PHOTOMASK

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BACUS N • E • W • S

APRIL 2017
VOLUME 33, ISSUE 4

PM16 Best Poster

Mechanical stress induced by external forces in the extreme ultraviolet pellicle

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ABSTRACT

EUV pellicle with very thin thickness is significantly affected when external forces are applied. The mechanical forces such as chamber-pellicle pressure difference and stage acceleration cause the mechanical stress in pellicle. We investigated the maximum stress that can be induced by the pressure difference for various materials by using finite element method (FEM). We also used theoretical model and FEM for predicting the pellicle deformation. Our results show the mechanical deformation and the stress of full size (152 × 120 mm^2) pellicle with 50 nm thickness, and the influence of the pellicle is increased with larger pressure difference. We also studied the maximum stress caused by the acceleration force of the scanner. The full size pellicle is greatly influenced with the specific pulse width causing resonance. Our study indicates that mechanical stress with acceleration is very small and can be ignored.

1. Introduction

Extreme ultraviolet lithography (EUVL) is one of the most promising lithography technologies for mass production of semiconductor devices. However, the critical issues such as throughput, resist sensitivity, and mask defect that should be improved for high volume manufacturing (HVM) still remain.[1] Defects on a mask will cause serious problems for high resolution patterning below 1x nm. Using the pellicle is a good way to protect the EUV mask against defects generated during the lithography process. The EUV pellicle should be very thin due to high absorption of the EUV light with 13.5 nm wavelength. The thickness is only about 50 nm and it is much smaller than ~100 mm of full-size EUV pellicle recently suggested by ASML.[2] For this reason, the pellicle would be easily affected by external forces such as gravity[3] and stage acceleration. The pellicle would be deflected or torn by the residual stress during manufacturing and thermal stress during exposure.[4]

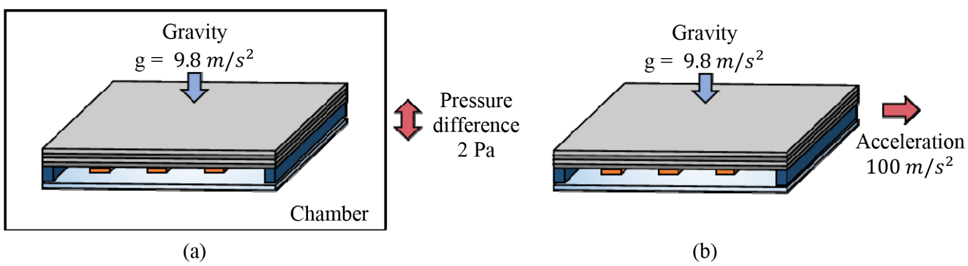

Figure 1. Schematic of mechanical forces. (a) The pressure difference of chamber-pellicle and (b) the stage acceleration during exposure.

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Editorial

"EUV is coming"

Moshe Preil, KLA-Tencor Corp.

After many years of hearing that EUV is almost ready for prime time, the tide is finally coming in. A decade of slow but steady progress has resulted in exposure tools that can expose on the order of 1,000 wafers a day on a regular basis. This may be shy of the requirements for high volume manufacturing (HVM), but it is certainly more than enough to support solid development programs and pilot line production. Almost all leading edge manufacturers have announced plans for early introduction in the 2018 time frame, with HVM to follow within 1-2 years if the economics and technology are proven to be viable. Recent papers at the BACUS symposium in San Jose, International EUVL Symposium in Hiroshima and the SPIE Advanced Lithography 2017 symposium all highlighted the emerging maturity of EUV tools and processes, as well as the remaining challenges. This month will see more results at PMJ in Japan. It is certainly an exciting time for the EUV community, and a time of impending change for the mask making world.

From a mask making perspective, the key technical issues have long been identified as mask blank and multi-layer defectivity, mask blank and patterned mask inspection, defect review and pellicles. Mask blanks, tools and processes are now able to support the needs of development and pilot line volumes, and inspection of patterned masks is satisfactorily addressed today using a combination of DUV mask inspection and broadband plasma-based wafer inspection focused on repeating defects on wafers. There is reasonable optimism that with continued progress there should be no showstoppers to HVM introduction by the end of the decade. Even if actinic patterned inspection and aerial image review are not fully mature by then, e-beam based mask inspection can satisfy almost all requirements for pre-pellicle inspection, and there will be continued evolutionary progress to extend DUV mask inspection. Significant progress towards developing pellicle solutions that can survive high power use in production and be integrated into the mask inspection and fab requalification cycle has been reported. Other issues relating to mask infrastructure, such as multi-beam mask writers, computational lithography solutions for OPC including the added complexity of mask 3D effects and non-telecentric optics with a 6 degree chief ray angle, and clean tools for handling, cleaning and storage of EUV reticles, are all well on their way to HVM readiness.

But while the mask making world is well aware of these issues and progress towards solutions, gaps still remain in the complete integration of mask and wafer processing to meet the final requirements for product wafers. In order to fully understand the requirements imposed on the mask side of the industry, we must develop a comprehensive view of EUV manufacturing requirements as a whole. Mask solutions which are not fully integrated with wafer production requirements run the risk of creating serious capability gaps. In particular, the mask making world must comprehend the implications of stochastic variability during wafer exposure in order to insure that the masks we make will print correctly in volume manufacturing.

The issue of stochastic variation was a major theme at the recent SPIE Advanced Lithography symposium. Despite all of the progress in EUV source power, the high throughput numbers being cited as targets for HVM introduction still require low dose resist exposures and associated penalties in line edge roughness (LER) and pattern placement roughness (PPR) caused by stochastic effects such as photon shot noise. Complete edge placement error (EPE) budgets must capture the contributions due to reticle LER and placement error, wafer process LER and PPR (including stochastic noise), and systematic terms such as pattern dependent focus and placement errors. With total EPE budgets in the low single nm range, it is increasingly difficult to allocate a specific number of nm to each term individually. Total EPE budgets will become the final metric of success or failure of the entire process. No part of the budget, whether mask or wafer related, can be fully specified independent of the other terms.

Stochastic effects also complicate metrology and inspection requirements. How small of a defect can be detected reliably or how accurately CD and placement errors can be measured is highly dependent on pattern roughness at both mask and wafer levels. Stochastic effects also create the possibility of a new class of defects known as "soft" repeaters, or more properly stochastic defects. Determining the printability of a suspect location on a mask may no longer be accomplished by simply exposing a wafer and seeing if the defect prints in every field; it is now important to see if the defect prints in even a small fraction of the fields. Detecting CD defects on a background pattern with 3-5 nm of LER will be challenging, to say the least. CD uniformity presents similar challenges. Recent papers at SPIE demonstrated how non-Gaussian tails on CD distributions require extensive analysis and consideration of up to 7 sigma of variation as opposed to the traditional 3 sigma values.

EUV is coming. The successful adoption of this technology for HVM may drive Moore's Law for another few nodes, but it will not be easy. The mask making community must play a key role in enabling viable EUV strategies for the entire process. Co-location of the next EUV Symposium with the BACUS conference in Monterey is a solid step in driving critical interactions between the mask and wafer process worlds. As a community, we can all contribute to breaking down artificial barriers between mask and wafer "silos" and developing comprehensive solutions to enable EUV in production.

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

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Table 1. The simulation conditions.

Pellicle size	152 × 120 mm^2
Pellicle thickness	50 nm
Max. pressure difference	2 Pa
Max. stage acceleration	100 m/s^2

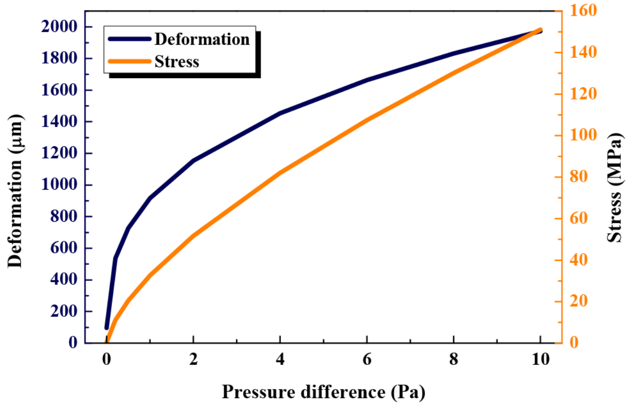

Figure 2. The deformation and stress of the pellicle with the pressure difference.

Table 2. Properties of EUV pellicle materials.

	c-Si	p-Si	SiC	Si_3N_4	Zr	Mo	Graphene
Density (kg/m^3)	2330	2328	3210	3310	6520	10280	2200
Young's modulus (GPa)	185	169	476	317	88	329	1050
Poisson ratio	0.28	0.22	0.19	0.23	0.34	0.31	0.186

In addition, the chamber-pellicle pressure difference would cause the mechanical deformation. In load lock chamber, the pressure is varied from atmospheric pressure to high vacuum environment. A filter located on the pellicle frame, and the filter material is placed over filters to prevent particles from entering the pellicle volume and interfering with the imaging process. The filter induces a significant flow resistance between the pellicle volume and the chamber volume. This resistance causes pressure difference between the gap of the pellicle-mask and outside.[5] Thus it is needed to study the maximum stress and deformation that can be induced by the pressure difference for various materials. FEM is used to predict the resulting stress in the pellicle.

The pellicle can be also affected by the acceleration force of the scanner with shear direction during exposure process. Especially, maximum deformation and stress are dramatically increased when the pulse width of the scanner movement is the same as the resonance frequency of the pellicle.[6] In this paper, the maximum stress for different acceleration pulse widths is presented. The full size pellicle is greatly influenced with the specific pulse width causing resonance. In order to check the maximum stress caused by resonance effect of a pellicle, we also considered various pellicle materials and number of acceleration cycle.

2. Simulation Conditions

In this paper, we consider chamber-pellicle pressure difference in load lock chamber before exposure process and the acceleration of the stage during scanning. For the NXE pellicle, the suggested maximum ambient pressure rate of change is 2 Pa, and the maximum acceleration is 100 m/s^2. Figure 1 shows the mechanical forces caused the stress in pellicle. The area of the full size pellicle is 152 × 120 mm^2, and we used single layered full size pellicle with 50 nm thickness. The simulation conditions are presented in Table 1.[7]

In order to investigate the maximum stress of the pellicle, we used various materials that are presented as candidates of pellicle. The materials are known to have a high transmission to EUV source and good mechanical properties. The mechanical properties of the materials are listed in Table 2.[8] Pellicle simulation was performed by FEM tool (ANSYS).

3. Load-deflection Calculation

Residual stress of production process gives considerable impact on pellicle. However, the FEM simulation has difficulty to take into account of residual stress. In order to consider the residual stress of the pellicle, we calculated the deflection with the pressure difference using the Timoshenko equation.[9] The load-deflection can be expressed by following equation.

$$P = C_1 \frac{\sigma t h}{a^2} + C_2 \frac{E t h^3}{a^4} \quad (1)$$

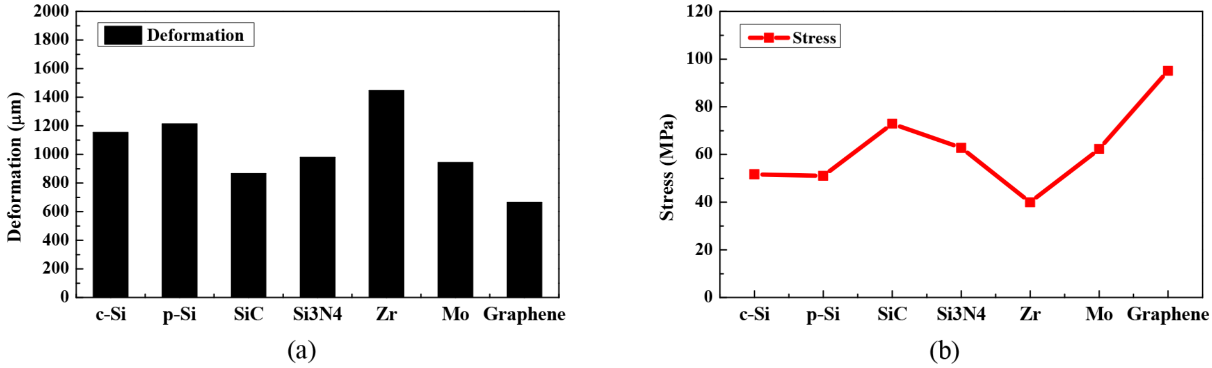

Figure 3. (a) The deformation of the pellicle and (b) the stress caused by the pressure difference.

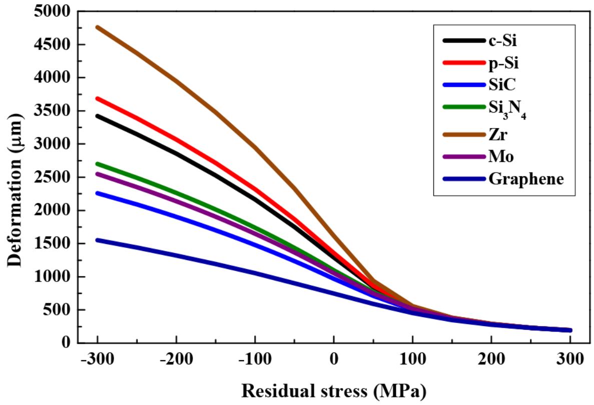

Figure 4. Deformation results considering residual stress with various materials.

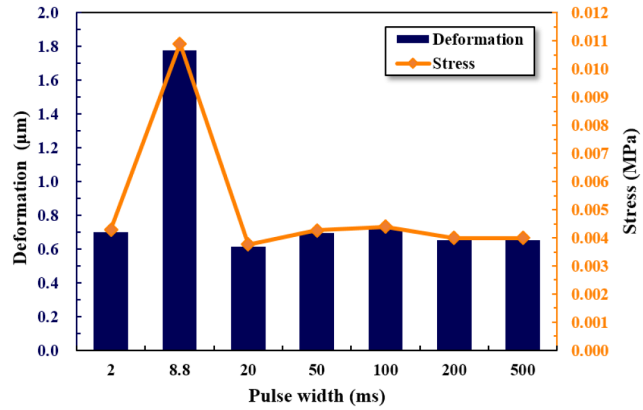

Figure 5. The maximum deformation and stress with several pulse width.

$$C_1 = \frac{\pi^4(1+n^2)}{64} \quad (2)$$

$$C_2 = \frac{\pi^6}{32(1-\nu^2)}\left\{\frac{(9+2n^2+9n^4)}{256} - \frac{(4+n+n^2+4n^3-3n\nu(1+n))^2}{2[81\pi^2\ 1+n^2)+128n+\nu(128-9\pi^2(1+n^2))]}\right\} \quad (3)$$

Where P is the applied pressure, σ is the internal stress, E is the Young's modulus, t is the membrane thickness, and h is the membrane deflection. C_1 and C_2 are the constant values determined by the membrane shape b/a = l/n. a and b are the side length of the membrane and υ is Poisson's ratio. Assuming that there is no residual stress, we can see that the error of simulation and calculation results is less than 10%.

4. Results

4.1 Impact of pressure change

We checked the deformation and the stress of the pellicle by changing the applied pressure. It is proceeded with full size pellicle with mechanical properties of crystalline silicon as presented in simulation conditions. Figure 2 shows that the deformation and the stress are gradually increased as the pressure difference grows from 0 to 10 Pa. The pressure difference should be less than 2 Pa if the deflection should be less than ~1 mm.

4.1.1 Result on various materials

We verified the impact of the pellicle induced by 2 Pa pressure change. We used the various materials that are presented as a candidate because of high transmission. Each material has different properties such as Young's modulus and Poisson's ratio, and it is related to the deformation and stress. Figure 3(a) shows the relation between deformation in the pellicle and the mechanical properties. Polycrystalline silicon, crystalline silicon and silicon nitride have a similar deformation. The stress of the each material is shown in Figure 3(b). The stress of polycrystalline silicon, crystalline silicon and silicon nitride is varied between 50 to 70 MPa. In the case of graphene, the result shows the smallest deformation because it behaves with a Young's modulus, which is much greater than other materials. On the other hand, we can check that the stress of the pellicle with graphene was the biggest at 95 MPa. Because the stress is calculated by Hook's law for tri-axial stress and it is increased in proportion to Young's modulus. The pellicle will break at large stress, therefore the material that represents the small stress is a need for the fabrication of pellicle.

4.1.2 Deformation calculation considering residual stress

So far, the results were proceeded without consideration of the residual stress. But the deformation of the pellicle is greatly influenced by residual stress. In order to consider the residual

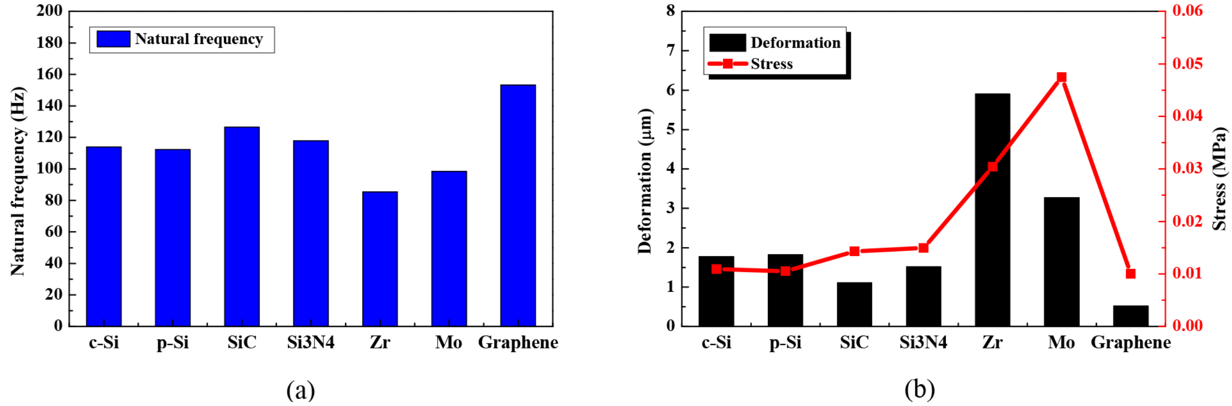

Figure 6. (a) The natural frequency and (b) the deformation and stress of the pellicle.

stress of the pellicle, we calculated the deflection using the Timoshenko equation. Figure 4 presents the deformation with several materials when the residual stress has a value from -300 to 300 MPa. As a result, zirconium with the smallest Young's modulus (88 GPa) has the biggest deformation, and graphene with the largest Young's modulus (1050 GPa) is the smallest deformation. Pellicle shows bigger deformation value if its residual stress is compressive stress (-). On the other hand, we can see that the deformation is smaller when it has tensile stress (+). Therefore, pellicle has to be stretched more than 100 MPa to reduce the deformation.

4.2 Stage acceleration

Pellicle can be affected by the acceleration force of the scanner during exposure process. Maximum acceleration during exposure is up to 10 g and the effect is expected to be substantial. When acceleration applied to the pulse shape, we studied the deformation and stress for pulse widths. We also considered various pellicle materials and number of acceleration cycle.

4.2.1 Resonance check with pulse width

We assume that the acceleration is applied by triangular pulse shape because we do not know how acceleration should be made in the actual equipment. The impact of pellicle will vary depending on the pulse width caused resonance. Maximum deformation and stress are dramatically increased when the pulse width of the scanner movement is the same as the resonance frequency of the pellicle. Figure 5 shows the maximum deformation and stress with several pulse width. It is proceeded using full size pellicle with mechanical properties of crystalline silicon. The natural frequency of silicon is 113.98 Hz and the pulse width of that time is 8.8 ms. The deformation and stress are appeared more than two times larger than other cases when the pulse width is the same as the natural frequency.

4.2.2 Result on various materials

In order to check the maximum resonance effect with pellicle materials, we investigated the deformation and stress for various materials. The natural frequency of the each material is represented in Figure 6(a). The natural frequencies of polycrystalline silicon, crystalline silicon and silicon nitride are similar, and it is less than 120 Hz. Figure 6(b) shows the maximum deformation and stress caused by resonance with various materials. The maximum deformation and stress (less than 0.05 MPa) with acceleration is quite small. Despite the same materials and structure of the pellicle, it is much smaller than the result by pressure difference. This is understandable by transforming the acceleration as force per unit area to pressure. Multiplied by the mass to the acceleration of 100 m/s^2 and divided by the area of full size pellicle, the corresponding pressure is only 0.0117 Pa. This is significantly smaller than the suggested pressure difference of 2 Pa.

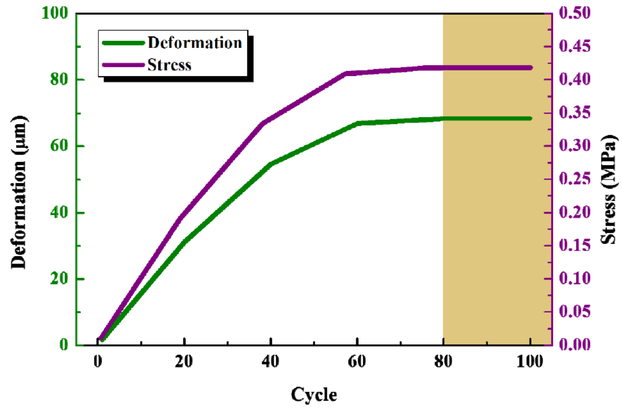

Figure 7. The deformation and stress with the repeated cycle.

4.2.3 Influence based on the repeated cycle

Now we identified the impact the repetition cycle. We defined one cycle until the velocity has increased and returned at initial velocity due to the repetition of the acceleration and deceleration. Figure 7 shows the influence of pellicle when the cycle repeats 1 to 100 times. At first, as the cycle is repeated, the deformation and stress are increased. But the influence in the pellicle is not increased when the cycle is repeated more than 80 times, and the maximum deformation and stress also is not increased any more.

5. Conclusion

The mechanical forces such as chamber-pellicle pressure difference and stage acceleration cause the mechanical stress in pellicle. Therefore, we studied the impact on the pellicle caused by pressure difference with various materials considering residual stress. We also investigated the maximum deformation and stress for different acceleration pulse widths, materials and number of acceleration cycle. The stress caused by pressure difference is 50 MPa and the stress affected by acceleration force is 0.01 MPa. The mechanical stress caused by the pressure difference cannot be ignored, while the mechanical stress caused by the stage acceleration is very small and can be ignored.

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7. Acknowledgement

This work was supported by the Future Semiconductor Device Technology Development Program #10045366 funded By MOTIE (Ministry of Trade, Industry & Energy) and KSRC(Korea Semiconductor Research Consortium)

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Industry Briefs

Life After Memory Chips - What's in the New Toshiba?

Reuters, March 14, 2017

Japan's Toshiba Corp , presenting its plan to sustain the firm after a $6.3 billion write-down, identified a "Rebuilt Toshiba" as a maker of components and machinery that will exclude its once-core memory chips arm and problematic nuclear power business.

The following is a breakdown of Toshiba, the conglomerate behind the first mass-market laptop and whose current output is as varied as train carriages and light bulbs.

WHAT HAS TOSHIBA SOLD OVER THE PAST YEAR?

- 9.9 percent of Toshiba Plant Systems & Services Corp ($136 million)
- 1.78 percent of Japan Display Inc
- Minority stake in Toshiba Machine Co Ltd ($134 million)
- Sigma Power Ariake Corp ($191 million)
- Toshiba Medical Finance Co Ltd ($27.3 million)

WHAT ELSE COULD IT SELL?

- Up to a majority of Toshiba Memory Corp to raise at least 1 trillion yen ($8.7 billion)
- Majority stake in Westinghouse Electric Co LLC
- Smart meter group Landis+Gyr for $2 billion, according to people familiar with the matter.

WHAT'S LEFT IN THE 'NEW TOSHIBA'?

The chips and nuclear businesses combined accounted for almost a third of revenue and over 70 percent of operating income in the financial year through March 2017.

Toshiba expects its rump business - which includes information technology and batteries - to earn revenue of over 4 trillion yen ($34.75 billion) and operating income of 210 billion in 2019.

Contributing about half of both will be a business domain the company dubs "Social Infrastructure," which includes:
- Public infrastructure (water treatment, logistics)
- Buildings and facilities (air conditioning, elevators)
- Railway Systems
- Printers and store retail registers

The next biggest domain will be Energy:
- Hydro, thermal and geothermal power
- Power transmission and distribution
- Nuclear power in Japan
- Next-generation energy

Rebuilt Toshiba's third pillar will be electronic devices:
- Semiconductors (automotive, industrial)
- Large-density hard drives for companies

The fourth and smallest division will be information communications technology (ICT) which Toshiba said will create services such as voice and image recognition systems using artificial intelligence (AI) and the Internet of Things (IoT).

http://www.reuters.com/article/us-toshiba-accounting-new-toshiba-factbo-idUSKBN16L0RI

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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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2017

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SPIE Photomask Technology and SPIE International Conference on Extreme Ultraviolet Lithography 2017
11-14 September 2017
Monterey, California, USA

The 24th Symposium on Photomask and NGL Mask Technology
5-7 April 2017
Pacifico Yokohama
Yokohama, Japan

The 33rd European Mask and Lithography Conference EMLC 2017
27-29 June 2017
Hilton Hotel
Dresden, Germany

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