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Introduction

The chairs of the Extreme Ultraviolet (EUV) Lithography VI Conference would like to thank the program committee, the session chairs, the presenters, and the attendees for a successful 2015 meeting at SPIE Advanced Lithography in San Jose, California. The number of conference oral talks this year was nearly identical to last year's number indicating that the interest in EUV lithography technology remains high. Peak session attendance at the keynote joint session topped 750. Key topics included EUV scanner and source performance, mask blank defectivity and actinic blank review, CAR and non-CAR resist status, EUV pellicle development, and EUV extendibility beyond the 7 nm technology node.

The EUV conference received 99 abstract submissions in 2015, of which 67 were accepted for oral presentation, 30 were accepted for presentation in the poster session, and 2 were withdrawn. The number of abstract submissions was ~25% lower than last year, perhaps because EUV technology is getting closer to HVM introduction. The 2015 SPIE Advanced Lithography Symposium attendance totaled 2,320, very nearly the same as 2014's count of 2,360. The average attendance at the EUV conference was 282 per session and the peak attendance in the keynote session was 752. The average attendance number was down slightly from the 2014 number of 332 but the keynote session attendance number was significantly higher than the 2014 number of 629.

Attendance by session is presented in Table 1.

Session	Count
Keynote	752
Resist Extendibility (Joint with 9425)	322
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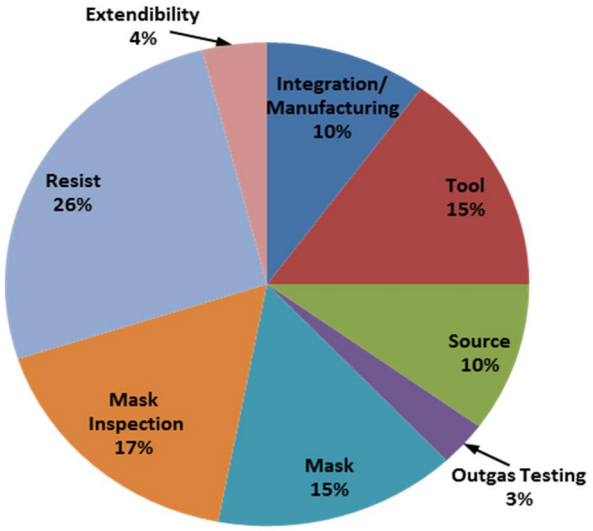
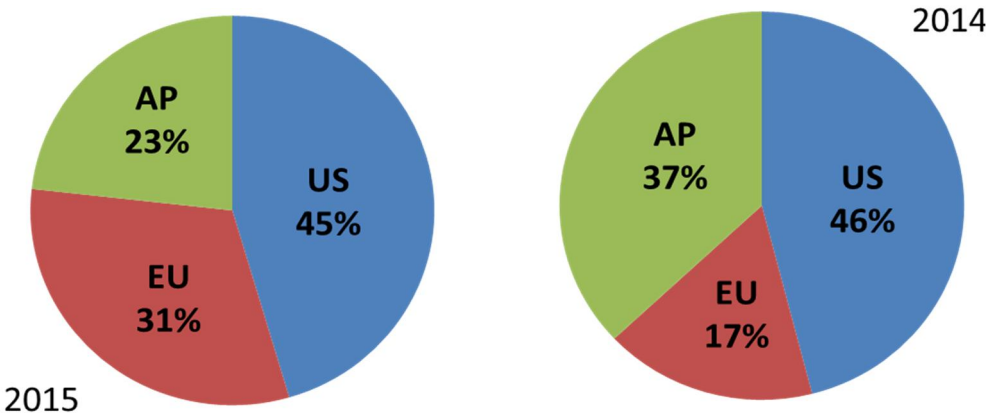


Submissions by region for 2015 and 2014 are shown in Figure 2.



2015 Conference Highlights

Scanners

ASML reported that 8 NXE:3300B scanners have been shipped to customers and 6 are already exposing wafers, that more than 600 wafers per day have been exposed on four scanners and more than 1000 wafers per day have been exposed in a 24 hour period with a NXE:3300B scanner at TSMC[1]. The current collector lifetime is > 3 months and the average availability on an NXE:3330B scanner at TSMC is current 55%. ASML also provided the following preliminary imaging performance data for NXE:3300B scanners: 22 nm resolution for dense lines and spaces with full-wafer CDU = 1.0 nm, dedicated chuck overlay < 1.8 nm, matched machine overlay of < 3.5 nm, focus control < 12 nm, a 10x reduction in added particles per reticle pass (< 0.001).

Sources

At the 2015 Advance Etch Technology for Nanopatterning IV Conference, TSMC reported the achievement of 90 W at IF from a MOPA+PP LPP 3300B source (with an 80 W source configuration)[2]. At the 2015 SPIE EUVL VI Conference, ASML-Cymer described the steady improvement in LPP source performance from 10 W at 1% conversion efficiency (CE) in 2011 to 30 W at 1.5% CE in Q2'12, to 50 W at 4.0% CE in Q3'12 and 80 W at 3.5% CE for 24 hours at TSMC, and 100+ W both in a custom system and in an in-house system at the ASML factory in Veldhoven in Q4'14[3]. These improvements in power were attributed to an evolution in the laser architecture, specifically to the addition of a pre-pulse to increase conversion efficiency and EUV emitting volume. ASML reported that 3 MOPA+PP 3300B sources (with 80 W source configuration) have delivered 110 W EUV of power for periods of one hour. At the 2015 SPIE EUVL VI conference, Gigaphoton described an LLP-EUV light

source with superconducting magnet debris mitigation that produced 130 W at 80 kHz rep-rate and 50% duty cycle for 130 minutes[4].

Masks and Mask Metrology

SEMATECH reported that using ion beam sputter deposition of Mo/So multilayer (ML) coatings at their Mask Blank Development Center in Albany New York, they have observed a 10% yield of ML-coated EUV mask blanks with 0 defects at 100 nm size and fewer than 5 defects at 80 nm size[5]. The final blank deposition run also resulted in 2 defect-free blanks (no defect adders > 54 nm in size). This result is the long awaited proof-of-concept that defect-free EUV mask blanks are possible! In a separate paper, SEMATECH reported that high quality Mo/Si ML coatings can be produced using commercially available PVD tools[6]. The Mo/Si coatings produced with the PVD tool had higher EUV reflectivity (68.4%) than those produced with an IBD tool (64%) and have already achieved comparable levels of added defects. Zeiss reported that their prototype AIMS™ EUV system has achieved 2nd light and that the system is expected to be available for customers in Q4 of this year[7]. Zeiss went on to say that the measured imaging optics flare was ~1% and that the tool already exceeds the specs for 16 nm hp resolution. In a presentation by LBNL, the SHARP EUV microscope demonstrated 7.5 nm L/S resolution using a 0.625 NA zone plate lens. The SHARP tool should be able to mimic the imaging of anamorphic projection optics like those recently proposed by AMSL/Zeiss for use in higher-NA EUV scanners when using an elliptical zone plate lens[8].

Resists

It was extremely gratifying to see a presentation by JSR showing that 13 nm half pitch (HP) lines and spaces (L/S) have been resolved by a new chemically amplified (CAR) resist patterned with the Berkeley 0.3 NA MET at 35.5 mJ/cm^2 dose[9]. This was an important result since progress in CAR resolution appeared to have been stalled for more than two years. Inpria reported that 13 nm HP L/S have been resolved by one of their Gen2 Platform metal-oxide materials also using the Berkeley 0.3 NA MET at 59 mJ/cm^2 dose[10]. Intel presented data for hybrid nanoparticle materials showing 2-3 weeks of shelf life and that the dose is also stable for 2 – 3 weeks[11]. In a presentation at a satellite meeting on the day before the start of the EUVL VI Conference, ASML announced that witness plate outgas testing of CAR resist materials will no longer be required before use in an ASML NXE scanner[12]. Given this relaxation of the outgas testing requirement, commercial resist suppliers should now be able to explore a wider range of PAG and quencher loadings than ever before possible leading to improved performance.

Manufacturing

SK Hynix reported that comparable yields of 2x DRAMs have been demonstrated with EUV single pattering and 193 nm immersion multiple patterning[13]. In a separate paper SK Hynix found that the particle adder rate in an NXE:3100 scanner is only 0 to 1 particle per day and that pellicle-less operation may be an better operational mode when the EUV source power exceeds > 300 Watts at intermediate focus[14].

ASML-Brion described new pattern-placement-aware SMO application software that simultaneously minimizes pattern placement errors, enhances through-focus contrast and reduces the impact of stochastic effects[15].

At the end of 2014, ASML reported the development of a full-size pellicle with 85% transmission and with excellent imaging performance. At 2015 SPIE Advanced Lithography, ASML announced that they will supply EUV pellicles to NXE customers and went on to described a design for a removable and re-mountable pellicle that enables current pattern mask inspection tools to be used to inspect EUV patterned masks[16].

Extendibility

ASML described the design of a EUV scanner with a 0.52 NA anamorphic half-field projection system[17]. The system's anamorphic 4x/8x design allows use of a conventional 6" mask and is expected to have a throughput of 150 wafers per hour when used with a 500 W source and a resist with 30 mJ/cm^2 sensitivity. In a companion paper by Zeiss, it was pointed out that the new anamorphic design has a central obscuration which blocks part of the 1st diffraction order and results in some contrast loss[18]. Zeiss also pointed out that the new system will require mirrors with extreme aspheric departures and tighter surface specs and a huge last mirror. In a third companion paper by Zeiss and ASML, the claim was made that Zeiss, ASML and Fraunhofer IISB all agree that the imaging differences between an isomorphic 8x system and an anamorphic 4x/8x system with a CRAO of 6° and NA > 0.5 are small[19], e.g., the images of circular contact holes will become slightly elliptical at extreme out of focus positions and that anamorphic-aware OPC and SMO will be required. The authors claimed that the "benefits of the anamorphic high-NA system come without noticeable loss of image quality."

2016 Conference Call for Papers

In 2015, the first group of EUVL production tools was fielded and dramatic increases in EUV source power were achieved. In 2016, chip makers will be focused on driving EUVL technology toward meeting HVM productivity and yield targets for the 7 nm logic technology node. Nevertheless, a number of critical technology challenges remain, i.e., meeting productivity and availability targets for HVM, developing mature mask handling protocols, improving mask yield, inspection, review, and repair infrastructure, and simultaneously improving resist resolution, sensitivity and LER. Looking longer term, to meet patterning challenges beyond the 7 nm logic technology node, innovative approaches in EUV source, mask and imaging materials will be needed and developing much higher power sources will be essential.

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