2015
International Symposium on
Extreme Ultraviolet Lithography

5-7 October
Maastricht,
The Netherlands

Abstracts of Poster Presentations

EUV Insertion in Manufacturing

P-IM-01

EUV PROCESS ESTABLISHMENT FOR NXE3300 AND BEYOND

Yuhei Kuwahara[1], Philippe Foubert[2], Anne-Marie Goethals[2], Shinichiro Kawakami[3], Koichi Matsunaga[3], Kathleen Nafus[1], Ming Mao[2], Eric Hendrickx[2]

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Advance EUV patterning on the ASML NXE:3300/ CLEAN TRACK™ LITHIUS Pro™ Z- EUV litho cluster is launched at imec, allowing for finer pitch patterns for L/S and CH. Tokyo Electron Limited (TEL™) and imec are continuously collaborating to develop manufacturing quality POR processes for EUV. TEL™ has new functionalities to enhance CD uniformity, defectivity and LWR/LER. The patterning is characterized and optimized in both litho and etch for a more complete understanding standing of the final patterning performance.

P-IM-02

LWR IMPROVEMENT ON EUV TRACK SYSTEM

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EUV lithography (EUVL) is well known to be a strong candidate for next generation, single exposure sub-30nm half-pitch lithography. Furthermore, high-NA EUV exposure tool(s) released two years ago gave a strong impression by finer pattern results. On the other hand, it seems that the coat develop track process remains very similar and in many aspects returns to KrF or ArF dry process fundamentals, but in practice 26-32nm pitch patterning coat develop track process also has challenges with EUV resist.

As access to EUV lithography exposures became more readily available over the last five (5) years, several challenges and accomplishments in the track process had been reported, such as the improvement of ultra-thin film coating, CD uniformity, defectivity, line width roughness (LWR) and so on. The coat-develop track process has evolved along with novel materials and metrology capability.

Line width roughness (LWR) control is demonstrated utilizing the SOKUDO DUO coat develop track system with ASML NXE:3100 and NXE:3300 exposures in the IMEC (Leuven, Belgium) clean room environment. Additionally, we will show the latest lithographic results obtained by novel processing approaches in the EUV coat develop track system.

P-IM-03

METAL CONTAINED MATERIAL INTEGRATION ON COATER/DEVELOPER SYSTEM

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Metal containing materials are attracting attention in extreme ultraviolet (EUV) lithography. These materials, such as Inpria, Nanoparticle and metal containing chemical amplified resist (CAR) are expected to be next generation materials for advances in resolution, etch durability and sensitivity.
Challenges of processing these metal materials need to be addressed in order apply this technology to manufacturing. Behavior of metal containing materials on coater/developer process including coating process, baking process, developer process and tool metal contamination is studied on CLEAN TRACK™ LITHIUS Pro™ Z (Tokyo Electron Limited; TEL™).
This paper reports the progress of metal containing materials process on Coater/Develper system.

P-IM-04

BENCHMARKING STUDY OF CONTACT HOLE IMAGING

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With the recent announcement by ASML that they signed an agreement with one of their major U.S.-based customers to deliver 15 ASML extreme ultraviolet (EUV) lithography systems, the effort to implement EUV appears to have received a much needed momentum boost. Discussions with major semiconductor suppliers indicate that the use of EUV lithography would be at the contact layer. It has been demonstrated that EUV can image very small contacts, typically in the range of 30nm[1, 2].

At last year's Advanced Lithography Conference, SUNY Poly SEMATECH demonstrated their benchmarking results, comparing the best available resist systems for EUV contact hole patterning using their micro exposure tool (MET), which produces a high-resolution center-of-the-wafer image that can be tested and characterized. At this point, the MET tools used by SUNY POLY SEMATECH are the highest resolving non–interference systems extant[3]. The authors will present continuing activities to further verify prior contact printing findings using a full-field ASML3300 system and then subsequently produce post-etch patterning. This study is intended to show the chip manufacturing applicability of the previously reported results.

References:

1. 2015 Proc. SPIE: Novel processing approaches to enable EUV lithography toward high volume manufacturing.
2. 2014 EUV Symposium, Washington DC, USA: Driving EUV Lithography toward HVM: Joint Project SEMATECH and Tokyo Electron, Limited.
3. Fan, Yu-Jen. "First Results of Outgas Resist Family Test and Correlation between Outgas Specifications and EUV Resist Development | (2015) | Fan | Publications | SPIE." First Results of Outgas Resist Family Test and Correlation between Outgas Specifications and EUV Resist Development | (2015) | Fan | Publications | SPIE. SPIE-International Society for Optics and Photonics, Feb. 2015.

P-IM-05

STUDIES DIRECTED TOWARDS DECREASE CONTACT HOLE PRINTABILITY

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Due to ever-increasing density in ULSI (ultra-large-scale integration) circuits, various techniques have been proposed to overcome the limits of the present semiconductor fabrication technology. It has been shown that ArF immersion lithography technology, using NTD (Negative Tone Development), can be used to form a contact hole having a minimum feature size of 40nm and 30nm using immersion lithography and EUV lithography, respectively. Published results clearly show that patterning 30nm is very difficult.[1,2] There have been a number of attempts to solve this resolution problem. Specifically, lithographers have tried to use an extension of ArFi/EUV lithographic technologies to pattern sub-30nm contact holes. The approaches include using DSA (for example at EUV) and a number of contact hole shrink materials such as WASOOM, RELACS, or NTO. Among these approaches, the chemically induced methods of contact hole shrinking seems to offer the best potential due to its simplicity and good resolution enhancement. For example, at the 2006 Interface Conference, Chun et al. showed a resolution enhancement photolithography process using WASOOM. They observed 50% CD size reduction without a loss in pattern integrity. However, the process with WASOOM is designed for positive tone resists. In this paper we will describe a negative tone contact hole shrink resist process, which we are calling negative tone over-coating, or simply NTO.

References:

1. 2015 Proc. SPIE: Novel processing approaches to enable EUV lithography toward high volume manufacturing
2. 2014 EUV Symposium, Washington DC, USA: Driving EUV Lithography towards HVM: Joint Project SEMATECH and Tokyo Electron Limited

P-IM-06

RESIST READINESS FOR N7 PATTERNING IN EUV

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With the introduction of the ASML NXE3300 (NA=0.33) full field exposure tool, imec has started the patterning exploration in EUV for N7 node. Single exposure EUV is considered for metal level as well as SAQP 193i litho in combination with block/cut mask in EUV. In this work the readiness of both the traditionally CAR and the NCAR-Metal Containing resist (MCR) is investigated. We will report on the imaging performance of resists and process selection for design rules for N7 BEOL layers (Metal, via, Block) with major focus on the Metal2 block mask. As in EUV the preferred mask tonality is dark field (due to mask defectivity and flare), a negative tone imaging resist might be seen as the most straightforward way to print the blocks. Using a dark field mask, a comparison will be made for printing a typical block mask layout 1) with positive tone imaging by CAR, printing trenches and subsequent tone inversion, and 2) with negative tone imaging printing blocks/dots directly by CAR and MCR without subsequent tone inversion.

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EUV Lithography Extendibility

P-LI-01

EUVL MICRO-FIELD EXPOSURE TOOLS WITH 0.5 NA

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In support of the Extreme Ultraviolet Lithography (EUVL) roadmap, a joint program between Zygo, SEMATECH, and CNSE is under way to develop 13.5 nm, 0.5NA R&D photolithography tools with small fields. Those tools are referenced as micro-field exposure tools, or *METs*.
In this paper, results from the completed POB systems are presented. The achieved single pass transmitted wavefront (CA – 30 cycles/aperture) on the first system was better than 0.25nm RMS at the center of the field and < 0.48nm RMS over the 30um x 200um field, less than half of the original specification. The flare, as calculated from the component roughness data, is less than the 5% specification.
The paper includes a presentation of results from the component mirror metrology, the system metrology, and the multilayer coatings. Preliminary aerial image modeling results will also be presented. Finally, the processes and mechanics that were used to align the POB, including some novel alignment techniques used to target specific aberrations, will be described.

P-LI-02

NON-CONVENTIONAL SHADOW EFFECT CAUSED BY ANAMORPHIC NUMERICAL APERTURE SYSTEM AT EXTREME-ULTRAVIOLET LITHOGRAPHY

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In order to make a pattern of 14 nm and below, a high NA (numerical aperture) system larger than 0.33 is required. The suggested high NA system has elliptical shape which has different magnifications for x-y axis each 8X and 4X. Owing to the elliptical shape of illumination optics, incident angle distribution is different between vertical and horizontal axis. In EUV lithography, the shadow effect such as pattern shift, HV (Horizontal-Vertical) bias and so on is one of the serious problems to realize the anamorphic system. In case of anamorphic NA system, incident angle distribution at direction of major axis is larger than direction of minor axis as EUV light incident obliquely with direction of minor axis. For these reasons, HV bias caused by oblique incidence of 6 ° is reduced at anamorphic NA system compared to the case of isomorphic NA system. With 16 nm pattern and circular illumination (σ=0.9), HV bias of isomorphic NA system (NA=0.33) is about 9 nm, but it reduces too much smaller about 1 nm at anamorphic NA system (NA=0.55). We will discuss this non-conventional shadow effect for various patterns including the contact holes and irregular patterns that are the main target patterns of logic devices which can be initial target devices of EUV high volume manufacturing.

P-LI-03

FABRICATION OF TRANSMISSION GRATING OF EUV INTERFERENCE LITHOGRAPHY FOR 1X NM HP EUV RESIST EVALUATION

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EUV lithography will be used for the high volume manufacturing (HVM) in 16 nm hp for the semiconductor devices. Around 2020, 10 nm hp is required for the HVM. To accelerate EUV resist development for 10 nm hp, the EUV interference lithographic exposure tool is necessary. The key technology for this tool is developing advanced transmission grating and reduction of vibration of the exposure tool.

For the fabrication process of the transmission grating, the resist processing in electron beam lithography is the key technology. For the transmission grating to evaluate EUV resist for 12.5 nm and 10 nm hp, the positive tone non CA resist for electron beam lithography and the negative tone non CA resist was employed, respectively. In addition, hard mask process was employed in the transmission grating fabrication of the absorber pattern using dry etching process. The dry etching condition was optimized to fabricate the transmission grating.

For the vibration reduction, the exposure tool mount was updated to reduce the vibration. The detail of the vibration reduction will be presented.

This work was support by the Grant-in-Aid for Scientific Research (B) (25289106), Society for the Promotion of Science, the Ministry of Education, Culture, Sports, Science and Technology, Japan.

P-LI-04

B-BASED MULTILAYER COATINGS FORNEXT GENERATION LITHOGRAPHY AT Λ = 6.X NM

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Beyond EUV lithography at 6.X nm wavelength has a potential to extend EUVL beyond the 10 nm node[1]. The highest reported experimental reflectivity of 64% @ 6.65 nm was recently achieved with LaN/B multilayers[2]. According to strong requirements of the lithographic industry a peak reflectivity of at least 70% has to be achieved in near future.

Currently, the most promising approaches to enhance the optical performance of B-based multilayers are the transition from conventional La/B to promising LaN/B multilayer coatings[3] as well as the application of ultrathin C-barriers in La/B multilayers[4]. The authors will present results for both approaches, where maximum reflectivities of 58.1% and 56.7% @ 6.65 nm were achieved with LaN/B_4C and La/C/B_4C multilayer mirrors, respectively. Additionally, authors will discuss the first results of utilization of other barriers as well as approaches to reduce residual stresses in B-based multilayers.

References:

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3. Makhotkin I.A. et al., Opt. Express **21**(24), 1610–1619 (2013).
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P-LI-05

DEVELOPMENT OF A HIGH NUMERICAL APERTURE EUV LITHOGRAPHY TOOL: THE BERKELEY MET5 PLATFORM

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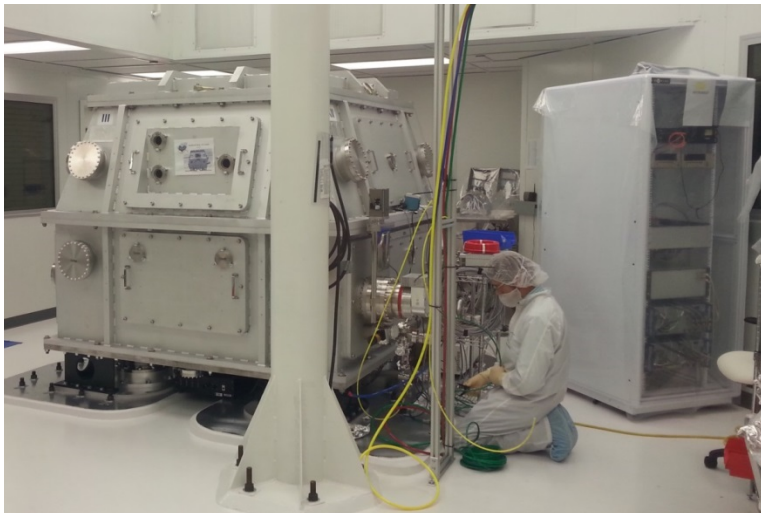
Microfield exposure tools (METs) have played a crucial role in the development of EUV resists over the past decade. The current generation of METs with a numerical aperture (NA) of 0.3, are approaching the end of their useful lifetime due to strong progress in EUV resists over the years. In order to support future resist developments into the sub-16-nm regime, a 0.5 NA MET development program is underway at LBNL. This program includes the development of a brand new exposure tool platform as well as a new cleanroom facility with a wafer track installed at the Advanced Light Source (ALS) synchrotron. The new tool and facility are being constructed at a separate location on the ALS floor, allowing the current MET to remain operational throughout the new tool integration process. As with the current MET, the new MET5 will harness the unique high brightness capabilities of the ALS to enable a lossless full programmable coherence illuminator. The lithography tool will also include integrated wavefront metrology capabilities using an in-situ EUV interferometer.

In this presentation, we provide a detailed overview of the new synchrotron beamline, tool platform and facility and an update on the status of the various components and the integration process. Figure 1 shows a photograph of the platform being assembled in the new cleanroom.



P-LI-06

ANAMORPHIC HIGH NA SOURCE OPTIMIZATION FOR HIGH QUALITY PATTERNING BELOW 10 NM NODE

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High numerical aperture (NA) optics is strongly required for achieving high resolution patterning below 10 nm or beyond. However, an incidence angle of 6 ° should be increased simultaneously with the higher NA due to overlapping of illumination cones which causes image distortion and then the larger incidence angle can make the shadowing effect more serious. For that reason, the anamorphic NA is introduced which has different reduction ratio in x and y directions. It is essential technology for the high NA optics, but there is lack of research on patterning results by using the anamorphic NA system. We performed patterning simulations with the anamorphic NA illumination over 0.5 NA. Not only the various types of patterns such as line and space, contact hole, and logic, but also the various shapes of illuminations such as dipole, annular, and quasar are considered. The contrast, normalized image log slope, and process windows are compared with each condition and an optimization result of source parameter is presented. The patterning results would be good references to estimate patterning issues for the anamorphic NA in advance.

P-LI-07

HIGH REFLECTANCE LA/B BASED MULTILAYER MIRRORS FOR 6.X NM WAVELENGTH

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For future photolithography processes, the wavelength of ~6 nm may offer improved imaging specs. The perspective of this technology however, will depend critically on the performance of multilayer reflective mirrors, which are likely to be based on La/B. One of the issues is formation of La_xB_y compounds at the interfaces, which decreases the optical contrast and reduce the reflectivity. To prevent such chemical interaction, passivation of La by nitrogen has been investigated. We successfully synthesized LaN layers that resulted in a new world record reflectivity of 64% at 6.6 nm at near normal incidence. This reduces the gap to the target of 70%, desired for a next generation lithography.

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EUV Resist

P-RE-01

IMPROVING PATTERN FIDELITY IN HELIUM ION BEAM LITHOGRAPHY USING PIXEL DOSE OPTIMIZATION

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There are remarkable similarities in the activation response of resists to He-ions and extreme-ultraviolet (EUV) photons[1]. Both primary beams produce low-energy secondary electrons (SEs) and are marginally hindered by proximity effects. Scanning Helium ion beam lithography (SHIBL) deploys a sub-nanometer ion probe size for low-volume high-resolution mask-less lithography with high pattern density[2]. EUVL lithography uses a mask for high volume reproduction of comparably challenging patterns. Maas et al. suggested SHIBL as a promising method for pre-screening chemically amplified resists (CARs) prior to their final performance evaluation in an EUV scanner[1].

Unlike EUV photons, which interact with one resist molecule only, He-ions scatter in-elastically in the resist and causes a chain of collisions with resist molecules. As a result, for SHIBL a low dose-to-clear of only 0.085 ions/nm2 in a CAR was measured[1]. Hence, ion shot noise likely impacts pattern fidelity. From the experimental data we extracted a point-spread function (PSF) that accounts for all factors contributing to resist activation. Ion shot noise was modelled through Poisson statistics. Decent agreement between model and SHIBL experiments on lines-and-spaces and contact-hole patterns was found. Furthermore, we show that pixel-dose optimization can reduce LWR by ~45% (~1.3 nm) with a concurrent 20% dose reduction.

References:

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2. V. Sidorkin et al., J. Vac. Sci. Technol. B 27, L18 (2009)

P-RE-02

CHARACTERIZATION OF HIGH RESOLUTION ELECTRON BEAM RESISTS UNDER EXTREME ULTRAVIOLET IRRADIATION

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In this work EUV performance of the positive tone resists PMMA, PMMA/MA33%, ZEP520A-7, CSAR62 and the negative tone resist XR1541-006 (hydrogen silsesquioxane - HSQ) have been investigated. Open frame exposures have been realized at the extreme ultraviolet laboratory exposure tool (EUV-LET) utilizing a high frequency discharge produced plasma source with optimized emission for a center wavelength of 10.77nm with a bandwidth of 3.12%. Sensitivity, contrast and the critical modulation transfer function have been extracted from the obtained characteristic exposure curves and analyzed. To determine the influence of the resist thickness the exposures have been carried out at two different thicknesses for CSAR62 and ZEP520A-7. Furthermore contrast enhancement by cold development has been investigated for ZEP520A-7 resist. For the bilayer system PMMA/MA33% exposures have been done for each layer individually and on the stack normally used for lift-off processes. Additionally outgassing mass spectra of the investigated resists have been recorded before, during and after exposure to qualify their outgassing behavior.

P-RE-03

DEVELOPMENT OF THE XANTHENDIOL DERIVATIVES APPLIED TO THE NEGATIVETONE MOLECULAR RESISTS FOR EB/EUVL

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We report the development of new xanthendiol derivatives applied to the negative-tone molecular resists for EB/EUVL. The new xanthendiol derivatives were easily synthesized by the condensation of aldehydes and dihydroxyaromatic compounds. We found 13,13'-biphenyl-bis(13H-benzoxanthen-2,11-diol), MGR203 and 13,13'-biphenyl-bis(13H-benzoxanthen-3,10-diol), MGR204 were showed the good applicability to the raw material for the resist for EB/EUVL.

Because of superior in heat resistance of the xanthene skeleton, the high thermal stability is obtained by these materials. Furthermore the etching rate of MGR203 and MGR204 at 400 degrees Celsius baking showed smaller than that of Novolac. And the EB patterning result also showed that the resist containing MGR203 could resolve the 20nm half-pitch pattern, and 15 nm half-pitch patterns were partially resolved. The xanthendiol derivatives are promising as materials of high-performance resist. We will also present the EUV patterning result at the presentation.

P-RE-04

NOVEL DDR PROCESS AND MATERIALS MEET NTD PROCESS

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We developed the novel process and material which can prevent the pattern collapse issue perfectly without any special equipment. The process is Dry Development Rinse (DDR) process, and the material used in this process is DDR material. DDR material is containing special polymer which can be replaced the Space area of the photo resist pattern. And finally, the reversed pattern will be created by dry etching process without any pattern collapse issue.
This novel technique is useful not only in Positive tone development (PTD) process but also in Negative tone development (NTD) process. We newly developed DDR material for NTD process. Novel DDR material was organic solvent system and it was no mixing with photo resist in exposed area. So pattern reverse was successfully achieved by DDR process keeping original pattern quality. In this paper, the combination of NTD and DDR process was demonstrated about fine trench, short trench and Contac Hole application for N7 and beyond.

P-RE-05

STUDY ON RESIST PERFORMANCE OF CHEMICALLY AMPLIFIED MOLECULAR RESIST BASED ON NORIA DERIVATIVE AND CALIXARENE DERIVATIVE FOR EUV LITHOGRAPHY

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The trade-off relationship between sensitivity, resolution and LWR is the most serious problem for the development of EUV resists. To meet these strict demand for next generation lithography, novel materials must be developed. In this study, we developed positive-tone chemically amplified molecular resists based on a Noria derivative and a calixarene derivative and evaluated the lithographic performance of them using EUV and EB.

Noria derivative and calixarene derivative resists were used as a resist. Triphenylsulfonium trifluoromethansulfonate (TPS-nf) were used as acid generator. Resist solutions were spin-coated onto Si substrates to form thin films. The resist samples were exposed to EUV and EB. After the exposure, they were baked at 110 ˚C for 60 s. Then, the resist performance of them was evaluated using EUV and EB.

When the pillar[5] arene resist containing 10wt% TPS-nf was used, a semi-isolated pattern with the line width of 20 nm (pitch: 100nm) was delineated. The etching rate of the noria derivative and calixarene derivative resists was similar to that of conventional resist materials such as ZEP520A and UVIII. Noria derivative resists and calixarene derivative are promising candidates for the resist material for nanolithography such as EB and EUV lithography.

P-RE-06

ABSORPTION COEFFICIENT AND DILL'S PARAMETERS OF CAR AND ORGANOMETALLIC SN-BASED RESIST

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Non-chemically amplified resists based on organometallic building blocks are gaining momentum as next generation materials for EUV lithography owing to their remarkable properties. These resists achieve high resolution, are directly patternable, and possess exceptional mechanical resistance to etch. Such resists have relatively high photosensitivity in the absence of traditional chemical amplification due to high absorbance. In this work, we studied the absorption coefficient and Dill's parameters A and B at 13.5 nm for a tin-based organometallic resist in comparison with a conventional CAR resist. These parameters were calculated from the measured transmission of EUV light across a thin film of photoresist which was previously spin coated on a semi-transparent silicon nitride membrane. Several strategies were used to accurately measure the thickness of the spin coated films, which is the main source of uncertainty in this technique. It was found that the A parameter is positive but much smaller than B for all resists. Moreover, the absorption of the tin-based resist was found ≈ 15 μm^{-1}, i.e. ≈ 4 times higher than that of the CAR resist. These results are promising for the industrial-scale implementation of organometallic compounds for EUV lithography.

P-RE-07

DEVELOPMENT OF METAL RESIST AND UNDERLAYER

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The EIDEC R&D program evaluates EUV containing inorganic components. For the development of EUV resist, the concurrently satisfaction of ultimate resolution, line width roughness and sensitivity requirements is necessary. But these performances have a relation of the trade-off. We have evaluated the EUV resist characteristics and lithographic performance using the several analysis tools and the small-field exposure tool (SFET) and EB exposure tool for fundamental study for breaking the deadlock of this trade-off. One possibility to break thorough the trade-off relationship is the employment of Non-chemically amplified resist (Non-CAR). Non-CAR resist does not depends on acid amplifying, and several non-CAR resist showed very high sensitivity compared to conventional CAR resist [1][2]. A distinctive feature of non-CAR metal resist is it has high etching resistance, and the character is the large advantage for etching resistance. In this work metal type non-CAR resist is investigated on several underlayers, and not only lithography performance but also etching mask property is also reported.

References:

1. M. E. Krysak, et al. Proc. of SPIE 2014 Vol. 9048 904805
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P-RE-08

A STUDY OF EUV RESIST SENSITIVITY BY USING METAL MATERIALS

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Studies are currently being carried out on developing a method for improving EUV resist sensitivity by enhancing EUV light absorption. The approach applied involves adding metals having high EUV light absorption to the resist polymer to increase secondary electron emission, enhance PAG reactivity, and improve acid generation efficiency[1]. One of our past studies confirmed that adding HfO_2 nanoparticles improves EUV resist sensitivity[2].

Our current study investigates a new metal, which exhibits higher EUV light absorption than Hf, to determine whether further improvements in sensitivity can be achieved.

In this time we added ZrO_2 to an acrylic-based resist in molar quantities of 0-2 relative to PAG. The resist was then subjected to EUV exposure at the NewSUBARU synchrotron radiation facility for sensitivity measurements and transmittance evaluations. The results show that adding ZrO_2 resin further increases sensitivity too.

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P-RE-09

INVESTIGATION OF LUMINESCENT MATERIALS FOR EUV METROLOGY APPLICATIONS

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In contrast to x-ray and ultraviolet excitation, properties of luminescent materials (i.e. phosphors and scintillators) under extreme ultraviolet irradiation have not been intensively and systematically investigated. Due to the non-linear energy response of luminescent materials and the short penetration depths of EUV light, available data for other wavelengths can only be used as guidance in the search for promising luminescent materials for EUV applications. State of the art phosphor-based EUV cameras mainly use Gd_2O_2S:Tb (P-43) to convert EUV light into visible light. However, x-ray investigations indicate several new promising materials with significantly higher light output. In this contribution, the identification of promising materials for EUV metrology applications is presented. Key material properties are conversion efficiency, degradation, hygroscopicity, emission wavelength, and self-absorbance. A table-top plasma source based setup, which is suitable for the investigation of conversion efficiency and degradation under EUV irradiation, is realised and will be discussed. Furthermore, experimental results on luminescent material properties under EUV irradiation will be presented and complemented with experimental investigations of self-absorbance, carried out with a commercial laser-based spectrometer setup. A summary of the most promising luminescent materials for EUV metrology applications and an outlook for material optimisation conclude this work.

P-RE-10

FUNDAMENTAL UNDERSTANDING OF EUV RADIATION INDUCED CHEMISTRY ON A MOLECULAR LEVEL

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Fundamental understanding of EUV induced chemistry in photoresist is essential for tailored design. Resists incorporating high cross-section elements efficiently utilize EUV photons via radiation absorption by core-level electrons, resulting in emission of primary and secondary (Auger) electrons. We utilize mass spectrometry and photoelectron spectroscopy techniques to study the response of individual prototype resist molecules to EUV radiation and electron beam exposure deciphering the energies of emitted primary and secondary electrons as well as fragmentation patterns. While gas-phase studies do provide insight into the primary EUV induced events in the individual molecules, we seek to understand these processes in the condensed phase as this is where industrially relevant processes will occur. We use aerosol techniques to condense the molecules into nanoparticles or deposit them onto EUV transparent nanoparticles. A novel photoelectron spectrometer will demonstrate how electrons, ions and radicals generated in the primary event interact with neighbouring molecules in the condensed phase.

P-RE-11

CALCULATION OF INELASTIC MEAN FREE PATH OF SECONDARY ELECTRONS IN EUV RESISTS WITH EELS MEASUREMENTS

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The precise mechanisms by which low-energy (<80 eV) photo-electrons and secondary electrons in a chemically amplified EUV resist participate in exposure chemistry are currently not fully understood and are being actively investigated by several researchers. One of the major unknowns is the mean free path of these electrons, which directly relates to the net electron blur, an important parameter. Here we present the experimental measurement of the inelastic mean free path of low-energy electrons in a chemically amplified EUV resist by using the optical properties of the resist measured in the <80 eV loss regime using electron energy loss spectroscopy (EELS). The interaction of low energy electrons with a solid has been described in literature using the dielectric function of the material[1], and the inverse inelastic mean free path follows the relation in equation 1:

$$\frac{d\lambda^{-1}}{d(\hbar\omega)} = \frac{1}{\pi a_o E}\int_{q_-}^{q_+}\frac{dq}{q}\,\mathrm{Im}\left[\frac{-1}{\epsilon(q,\omega)}\right]$$

Here, λ is the mean free path of an electron propagating with energy E, q is the momentum transferred while $\hbar\omega$ is the energy transferred to the material by the electron. $Im\left[-\frac{1}{\epsilon(q,\omega)}\right]$ is referred to as the energy loss function (ELF) of the material, and a_o is the Bohr radius. The optical ELF of a material can be estimated using experimental techniques such as XAFS [3] or EELS [6], as well as calculated from first principles using density functional theory[2]. Provided the optical ELF, the q-dependent ELF needed to evaluate equation 1 can be approximated by expressing it as a linear combination of oscillators *(equation 2)* with a precise mathematical description and q-dependence[1-5]. The Lindhard and the Mermin dielectric functions are the mostly widely used for this purpose.

$$\mathrm{Im}\left[-\frac{1}{\epsilon(q,\omega)}\right] = \sum_i A_i\,\mathrm{Im}\left[-\frac{1}{\epsilon_M(\omega_i,\gamma_i;q,\omega)}\right]$$

Here, A_i, ω_i and γ_i are constants that result in the closest match between the approximated q-dependent ELF and the measured ELF in the optical limit. This approach has been used to estimate the mean free path values for low-energy electrons (<100 eV) in Zinc Selenide by Bourke et. al.[2], and for PMMA by Dapor[5]. Dapor used the best fit values of A_i, ω_i and γ_i calculated for the optical ELF of PMMA measured using EELS[1, 6], and performed mean free path calculations (Fig. 1) by assuming a linear combination of Mermin dielectric functions. A 10 eV electron is expected to travel 2.5 nm, while an 80 eV electron travels 0.5 nm. The plot on the right in Fig. 1 shows the energy loss function for a chemically amplified EUV resist that we measured using EELS. The 5eV peak is about 1/3x as strong as the collective oscillation peak at 23 eV. The techniques in literature illustrated above will be used to extract secondary electron mean free path from these measurements of low-energy optical properties.

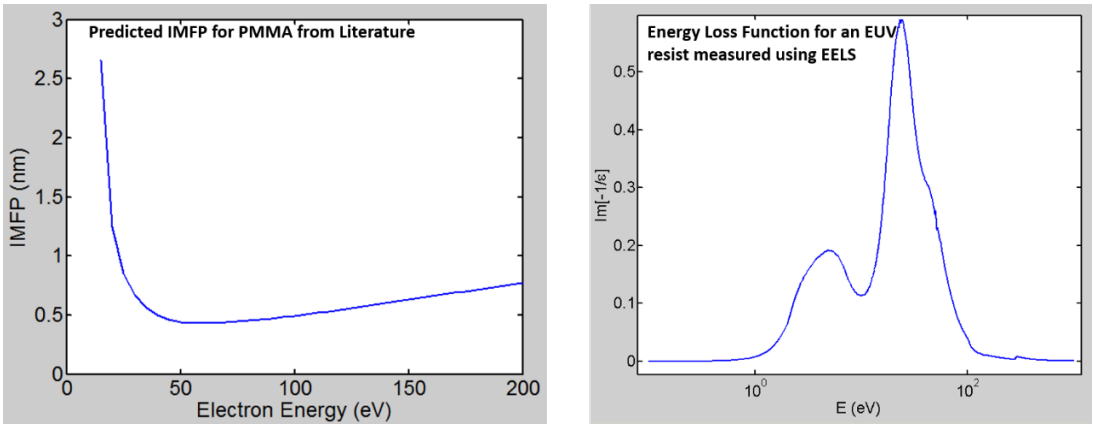

Figure 1 (left): *Prediction for e⁻ inelastic mean free path in PMMA[5];* ***(right):*** *Energy loss function for an EUV resist evaluated using our EELS data, that will be used for secondary e⁻ mean free path calculation*

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P-RE-12

MODELING THE INTERACTION OF EUV RADIATION WITH PHOTORESIST MATERIALS

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The fundamental details of extreme ultraviolet lithography (EUVL) remain poorly understood. Given the higher photon energy (92 eV), the exposed photoresist materials can potentially produce new photochemical products previously inaccessible to photon energies at the current DUV standard (6.4 eV). EUV photons impinging on tailored photoresist materials may additionally ionize semi-core or deep valence electrons of the atomic elements with high optical cross-sections at these energies, leading to various products depending on the initial electronic states. As these electronic orbitals are generally spatially localized, this suggests the possibility of tailoring the chemistry to break specific bonds, guided by predictions from theory. We adopt an ab initio approach to understanding the interaction of EUV radiation with matter. Modeling the excited state chemistry initiated by particular electronic excitations yields new insight into potential photoproducts and provides guidance for molecular design of novel EUV-optimal photoresists.

P-RE-13

UNDERSTANDING EUV RESIST EXPOSURES – MEASUREMENTS OF PAG REACTION CROSS SECTIONS TO LOW ENERGY ELECTRONS

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Optimizing the photochemistry in extreme ultraviolet (EUV) photoresists due to EUV exposures may enable faster, more efficient resists which would lead to greater throughput in manufacturing. Since the fundamental reaction mechanisms in the resist are believed to be due to electron interactions after an incident EUV photon generates a photoelectron during an ionization event, understanding how these photoelectrons interact with resist components is critical to optimizing the performance of EUV resists. We will present an experimental method to measure the cross section of incident electron induced decomposition of three different photo-acid generators (PAG).

To study the photoelectrons generated by the EUV absorption and measure their effect within the resist, photoresists were exposed to incident electron beams. The reactions between PAG molecules and electrons were measured by using a mass spectrometer to monitor the number of outgassed molecules produced by PAG decomposition. This methodology allowed us to determine the number of PAG molecules decomposed per incident electron. Combining this result with the average penetration depth of an electron at a given energy, the cross sections of PAG molecules were determined for energies ranging between 80 to 250 eV. Comparing the cross sections of all three PAG molecules can provide insight into the relationship between chemical structure and reactivity to the electrons.

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Abstracts of Poster Presentations

EUV Source for Metrology and Inspection

P-MI-01

LASER DRIVEN TABLE-TOP COHERENT EUV SOURCE FOR HIGH RESOLUTION DIFFRACTIVE MICROSCOPY

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High Harmonic Generation (HHG) is a strongly non-linear process where a high intensity, short pulse laser field is focused into a gas resulting in a spectrum of short wavelength radiation in the extreme ultraviolet (EUV) range generated at harmonic frequencies of the fundamental laser field. The resulting radiation conserves the properties of the driving field. The produced EUV beam has low divergence with lateral coherence comparable with the beam size, which allows tight focusing and achieving high photon flux density of highly coherent EUV radiation.

Coherent Diffractive Imaging (CDI) is a microscopy method that allows recovering both amplitude and phasing shift of the exit-wave from sample without the need for any EUV objective lens at the diffraction limited resolution. Results, from our experiment on test samples demonstrate 60nm resolution using far-field scanning CDI method (ptychography) and 2x2mm field of view in the near-field mode.

Further, spectral data is presented from analysis of a diffraction pattern of a double slit mask showing the option to use the HHG source as a monochromatic or polychromatic depending on the multilayer focusing optics used.

P-MI-02

LIGHT SOURCES FOR HIGH VOLUME METROLOGY & INSPECTION APPLICATIONS

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Recent progress on source cleanliness with a focus on our 3 layer debris mitigation strategy will be provided, together with the impact on operating time, availability and cost-of-ownership. Update on the main focus of development, namely 24/7 operation, has shown significant progress in demonstrating source stability, brightness as well as cleanliness requirements for high volume manufacturing needs for all actinic mask inspection needs, such as pattern inspection, AIMS, as well as mask blank. The latest research achievements program, which includes fast imaging of the EUV plasma and debris, will be presented showing the effectiveness of the debris mitigation system. In a recent effort, the emission wavelength window has been tuned for applications seeking sub-200 nm emission, such as wafer inspection. The continuous increase in technology readiness enables Adlyte, while working hand-in-hand with industry leaders, to move towards productization of the light source. Trade studies to assess mask throughput for different brightness levels and node sizes have been performed.

P-MI-03

COMPACT DISCHARGE BASED EUV SOURCE FOR METROLOGY AND INSPECTION

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Discharge based EUV sources offer a compact and cost effective alternative for metrology and inspection applications. Such sources are commercially available and being used in the environment of EUV lithography development, e.g., mirror contamination studies, mask blank inspection or resist development.
This paper reports on the current status of the FS5420 source generation, which is under development at Fraunhofer ILT. The concept is based on a hollow cathode triggered Xenon pinch plasma (HCT).
The average source power is 20 W/(2psr 2% b.w.) at 13.5 nm at a typical repetition rate in the range of 1-2 kHz. Progress on long-term stability considering the 20 W/(2psr 2% b.w.) and the 40 W/(2psr 2% b.w.) power level, will be presented and a high pulse energy mode with 32 mJ/(2psr 2% b.w.) will be introduced. Key improvements are the use of new electrode materials showing less electrode erosion, as well as the development of an improved triggering concept reducing the influence of electrode erosion on the source performance. Both yield longer maintenance intervals and therefore a benefit for commercial use.

P-MI-04

METROLOGY TOOLS FOR THE CHARACTERIZATION OF LIGHT SOURCES IN THE SPECTRAL REGION AROUND 6.X NM

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A set of metrology tools is presented, which allows for the measurement of absolute photon flux and spatial distribution of light sources around 6.x nm. All tools are using especially adapted multilayer mirrors fabricated at Fraunhofer IOF in Jena. Two versions for the energy monitor are available having either a single 45° multilayer mirror or two near normal incidence mirrors in combination with a thin broadband transmission filter and a photo diode. For the spatial characterization of the source two cameras with different magnifications of M = 3.3 (track length ~ 1540 mm) and M = 9 (track length ~ 1720 mm) are used with a spatial resolution of down to a few micrometers. Both cameras were equipped with curved LaN/B_4C multilayer mirrors providing R > 50 % at 6.7 nm. Examples for the characterization of discharge based and also Laser induced plasma sources are presented.

P-MI-05

COHERENT DIFFRACTIVE IMAGING FOR ACTINIC INSPECTION WITH EUV LIGHT PRODUCED BY A LABORATORY-SCALE GAS-DISCHARGE PLASMA SOURCE

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Coherent diffraction imaging (CDI) in the EUV spectral range offers the possibility to replace expensive optics completely by image reconstruction algorithms and additional gain more information about the object. We present transmission CDI and ptychography experiments with our compact pinch plasma gas-discharge source. FIB structured membranes were illuminated at the oxygen VI emission line (17.3 nm) and successfully reconstructed. To account for spatial and temporal incoherence a dynamical kernel and a background subtraction algorithm adapted to the source characteristics were developed.

Furthermore, we propose here an experiment for CDI in a reflective setup with our EUV source. Our special focus will be at wavelength investigation of multilayer (ML) mirrors modified by programmed, buried defects. Coherent imaging can recover the phase and amplitude change induced by the buried defects. This information is not accessible by other methods and allows improvements in the ML fabrication.

P-MI-06

EUV SCATTERING METROLOGY WITH HIGH-BRIGHTNESS DISCHARGE PLASMA SOURCE

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EUV light scattering experiments on rough, periodic and quasiperiodic nanostructured surfaces were accomplished at grazing incidence angles below total external reflection (2° – 10°). High brightness EUV plasma source with in-band radiation energy of ~ 4 mJ per pulse/sr/2%bw operated at 1 kHz was used in our compact laboratory table-top scatterometer setup. Scattering patterns were recorded and analyzed at wavelength 13.5 nm for several different multilayer coated mirrors as well as for reference single layer carbon coated mirror with roughness below 1 nm. Complementary, different periodic structures with pitch sizes down to 100 nm were investigated. Up to 14th diffraction orders were observed at 5° grazing reflection from a test 1200 l/mm gold-coated blazed grating. It shows that resulting scattering signal emerging after grazing reflection of EUV from rough surfaces at 13.5 nm can be recorded in reasonably short times (from 5 sec to 10 min) with a high-brightness gas discharge source. The results demonstrate strong sensitivity to a period and roughness of investigated surfaces. Results of periodicity and roughness estimation will be analyzed and discussed.

P-MI-07

HIGH STABILITY DROPLET GENERATOR FOR EUV ACTINIC INSPECTION APPLICATIONS

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One of the possible solutions for masks and wafers inspection is the actinic inspection – the inspection using the same wavelength as the exposure wavelength. It requires EUV source with less power but more brightness and higher pulse-to-pulse EUV energy and spatial stability. It was shown that laser produced plasma based on tin droplets is suitable for this task due to a small source size defined by droplet size. In order to achieve requirements of energy and spatial stability, it is first necessary to have a high stability droplet generator.

In this work we represent various droplet generator designs; their main difference is the principle of droplet formation – droplet on demand type or Rayleigh breakup of jet. The parameters of best operation mode are the following: droplet diameter of 46 um, repetition rate 40 kHz, droplet-to-droplet position stability ~ 1% (of droplet diameter) at the 2 cm from the nozzle, time of operation – 2 hours.

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EUV Source for Patterning

P-PA-01

THE TARGET FORMATION FOR LPP EUV SOURCE WITH LASER PULSES OF FEMTOSECOND AND PICOSECOND DURATION

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This work presents the vast variety of targets for LPP EUV light source. It was shown earlier that the long pre-pulses (~ 10 ns) result in splashing of droplets in a disk-like form and short pre-pulses (~ 10 ps) result in more complicated target geometry (mist target). Using of pre-pulse of nanosecond duration allows increasing CE up to 3-4 % and 5 % in case of picosecond pre-pulse.

In this work we first have studied the droplets (liquid Sn-In eutectic alloy) irradiated by focused laser pulses from laser system consisted of Ti:Sapphire generator with regenerative amplifier. The ultrafast shadowgraph technique was used to take images at angle 90° to laser axis and Faraday cups were used to measure the ions energy in different directions. Several experimental conditions were performed: pulse durations (50 fs – 50 ps), focal spot sizes (50 – 100 um) and pulse energies (0.4 – 2.3 mJ). Shadowgraphs obtained at different time delays after laser pulse explain the target formation behavior.

The work was supported by the Ministry of Education and Science of the Russian Federation under the Agreement № 14.579.21.0004 (a unique identifier for Applied Scientific Research (project) RFMEFI57914X0004).

P-PA-02

PICOSECOND, KW THIN DISC LASER TECHNOLOGY FOR LPP AND FEL EUV SOURCES

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Picosecond pre-pulse is one of the key technologies in the Sn droplet HVM LPP source for higher CE and full ionization by the main ns CO_2 laser pulse. Pulse energy of mJ level is available at 100 kHz from a compact thin disc laser regenerative amplifier. Shorter wavelength is preferable and an efficient and stable wavelength conversion is desired. EUV FEL is now under preliminary consideration in the industry for ultimate 40kW operation. More advanced picosecond laser technology is necessary for photocathodes, laser e-beam heating, and HGHG seeding for the operational target. HiLase Centre is dedicated for the high average power, picosecond laser technology, which is best suited for these advanced applications.

P-PA-03

LPP LIGHT SOURCE DEVELOPMENT FOR HVM

Igor Fomenkov, David Brandt, Alberto Pirati, Daniel Brown, Alex Ershov, Alex Schafgans, Michael Purvis, Matthew Graham, Daniel Riggs, Robert Rafac, Silvia De Dea, Georgiy Vaschenko, Slava Rokitski, Yezheng Tao, Andrew LaForge, Jayson Stewart

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This paper describes the development of a laser-produced-plasma (LPP) extreme-ultraviolet (EUV) source for advanced lithography applications in high volume manufacturing. In this paper we discuss the most recent results from high power testing on our development systems targeted at the 250W configuration, and describe the requirements and technical challenges related to successful implementation of these technologies. Subsystem performance will be shown including Master Oscilator Power Amplifier (MOPA) Prepulse operation with high Conversion Efficiency (CE), dose control with high die yield, collector protection, in-situ cleaning, and out-of-band (OOB) radiation measurements. Results from testing high power MOPA CO2 laser systems with Prepulse at high repetition rate will be shown. We describe the most effective optimized modes of operation to control the plasma dynamics at high frequency. Advances in EUV metrology systems, plasma diagnostics, optics and controls will also be described. This presentation reviews the experimental results obtained on systems with a focus on the topics most critical for a 250W HVM LPP source.

P-PA-04

LENSLESS INTERFERENCE PATTERNS FOR SEVERAL TYPES OF EUV SOURCES

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In this work we demonstrate the interference lithography with several types of extreme ultraviolet (EUV) sources. 1st one is a highly coherent EUV light source of 46.9 nm wavelength based on capillary discharge Ne-like Ar laser. 2nd one is a Xenon gas discharged plasma generating EUV at 10.88 nm wavelength. And 3rd one is a short-pulse EUV radiation of 27 nm wavelength produced using high harmonic generation (HHG) technique. We perform the lensless proximity interference patterning using those EUV sources and compare them with regard to the patterning capability, stability, feasibility, etc. Transmissive diffraction gratings, which are defined directly into Si_3N_4 membranes by focused ion beam milling, are utilized to achieve the sub-micron structuring. As a result, the interference patterns are reproduced with fine detail in photoresist. The patterns are compared to theoretical predictions, and good agreement is obtained.

P-PA-05

KEY COMPONENTS TECHNOLOGY UPDATE OF 100W EUV LIGHT SOURCE FOR HVM

Tamotsu Abe, Yasufumi Kawasuji, Takeshi Okamoto, Hiroshi Tanaka, Yukio Watanabe, Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Hiroaki Nakarai, Taku Yamazaki, Shinji Okazaki, Takashi Saitou, Hakaru Mizoguchi

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This paper introduces key components technology update of 100W LPP-EUV (laser produced plasma extreme ultraviolet) light source for high volume manufacturing which enable sub-10nm critical layer patterning for semiconductor device fabrication.

This EUV light source system is composed of several key components such as a magnetic debris mitigation system, a high power short pulse CO2 drive laser system, unique pre-pulse laser system, small droplets generator and a laser-droplet shooting control system. These components are perfectly controlled and worked harmoniously to produce stable plasma and to evacuate Tin debris from a EUV vessel effectively in order to realize a high power and a long life EUV light source system.

This paper describes the latest results obtained from our proto systems with key components which support 100 watt LPP-EUV light source.

P-PA-06

A WIDE BAND TRANSMISSION MODE SPECTROMETER FOR DIAGNOSIS OF EUV SOURCES

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The interest in getting high-power and clean EUV radiation from lithography sources is increasing nowadays to move towards high volume chip production with EUV lithography. The current EUV sources emit strong radiation around 13.5 nm but also at some undesired longer wavelengths, which is usually called the out-of-band range. The intensity at a particular wavelength in the out-of-band radiation might be small but the spectral extent of the out-of-band radiation is very wide, from EUV to visible wavelengths. Therefore small intensities per wavelength can add up to considerable powers when integrated over the complete out-of-band spectrum. Hence for a comprehensive spectral diagnosis of the EUV source, characterization of the EUV sources around the 13.5 nm wavelength as well as in the out-of-band spectrum is highly desired. Currently characterization of such a wide bandwidth can be done only with multiple spectrometers or after going through the cumbersome process of changing gratings in a spectrometer. Here we present a compact transmission mode spectrometer that can measure a wide spectrum with high precision and detail. This diagnostic then allows critical EUV source optimization of both EUV in band and reduction of out of band light.

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Mask Inspection and Review

P-MR-01

3D RETICLE BACKSIDE INSPECTION

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EUVL reticles are chucked electrostatically in the wafer-stepper. Particles present between the reticle and chuck that are higher than the e-chuck pins can deform the reticle or are crushed due to the clamping force. Reticle deformation causes image distortion and reduced overlay performance, while crushed micro-particles can break-down into thousands of nano-particles that could contaminate the front-side of the reticle. Furthermore, particles brought in on the back-side of a reticle can be embedded into the e-chuck surface, deforming all subsequent reticle that are loaded on this chuck.
Current scatterometry based reticle back-side inspection (RBI) tools finds many large defects that need individual review for height. This review is not available online on most RBI tools and/or a time consuming process.
We have developed a direct 3D inspection tool for the full reticle back-side surface. This tool uses white-light interferometry to measure the height of all defects on a reticle. The inspection time with our technology can be less than two minutes for a full reticle. This inspection time makes RBI screening of reticles before each chucking action possible.

P-MR-02

QUANTITATIVE PHASE-CONTRAST IMAGING OF A PHASE DEFECT USING A LENSLESS MICROSCOPE

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A EUV mask has 3-dimensional (3D) structure. The mask is reflective type, which consists of glass substrate, reflective Mo/Si multilayer (300-nm thick), and absorber pattern (70-nm thick). Since the 3D structure affects the reflective phase, a phase-imaging microscope for the EUV mask metrology is necessary for EUV mask development.

We have developed a lensless EUV microscope of micro coherent EUV scatterometry microscope (micro-CSM) to observe phase defects with quantitative phase contrast. The micro-CSM records diffraction image from a defect directly that is exposed with focused coherent EUV light of □140-nm in diameter. The focusing optics is Fresnel zoneplate of off-axis type. The acceptance angle of the CCD camera is approximately ±16° (NA 0.27). With a coherent illumination, phase information is embedded in the diffraction signal. Using the diffraction signal, phase images of the phase defect is reconstructed by the coherent-diffraction-imaging method.

The phase defects are observed with quantitative phase contrast and 30-nm spatial resolution. This phase image will be helpful for the defect reduction.

This work is re-contract research from EUVL Infrastructure Development Center (EIDEC). EIDEC programs are supported by New Energy and Industrial Technology Development Organization (NEDO).

P-MR-03

ACTINIC CHARACTERIZATION OF EUV PHOTOMASKS BY EUV SCATTEROMETRY

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EUV photomasks utilize a multilayer stack to provide high and uniform EUV reflectance and a patterned absorber which defines the features on the mask. Illuminating at an oblique angle as necessary in a stepper gives rise to horizontal-vertical print differences and through-focus pattern placement errors due to shadowing. These 3D mask effects depend on the full 3D mask structure. Characterization by EUV Scatterometry may use zero order specular reflection to assess the multilayer and absorber stack homogeneity. For structured areas the zero order reflectance depends on structure details like CD and can be used to check patterning homogeneity. Intensity measurements of several diffraction orders can be used for the reconstruction of the line shape.
We present data obtained at EUV photomasks featuring large periodic lines & spaces fields suitable for scatterometry with the instruments of PTB which are not specially designed for small measurement spots. We use a FEM-based Maxwell solver for the evaluation of the data with respect to the geometrical parameters linewidth, lineheight, sidewall angle and corner rounding. Using statistical procedures for the inclusion of roughness we could also derive reliable estimates for the line roughness. Results of the EUV measurements were compared to AFM and CD-SEM data.

P-MR-04

RAPIDNANO: AN AFFORDABLE PARTICLE DETECTION PLATFORM FOR EUV MASK BLANKS

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TNO, Delft, The Netherlands

Defect inspection for EUV masks is an area where further development is required. Detection of defects of 20 nm is not only challenging but also time consuming and costly. For the qualification of EUV reticle handling equipment TNO develops the RapidNano, a tool that is capable of detecting nanoparticles on flat substrates. Over the last decade, the size of the smallest detectable defect in the RapidNano was decreased while the inspection rate was increased. This effort leads to a stable and affordable detection platform that is capable of inspecting the full surface of a reticle substrate.

At the core of RapidNano is a dark-field imaging technique. By illuminating the inspection area from nine different angles, the signal-to-noise ratio is optimized. Every substrate type has a typical background characteristic, which in turn strongly affects the lower detection limit. The RapidNano3 is capable of detecting 42nm LSE (and larger) on silicon surfaces. RapidNano4, the next generation, will use 193 nm light. Camera sensitivity and available laser power set the achievable throughput. Therefore, special care was given to the optical design, particularly the projection optics. With RapidNano4, TNO pushes the detection limit of defects on EUV blanks to below 20nm.

P-MR-05

ACTINIC EUV MASK INSPECTION USING SCANNING COHERENT DIFFRACTION IMAGING METHODS

Patrick Helfenstein, Manuel Guizar-Sicairos, Yasin Ekinci
Paul Scherrer Institut, Villigen, Switzerland

Extreme ultraviolet (EUV) lithography is regarded as the most likely successor to deep UV lithography for future technology nodes. As one of the major challenges in the implementation of EUV lithography into high-volume semiconductor manufacturing remains the realization of defect-free reflective masks, a stable and reliable method is needed for detecting and repairing defects. Actinic mask inspection – illumination at 6° using EUV light - is capable of detecting buried defects that are elusive to conventional methods.
There is an immediate need for actinic mask metrology, i.e. review and inspection. To this end, we developed an actinic mask metrology tool based on scanning coherent diffraction imaging (SCDI) methods. SCDI provides high-resolution phase and amplitude mapping of an extended object without optics. Aforesaid tool has been implemented at the XIL II beamline of the Swiss Light Source (SLS), demonstrating about 20 nm (on wafer) resolution. It was recently upgraded to provide 10 nm resolution. Here we present our experimental results and also extensive simulations to address resolution, sensitivity, throughput, and coherence control to estimate the performance of a stand-alone mask tool based on this technology.

P-MR-06

PARALLEL AFM STATUS: DEMONSTRATION OF 3D METROLOGY AND INSPECTION WITH 1000 TIMES INCREASE IN SPEED

Hamed Sadeghian[1,2], Rodolf Herfst[1], Jasper Winters[1], Bert Dekker[1], Alexander Eigenraam[1], Ramon Rijnbeek[2]

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With the device dimensions moving towards the 1X node and below, the semiconductor industry is rapidly approaching the point where existing metrology, inspection and review tools face huge challenges in terms of resolution, the ability to resolve 3D and the throughput.
Scanning probe microscope (SPM) and specifically atomic force microscope (AFM), due to the advantages of sub-nanometer resolution and the ability of true 3D scanning are considered as alternative technologies for CD-metrology, defect inspection and review of 1X node and below.
In order to meet the increasing demand for resolution and throughput of CD-metrology and defect inspection and review, we have previously introduced the parallel SPM concept, consisting of parallel operation of many miniaturized SPMs on a wafer. In this talk we will present the status of proof of principle of the ultimate parallelization and measurement results on the performance of the system.
In conclusion, we show the ultimate proof of principle of parallel AFM equipment for nanoimaging, metrology and inspection. With 4 parallel AFMs system we show the feasibility of all technical challenges involved. The system can now be scaled up for the ultimate required throughput by parallelizing more than 40 scan heads.

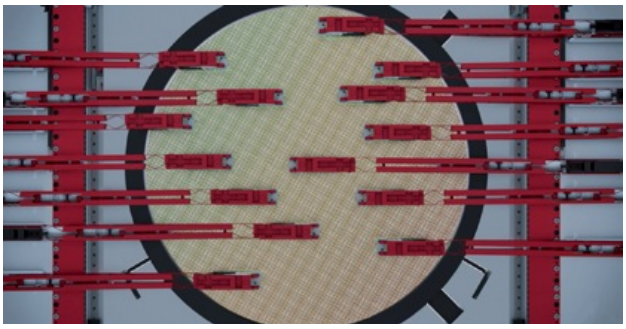

Figure 1 Illustration of parallel SPM to image several locations on a wafer or mask. Multiple positioning arms on two sides of the wafer stage, each capable of moving a miniaturised SPM scan head on to a large sample. Many parallel miniaturised SPM heads enable full area coverage at high throughput

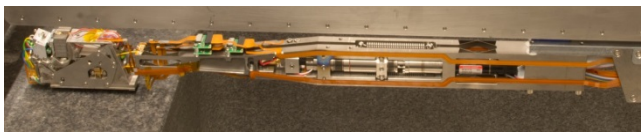

Figure 2 Picture of one of the demonstration arm that carries one miniaturized SPM head.

P-MR-07

SCATTERING ANALYSES OF DEFECTS IN EUV MULTILAYERS

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Distinguishing between pure surface defects and multilayer deformations in EUV mask blanks and masks is essential for choosing the optimal repair strategy, but currently requires multiple investigation steps with different inspection tools. In the present study the scattering behavior of both types of defects is investigated experimentally by EUV dark-field reflection microscopy and theoretically by simulation and modelling.

It is shown that it is possible to distinguish between surface defects, which are pure absorbing structures on top of a multilayer, and composite defects, which are deformations of the multilayer going from the substrate up to the surface, utilizing differences in the scattering behavior of the defects depending on the incidence angle.

Possible extensions of the method are discussed and investigated simulatively with the aim to unveil further information about the defects, which can be essential for the subsequent defect repair.

P-MR-08

OVERLAY IMPROVEMENT VIA LARGE DYNAMIC RANGE SCANNING PROBE MICROSCOPE

Stefan Kuiper, Erik Fritz, Will Crowcombe, Thomas Liebig, Geerten Kramer, Ton Overtoom, Tom Duivenvoorde, Erwin van Zwet
TNO, Delft, The Netherlands

Most overlay metrology tools evaluate the overlay performance based on marker features which are printed along with the product features within each layer. However, due to various errors, correct overlay of marker features does not directly guarantee correct overlay of the product features.
This project is aimed to develop a metrology tool for measuring the positioning error of product features with respect to the marker grid, in order to allow for process improvements.
Within this concept scanning probe microscopy (SPM) techniques are used to measure the location of both the marker and product features within each layer. The major advantages of scanning probe microscopy are the direct nature of the imaging method, the high imaging resolution at (sub-) nanometer level, and being non-destructive. However, to allow measuring the marker to feature distances over several millimeters with sub-nanometer measurement uncertainty, the metrology concept of conventional SPM had to be improved.
A technology demonstrator is developed featuring a highly stable metrology concept and a 6DOF controlled SPM positioner to minimize the measurement errors. Current activities are aimed at proving the feasibility of the concept by demonstrating the high measurement accuracy of the developed SPM system.

P-MR-09

CHALLENGES IN CONSTRUCTING EUV METROLOGY TOOLS TO QUALIFY THE EUV MASKS FOR HVM IMPLEMENTATION

Ruper Perera
EUV Tech, Martinez, USA

Extreme Ultraviolet (EUV) Lithography is still viewed as the most promising approach for maintaining the pace of Moore's Law. Recent real achievements in extreme ultraviolet (EUV) lithography have encouraged semiconductor manufacturers to reconsider their road maps. One of the principal challenges in the ongoing EUVL implementation for high volume manufacturing (HVM) is the availability of necessary clean at wavelength metrology tools. The development of the required metrology tools have been stalled due to the slow progress with the throughput and source power of the EUV scanners.

Started in 1999, EUV Tech pioneered the development of standalone EUV Metrology tools and is one of the world's leading manufacturers of EUV metrology tools. In this paper, EUV Tech's R&D program to minimize particle adders in our EUV Reflectometer along with the ongoing effort to minimize the reflectivity and wavelength, precision and accuracy required to qualify the EUV masks for HVM. In addition preliminary results from our stand alone EUV Scatterometer developed to characterize the phase roughness of an EUV mask and our latest product, "EUV Pelicle Suite" will be presented.

P-MR-10

IMPROVING SCAN SPEED AND RESOLUTION OF AFM FOR ELUCIDATING RESIST DISSOLUTION DYNAMICS

Dominik Ziegler[1], Andreas Amrein[1], Ken Matthews[2], Adrian Nievergelt[1], Arnaud Benard[1], Travis Meyer[3], Frank Ogletree[1], Andrea Bertozzi[3], Deirdre Olynick[1], Patrick Naulleau[4], Paul Ashby[1]

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Understanding the resist dissolution process and resist-developer interactions can facilitate high resolution patterning by avoiding pattern failure originating in swelling and poor dissolution contrast. In-situ AFM is the only tool that can provide high resolution spatial information about resist swelling and development dynamics. Imaging more gently will reduce deformation of the sample and provide higher resolution bringing out finer details of the sample roughness. We developed encased AFM cantilevers which have lower damping and higher resolution for imaging in solution. Also, spatial resolution and temporal resolution suffer a tradeoff. This problem is accentuated by the traditional scan pattern of raster scanning that throws away half the data. We developed spiral scanning to display 100% of the data instantly improving speed by a factor of two and when mated with an appropriate height controller improve speed another factor of 10. These methods will allow us to image resist dissolution with exquisite resolution at faster than 10 images per second.

2015
International Symposium on
Extreme Ultraviolet Lithography

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The Netherlands

Abstracts of Poster Presentations

Mask, Pellicle, Mask Cleaning and Thermal Expansion

P-MP-01

TEMPERATURE DISTRIBUTION OF MULTI-STACK EUV PELLICLE WITH VARIOUS STRUCTURES AND MATERIALS

Jong-Hoon Lee, In-Seon Kim, Eun-Sang Park, Sung-Gyu Lee, Hye-Keun Oh
Hanyang University, Seoul, South Korea

During the exposure process, an extreme ultraviolet (EUV) pellicle is needed to protect the EUV mask from contamination. The EUV pellicle consists of very thin film because of its strong absorption of EUV light.
However, the very thin structure of EUV pellicle can be deflected, therefore, a multi-stack EUV pellicle was suggested. As compared to a single layer EUV pellicle, a multi-stack EUV pellicle can reduce film deformation caused by oxidation and film deflection caused by gravitational forces. However, the thermo-mechanical problem of the multi-stack EUV pellicle that causes the breakdown of the pellicle needs to be studied. In order to solve the problem, temperature distribution of the multi-stack EUV pellicle with various thickness and material of each layer is simulated. For example, the maximum temperature of multi-stack EUV pellicle which consists of capping layer with zirconium and core layer with poly-silicon is 580 K.
Compared to previous pellicle which consists of capping layer with silicon nitride and core layer with the poly-silicon, the temperature of the new pellicle rises 150 K less. The optimized multi-stack number of layers, materials, and thicknesses that give minimal influence to optical problem and thermo-mechanical breakdown is suggested.

P-MP-02

FEASIBILITY STUDY OF THROUGH PELLICLE INSPECTION FOR PATTERNED EXTREME ULTRAVIOLET MASK

Guk-Jin Kim[1], In-Seon Kim[1], Michael Yeung[2], Hye-Keun Oh[1]
[1]Hanyang University, Seoul, South Korea; [2]Fastlitho, San Fransisco Bay Area, USA

The pellicle of extreme ultraviolet (EUV) lithography is required to protect the EUV mask from contaminations during EUV lithography process. The particle and contamination caused by exposure and cleaning can be generated on EUV mask surface, even though EUV pellicle is used. To detect these defects on EUV mask covered with pellicle, a through pellicle inspection is needed. However, the EUV pellicle reduces transmissions of both 13.5 nm and 193 nm wavelengths for EUV mask inspection. The transmission loss by EUV pellicle is a critical problem for the EUV mask inspection which used to an intensity difference of inspection images because a whole intensity declined by absorption of EUV pellicle. Thus, a judgment of inspection for defects will be worsened. In this paper, we tried to overcome the intensity drop due to EUV pellicle. To detect defects on EUV mask covered with pellicle, an intensity ratio of inspection image is suggested instead of the intensity difference. Here we used intensity ratio between the image intensity with defect divided by the image intensity without defect from inspection results. We found that through pellicle inspection efficiency was not much affected from the inspection result without pellicle. Thus, the through pellicle inspections with 13.5 nm and 193 nm wavelengths can be used similarly to the inspection without pellicle.

P-MP-03

THERMO-MECHANICAL DISTORTION OF EXTREME-ULTRAVIOLET PELLICLE

Sung-Gyu Lee, Eun-Sang Park, Jong-Hoon Lee, Hye-Keun Oh
Lithography Laboratory, Dept. of Applied Physics, Hanyang University, Seoul, South Korea

For the reflective optics system used in EUV lithography, EUV light passes through the pellicle twice during exposure process. Internal temperature of EUV pellicle is increased due to absorbed EUV radiation. This can cause the EUV pellicle deformation (e.g., sagged and wrinkled pellicle). It is obvious that deformed EUV pellicle can cause a serious patterning error at the wafer and finally will be broken. Therefore, thermo-mechanical distortion caused by absorbed EUV radiation is investigated. In order to know accurate effect of thermo-mechanical distortion, the change of thermal property caused by EUV absorption is calculated. 50 nm single layers of silicon (Si), zirconium (Zr), niobium (Nb), and molybdenum (Mo) are tested. The increased internal temperature can lead to thermal stress variation. Based on this calculation, the relation between internal temperature, thermal stress, and pellicle deformation is demonstrated. The optimized EUV pellicle structure that does not give serious influence on thermo-mechanical distortion is suggested.

P-MP-04

A CONDUCTIVE UNDER LAYER FOR AN ETCHED MULTILAYER TYPE BLACK BORDER: INFLUENCE OF THE MASK STRUCTURE ON MASK PATTERN IMAGES CAPTURED BY EB OPTICS

Tsuyoshi Amanon[1], Susumu Iida[1], Ryoichi Hirano[1], Tsukasa Abe[2], Yasutaka Morikawa[2], Hidehiro Watanabe[1]
[1]EUVL Infrastructure Development Center, Inc. (EIDEC), Tsukuba; [2]Dai Nippon Printing Co., Ltd., Saitama, Japan

This presentation is about the effect of an etched multilayer type black border on qualities of the mask pattern images captured by electron beam (EB) optics like a mask pattern inspector or a metrology tool. To analyze the impact of the black border structure on the EB images, two types of the mask structure was prepared. One was a normal mask structure that is to say the multilayer was coated on the substrate directly. The other was a mask structure with an under layer inserted between the substrate and the multilayer. The role of the under layer is to keep electrical conductivity between the inside and the outside of the black border, and also etching stopper layer during the multilayer etching process. The under layer was made of ruthenium and the thicknesses were changed from 1.5 to 10 nm to investigate the impact of the sheet resistivity on EB images. It was confirmed that the defect counts on the multilayer did not change even if the under layer were coated below the multilayer. The sheet resistivity will be measured and the influence of the sheet resistivity on the EB images will be described.

This work was supported by NEDO.

P-MP-05

FEASIBILITY STUDY ON INSERTING GRAPHENE LAYERS INTO EUV PELLICLE STRUCTURE

Jung Hwan Kim[1], Seong Chul Hong[1], Seung Min Lee[1], Jung Sik Kim[2], Jinho Ahn[1,2]

[1]Dept. of Materials Science and Engineering, Hanyang University, Seoul; [2]Dept. of Nanoscale Semiconductor Engineering, Seoul, South Korea

Development of EUV pellicle is hot issue for the insertion of EUV lithography into production line. Even though there are several approaches to minimize mask contamination during exposure by controlling chamber environment, pellicle is direct protection method as it has been working for DUV lithography. The strong absorption characteristics of EUV wavelength, however, delayed realization of EUV pellicle, and Si (and its compound) is the mostly researched material due to its low absorption coefficient for EUV. Full-size EUV pellicle with SiN-capped poly-silicon has been demonstrated, but its stability under real exposure condition has not been proved yet. Furthermore, the higher EUV source power for better throughput is going to be disaster for EUV pellicles due to higher thermal load. This is why we need better materials, and composite with graphene is one of the candidates. Since graphene is known to be one of the strongest materials, silicon-graphene composite was fabricated and its properties were investigated. Transmittance of monolayer graphene is about 99.76% at 13.5nm, which is much higher than that at visible wavelength. Nano-indentation test shows higher mechanical strength in Si/graphene/Si composite compared to the Si single layer. These results exhibit possibility of using graphene composite as EUV pellicle membrane.

P-MP-06

OPTICAL TESTING OF EUV PELLICLE MATERIALS

Ivan Pollentier[1], Johannes Vanpaemel[1], Houman Zahedmanesh[1], Christoph Adelman[1], Cedric Huyghebaert[1], Sascha Brose[2], Klaus Bergmann[3], Serhiy Danylyuk[2], Emily Gallagher[1]

[1]imec, Leuven, Belgium; [2]RWTH Aachen University, Aachen; [3]Fraunhofer ILT, RWHT Aachen University, Aachen, Germany

To enable high volume manufacturing using EUV lithography, a pellicle solution is crucial in order to mitigate defects from the mask surface. The development of such a pellicle is very challenging, since there are strict specifications imposed on the pellicle's properties with respect to transmission and film durability at high power EUV exposure. To identify novel candidate materials, high-throughput characterization methods are needed to speed up this screening process.

This work reports the optical testing of candidate pellicle materials, with primary focus on the transmission characteristic of the membranes. A novel but simple approach has been developed, based on EUV exposure of photoresist with and without a membrane in the beam path. The transmission is then obtained by comparing the test and reference resist contrast curves as is illustrated in the figure below. The results of this measurement approach will be discussed for a variety of sample materials and compared to complementary measurement techniques. In addition to the film transmittance, the film durability in EUV scanner environment and/or optical scattering is a concern. These items and options for testing them are also investigated.

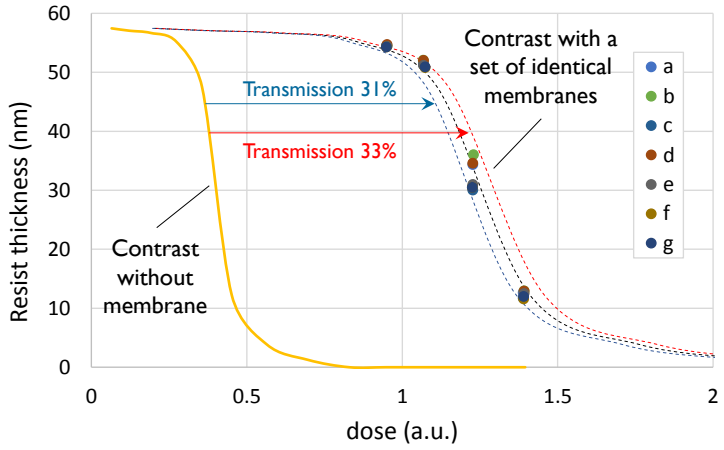

Figure: Measurement of membrane transmission by comparing the resist contrast curves of EUV exposures with and without a membrane in the beam path. Nominal transmission of these membranes was 32% with a measurement variation of +/- 1% (difference between blue and red dashed lines).

P-MP-07

EXTENDING FINAL CLEAN OF EUVL RETICLES TO 100X CLEANING CYCLES

Jens Kruemberg[1], Davide Dattilo[1], Jyh-Wei Hsu[2], Uwe Dietze[3].
[1]SUSS MicroTec Photomask Equipment, Sternenfels, Germany; [2]SUSS MicroTec (Taiwan) Co., HsinChu, Taiwan; [3]SUSS MicroTec Inc., Sunnyvale, USA

In the absence of pellicles, EUV reticles are exposed to contaminants and particles, resulting in the need for frequent cleaning. However, frequent cleaning cycles are reported to lead to surface damage especially in respect to the Ruthenium capping layer.[1] Thus, until EUV pellicle will be available to the industry, a cleaning procedure that guarantees surface integrity over repetitive cleanings has become a must. Direct oxidation and Oxygen inter-diffusion through the capping layer are the most agreed root-causes for surface damage.[2,3] This work describes how alternative cleaning media in combination with UV-light can avoid surface damage if both mentioned root-causes are addressed. The photo-active species have been studied and their reactivity in different media concentrations has been evaluated. The results show that Ruthenium integrity can be preserved for at least 100X repetitive cleaning cycles by altering the electrochemical potential, as well as taking into account molecular contributes from the media which minimize Oxygen inter-diffusion.

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P-MP-08

UNDERSTANDING THE EFFECTS OF TRANSMITTANCE AND STAND-OFF DISTANCE OF EUV PELLICLE

Seung Min Lee, Seong Chul Hong, Jung Hwan Kim, Dong Gon Woo, Hanku Cho, Jinho Ahn
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As EUV lithography approaches high-volume manufacturing, protection of mask becomes an even more critical issue. So the effect of EUV pellicle on the lithographic performance should be evaluated because of double pass mechanism with limited transmittance. However, the effect of EUV transmittance on imaging properties has not been reported yet. In this study, SiNx single layer pellicles with various membrane thicknesses have been fabricated, and the imaging properties such as image contrast, NILS, and H-V CD bias have been evaluated as functions of EUV transmittance of pellicle by using coherent scattering microscope (CSM). In addition, the influence of stand-off distance of pellicle on imaging properties has been evaluated.

P-MP-09

THERMOMECHANICAL BEHAVIOR OF THE EUVL PELLICLE DURING THE EXPOSURE

Eun-Sang Park, Zahid Hussain Shamsi, Sung-Gyu Lee, Jong-Hoon Lee, Dai-Gyoung Kim and Hye-Keun Oh
Hanyang University, Seoul, South Korea

To achieve high resolution patterning below 10 nm half-pitch node, the extreme ultraviolet lithography (EUVL) with 13.5 nm short wavelength should be used. However, the decrease in image quality due to a defect on the mask is one of the serious problems to be resolved for high volume manufacturing (HVM). Therefore, a pellicle (protective membrane) could be used to prevent the defect before it could reach the mask. However, the thickness of the pellicle should be ~ nm thin since most of the materials have high absorption rate for EUV light. Furthermore, the pellicle may be damaged due to thermal stress induced by EUV light exposure. Therefore, thermal stress analysis is desirable for various materials possessing low absorption at EUV wavelength. Here, we revisited thermal stress analysis for EUV pellicle by considering various materials having high transmission at EUV wavelength. By using thermal stress equation in radial direction along with thermal and mechanical properties for various materials, we obtain the maximum stresses within the range 0.08 ~ 0.12 GPa at the center during 10 ms EUV exposure time for silicon pellicle. The stress monotonically decreases away from the center and follows the temperature profile produced by EUV radiation.

P-MP-10

MULTILAYER MASK ROUGHNESS: CORRELATION BETWEEN SCATTEROMETRY AND IMAGE-PLANE SPECKLE

Patrick Naulleau[1], Kenneth Goldberg[1], Eric Gullikson[1], Antoine Wojdyla[1], Henry Wang[2], Andy Neureuther[2]
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It is now well established that extreme ultraviolet (EUV) mask multilayer roughness leads to wafer-plane line-width roughness (LWR) in the lithography process [1-4]. The conventional way to characterize this roughness has been through atomic force microscopy (AFM), however, the inability of this method to probe within the bulk of the multilayer stack limits its accuracy in predicting true imaging effects. To get around this problem, angle resolved EUV scatterometry [5] has been proposed as an alternative measurement since such capabilities could in principle readily be incorporated into reflectometers already required for mask blank reflectivity characterization.

In this presentation we directly compare AFM, scatterometry, and image-plane speckle as measured using the SHARP EUV microscope [6]. From the results we explicitly explore the limitations of AFM-based measurements and the suitability of scatterometry measurements noting that scatterometry cannot distinguish between phase and amplitude perturbations of the reflected field whereas these two components have dramatically different impact on imaging.

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P-MP-11

ULTRAHIGH EFFICIENCY CONTACT-HOLE PRINTING WITH PHASE SHIFT MASK

Patrick Naulleau[1], Weilun Chao[1], Kenneth Goldberg[1], Eric Gullikson[1], Farhad Salmassi[1], Antoine Wojdyla[1], Frank Goodwin[2], Mark Neisser[2]

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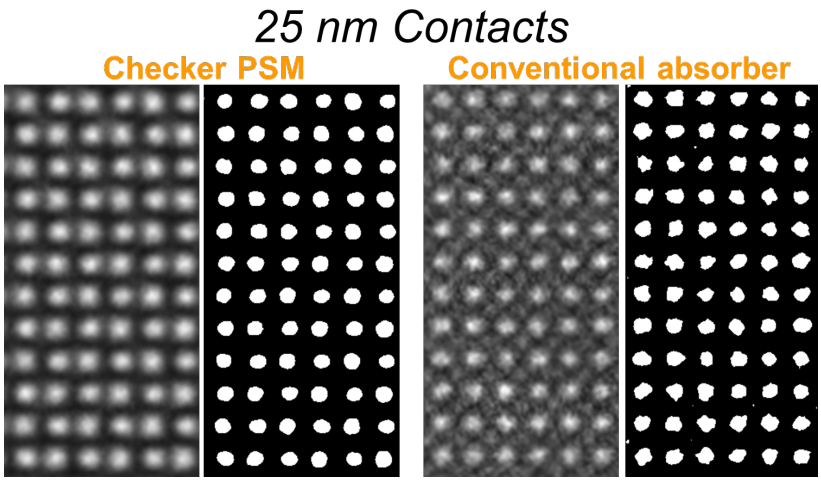
Contact-hole layer patterning is expected to be one of the first applications for EUV lithography. Conventional darkfield absorber masks, however, are extremely inefficient for contact-hole layers, placing even more burden on the already challenging source power demands. To address this concern for dense contact arrays, a checkerboard phase shift mask configuration has been proposed [1] yielding theoretical throughput gains of 4x or higher.

In this presentation we describe the fabrication of such a mask and demonstrate its imaging performance using the SHARP EUV microscope [6]. We demonstrate throughput gains of 4.6x on 32-nm contacts and 8x on 25-nm contacts. Moreover, improvements in horizontal-vertical bias are demonstrating due to reduced shadowing effects and performance on slots and line space patterns down to 12-nm is also presented.



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P-MP-12

USING THE SHARP EUV MICROSCOPE'S AERIAL IMAGES TO STUDY LINE EDGE ROUGHNESS

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At progressively smaller features sizes, line-edge and line-width roughness (LER/LWR) on printed wafer patterns becomes more sensitive to mask surface (i.e. phase) and pattern roughness. These affects can only be fully appreciated and observed at wavelength. Furthermore, it is well known that the illumination coherence properties strongly control the aerial image roughness and through-focus behavior.
In addition to defect density and defect detection, issues of pattern metrology, pattern repair and placement evaluation may dominate mask qualification at future EUV nodes. Using aerial images collected with the SHARP EUV microscope at Lawrence Berkeley National Laboratory, we are exploring the limits of actinic LER/LWR measurement, and its dependence on imaging conditions. Specifically, we are analyzing the interdependence of photon shot noise, image slope, and measured roughness under a variety of conditions, and in comparison to theoretical models or roughness formation. These results are applicable to current SHARP users and for future EUV generations with exotic illumination conditions and optical systems that SHARP was designed to emulate. Furthermore, SHARP can directly extract aerial image phase information that as feedback in repair and roughness analysis.

P-MP-13

SHARP IMAGING AT HIGH MASK-SIDE NA

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The **S**emiconductor **H**igh-NA **A**ctinic **R**eticle review **P**roject (SHARP) is an EUV-wavelength, synchrotron-based microscope dedicated to advanced extreme ultraviolet (EUV) photomask research. The instrument is designed to emulate current and future generations of EUV lithography, including customizable source profiles, and variable numerical aperture values.

The performance of the SHARP microscope has been well characterized for its low-NA lenses, emulating imaging in 0.25 and 0.33 NA lithography scanners. Evaluating the resolution of its higher-NA lenses, intended to emulate future generations of EUV lithography, requires a photomask with significantly smaller features.

We have fabricated an ultra-high resolution test mask with patterns as small as 20-nm hp to use with SHARP's high-NA zoneplates. Printing the pattern on a multilayer-coated silicon wafer in the Berkeley MET and using metal-oxide based photoresist directly, as an absorber, is a fast and economical approach to achieve the required feature size. We have now demonstrated real-space imaging down to 22 nm hp, on the SHARP microscope.

The high-resolution performance of SHARP's high-NA zoneplates, together with the extended capabilities of the tool, provide a platform that is available today, suited for research targeted at upcoming generations of EUVL, many years into the future.

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Abstracts of Poster Presentations

Outgas and Contamination Monitoring

P-OC-01

A TRAFFIC LIGHT FOR CLEAN VACUUM: THE MASS-FILTERED ION GAUGE (MFIG)

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Yield is a critical business driver within Semiconductor Manufacturing. A critical, yet often overlooked yield-impacting factor in nano-fabrication and -inspection is vacuum cleanliness. When the vacuum environment is "out of spec", the production tool runs outside its process window, which impacts yield.
For instance, when using ionization radiation like EUV, ions or electrons, hydrocarbon molecules can react with sample and tool and thus impair either product quality or shorten tool lifetime. To prevent this, tools are maintained following a fixed periodic cleaning cycle. Since there is no real-time monitoring of contaminant molecules, maintenance may be either too early or, even worse, too late as incidents are not detected.
To address this issue, TNO developed a *real-time* vacuum monitoring system, thus providing a "traffic light" signal for production process control. At the heart of this system is a mass filtered ion gauge (**MFIG**), which detects all molecules with a mass above 100 amu simultaneously with a detection limit that is 10-100 times better than a residual gas analyzer offers. The output of this sensor provides a real-time signal on the contaminant level. By comparing this signal to use-case-specific thresholds, the sensor can act as a "traffic light" for clean operation.

P-OC-02

EBL2: EUV EXPOSURE AND SURFACE ANALYSIS SYSTEM

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The introduction of ever higher source powers in EUV systems causes increased risks for contamination and degradation of optics, reticles, pellicles, and sensors. Appropriate testing can help to inventory and mitigate these risks. To this end, we are developing EBL2: a laboratory EUV exposure system capable of operating at high broad band EUV powers and intensities.
The system architecture is similar to the EBL which has been operated jointly by TNO and Carl Zeiss SMT since 2005. EBL2 contains a Beam Line, in which samples can be exposed to EUV irradiation in a controlled environment. It also features an XPS system, which can be reached from the Beam Line via a fully automated in-vacuum transfer system. This enables surface analysis of exposed samples without breaking vacuum.
Both the Beam Line and the XPS can accept a range of sample sizes, including standard EUV reticles with or without pellicles. Compared to the existing system, large improvements in EUV power, intensity, reliability, and flexibility are achieved. Also, in-situ measurements by ellipsometry will enable real time monitoring of the sample condition.

P-OC-03

IMAGE DISTORTION BY VERY SMALL DEFECT WITH LARGER DENSITY

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In extreme ultraviolet lithography (EUVL) the cleaning efficiency is decreased with the size decrease of a defect, because it is harder to clean the smaller size of the defect. We studied 16 nm L/S pattern. The critical defect size that makes 10% critical dimension (CD) error for various materials were previously studied. Among them, the critical size of Fe is 26.5 nm at center of the space. A Fe defect smaller than 26.5 nm does not make 10% CD error. However we found that a defect smaller than the critical size still could make CD error if the defect density was very large. For example, 3 Fe defects with 20 nm size which is smaller than the critical size causes CD error and 22 Fe defects with 10 nm size also causes CD error. We will present several cases showing that very small defect can cause serious CD error if the density of defect is large although a single defect smaller than the critical size would not make any image distortion.

P-OC-04

PATTERNING DEPENDENCY ON HIGH NA ANAMORPHIC DIRECTIONALITY THROUGH CONTAMINATION STUDY

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EUV lithography for resolution below 10 nm node requires high numerical aperture (NA). However, as the NA increases, two light cones are overlapped. Therefore, a problem arises that the chief ray angle also increases. Anamorphic illumination system is suggested in high NA EUV lithography because it has a high NA without overlap of two light cones. Anamorphic illumination system has directionality unlike the isomorphic illumination system and which has different magnification in each direction. Our study indicated allowable maximum thickness of the contamination that caused 10% critical dimension (CD) error depend on horizontal and vertical direction of the anamorphic illumination system. As a result, for 16 nm line and space pattern, the allowable thickness shows huge difference; the horizontal direction was 2.0 nm, and the vertical direction was 6.7 nm. We will show printed CD variation caused by contamination when using anamorphic illumination system with various pattern sizes and pattern density.

P-OC-05

RECENT PROGRESS IN RESIST OUTGAS TESTING FOR THE NEW PLATFORM AT EIDEC

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Recently ASML removed the resist outgas specifications for both cleanable and non-cleanable contamination for the traditional chemically amplified resists (CAR). On the other hand, EUV resist communities are accelerating the development of high sensitivity resist to compensate the low power of EUV source. Non-chemically amplified resist (Non-CAR) with new platform is one of the candidates for high sensitivity resists. The Non-CAR includes some kinds of metal elements which has high absorbance for EUV light. However there is very few knowledge about outgassing characteristics for Non-CAR. ASML required a particular test condition; hydrogen environment, for Non-CAR outgas testing. Because, there is possible risk that hydrogen radical generated by EUV light reacts with the metal element in Non-CAR and the metal hydride outgases from the resist. Then outgassing from Non-CAR has potential risk to be non-cleanable contamination on EUV mirror. EIDEC is preparing the outgas test infrastructure for Non-CAR and/or new platform resist. This paper reports on the recent progress in resist outgas testing for the new platform at EIDEC.

P-OC-06

COMPARISON OF EUV RESIST OUTGASSING BETWEEN ORGANIC AND INORGANIC MATERIALS

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It is expected that the EUV lithography will be introduced in the semiconductor industry for the sub-10 nm device manufacturing. It means that the lithographic performance of resist will be conducted by photoelectron leading chemistry. Besides the patterning ability, one of the great concerns is the outgassing behavior of resists exposed in vacuum by EUV light. EIDEC had been performing the characterization of cleanable and non-cleanable contamination on Witness Samples by outgassing of chemically amplified resists (CAR) using EB and EUV test tools. In some CARs, the higher carbon growth rates were found in EB more than EUV characteristically when the outgassing from protecting group was extraordinarily large. But no other remarkable differences were found and the non-cleanable contaminations of CARs were proved to be not the problem. Recently the inorganic resists are highly noticed to make the breakthrough for RLS tradeoff of CARs. But the behavior of inorganic material with EUV has been not well studied yet. In view of outgassing the risk of non-cleanable contamination is a big concern. We will show the preliminary study of outgassing of inorganic materials compared with organic CARs.

P-OC-07

CHEMOMETRICS STUDY OF EUV RESIST MATERIALS FOR WITNESS SAMPLE BASED OUTGAS TESTING

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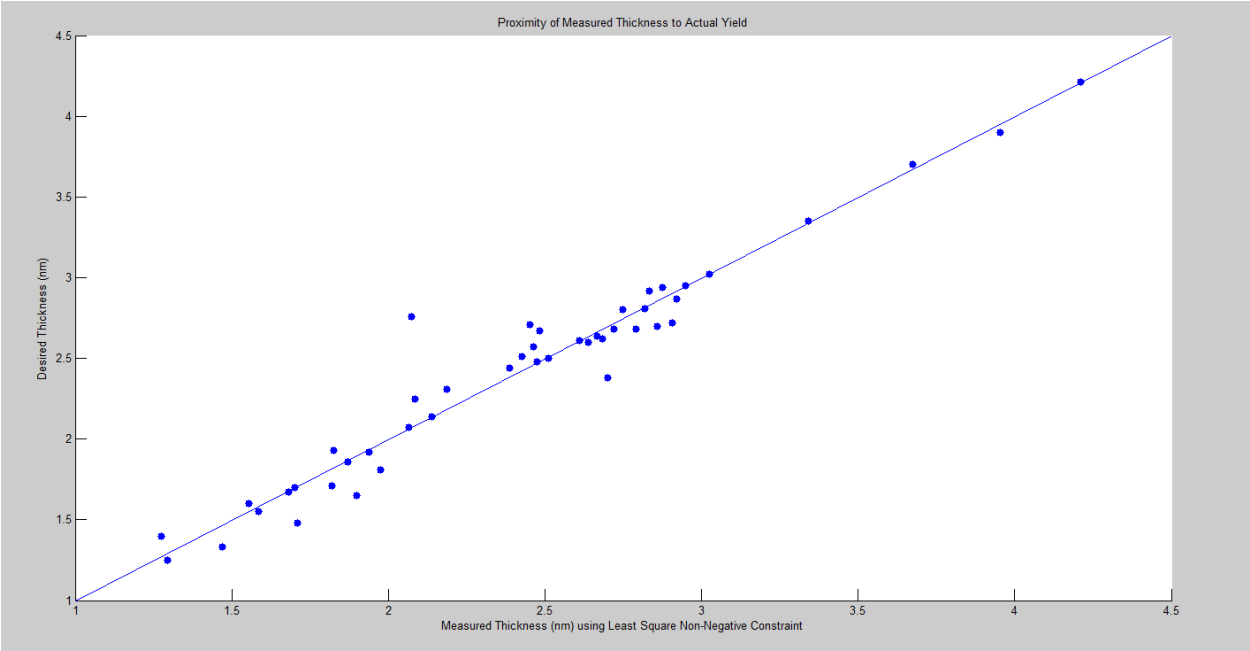
Witness sample based resist outgas testing has been used to determine the relative risk of contamination from many materials. The test is time consuming, so there is an interest in developing a faster testing method to predict the contamination risk from new materials. Prior work has demonstrated a general correlation between higher mass species detected by a mass spectrometer during resist exposure and larger rate of contamination per outgassed molecule[1].
The results presented here are a chemometric analysis to specifically identify the correlation between the contamination rate for each molecular species outgassed. This analysis is based on optimization algorithms for solving multiple coupled linear equations, and applying appropriate physical constraints and suppression of statistical variations in the mass spectrometer raw data. The resulting correlation for contamination rate of each species is important both to predict contamination rates for a new resist based on much simpler outgassing exposures, and to provide information to resist suppliers about the contamination rate from each of the species outgassed by their materials so that resists can be designed to reduce the risk of optics contamination.

Reference:

1. Pollentier, I. et al., “Direct measurement of carbon contamination topography on patterned EUV masks,” Proc. SPIE 7636, 76361W (2010).



P-OC-08

SPECTROSCOPIC EUV REFLECTOMETRY FOR CHARACTERIZATION OF THIN FILMS AND LAYERED STRUCTURES

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Modern nanotechnology is continuously raising demands on quality and purity of thin films and interlayer interfaces. As thicknesses of employed layers decrease to single nanometers, traditional characterization tools struggle to satisfy simultaneously throughput, precision and non-destructibility requirements. Spectroscopic reflectometry with extreme ultraviolet radiation (EUV, 5-40 nm wavelengths) offers a possibility of non-destructive study of surfaces. To this end, EUV spectroscopic reflectometry has been employed as a non-destructive metrology tool, which also allows controlling in-depth structure of the produced materials. We report on a series of reflectivity measurements on the samples of interest, e.g. different high-k thin films, that has been performed using a newly developed tabletop Polychromatic Angle-resolving Non-destructive Tool for High-speed Extreme ultraviolet Reflectometry (PANTHER). For the purposes of detailed structural characterization, information about chemical bonds structure and local-site symmetry is obtained through analysis of near-edge reflectivity data. Collection of spectral “fingerprints” and analysis of near-edge reflectivity of samples have been done additionally at the ELETTRA synchrotron facility, Trieste. The experimental and analytical results along with the outlook on the development of the method will be presented and discussed. In addition to that, a suitability of the tool to the industrially relevant applications such as analysis of surface contamination, will be illustrated by results of experiments with test samples exposed to real EUV source operation environment.

P-OC-09

STRUCTURAL SPECTROSCOPY BY EXTREME ULTRAVIOLET REFLECTOMETRY

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For advancements of modern products, functionalization of materials on the nanometer scale is mandatory. This raises not only the demands to the shrinkage of dimensions, but also to quality and purity of materials and thus to metrology tools for quality control of those materials. Consequently, traditional metrology tools are no longer able to satisfy throughput, precision or non-destructibility requirements for quality control.

Novel plasma source-based metrology tools have emerged in the extreme ultraviolet (EUV), which features high spatial resolution and strong material interaction. The strong interaction enables sub-nm thickness sensitivity of layered material compositions in EUV reflectometry. The possibility to achieve high spatial resolution enables locally resolved structural reflectometry.

In this contribution a method of spectrally resolved, multi-angle EUV reflectometry with high spatial resolution for investigation of structural composition of different samples will be presented. Rapid measuring times on the order of milliseconds to seconds make the reflectometer a promising metrology tool for future demands of nanotechnology.