# PHOTOMASK

BACUS—The international technical group of SPIE dedicated to the advancement of photomask technology.

BACUS NEWS

MARCH 2018
VOLUME 34, ISSUE 3

PMJ17 Best Poster

# The capability of measuring cross-sectional profile for hole patterns in nanoimprint templates using small-angle X-ray scattering

**Kazuki Hagihara, Rikiya Taniguchi, Eiji Yamanaka,** Process Technology Research & Development Center, Toshiba Memory Corporation (Japan)

**Kazuhiko Omote, Yoshiyasu Ito, Kiyoshi Ogata,** X-Ray Research Laboratory, Rigaku Corporation (Japan)

**Naoya Hayashi,** Dai Nippon Printing Co., Ltd. (Japan)

1, Komukai Toshiba-Cho, Saiwai-Ku, Kawasaki 212-8583, Japan

## ABSTRACT

Nanoimprint lithography (NIL) is one of the highest potential candidates for next generation lithography in semiconductors. NIL is very useful technology for pattern fabrication in high resolution compared to conventional optical lithography. NIL technology makes use of replication from quartz templates. The cross-sectional profile of the template is directly transferred to the resist profile on a wafer. Accordingly, the management of the cross-sectional profile on the template pattern is much more important than on each photomask.

In our previous report, we had studied the performance of measuring cross-sectional profiles using grazing-incidence small-angle X-ray scattering (GISAXS). GISAXS has made it possible to analyze the repeated nanostructure patterns with a 2D X-ray scattering pattern. After various researches, we found the application is very effective in the method of cross-sectional profiling of sub-20 nm half-pitch lines-and-spaces (LS) patterns.

In this report, we investigated the capabilities of measuring cross-sectional profiles for hole patterns using GISAXS. Since the pattern density of hole patterns is much lower than that of LS patterns, the intensity of X-ray scattering in hole measurements is much lower. We optimized some measurement conditions to build the hole measurement system. Finally, the results suggested that 3D profile measurement of hole pattern using GISAXS has sufficient performance to manage the cross-sectional profile of template. The measurement system using GISAXS for measuring

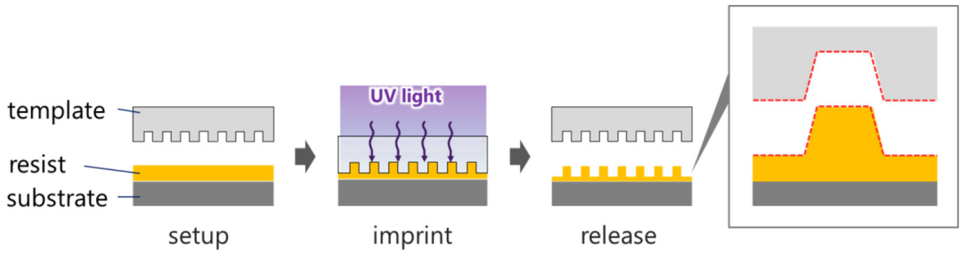


*Figure 1. Process flow in UV-NIL.*

## TAKE A LOOK INSIDE:





10454-28

# Editorial

## What does the future hold for Photomask Conferences?

**Thomas Scherübl,** Carl Zeiss SMT GmbH

For around 10 years now I have been working in the photomask industry. During this time, I have attended several photomask conferences on a regular basis, starting with Photomask Japan (PMJ) in April, then the European Mask and Lithography Conference (EMLC) in June, and finally SPIE Photomask in September. From the beginning, I felt each of these conferences was special and contributes positively to our industry. Over the years, each conference has developed a specific character, due to the special events in addition to the regular conference program: PMJ with the famous movies and PMJ band, EMLC with its special locations and SPIE Photomask with the legendary banquet comedy show. This framework has always been a great opportunity, not only to listen to technical talks but also for networking and meeting customers and partners.

However, over the last five years or so, gradually all photomask conferences began to face the challenge of shrinking participation and paper submission. I remember the first Bacus conferences I attended were held in two parallel sessions. Today, all three conferences run in a single track as the number of papers has decreased significantly. What are the reasons for this? First, the industry has become more mature. Naturally, there is less real new material to present. Secondly, the industry has become more consolidated. There are fewer players in an already small community with increased competition. Under these circumstances, it is really challenging to prepare high quality contributions for three or more conferences per year (taking also into account SPIE Advanced Lithography or EUVL symposium).

So, what could be done to improve the situation? Well, one measure is that the program committees need to work harder to get abstracts in. This is already happening, but will it be enough? Last year, Bacus and the EUVL decided to have a joint conference. This kind of "consolidation" turned out to be a success story. The joint conference had more participation and an increased number of mask papers. As a result, this year EUVL and SPIE Photomask will be held as joint conferences again.

For me, this indicates that we need to continue to be creative regarding the proper set-up of conferences in our community. Can our small industry afford three or more annual events in future? Wouldn't it be more efficient to have one only photomask conference per year? As EUVL did in the past, the conference location could rotate between Japan, Europe and US? Or, do we have to broaden the scope of the conferences in order to improve the situation? And, how can we attract more students and young professionals to participate?

I admit I do not know what the perfect answer is, but I think we need creativity to make sure that the photomask industry continues to have great conferences in the future.

BACUS
N • E • W • S

*BACUS News* is published monthly by SPIE for BACUS, the international technical group of SPIE dedicated to the advancement of photomask technology.

**Managing Editor/Graphics** Linda DeLano
**Advertising** Melissa Farlow
**BACUS Technical Group Manager** Marilyn Gorsuch



SPIE.

P.O. Box 10, Bellingham, WA 98227-0010 USA
Tel: +1 360 676 3290
Fax: +1 360 647 1445
www.SPIE.org
help@spie.org

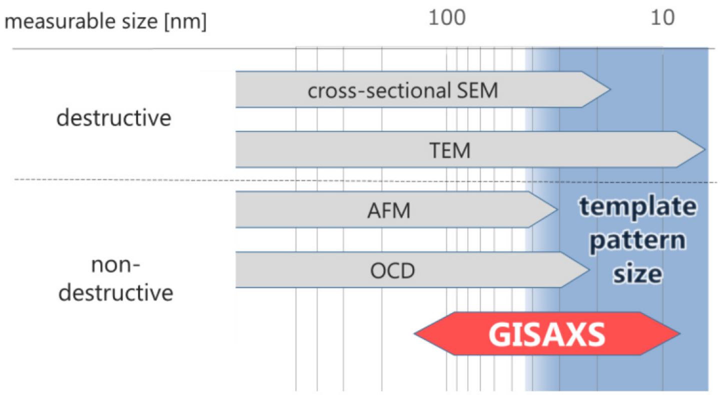


*Figure 2. Potential candidates for measuring cross-sectional profile.*

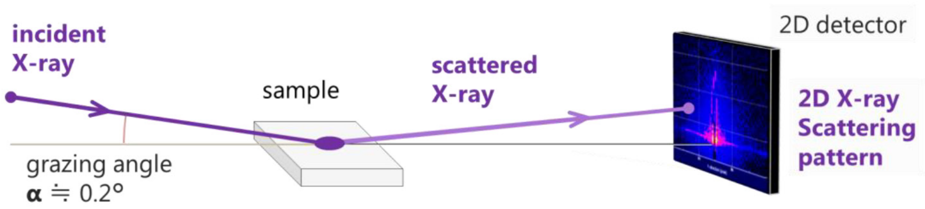


*Figure 3. Description of geometry in GISAXS.*

3D profiles establishes the cross-sectional profile management essential for the production of high quality quartz hole templates.

## 1. Introduction

In the proceeding nanofabrication technology, nanoimprint lithography (NIL) has big potential for next generation lithography. It is expected to reduce costs in high resolution patterning. Figure 1 illustrates the general process flow in UV-NIL. First, an ultraviolet (UV) curing resin is dropped on a silicon wafer. Next, a quartz mold called "template" is pressed thereon, and the UV curing resin is cured by the irradiation of ultraviolet rays. Then the template is released. UV-NIL is not a reduction transfer adopted in optical lithography, but a technology to transfer a template at the same magnification. Therefore, its basic lithography performance is largely dependent on the quality of the template. In particular, determination of the resist profile affects directly the processing controllability of the pattern on a silicon wafer. Therefore, it is essential to manage not only the top-down CD of the template but also the cross-sectional profile. To meet the requirement, the management technique of cross-sectional profiles on the quartz templates needs to be established.

There are various technologies used to measure cross-sectional profiles. The instances are shown in Figure 2. In Figure 2, the horizontal axis is the measurable size in each of the technologies, and the size gets smaller going to the right. The blue (colored) zone, which is less than around 40 nm, indicates the quartz template pattern size. Each technology is divided into two groups. In the upper row, these are destructive methods to measure cross-sectional profiles. On the other hand, in the lower row, these are non-destructive methods. Considering the use of the measurements at mass production sites, it is desirable to have non-destructive. AFM has a limit due to the shape of a probe. Optical Critical Dimension (OCD) has a disadvantage that the sensitivity is not sufficient caused by the low reflectivity in the quartz templates. We focused on Grazing Incidence Small-Angle X-ray scattering (GISAXS).[1,2] It is advantageous for measuring the nanostructure patterns.[3,4] In the previous report, we had showed that GISAXS has sufficient capability for measuring cross-sectional profile in Lines and Spaces (LS) template patterns.[5] In this report, we clarify the capabilities of measuring the cross-sectional profile of hole patterns using GISAXS as the next step. The motivation of this development is the establishment of cross-sectional profile management for the production of high quality quartz templates.

## 2. Development of Hole Pattern Measurement System

### 2.1 Nanostructure measurement using GISAXS

The description of geometry as GISAXS illustrates in Figure 3. A sample is located at the center of the figure, and incident X-rays are irradiated from the left side of the figure with a small grazing angle. The angle is set to close to the critical total reflection angle. On the sample surface, the X-rays are scattered and proceeds to the right of the figure. The scattered X-rays forms a two-dimensional X-ray scattering image on the detector. The image depends strongly on the average cross-sectional profile in the irradiated area. The two-dimensional X-ray scattering image is recorded by the detector as the intensity at each pixel of the detector. To obtain accurate nanostructure profile of the sample surface, the analysis of the two-dimensional X-ray scattering image is performed using a structural model optimized to the measuring object.

### 2.2 Hole pattern measurement system

The comparison of measurement systems between hole and LS is shown in figure 4. There are three major differences. The first is

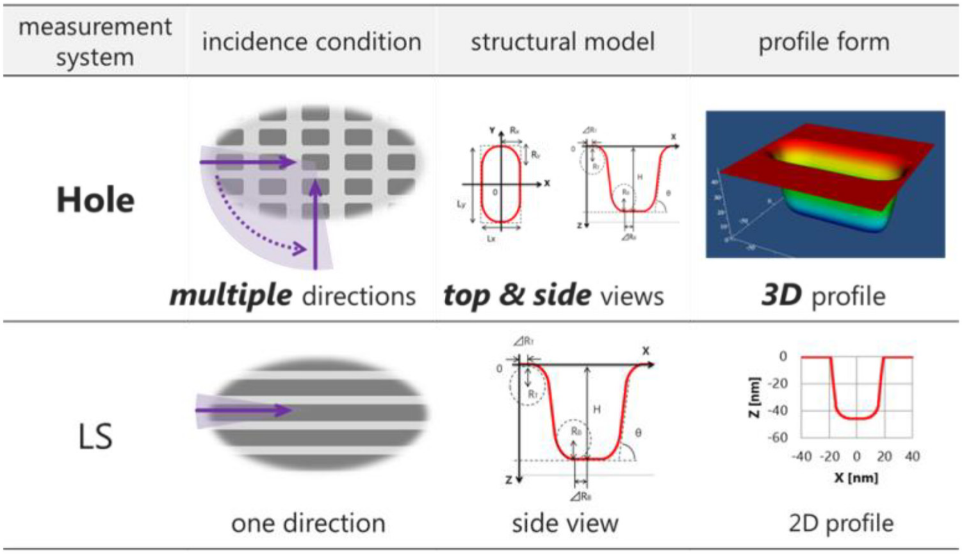


*Figure 4. Comparison of measurement system between hole and LS.*

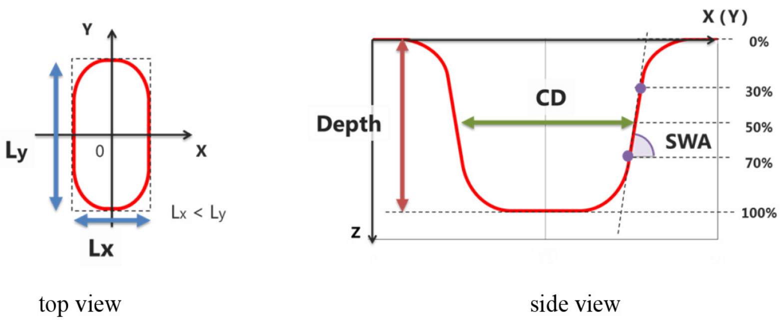


*Figure 5. Definition of metrics.*

**Table1. Designed hole dimensions of each sample.**

| sample name | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| short side [nm] | 40 | ← | ← | ← | ← | ← |
| long side [nm] | 40 | 80 | 110 | 130 | 150 | ← |
| depth [nm] | 45 | ← | ← | ← | 40 | 30 |

azimuth angle of the X-rays. The relation between azimuth angle of incident X-ray and cross-section to be measured are perpendicular. In the measurement for LS pattern, a single azimuth angles are used to obtain the information of cross-sectional profile in multiple directions. The azimuth angle of incident X-ray is continuously changed in the range of 0 to 90 degrees. The second is structural model. In the measurement for LS pattern, the model is used for only side view, which means cross-sectional view. On the other hand, in the measurement for hole pattern, the model is given not only for side view but also for top view. The top view of the modeled shape is oval. Using oval model, it is possible to express circles, ellipses and rounded corner rectangles. And the third is profile form. The result of LS pattern measurement is obtained from a normal two-dimensional profile; X-Z. On the other hand, the result of hole pattern measurement output a three-dimensional profile; X-Z and Y-Z.

## 3. Experimental Methods

The evaluation items are “accuracy” and “precision”. At first, three-dimensional profiles were measured with GISAXS. Next, top view and side view profiles were extracted from the three-dimensional

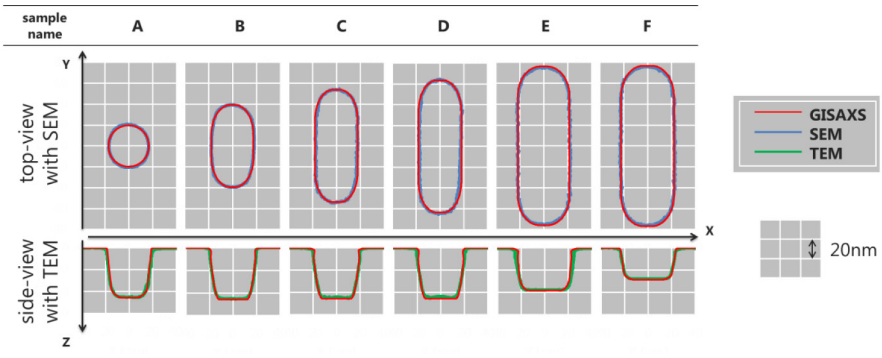


*Figure 6. Comparisons of profiles.*

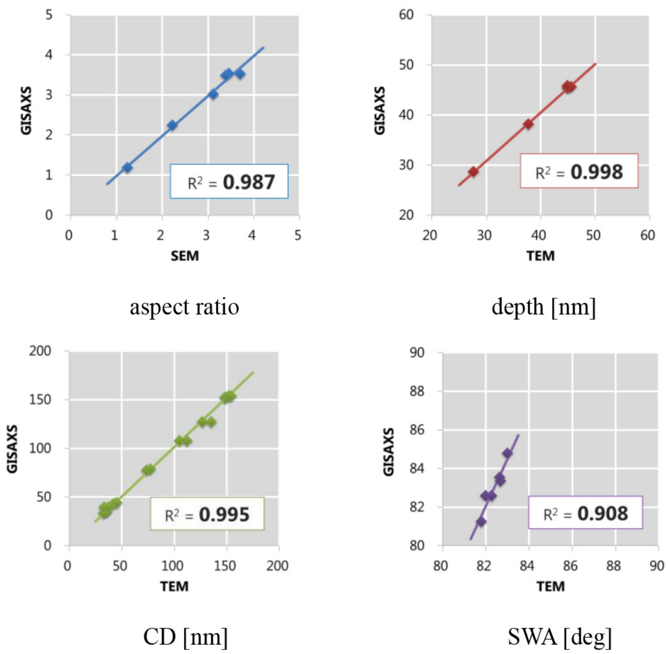


*Figure 7. Accuracy results.*

profiles. The images of SEM for top view and TEM for side view were obtained as comparison targets. Then, similarly, top view and side view profiles were extracted from the SEM and TEM images respectively. Each top view and side view profiles are calculated as averaged profile of plural hole patterns in the sample to reduce variation of pattern formation. In the accuracy evaluation of hole pattern measurement, the metrics for comparing the profiles between GISAXS and SEM/TEM are defined as shown in Figure5.

As mentioned above, top view profiles were obtained from the measurement using GISAXS and SEM, and side view profiles were obtained from the measurement using GISAXS and TEM. From the top view profile (top view in Figure 5), aspect ratio was defined, which equals $L_y/L_x$. $L_x$ and $L_y$ are the maximum width of the profile along X-axis and Y-axis in the top view. And from the side view, depth, CD, and side wall angle (SWA) are defined. Depth is the distance between the surface of the sample and the bottom of the hole. CD is the width at half of the depth. SWA is the slope angle of the connected line between 30% and 70% when the depth made 100%. The unit of CD and depth are nm, and that of SWA is degrees (deg). In total, four metrics are defined for our experiments. For the accuracy evaluation, the coefficient of determination ($R^2$) is calculated. The $R^2$ is degree of linear correlation between the values obtained from the measurement using GISAXS and SEM/TEM. For the precision evaluation, the standard deviation ($3\sigma$) of each metric is calculated from the result of 10 loop measurements. In this experiment, all samples are quartz template, and layout is dense hole patterns. The variations of designed hole dimension, the hole size and the depth are listed in table 1. In total, six kinds of samples from A to F were prepared.

## 4. Results and Discussions

Figure 6 shows the comparison results of top view and side view profile of each sample by measurement using GISAXS and SEM/TEM. As shown, good agreements are obtained in each of the profiles, even if the hole size or depth changes. Next, Figure 7

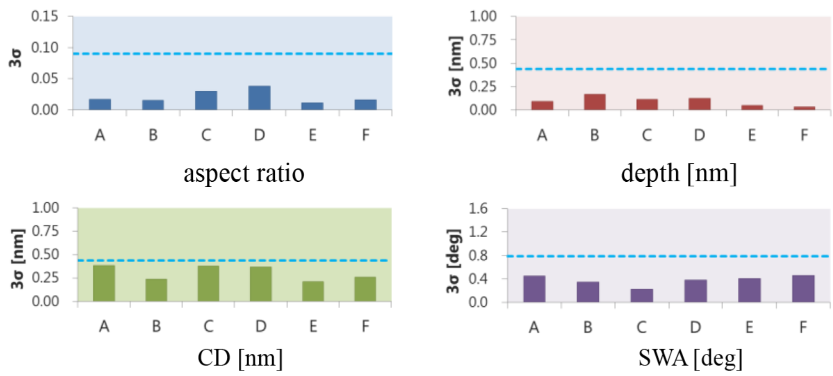


*Figure 8. Precision results.*

**Table 2. Maximum value of 3σ in each metric in precision result.**

| metrics | Aspect Ratio | Depth [nm] | CD [nm] | SWA [deg] |
|---|---|---|---|---|
| target | 0.09 | 0.44 | 0.44 | 0.79 |
| results($3\sigma_{max}$) | **0.04** | **0.17** | **0.39** | **0.46** |

shows the accuracy results regarding four metrics: aspect ratio, depth, CD, and SWA. In each graph, the horizontal axis is the obtained value using SEM or TEM, and vertical axis ise the ones using GISAXS. $R^2$ of each metric: aspect ratio, depth, and CD and SWA are calculated as 0.987, 0.998, 0.995, and 0.908, respectively. $R^2$ of aspect ratio, depth and CD are almost 1. Therefore, it was found that high-linear correlations between SEM/TEM and GISAXS exist. However, the slope of the graph in SWA is far from 1. It is considered that the precision of GISAXS measurement using the current structural model is still insufficient. Further optimization of the structural model is required to obtain more accurate profiles.

The precision results are shown in Figure 8. In the each graph, the horizontal line shows the sample names, and the vertical axes are 3σ of each metric in 10 loop measurements. The blue colored dotted lines in the graph show each target. Target values are 0.09, 0.44, 0.44, and 0.79 in aspect ratio, CD, depth, and SWA respectively. The target of CD is referred to ITRS2012.[6] Other metrics are estimated value from it. Lower bar than the dotted line means that the precision meets the requirement. The maximum values of 3σ in each metric are shown in table 2. All precision results have been achieved for each target.

## 5. Summary

We presented the measurement system using GISAXS for measuring 3D profiles of hole templates we have developed, and the measurement capability results. The accuracy results for hole pattern measurement reflected good linear correlations between GISAXS and SEM/TEM. It is useful for managing cross-sectional profiles in template manufacturing. However, the slope of the correlation graph in SWA was far from 1. In order to obtain more accurate cross-sectional profile, further optimization of the current structural model is required. The precision results as measurement repeatability showed sufficient performance for the targets. The results suggested that 3D profile measurement of hole pattern using GISAXS has sufficient performance to manage the cross-sectional profile of template.

In conclusion, the measurement system using GISAXS for measuring 3D profiles establishes the cross-sectional profile management essential for the production of high quality quartz hole templates.

## 6. Acknowledgments

The authors would like to thank Toshiba Memory Corporation colleagues: Mitsuyo Kariya for extracting profile of pattern from SEM images and Mana Tanabe for assisting with the preparation of samples.

## 7. References

[1] K. Omote, Y. Ito, and S. Kawamura, *Appl. Phys. Lett. 82,* 544 (2003).
[2] J. M. Mane, C. S. Cojocaru, A. Barbier, J. P. Deville, B. Thiodjio, and F. L. Normand, *Phys. Stat. Sol. (a)* 204. 4209 (2007).
[3] S . K. Shinha, E. B. Sirota, S. Garoff, and H. B. Stanley, *Phys. Rev. B. 38*, 2297 (1988).
[4] K. Omote, Y. Ito, and Y. Okazaki, **Proc. of SPIE 7638,** 763811 (2010).
[5] E. Yamanaka, R. Taniguchi, M. Itoh, K. Omote, Y. Ito, K. Ogata, and N. Hayashi, **Proc. of SPIE 9984,** 99840V (2016).
[6] ITRS2012 Lithography Metrology (Wafer) Technology Requirements.

# Industry Briefs

## EUV, 7-nm Roadmaps Detailed

Extreme ultraviolet lithography (EUV) is set to enable 10-nm and 7-nm process nodes over the next few years, but significant work is still needed on photoresists to enable 5-nm chips, according to an analysis released at the Industry Strategy Symposium held January 15th.

https://www.eetimes.com/document.asp?doc_id=1332860

## E-Beam Inspection Makes Inroads

Technology is being used to examine hard-to-find defects, but speed remains an issue.

https://semiengineering.com/e-beam-inspection-makes-inroads/

## Virtual Reality, Augmented Reality, and Mixed Reality take Center Stage at Photonics West

Photonics West attendees got to play with some of the newest demos in virtual, augmented, and mixed reality, while experts discussed the industry's technical challenges to a packed room on Monday, 29 January. The technical session and demos ran side by side, and both were standing room only from the opening at 9am until the close at 5:30pm.

https://spie.org/conferences-and-exhibitions/photonics-west/2018-onsite-news/virtual-reality-at-photonics-west?SSO=1

## IHS Markit Identifies Top Trends Driving the Internet of Things in 2018 and Beyond

Driven by the need for intelligent connected devices in industrial and commercial applications, the number of connected Internet of Things (IoT) devices globally will grow to more than 31 billion in 2018, according to new analysis from business information provider IHS Markit (Nasdaq: INFO). The commercial and industrial sector, powered by building automation, industrial automation and lighting, is forecast to account for about half of all new connected devices between 2018 and 2030.

http://electroiq.com/blog/2018/02/ihs-markit-identifies-top-trends-driving-the-internet-of-things-in-2018-and-beyond/

## Chip Aging Accellerates

As advanced-node chips are added into cars, and usage models shift inside of data centers, new questions surface about reliability.

https://semiengineering.com/chip-aging-accelerates/

## US Demand for Semiconductor Machinery to total $7.4B in 2021

US demand for semiconductor machinery is forecast to reach $7.4 billion in 2021, according to *Semiconductor Machinery: United States,* a report recently released by Freedonia Focus Reports. Growth in demand for wafer processing equipment will account for the majority of value increases. Ongoing expansion in global production of mobile electronics will support demand for smaller, faster, and more energy-efficient logic integrated circuits, as well as the increasingly advanced wafer processing machinery required for production. Specifically, rising adoption of lithography equipment that utilizes extreme ultraviolet (EUV) technology will spur gains.

http://electroiq.com/blog/2018/02/us-demand-for-semiconductor-machinery-to-total-7-4b-in-2021/

## Will China Succeed in Memory?

The country is banking on DRAM and NAND to reduce its trade deficit.

https://semiengineering.com/will-china-succeed-in-memory/

# Join the premier professional organization for mask makers and mask users!

## 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.

### Individual Membership Benefits include:

- Subscription to BACUS News (monthly)
- Eligibility to hold office on BACUS Steering Committee

www.spie.org/bacushome

### Corporate Membership Benefits include:

- 3-10 Voting Members in the SPIE General Membership, depending on tier level
- Subscription to BACUS News (monthly)
- One online SPIE Journal Subscription
- Listed as a Corporate Member in the BACUS Monthly Newsletter

www.spie.org/bacushome

## Calendar

### 2018

**SPIE Advanced Lithography**
25 February-1 March 2018
San Jose Marriott and
San Jose Convention Center
San Jose, California, USA
www.spie.org/al

**Photomask Japan 2018**
18-20 April 2018
Pacific Yokohama
Yokohama, Japan
www.photomask-japan.org

**The 34 European Mask and Lithography Conference, EMLC 2018**
19-20 June 2018
MINATEC Conference Centre
Grenoble, France
www.emlc-conference.com

**SPIE Photomask Technology + EUV Lithography**
17-20 September 2018
Monterey Convention Center
Monterey, California

SPIE is the international society for optics and photonics, an educational not-for-profit organization founded in 1955 to advance light-based science, engineering, and technology. The Society serves nearly 264,000 constituents from 166 countries, offering conferences and their published proceedings, continuing education, books, journals, and the SPIE Digital Library in support of interdisciplinary information exchange, professional networking, and patent precedent. SPIE provided more than $4 million in support of education and outreach programs in 2017. www.spie.org

**SPIE.**
*International Headquarters*
P.O. Box 10, Bellingham, WA 98227-0010 USA
Tel: +1 360 676 3290
Fax: +1 360 647 1445
help@spie.org • www.SPIE.org

*Shipping Address*
1000 20th St., Bellingham, WA 98225-6705 USA

**Managed by SPIE Europe**
2 Alexandra Gate, Ffordd Pengam, Cardiff,
CF24 2SA, UK
Tel: +44 29 2089 4747
Fax: +44 29 2089 4750
spieeurope@spieeurope.org • www.spieeurope.org

You are invited to submit events of interest for this calendar. Please send to lindad@spie.org; alternatively, email or fax to SPIE.