, ASET of Japan, EUVA[8] of Japan and SEMATECH of the U.S. IEUVI membership and organizational structure are shown in Figure 1. Its four international Technical Working Groups (TWGs) are led by technical experts at SEMATECH, CEA/LETI, ASET, MEDEA+ and EUVA. TWG membership is open to the public by invitation. The following four sections describe activities of these four collaborative TWGs.

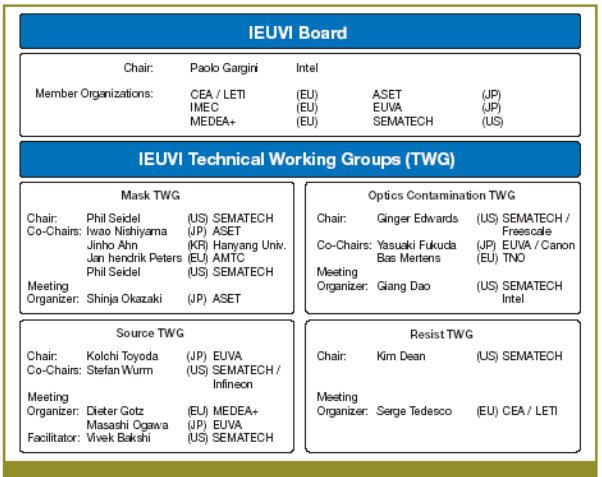

Figure 1. The IEUVI Membership and Organization

The IEUVI Optics Contamination TWG

The short wavelength of incident EUV illumination allows for a considerable decrease in printed integrated circuit feature size but also creates a range of technological challenges for projection optics not present with traditional lithographies. This has meant that the IEUVI Optics Contamination TWG, founded in 2003 to address EUV optics lifetime issues, finds itself more often occupied with fundamental surface science investigations rather than with the development of detailed optics manufacturing specifications.

Materials absorb EUV radiation, meaning that reflective rather than transmissive optics are required. For the same reason, exposure tools and their associated components must be kept under vacuum, but high-volume manufacturing requirements and the structure of the optics preclude traditional strategies for maintaining ultra-high vacuum. Contamination and oxidation that form on the surfaces of EUV optics produce unacceptable

losses in system throughput.[9] Despite recent progress[10-15], optics lifetimes still fall short of specifications for high-volume manufacturing by nearly two orders of magnitude.[16]

The development of a commercially viable exposure tool requires the creation of a stable process window for in situ optics cleaning that strikes the appropriate balance between carbon deposition and oxidation by finding the “right” combination of protective cap layer and background chamber gases. This activity is highly proprietary, and the choice of capping layer and mitigating gases is closely guarded by exposure tool manufacturers and their optics suppliers.

However, understanding the entire range of gas/surface interactions for relevant materials is a Herculean task that naturally lends itself to cooperation. This is the focus of the IEUVI Optics Contamination TWG, which shares fundamental surface science information and lifetime testing benchmarking data on mutually agreed-upon model surfaces. Current investigations focus upon ruthenium. The TWG has brought leading surface scientists from Asia, Europe and the U.S. together with optics researchers developing capping layer oxidation models. Additionally, a Ru-capped multilayer EUV mirror benchmarking sample set is currently being exchanged among the three regions. The samples not only allow meaningful comparison of optics lifetime test facilities worldwide but also provide a neutral reference for communicating proprietary capping layer lifetime results.

The IEUVI Optics Contamination TWG is chaired by Ginger Edwards of SEMATECH/Freescale and co-chaired by Bas Mertens from TNO[17] and Yasuaki Fukuda from EUVA, and supported by Giang Dao from SEMATECH/Intel, who is the meeting organizer for this TWG (see Figure 1). Its 37 members include representatives from AMD, ASET, ASML, BOC Edwards, CEA/LETI, Carl Zeiss AG, Fraunhofer IOF[18], Infineon, Intel, LLNL [19], Nikon, NIST[20], PTB[21], Rutgers University, the University of Albany and the University of Hyogo.

The IEUVI Resist TWG

The IEUVI Resist TWG was formed to increase cooperation among members of the worldwide EUV resist community. The first task of the Resist TWG was to develop a resist specification roadmap with resist performance goals for 2005, 2007 and 2009.[1] Since then, this TWG’s major goal has been to coordinate efforts to address the top three issues facing EUV resist development. Those issues and respective TWG activity are shown in Figure 2.

Critical Resist Issue	Resist TWG Action
Simultaneous optimization of photospeed, line width roughness (LWR), and resolution.	Provide exposure tool access for cycles of learning.
Fundamental limitation of chemically amplified resist (CAR) resolution.	Provide exposure tool access for cycles of learning.
Safe level of resist outgassing.	Determine specifications and methodology.

Figure 2. Critical Resist Issues Identified by the Resist TWG and Respective TWG Actions

The most critical problem facing resist performance is simultaneously meeting the specifications for photospeed, line width roughness (LWR) and resolution. There exists a fundamental trade-off between photospeed and LWR that has been documented by many researchers[22]: Faster resists have a higher LWR and vice versa.

Resist outgassing is a challenging technical topic. To protect EUV optics, all materials used in EUV vacuum exposure chambers must be screened prior to use. Photoresists are a concern since in a high-volume production tool a freshly coated wafer will be introduced into the chamber approximately every minute. Therefore, it is very important to be able to quantify the amount of material that outgasses from the photoresist. One of the first successes of the TWG was to define a commonly accepted resist outgassing limit for micro exposure tools (METs).[1]

At the 4th International EUVL Symposium[23], EUV resist was named the top critical issue for EUV lithography.

The Resist TWG will play an important role in helping remove resist as the No. 1 issue for EUVL. It will do so by strengthening collaborative efforts to work together toward sharing EUV tool access and schedule information to make the best use of the EUV photons available worldwide, by sharing resist screening data, and by improving a resist outgassing methodology.

Recently, the TWG started sharing resist screening data. The best results presented so far are shown in Figure 3 with the champion resist demonstrating 35nm 1:1 dense lines, 4.5nm line edge roughness (LER) and 11 mJ/cm2 photospeed.[24] Clearly, there is good progress toward meeting the 2007 IEUVI beta specifications targets of 32nm 1:1 resolution, <4.2nm LER and 7 mJ/cm2 photospeed.[1]

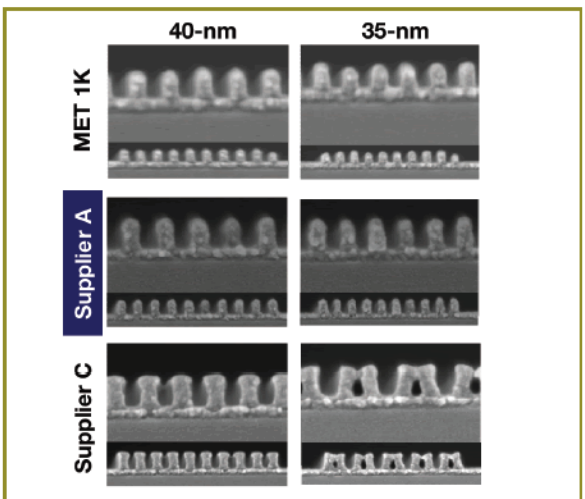

Figure 3. Resist Images Recorded with the SEMATECH MET at LBNL [25]; picture courtesy of AMD.[24]

The IEUVI Resist TWG is chaired by Kim Dean of SEMATECH; Serge Tedesco of CEA/LETI is the meeting organizer (see Figure 1). Its membership includes representatives from AMD, ASET, ASML, BOC Edwards, Canon, DongJin, Fujifilm, IBM, IMEC, Infineon, Intel, JSR, Nikon, Philips, Samsung, SELETE[26], ShinEtsu, Sumika, Texas Instruments, TOK, the University of Albany, and the University of Hyogo.

The IEUVI Mask TWG

The IEUVI Mask TWG consists of key stakeholders in the EUV mask development community. This TWG was initiated along with the original IEUVI charter in 2003, and more than 30 organizations have participated over the last two years[1] with each organization sending one primary representative. Such organizations range from tool suppliers, mask manufacturers, IC manufacturers, EUV mask materials suppliers and consortia to national laboratories and universities. Currently four major geographic regions are represented and participate in the IEUVI Mask TWG: Europe, Japan, Korea and the U.S. Each region nominates and selects its co-chair who provides periodic regional updates and helps define the topics for each meeting. This TWG meets face-to-face twice a year with additional teleconferences as needed.

The mission of the IEUVI Mask TWG is to foster improved EUV mask infrastructure development, provide key regional updates to increase the global knowledge base (deter the duplication of efforts) and collaborate on key areas. The TWG builds consensus with respect to required progress against EUV mask specifications (roadmaps) for alpha, beta and production tool phases and closely monitors the critical issues to identify areas that need accelerated development efforts. Figure 4 shows the top technical mask challenges identified by the TWG.[1] The color codes used in Figure 4 for risk-ranking range from red (very high risk), to yellow (significant risk), to white (solution exists) and are similar to the ones used in the International Technology Roadmap for Semiconductors (ITRS).[27]

Rank	Critical Issue Description	Status	Progress
1	Multilayer defect density (includes substrate)		Significant progress, limited by defect inspection capability
2	Metrology / defect inspection and potential need for actinic inspection for blanks κ Optical inspection tool path to <30nm PSL (micro field optical inspection sys to prove < 30nm PSL) κ Actinic inspection tool path – commercialization (yellow)		Limiting further progress in multilayer defect reduction
3	Handling & protection of patterned masks		Data just becoming available; Limited by defect inspection capability
4	Patterned mask defect inspection & defect printability		Recently elevated concern
5	Patterned mask cleaning		
6	Multilayer repair for amplitude defects		Phase repair "not likely"; amplitude repair unchanged
7	Substrate flatness and thickness variation		Progress, but discrepancy on methods
8	Image placement distortion caused by chucking, included multilayer stress, and backside Cr layer requirements (adoption)		Continued discrepancy on best methodology

Figure 4. Top Technical EUV Mask Challenges Identified by the IEUVI Mask TWG.[1]

The IEUVI Mask TWG is increasingly concerned that the availability of defect inspection tools capable of locating smaller and smaller defect sizes is gating progress on many EUV mask critical issues; this is especially true for reducing mask blank defects, zero-defect adder reticle handling and improving cleaning capabilities. In addition, the industry's ability to provide commercial solutions to maintain zero mask defects at all stages of a mask's useful lifetime must be supported by continued, rapid development of industry standards. Recent progress in reticle handling and shipping is encouraging, but more work is needed to protect against smaller defect sizes and to provide for longer mask usage intervals between defect inspections. Mask flatness and its related substrate flatness performance continues to be a critical issue, specifically with respect to demonstrating 35nm peak-to-valley (P-V) flatness repeatability under standard measurement conditions.

The IEUVI Mask TWG is chaired by Phil Seidel of SEMATECH, who is also the regional co-chair for the U.S. He is supported by co-chairs Iwao Nishiyama from ASET/NEC, Japan; Jinho-Ahn from Hanyang University, Korea; Jan Hendrik Peters from the AMTC, Europe; and Shinji Okazaki from ASET, the meeting organizer for this TWG (see Figure 1). TWG meetings have been attended by representatives from AMD, Alcatel, Asahi Glass, ASML, Canon, Corning, Dai Nippon Printing, Entegris, HOYA, Hitachi, IBM, IMEC, Infineon, Intel, JEOL, KLATencor, Lasertec, LBNL, Nikon, Ohara, Photronics, SCHOTT Lithotec, Samsung, Toppan, Toshiba, TOSOH, and the University of Albany.

The IEUVI Source TWG

The first IEUVI Source TWG meeting was held in February 2004. Since then TWG meetings have been held twice a year, always closely linked to the SEMATECH Source Workshops.[28] The mission of the Source TWG is to contribute to the timely availability of EUV sources in line with the overall EUVL roadmap requirements and to establish source roadmaps for successive exposure tool generations supported by integrated device manufacturers, by lithography tool and source suppliers and by source component suppliers. The TWG provides a forum for creating liaisons among collector suppliers, source suppliers and exposure tool manufacturers that help address critical EUV source infrastructure challenges on the way to EUVL volume production.

As high-power EUV source technology continues to make steady progress toward the 115 W of EUV power required at the intermediate focus[29-30], the IEUVI Source TWG updates the consensus specifications for alpha-, beta- and production-level EUV source specifications that are being used to track source technology advancement. Figure 5 shows the TWG's EUV source requirements table last updated in March 2006. The risk ranking ranges from red (very high risk), to yellow (significant risk), to white (solution exists) and is similar to the one used in the ITRS.[27] A major focus of the TWG is to generate consensus on technical solutions to encourage standardization, which may not be easily achieved in the larger setting of the EUV source workshops. In addition, the Source TWG provides a forum to discuss EUV source specifications that have yet not been agreed upon, e.g., the need for a spectral purity filter, collector lifetime requirements and standards related to EUV source and EUV source metrology.

Metric	Unit	Alpha	Beta	Production	Next Generation	
Scanner Delivery	Date	2006	2007	2009	2011	2013
Potential Source Technology	NA	DPP	DPP	DPP	DPP/LPP	LPP/DPP[1]
Target Material	NA	Xe / Sn	Sn / Xe	Sn	Sn	Sn
Wavelength	[nm]	13.5	13.5	13.5	13.5	13.5
Throughput	[wph]			100	100	100
EUV Power @ IF	[W]	10	30	115[2]	>150[3]	>180[3]
Repetition Frequency	[kHz]	2	5	7-10	10	> 10
Integrated Energy Stability	[%]	5	1	0.3	0.3	0.1
Source Cleanliness	[hours]			>30,000	>30,000	>30,000
Collector Lifetime	10^9 Pulses	1	10	80	> 80	> 80
	[month]	1	3	12	12	12
Electrode Lifetime	10^9 Pulses	1	10	80	> 80	> 80
	[month]	1	3	12	12	12
Projection Optics Lifetime	[hours]			30,000	30,000	30,000
First Illuminator Mirror Lifetime	[hours]	TBD	TBD	TBD	TBD	TBD
Etendue of Source Output	[mm^2-sr]	TBD	TBD	< 3.3	< 3.3	< 3.3
Max. Angle to Illuminator	[sr]	TBD	TBD	0.03-0.2	0.03-0.2	0.03-0.2
Spectral Purity (130-400 nm)	[%]	TBD	TBD	3-7	3-7	3-7
Spectral Purity (>400 nm)	[%]	TBD	TBD	TBD	TBD	TBD
Spectral Purity (20-130 nm)	[%]	TBD	TBD	TBD	TBD	TBD

1) Multiplexed DPP
2) Assumes resist with 5mJ/cm^2 sensitivity
3) Assumes resist with > 5 mJ/cm^2 sensitivity

Figure 5. IEUVI Source TWG EUV Source Requirements Table.[1]

Recent achievements of the IEUVI Source TWG include[1] the generation of specifications for alpha- and beta-level sources and next-generation sources (requirements beyond 115 W sources) as shown in Figure 5; identification and ranking of EUV source critical issues; reconciliation of collector lifetime specifications; and first progress toward standards for intermediate focus metrology.

The Source TWG is chaired by Koichi Toyoda of EUVA, co-chaired by Stefan Wurm of SEMATECH/Infineon; meeting organizers are Dieter Gotz of MEDEA+ and Masashi Ogawa of EUVA; Vivek Bakshi of SEMATECH is the meeting facilitator (see Figure 1). Membership consists of representatives from source suppliers, exposure tool manufacturers, tool users and optics makers including AMD, ASML, Canon, Carl Zeiss, Cymer, EUVA, Infineon, Intel, MEDEA+, Media Lario, Nikon, Philips Extreme, PLEX LLC, SEMATECH, Usiho and XTREME technologies.

Summary

This article describes the background, objectives, membership, TWG activities and future plans of the IEUVI. Technology and infrastructure development for tomorrow's lithography manufacturing technologies have become truly global efforts requiring new approaches toward cooperation. The IEUVI is the industry's effort to facilitate information exchange and coordination among the world's major research consortia working on EUV. As the industry prepares itself for EUVL commercialization, the IEUVI is expected to be even more active in the coming years.

Acknowledgments

Many people at IEUVI member organizations have been contributing to the IEUVI. The IEUVI would like to thank them and all the other TWG participants for making the IEUVI TWGs so successful. Specifically, the IEUVI would like to thank Kevin Kemp from Freescale for his leadership and support over the past three years while serving as the IEUVI SEMATECH board representative.

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