Literature Digest
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Highlights of SPIE 28-th Annual Symposium on Microlithography
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For this summary, we selected three topics among the presented material: CD measurement technology, line edge roughness effects, and immersion lithography. The first two topics were chosen because CD measurement techniques and line edge roughness are two subjects that are at the interface between advanced photolithography and plasma etching. Immersion lithography is of interest because it is an emerging technique that could extend 193 nm lithography to below 65 nm L/S.

Optical CD measurement Techniques

A paper by S. Hodges et al. (paper 5038-22 by **Texas Instruments** and **KLA-Tencor**) reported on the correlation between the physical in-line **profile measurements** and back-end-of-line device **parametric test results**. Spectroscopic ellipsometry measurements allowed to detect excursions ranging from etch profile changes to gate oxide punch through in a production environment.

M. Sendelbach and C. Archie (paper 5038-23 by **IBM**) presented a **methodology for 3D metrology assessment** involving 70 nm structures that combines CD-SEM, AFM, TEM, and XSEM to create a Reference Measurement System. Several optical and analysis techniques were compared.

D. Herisson et al. (paper 5038-27 by **STM**, **CEA LETI** and **KLA-Tencor**) presented data on **gate structures from the 120, 90, and 65 nm** (e-beam) technology nodes and compared to CD-SEM and cross section SEM.

T. Hingst et al. (paper 5038-28 by **Infineon** Technologies and **KLA-Tencor**) used a spectroscopic ellipsometer for the 110 nm node and 193 nm resist. The capability of the technique was tested for **CD control for a WSix gate etch** after lithography, mask open and gate etch. The main challenges were the modeling of the optical properties of the WSix layer, top rounding, surface and interface roughness and 193 nm resist edge roughness. Specially designed test structure were used.

J. Opsal et al. (paper 5038-50 by **Therma-Wave** and **U. of Illinois**) and C. Raymond et al. (paper 5038-61 by **Accent** Optical Technologies and **SAMSUNG**) reported results of **contact hole measurements**. The Therma-Wave approach uses a spectroscopic ellipsometer with rotating compensator and large bandwidth (190 to 820 nm) to extract maximum information. Accent also uses angular scatterometry and claimed to have achieved correlation results greater than 0.9.

L.J. Chen at al. (paper 5038-60 by **TSMC** and **Timbre** Technologies,) used scatterometry (Optical Digital Profilometry) for **193 nm lithography process development** (CD uniformity, resist profile, focus exposure matrix, pre- and post-exposure bake temperature effect, pitch effect). It was found that scatterometry provides high sensitivity, as well as a higher repeatability and reproducibility compared to existing CD-SEM. It was found that slight changes in the algorithm can impact the measurement results.

E. Maiken et al. (paper 5038-148 by **AMD** and **Sensys** Instruments) presented a poster on **lithography process control** by normal incidence spectroscopic scatterometry. Across field, multiple wafer process variations were tracked over time.

Finally, F. Terry (paper 5038-58, **U. of Michigan**) reported on the **accuracy limitations of specular mode optical CD metrology**. Spectroscopic ellipsometry (SE) and spectroscopic reflectometry / scatterometry (SR) were used. In general, as the CD is reduced, small variations in the line shape begin to produce less change in the structural shape of the signal, which implies limitations for future technology nodes.

Line edge roughness

B. Bunday et al. (paper 5038-71 by SEMATECH and NIST) presented a special 193 nm reticle that includes structures with **intentionally created LER** with various special frequencies and amplitudes.

A. Yamaguchi et al. (paper 5038-72 by Hitachi) introduced a **guideline for choosing optimum measurement parameters** such as inspection-area length and number of measurement points. The authors found a 1/f-dependence of LER in a high frequency region (larger than 3 μm^{-1}) and an almost constant behavior in the lower frequency region (0.01 – 1 μm^{-1}). For several resists, they observed a special period a around 100 nm.

G. Eytan et al. (paper 5038-116 by Applied Materials) presented a poster with a new **algorithm for LER measurements**.

IBM was represented with three papers on the subject of line edge roughness. In the first paper (A. Mahorowala et al., paper 5039-23), the **impact of thin resist processes on LER** was studied. An AFM technique was used to measure feature sidewall roughness as a function of depth. LER of the different layers of stacked films and their relationship could be studied.

In a second paper (M. D. Stewart, in collaboration with University of Texas, paper 5039-45), **diffusion induced line edge roughness** was studied. In order to separate out exposure related issues like mask dimension variation or local dose variation, a bilayer resist approach was used. With this method, the effect of such factors as post exposure bake time, photoacid generator loading, and base additive loading on roughness generation could be studied via AFM. 193 nm photoresist resin and APEX-like 248 nm resist resins were studied.

In a third paper (Q. Lin, paper 5039-122), the **impact of LER on device performance** has been studied. The paper provides theoretical evidence that LER in FEOL causes at least as much variation as the discrete dopant effect. In the BEOL, the impact of LER on the performance of barrier layers in dual damascene copper interconnects was investigated experimentally. No degradation of the ALD barrier was found with increasing LER.

J. Cobb et al. (paper 5039-41 by **Motorola** and **AMD**) investigated the question on how much LER is acceptable for a given technology via process and 3D device modeling as well as experiments. The paper shows that much of the **high-frequency, high-amplitude roughness can be reduced through tuning of the etch and implant processes**. The low frequency roughness is much harder to eliminate.

In another paper by **Motorola** and **AMD** (R. D. Peter et al., paper 5039-43), **ultrathin (90 to 240 nm) 193 nm photoresists** were investigated with respect to LER. The LER increased with decreasing thickness; however, increasing the concentration of the PAG and base quencher reduced LER. Decreasing the viscosity resulted in increased LER. Increasing the spin speed (decreasing thickness) resulted in increased LER.

Intel's contribution (B. J. Rice et al., paper 5039-42) focussed on the **effect of processing parameters** on LER.

W. G. Lawrence presented a poster (paper 5039-80 by **Shipley** Company) with a study of **nine chemically related resists** with respect to LER. While the absolute amplitude of the spectral density functions was found to be different for each resist, **similar functional forms for LER** were found (maximum amplitude LER near the low frequency limit with exponential decay at higher frequencies).

L. Voelkel et al. (paper 5039-84 by **Infineon** Technologies) presented a study on LER of 193 nm resits using **CD-SEM beam tilt**. The results suggest that the LER of the resist has only small influence on the LER of the side wall after etch. Different integration schemes have a much more significant influence on the optical roughness after etch.

A poster by T. Yamaguchi et al. (paper 5039-142 by **NTT** Basic Research Laboratories) focused on the molecular weight effect on LER. A significant dependence is found and explained by the concept of aggregate extraction. **The magnitude of LER is found to be larger for resists with lower molecular weight**.

Immersion lithography

Three papers presented simulation results. The contribution by the **U. of Wisconsin** and **MIT** (A. C. Wei, paper 5040-61) was dedicated to **microfluidic effects** with the goal to ensure reliable filling of the lens-wafer gap.

A **simulation package to address optical aspects** of immersion lithography was presented by S.-Y. Yeon et al. (paper 5040-187 by **Boston University** and **MIT**). The package accounts for high NA imaging, polarization effects, multilayers of thin film media of arbitrary complex index of refraction.

A paper by S. Hafeman et al. (paper 5040-60 by **UC Berkeley**) showed simulations of stray light effects in immersion lithography addressing the issue of **resist raggedness** in immersion lithography.

The contribution by S. Owa et al. (paper 5040-186 by **Nikon**) mentioned liquid supply and recovery as well as **chemical reactions of the resists** under the liquid as issues for immersion lithography.

Finally, experimental results for three different liquids (**DI water, cyclo-octane and a perfluoropolyether oil**) were presented in a paper A. K. Raub et al. (paper 5040-57 by the **U. of New Mexico**). All three liquids showed compatibility with 193 nm resists.