PHOTOMASK

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The Capability of High Magnification Review Function for EUV Actinic Blank Inspection Tool

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ABSTRACT

One of the most challenging tasks to make EUVL (Extreme Ultra Violet Lithography) a reality is to achieve zero defects for mask blanks. However, since it is uncertain whether mask blanks can be made completely defect-free, defect mitigation schemes are considered crucial for realization of EUVL. One of the mitigation schemes, pattern shift, covers ML defects under absorber patterns by device pattern adjustment and prevents the defects from being printed onto wafers. This scheme, however, requires accurate defect locations, and blank inspection tools must be able to provide the locations within a margin of the error of tens of nanometers. In this paper we describe a high accuracy defect locating function of the EUV Actinic Blank Inspection (ABI) tool being developed for HVM hp16 nm and 11 nm nodes.

1. Introduction

EUVL will eventually become reality in semiconductor manufacturing in the near future, and it is highly expected that both high sensitivity and reasonable throughput can be achieved for inspection of EUV blanks in high volume manufacturing. Blank inspection tools using the wavelength of 488 nm (M1350) or 266 nm (M7360) have been commonly used for EUVL blank development in an effort to satisfy this requirement of high sensitivity and throughput. However, these tools have limited sensitivity according to various printability evaluation studies, and non-actinic inspection is unlikely to have sufficient capability to detect all printable defects in the multilayer.[1,2,3]

Meanwhile, dark field actinic blank inspection concept was proposed by AIST and MIRAI-ASET[4] more than 10 years ago, and it was later developed into a full-field prototype by MIRAI-

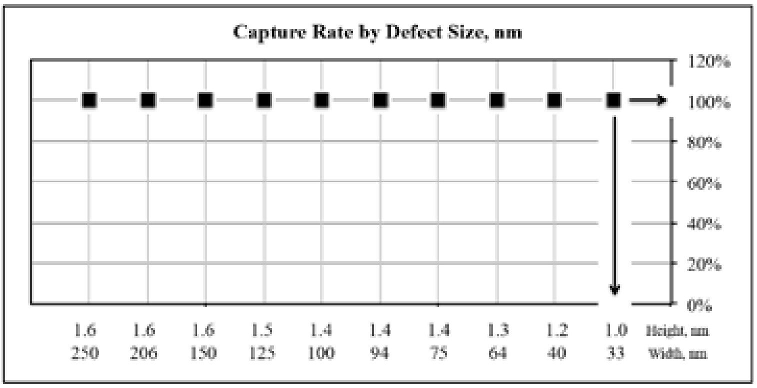

Figure 1. Inspection performance across the entire range of defect sizes.

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EDITORIAL

20th Anniversary of Photomask Japan

Naoya Hayashi, Dai Nippon Printing Co., Ltd.

This year, the Photomask Japan Symposium celebrated 20th Anniversary at Yokohama, Japan. Photomask Japan (PMJ) has been started in 1994 at Kawasaki Science Park (KSP) by a small group of Steering Committee Members inspired by Jim Reynolds from BACUS. The first event was just a one day session with 263 attendees including over 50 people from overseas, so we could start it as an International Symposium of Photomask.

In 1999, PMJ has moved to the Pacifico Yokohama in proportion to the increase in the attendees, close to 600 people, and presentations close to 130, at the peak in 2007. Since then, PMJ was affected by several environmental changes such as the Lehman Shock and the Tohoku Earthquake, the latter one forcing to cancel the Symposium in 2011. At that time, both physical and emotional support to PMJ Committee, especially from SPIE and BACUS, encouraged us to resume the PMJ in 2012. We would like to express our deepest appreciation to all of you for this.

I participated in the first PMJ and have been one of the Steering and Program Committee Members for a long time. From my experience in the history, the spirit of PMJ has been not only to provide technical reports but also to contribute to the related industries by sharing the practical experience with the attendees. This spirit, which should be followed in future, has been based on Japanese manufacturing and craftsmanship.

In addition, PMJ has been managed by the members of the actively working community, who take care of operation policies, operating funds, plans of the exhibition and related events, and even run the Symposium as the reception desk clerks cooperating with the professional secretariat company, the ICS. Those people make the PMJ to be also very practical. Since there are many photomask related companies in Japan, we can actively support the PMJ to keep this spirit.

Clearly, PMJ has been modeling its style after BACUS, our “elder brother” Symposium, including planning the related exhibitions, panel discussions, and banquets with entertainment. I have been the “entertainment committee member” since 2004, when we celebrated the 10th anniversary of PMJ with a special event. At that time, BACUS Entertainment also held a concurrent event.

We enjoyed the famous entertainment show taking over 2 hours, with plays and songs at the theatre. The entire cast in the show was the engineers, but their performance reached a professional level due to the great screenplay, the stage set, the direction, and their acting ability. In addition, the plot of the show focused on the specific subjects understandable only by the “mask makers”, including self-deprecating humor laughing off the difficulties. I got the video copies from the SPIE to enjoy them at home. I miss this BACUS Entertainment and I am eager to restart it in near future!

On the other hand, I have never experienced such an event in Japan at any other symposium, as we usually invite professional performers of traditional Japanese art, and I felt there was a lack of humor.

So we planned a special entertainment program at 10th anniversary of PMJ in 2004, with the “PMJ lock band”, the “Mask horse race”, and some fun presentations. In addition, DNP started the Symposium by showing a short movie satirizing the mask industry with a recent famous Japanese movie motif, casting the engineers from DNP and directed by me, in 2006. We thought our acting skills were behind the level of BACUS, but it was welcomed due to the freshness. Since then, I make a short movie every year, total eight movies until now, with demonstrations such as “Hula Girls” trying to make a variety show. I would like to continue to contribute to PMJ entertainment with such activities to encourage the whole industry.

If someone asks me “which movie was your masterpiece?” I should say “that’s the next one!”

PMJ Forever!

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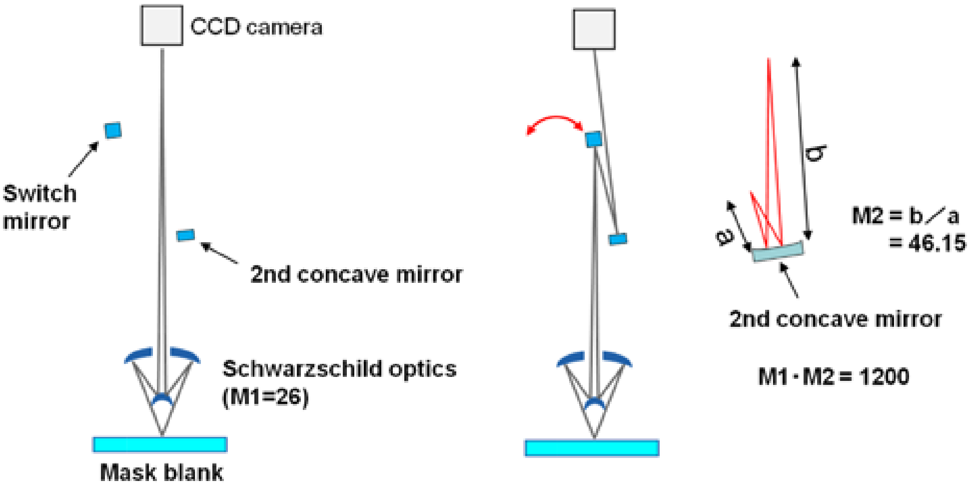
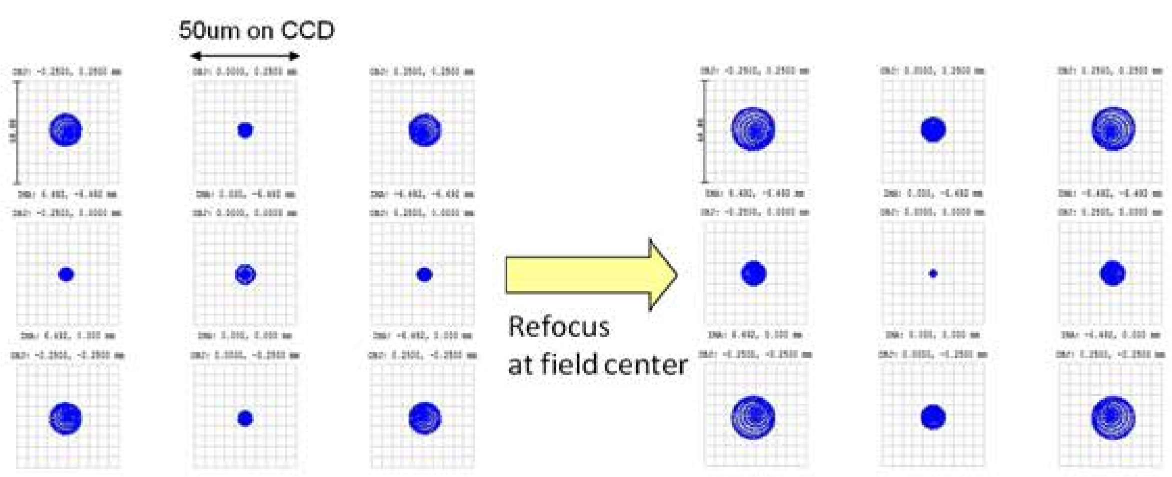


(a) Inspection mode (26x) (b) Review mode (1200x)

Figure 2. Optical configuration.



(a) Focus setting for Inspection mode (b) Focus setting for Review mode

Figure 3. Spot diagrams in a 0.48mm x 0.48mm field for the 26x Schwarzschild optics.

SELETE.[5,6,7,8] In 2011, its core technology was transferred to Lasertec so that an HVM tool that meets the requirement of 16 nm node can be developed with technical support from EIDEC. Since the MIRAI-SELETE prototype does not have sufficiently high throughput for high volume manufacturing, the new HVM tool is designed to achieve a scan time of less than 45 minutes per blank, which is considered fast enough for EUVL mask production. The tool is now fully assembled, and its sensitivity for phase defects has been verified under practicable inspection conditions.[9]

From the view point of EUV mask blank manufacturing, it has been a common belief that defect-free EUVL ML masks would be extremely difficult in practice, and, as a result, defect mitigation schemes are currently proposed, including methods to effectively hide remaining defects under absorber patterns.[10] The mitigation schemes allow EUV blanks to have a certain number of defects, but they assume that the location and size of defects on mask blanks will be detected and measured precisely so that patterning can be made to cover these defects under absorber patterns.

The actinic blank inspection design for the HVM tool is based on dark field inspection with fundamental capability to detect defects much smaller than its pixel size. A relatively small pixel size of around 0.5um at mask blank and low magnification 26X optics are used to achieve high-speed inspection. This original setup, however, makes it inherently difficult to measure defect locations with the level of accuracy required for mitigation because the pixel size is not small enough. This

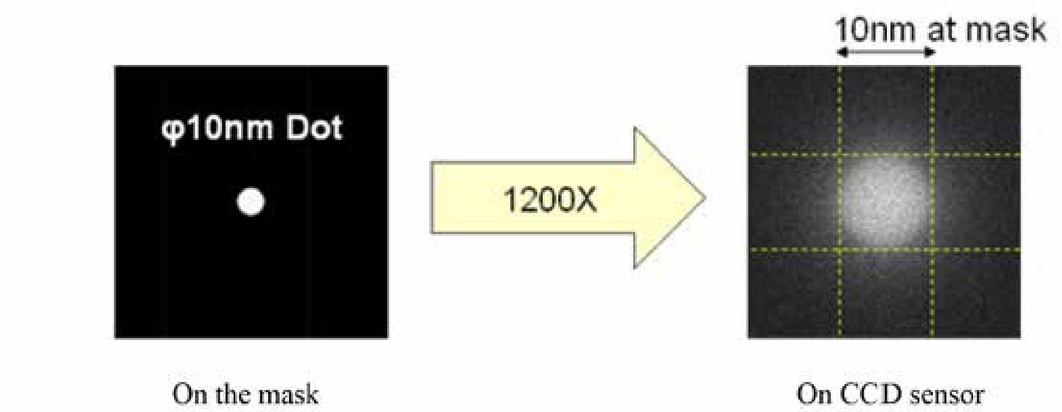


Figure 4. Result of simulation of 10nm dot projected on CCD sensor.

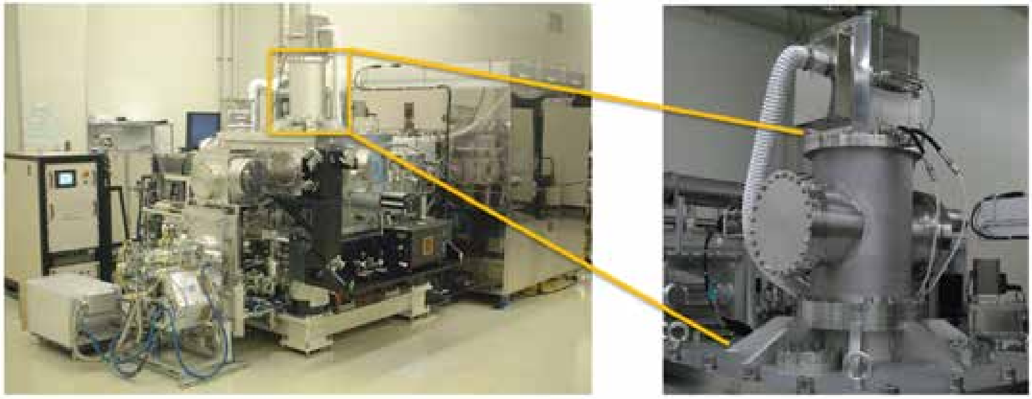


Figure 5. High magnification review unit installed on ABI HVM.

has led us to development of a defect review capability by adding high magnification optics on the ABI HVM tool. How the new inspection tool can achieve precise measurement of defect coordinates has already been presented in previous papers.[11, 12, 13] This paper presents the status of the ABI HVM tool development, including the fabrication and evaluation of the high magnification review capability mentioned above.

2. ABI Inspection Status

For requirements of the ABI HVM tool, sensitivity is specified as a minimum size of detectable defects measured at the surface of multilayer. The sensitivity requirement for the 16 nm node HVM tool is 1 nm (height) by 50 nm (width) and it is 0.7 nm by 35 nm for 11 nm node HVM, with capture rate of 95% in either case. Inspection time is specified not to exceed 45 minutes per blank. We have evaluated sensitivity of the HVM tool using programmed bump defects. Programmed bump defects used for this sensitivity evaluation were formed by coating multilayer on seeds of defects in various sizes planted on substrate. The number of defects was equal for each size. The size of programmed defects at the surface of the multilayer ranged from 1.0 nm by 33 nm to 1.6 nm by 250 nm FWHM, based on measurement with AFM.

However, since the size variability of small-programmed defects is not small enough, we verified capture rate from ten inspections of each size of programmed defects directly measured using AFM. The result was 100% capture rate for all defect sizes as shown in Figure 1. This was achieved while false defect rates were kept lower than a specified level.

3. High Magnification Optics

3.1 Configuration of high-magnification review optics using the 26X Schwarzschild

The ABI HVM tool uses low magnification 26X Schwarzschild optics to meet the requirement of high-speed 45-minute inspection for 16nm node. We have added two mirrors – a retractable plane mirror ("switch mirror") and a spherical concave mirror ("2nd concave mirror") – between Schwarzschild optics and CCD camera for a high magnification review function as shown in Figure 2. In inspection mode, the switch mirror is retracted to allow projection beam through the Schwarzschild optics to directly reach the 2nd concave mirror, which in turn reflects the beam to the CCD camera. The 2nd concave mirror also provides a 46.1 5x magnification. With this combination of Schwarzschild optics and two additional mirrors, we have achieved a total magnification of 1200x.

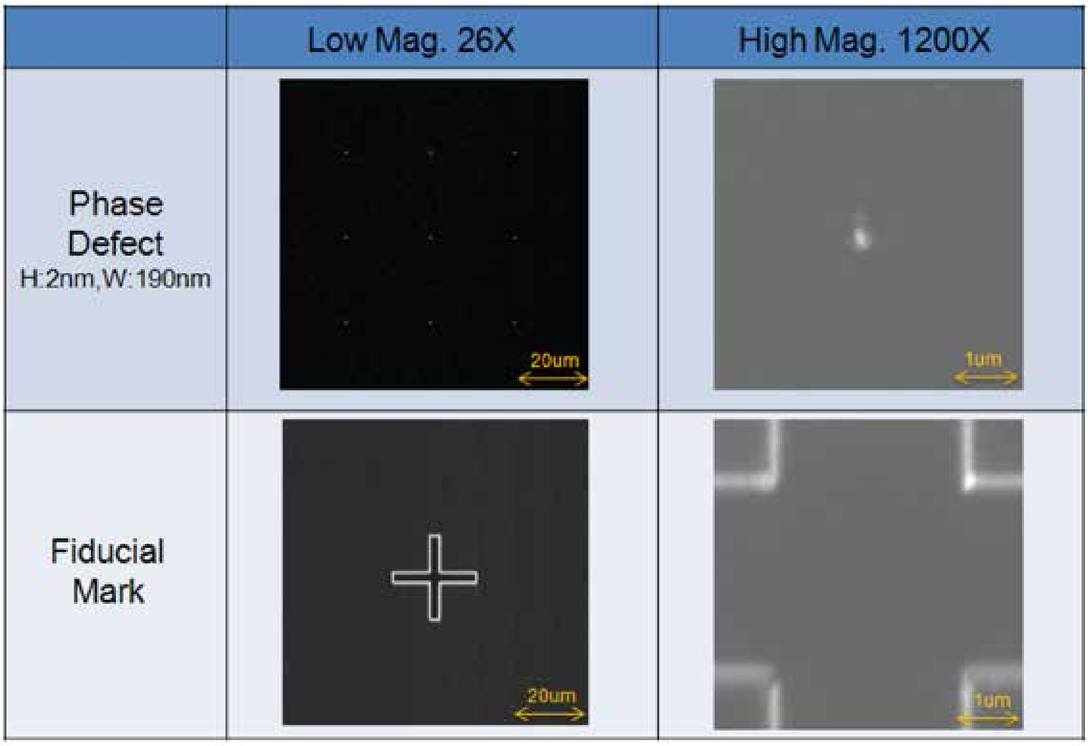


Figure 6. High magnification review images from the ABI HVM tool.

Feasibility of high magnification review has been verified using optical simulation. Figure 3 shows spot diagrams used for the 26X Schwarzschild optics in two different focus settings to make smallest possible aberrations in high magnification images. Both images simulate nine locations in a 0.46 mm x 0.46 mm field on a mask surface. The entire field of a diagram is used for inspection, and focus is adjusted so that the maximum aberration of the 9 areas becomes smallest. An example of spot diagram in the focus state is shown in Figure 3 (a). For the 2nd magnified additional optics, on the other hand, we need extremely small aberrations at the center of imaging plane of the 1st magnified Schwarzschild optics. Figure 3 (b) shows that, as a result of refocusing we have smaller spot sizes at the center of imaging plane in order to limit aberrations to the smallest degree possible. In this optimized refocus condition, we have simulated the 1200x projection image of 10nm dot on a mask as shown in Figure 4. The result of simulation shows that the 10 nm dot can be projected to the CCD sensor with a sufficiently high resolution.

3.2 Installation of high magnification review optics

High magnification review optics was installed on the ABI HVM tool in March 2013. Two additional ML mirrors were assembled and placed inside the cylindrical vacuum chamber, which is now located at the upper part of the ABI HVM tool as shown in Figure 5. As a result of this installation, ABI HVM now has a switch mirror control function, allowing easy mode change from inspection to high magnification review and vice versa. With that, the ABI HVM tool is capable of capturing images in either low magnification (26x) or high magnification (1200x).

Figure 6 shows examples of low magnification and high magnification images. The images on the first row show programmed phase defects of 2 nm by 190 nm FWHM on multilayer while the ones on the second row show a fiducial mark pattern with 3 um width etched on multilayer. High magnification review images are captured with the smallest average aberration under optimized refocus condition.

We have successfully developed a new function for the ABI HVM tool that allows to capture high magnification images by specifying an area to be magnified on low magnification images. This function works well and pattern features such as phase defect and fiducial mark can be easily captured by the ABI HVM tool. Since the optics uses dark field actinic illumination, bright areas indicate scattered EUV signals from phase changes in multilayer such as pattern edges and phase defects.

We have verified the ability of the ABI HVM tool to capture high magnification review images. Development of analytical functions such as defect location measurement, defect size measurement, and defect classification will be pursued next.

4. Conclusion

The ABI HVM tool for 16nm node has been fully assembled with its sensitivity requirement satisfied. We have demonstrated detection of programmed phase defects smaller than the sensitivity requirement with 100% capture rate. The inspection functionality check has been finished, and the high magnification optics with two additional mirrors has been successfully installed on the ABI HVM tool. The 1200x magnified dark field review images can be captured with a review function that enables defects to be located with high accuracy. The ABI

HVM tool with high magnification review provides valuable information for defect characterization and printability study.

5. Acknowledgments

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Industry Briefs

Rolith Successfully Demonstrates ITO-Alternative Technology Based on Rolling Mask Lithography

Solid State Technology

Rolith, Inc., a developer of advanced nanostructured devices, announced the successful demonstration of Transparent Metal Grid Electrode technology based on its disruptive nanolithography method (Rolling Mask Lithography – RMLTM). The only viable alternative to ITO (and the only solution for large touchscreen displays) is a metal wire grid. The requirement for a metal wire grid to be invisible to human eye means that width of the wire should be < 2 micron.

Rolith, Inc. has used its proprietary nanolithography technology called Rolling Mask Lithography (RMLTM) for fabrication of transparent metal wire grid electrodes on large areas of substrate materials. RML is based on near-field continuous optical lithography, which is implemented using cylindrical phase masks.

Transparent metal electrodes on glass substrates were fabricated in the form of submicron width nanowires, lithographically placed in a regular 2-dimentional grid pattern with a period of tens of microns, and thickness of a few hundreds of nanometers. Such metal structure is evaluated as completely invisible to the human eye, highly transparent (>94 percent transmission) with a very low haze (~two percent), and low resistivity (<14 Ohm/?).

Gigaphoton Successfully Achieved Two Hour Continuous Operation of its EUV Light Source

Gigaphoton

Gigaphoton, Inc. a major lithography light source manufacturer, announced today that it has successfully achieved 2 hour continuous operation of its laser-produced plasma (LPP) light source for EUV lithography scanners. This milestone was confirmed using a prototype LPP system which generates EUV light by irradiating Tin (Sn) Droplets with a solid-state pre-pulse laser and a CO2 main pulse laser. The Tin debris generated from the irradiation is mitigated through the combination of a high power superconducting magnet and Sn etching using H2 gas. The 2 hour continuous operation produced an averaged output power of 5W at 2% conversion efficiency (CE). Considering the current commercially accepted EUV output level is around 10W, the results demonstrated by Gigaphoton represents that yet another critical milestone has been reached for achieving initial production level laser performance. Gigaphoton is committed to continuing its development efforts targeting 250W output.

Photomasks for Extreme Ultraviolet (EUV) lithography and everything in between. “The new TDC will help us bridge between the lab and the fab by taking research conducted with partners and further developing the technologies to make them ready for volume manufacturing.” said GLOBALFOUNDRIES CEO, Ajit Manocha.

The Big Five Challenges of the Semiconductor Industry was Discussed by SEMICON West Keynote Speaker

Solid State Technology

The technology business is booming, according to Ajit Manocha, GLOBALFOUNDRIES CEO, who shared with SEMICON attendees that the mobile business is forecast to be double the size of the PC market in 2016. The mobile business drives many new requirements, said Manocha, including power, performance and features, higher data rates, high resolution multicore processors and thinner form factors.

This incredible growth is driving new dynamics, said Manocha, and pushing the industry to the new technology node each year, which is presenting the industry with what Manocha deems the Big Five Challenges. Manocha believes these challenges are: cost, device architectures, lithography and EUV, packaging and the 450mm wafer transition.

Cost, said Manocha, continues to be the underlying challenge of the entire industy, because, without focusing on wafer cost, even in good times, a company can enter into what he called “profitless prosperity.” Unfortunately, with the introduction of a new technology node each year, advanced technology costs are rapidly rising.

“Fab cost alone escalates 40 percent year after year,” said Manocha.

To keep wafer costs down, what Manocha believes the industry needs for success is a new foundry model altogether. His model, which he calls Foundry 2.0, hinges on industry collaboration rather than wafer price competition. By encouraging the industry to work together on products and meet the same goals, the industry can see a faster rate of change and tap into global R&D talent.

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About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

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