PAPER Special Section on Fundamentals and Applications of Advanced Semiconductor Devices

Improvement of ArF Photo Resist Pattern by VUV Cure

Hisakazu MIYATAKE[†a)], *Nonmember and* **Takashi ITO**[††], *Member*

SUMMARY The dry etching resistance of ArF resist patterns was improved by irradiating vacuum ultraviolet (VUV) light with a wavelength of 172 nm to ArF resist patterns in N_2 atmosphere. The density of C=O bonds of the resists is decreased, and the dry etching rate of resist is also decreased after VUV irradiation. The line width shrinkage by the electron beam irradiation of CD-SEM was greatly improved from 9 nm to 2 nm, and LER (Line Edge Roughness) of resist patterns was approximately 2 nm improved from 8.4 nm to 6.5 nm under VUV irradiation. Using VUV cure, the dry etching pattern of a SiN film showed a rectangle-like cross-sectional view, and indicated almost the same LER value as the resist mask pattern. The VUV cure technique is an attractive method of fine resist pattern fabrication by ArF lithography.

key words: *UV cure, ArF, resist, dry etching resistance, LER*

1. Introduction

Recently, ArF immersion lithography has been developing rapidly towards high-density IC mass production [1]. In initial stage of ArF immersion lithography, a top-coat film which protects the leaching of solvents, PAG (Photo acid generator) or the contamination from high refractive-index liquid component into resist, has been developing [2], [3]. The photo resist itself for the immersion lithography will not need a big change from the conventional dry ArF lithography [4].

The resist of ArF lithography has been revealed weak resistance for the dry etching and has the line width shrinkage problem by the electron beam irradiation of CD-SEM. Moreover, LER of resist becomes serious in integrated circuit fabrication.

In order to improve the dry etching resistance of a resist, the UV cure using 250–300 nm light is a traditionally well known method for KrF resist [5], [6]. A wave length of 185 nm light, shorter wave length than that of the UV light was reported to be more effective to improve the dry etching resistance of KrF resist [7]. As for the ArF resist, the irradiation of a wave length shorter than 250 nm in N_2 atmosphere is effective to improve the dry etching resistance of ArF resist [8].

In this research, ArF resist patterns after irradiation of the wavelength of 172 nm in VUV range were investigated. As a result, VUV cure brought to good results for improvement of the dry etching resistance, the line width shrinkage under the electron beam of CD-SEM and LER. Line and space (L&S) patterns of SiN films fabricated by ArF lithography after VUV cure and the dry etching revealed almost the same LER value as the case of the resist pattern. VUV cure is a hopeful technique for ArF photo resist pattern improvement.

Manuscript received August 21, 2006.
Manuscript revised December 11, 2006.

[†]The author is with the Advanced Planning (Tokyo), Electronic Components and Device Development Group, Sharp Corporation, Tokyo, 162-8408 Japan.
[††]The author is with the Department of Electronics Engineering, Graduate School of Engineering, Tohoku University, Sendai-shi, 980-8579 Japan.
a) E-mail: miyatake.hisakazu@sharp.co.jp

DOI: 10.1093/ietele/e90–c.5.1006

2. Experimental

The VUV lamp was the Xe_2^* excimer laser by USHIO INC, which emitted light with a wave length light of 172 nm and a half value-width of 14 nm. The intensity of the VUV light on a wafer was 65–80 mW/cm^2 in N_2 atmosphere.

The photo resist was methacrylate polymer with acrylate resin for ArF lithography. 130 nm L&S patterns were formed by the ArF light exposure system with annular illumination and 2.38% TMAH (tetra methyl ammonium hydroxide) developer. The resist thickness was 400 nm on a BARC (bottom anti-reflection coating) film of 77 nm thickness. Binary mask was used. The temperature of PAB (post applied bake) and PEB (post exposure bake) were 110°C and 100°C, respectively.

The dry etching for 130 nm L&S patterns were done by using $CHF_3/CF_4/Ar/O_2$ gas for a 200 nm thick SiN film on a Si wafer of 300 mm in diameter.

For the line width measurements, Hitachi S-8C40 was used with the acceleration voltage of 700 V and the beam current of 3 pA. LER measurement for 130 nm L&S resist patterns was done by scanning 256 times using e-beam of SEM in the range from 0.1 to 6 μm in the direction towards the line of the L&S pattern by KLA-Tencor Model 8450i.

3. Results and Discussion

3.1 Resist Film Shrinkage by VUV Cure

The resist film thickness was reduced by VUV cure. So, the reduction of resist thickness, that is, the resist film shrinkage was measured on a blanket resist film on a wafer. After coating the resist on a wafer and PAB treatment, VUV irradiation was executed.

Figure 1 shows the resist film shrinkage increase with VUV cure time. The resist film thickness decreases by 30%

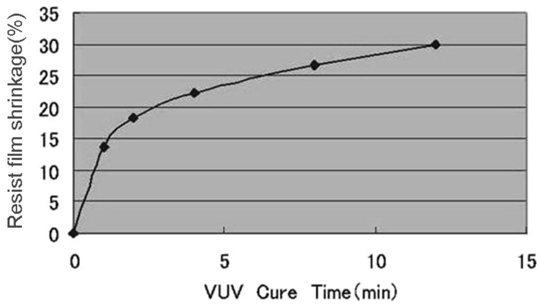


Fig. 1 Resist film shrinkage by VUV cure.

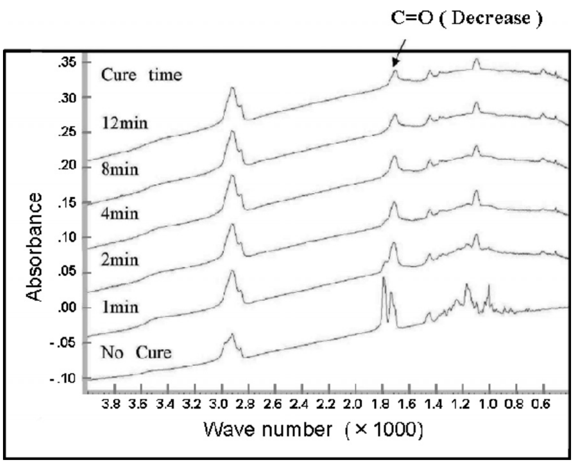


Fig. 2 Decrease of carbonyl bond by VUV cure.

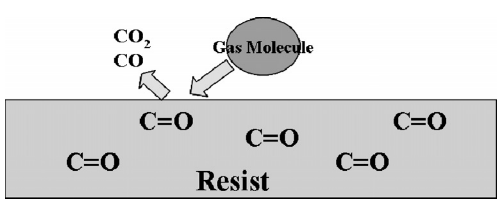


Fig. 3 Sublimation of decomposed C=O bonds into CO/CO_2.

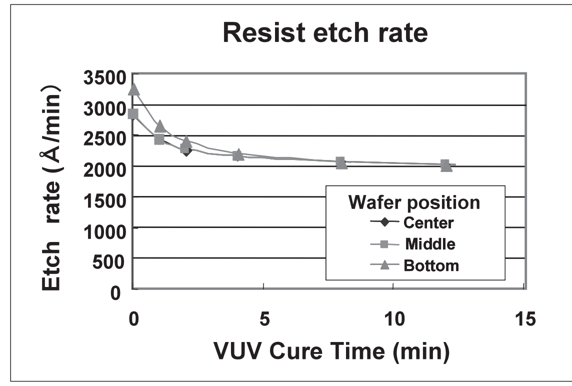


Fig. 4 Etching rate of resist vs. VUV cure.

of the no cure film thickness at VUV cure time of 12 minutes.

The infrared absorption spectrum was examined to investigate the origin of film thickness decrease. In Fig. 2, the feature of peak in the vicinity of 1700 cm^{-1} is revealed. This peak is assigned to the carbonyl group (C=O) absorption. The other peaks including the peak at 2900 cm^{-1} of the absorption of C-H bond are almost no changed. So, during the resist thickness decreasing, C=O bonds mainly decreases.

It was explained that the carbonyl group (C=O) had a large absorption below 250 nm wave length and easily was decomposed [9]. In this experiment, the effectiveness to C=O bonds reduction by VUV was recognized.

As for the dry etching, the dry etching rate is high under a lot of oxygen atoms contained in a resist, and under the dry etching gas including O_2 [10].

Figure 3 shows the reaction between gas molecules of dry etching and the resist. It is thought that the resist is sublimated as CO or CO_2 at the bombardment of gas molecules during the dry etching. Therefore the quantity of carbonyl group in the resist is one of the key factors for the dry etching resistance.

According to the above considerations, the small amount of C=O bonds in the resist is preferable to make the dry etching resistance higher. Therefore, VUV cure was thought to be effective to increase the dry etching resistance.

3.2 Etching Rate after VUV Cure

The etch rate of the dry etching after VUV cure was examined. Blanket resist films on wafers were used. Figure 4 shows results of dry etching rate at 3 measuring points within a wafer.

The etch rate of resist shows almost a constant value, approximately 200 nm/min after 8 min of VUV cure at 3 measuring points in a wafer. The constant etch rate of the dry etching for the resist suggests that the resist film property became uniform towards the depth direction after 8 min VUV cure and that the number of residual C=O bonds in unit area of the resist bombarded by the dry etching gas molecules might be saturated to a constant value.

In actual dry etching processes, the constant dry etching rate makes easy to calculate the dry etching time and to determine a film thickness combination of both resist and a film such as SiO_2 or SiN. So, the longer than 8 min VUV is good for the control of dry etching of resist masked film all over the wafer.

3.3 Surface Roughness of Resist

The surface roughness of resist is one of the important factors to prevent the so-called spike etching during a dry etching. The rough surface of the resist has sometimes weak spots for dry etch molecules and allows the localized dry etching to a film.

The surface roughness of the resist treated VUV cure after the dry etching was examined. VUV exposure time was changed from 0 (No cure) to 12 min. Figure 5 shows the surface roughness by SEM observation. The surface roughness was improved by the VUV cure of 4 min. Figure 6

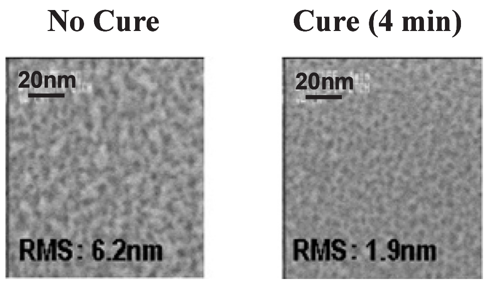


Fig. 5 Surface roughness of resist after dry etching with and without VUV cure.

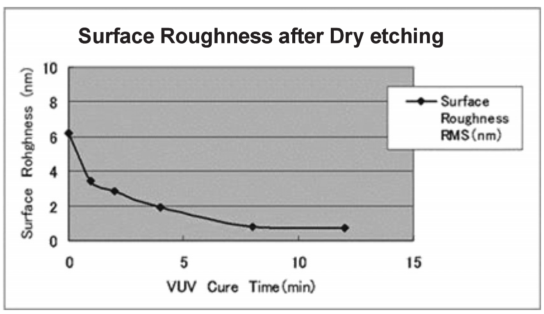


Fig. 6 Surface roughness of resist after dry etching vs. VUV cure time.

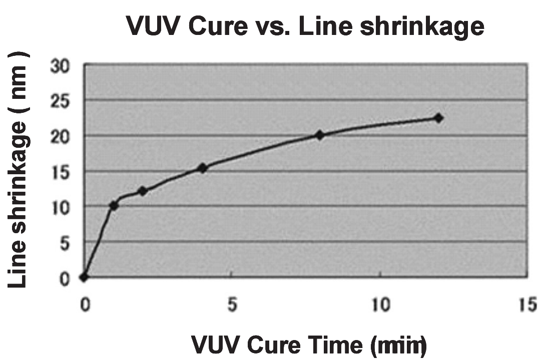


Fig. 7 Line pattern shrinkage by VUV cure.

shows the surface roughness with VUV cure time.

The surface roughness became almost a constant value of the lower than 1 nm rms after 8 min VUV cure.

3.4 Shrinkage of the Resist Line Width

The shrinkage of the resist line width by the VUV cure was examined by using the mask pattern of 130 nm L&S. Figure 7 shows the result.

The line width shrinkage increased with VUV cure time. The shrinkage ratio of the line width decreased gradually after 8 min. But the 22 nm of the line width shrinkage occurred at 12 min by VUV cure was thought to be too large for 130 nm L&S pattern. Therefore, it is necessary to control the line width at applying VUV cure to lithography of Integrated Circuit (IC) pattern.

IC patterns have various line widths in a dye, so the investigation of the line width shrinkage of various line widths

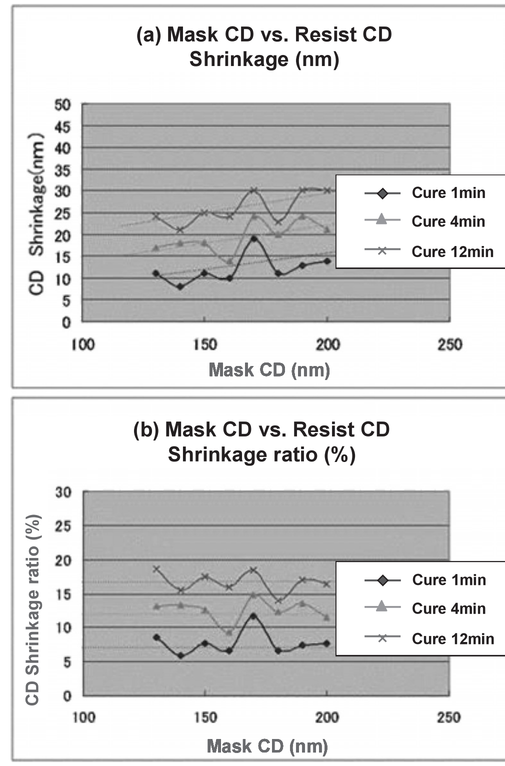


Fig. 8 (a) Mask CD vs. resist CD shrinkage (nm) (upper side). (b) Mask CD vs. resist CD shrinkage ratio (%) (under side).

after VUV cure was implemented. Figure 8 shows the relation between the mask line width (CD: critical dimension) and the resist pattern line width. Figure 8(a) shows the amount of shrinkage of the line width (CD) to the longitudinal axis. The amount of the line width shrinkage increased in proportion to increase of the mask line width. By the calculation with Fig. 8(a), Fig. 8(b) shows the line width shrinkage ratio (%) to VUV cure time. The line width shrinkage at a condition of VUV cure time indicated the same ratio of shrinkage as various mask CD from 130 nm to 200 nm, except for the data fluctuation.

A result shown in Fig. 8(b) indicates that the line width is controllable by the calculation of the shrinkage ratio to the line width after VUV cure time.

In addition, the shrinkage of each pattern was considered to progress from the surface of resist. Therefore, the center position of each pattern after VUV cure is not move from the original patterned position. From this consideration, in a mask pattern alignment which adjust a center of pattern, the alignment to the fabricated pattern with the shrink resist pattern after VUV cure might be available.

3.5 Line Width Shrinkage by Electron Beam of CD-SEM and LER

The line width shrinkage by electron beam by CD-SEM was observed in methacrylate resist, which has the main-chain scission-type polymers [11]. The amount of the line width shrinkage by the electron beam irradiation of CD-SEM was examined for the methacrylate base polymer mixed acrylate system resist of 130 nm L&S pattern.

Figure 9 shows the results of line width shrinkage by the electron beam irradiation of CD-SEM. The line width shrinkage after VUV cure of over 4 min shows only 2 nm, compared with 9 nm shrinkage in the case of no VUV cure. Therefore, a stable measurement in CD-SEM is available using VUV cure.

LER of 130 nm L&S pattern with VUV cure was examined. Figure 10 shows the result of both cases of with and without VUV cure. In the case of no VUV cure, the value of LER was 8.4 nm. The VUV cure improved the LER to 6.5 nm at only 1 min. However, over 1 min, LER was almost no changed.

3.6 Improvement of Dry Etching Resistance by VUV

The dry etching of the SiN film was executed in 130 nm L&S pattern resist treated VUV cure of 4 min. The cross-sectional view of resist and SiN pattern were observed by SEM, and also LER of both resist pattern and SiN pattern after dry etching were evaluated. Figure 11 shows these results.

In the no VUV cure case, as for shape of the cross- sectional view of resist pattern, the so-called skirt shape was observed. LER of SiN line pattern showed the value of 7.6 nm. On the other hand, in the case of VUV cure, the resist pattern showed no skirt and protected to the top portion of SiN pattern.

The value of LER of SiN pattern was 6.1 nm as same value as that of resist pattern. This same value of LER between the resist pattern and the SiN dry etch pattern suggests that the dry etch pattern was faithfully tranformed from the resist pattern by VUV cure.

3.7 Resist Pattern Improvement by VUV Cure

All of the experimental results on the resist pattern are summarized in Fig. 12. Although the VUV cure in N_2 atmosphere reduced the resist film thickness with C=O bonds decrease and caused the line width shrinkage, the VUV cure improved ArF lithography pattern in various aspects for the dry etching pattern fabrication of SiN film, namely, the surface roughness, the line width shrinkage by EB irradiation of CD-SEM, LER, and the dry etching resistance which was shown as the constant and low dry etch rate, and the no skirt shape on SiN film during the dry etching.

4. Conclusion

The improvement of ArF resist pattern by VUV cure was demonstrated.

VUV cure, using $Xe_2{}^*$ light (λ=172 nm) which has a shorter wave length than that of UV light (λ=250 to 300 nm) in the well known UV cure, causes the decrease of C=O bonds in the resist of methacrylate with acrylate resin, and decreases the resist thickness. The line width shrinkage by electron beam irradiation of CD-SEM is decreased in L&S pattern by VUV cure, and LER in the pattern is also improved. The resist pattern on a SiN film after VUV cure reveals a strong dry etching resistance enough to fabricate the rectangle pattern shape of SiN in the cross-sectional view. Moreover, LER on the line pattern of SiN indicates same

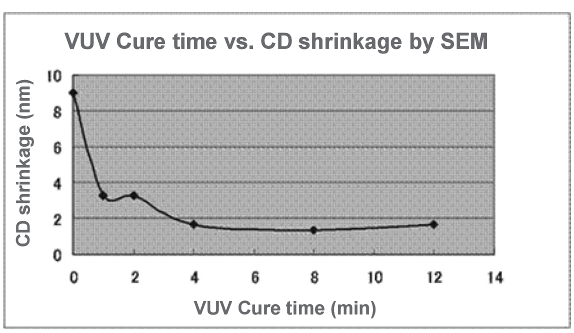


Fig. 9 CD shrinkage by SEM vs. VUV cure time.

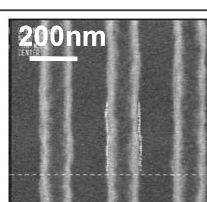
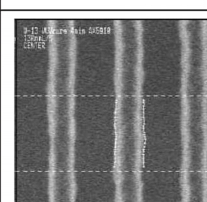
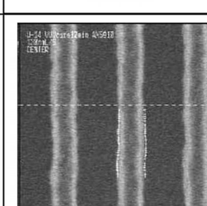
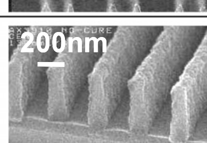
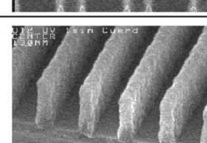
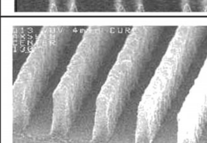
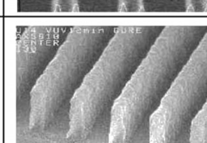
	No Cured	1min	4min	12min
Top view				
Oblique view				
LER	**8.4nm**	**6.5nm**	**6.7nm**	**6.6nm**

Fig. 10 Improvement of LER of resist by VUV cure.

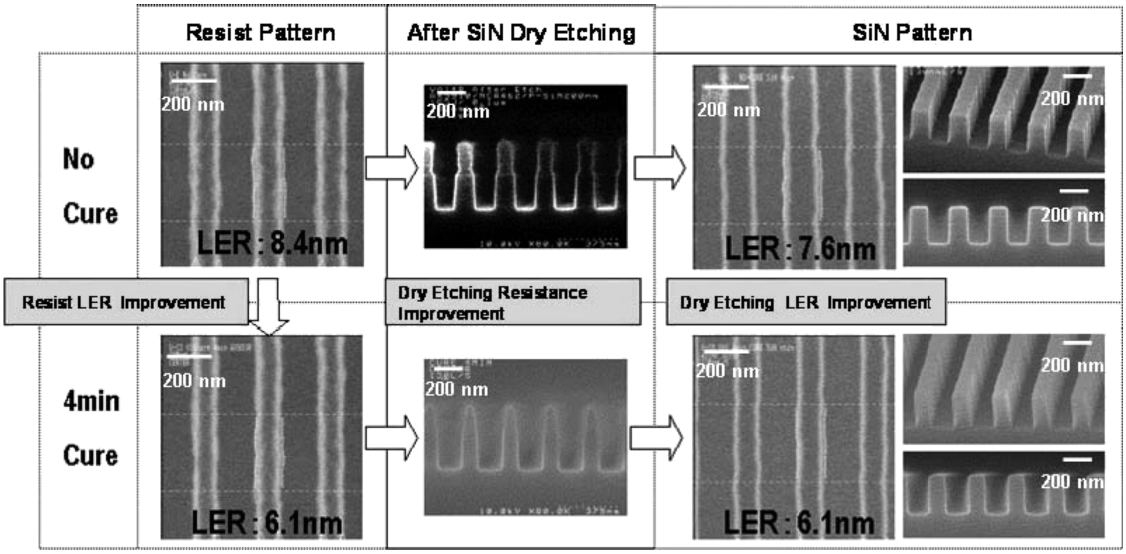


Fig. 11 Improvement of LER and dry etching resistance by VUV cure.

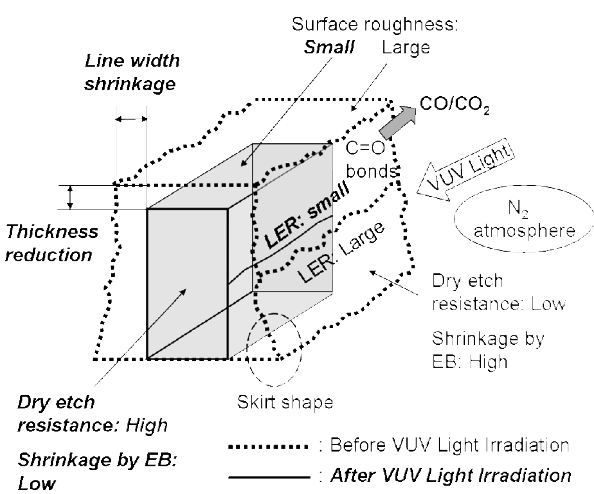


Fig. 12 Summary of VUV cure on ArF resist pattern.

value as that of the resist pattern before the dry etching. So, this fact implies that a dry etch pattern is faithfully tranformed from the resist pattern by VUV cure.

According to these results, VUV cure is a promising method to improve the ArF resist pattern formation.

Acknowledgments

The authors wish to express our gratitude to Dr. Tetsuro Hanawa and Mr. Hirokazu Asahara, former Selete researchers, in great contribution on this research.

References

[1] B.J. Lin, “Semiconductor, foundry, lithography, and partners,” Proc. SPIE, vol.4688, pp.11–24, 2002.

[2] S. Kishimura, R. Gronheid, M. Ercken, M. Maenhoudt, T. Matsuo, M. Endo, and M. Sasago, “Impact of water and top-coats on lithographic performance in 193-nm immersion lithography,” Proc. SPIE, vol.5753, p.20, 2005.

[3] H. Nagasaka, “Immersion lithography,” SEMI Technology Symposium, pp.8–23, 2005.

[4] T. Miyamatsu, Y. Wang, M. Shima, S. Kusumoto, T. Chiba, H. Nakagawa, K. Hieda, and T. Shimokawa, “Material design for immersion lithography with high refractive index fluid (HIF),” Proc. SPIE, vol.5753, p.11, 2005.

[5] H. Hiraoka and J. Pakansky, “High temperature flow resistance of micron sized images in AZ resists,” J. Electrochem. Soc., vol.128, pp.2645–2647, 1981.

[6] Y. Takasu, T. Ohkuma, and Y. Todokoro, “Deep UV hardening of photo- and electron resist patterns,” Proc. 6th Symp. on Dry Process, Tokyo, the Institute of Electrical Engineers of Japan, p.60, 1984.

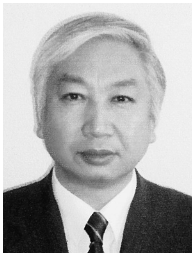
[7] Y. Kawai, A. Otaka, A. Tanaka, J. Nakamura, K. Sakura, T. Matsuda, and Y. Sakakibara, “New resist technologies for 0.25-μm wiring pattern fabrication with KrF lithography,” Jpn. J. Appl. Phys., vol.36, Part 1, no.4A, pp.2085–2090, April 1997.

[8] S. Kishimura, Y. Kimura, J. Sakai, K. Tsujita, and Y. Matsui, “Improvement of dry etching resistance of resists by deep UV cure,” Jpn. J. Appl. Phys., vol.38, Part 1, no.1A, pp.250–255, 1999.

[9] K. Tokumaru, Yuki Hikari Kagaku Hanno-ron (Organic Photo Chemical Reaction), Chap.1, p.7, Tokyo Kagaku Dojin, Tokyo, 1973.

[10] H. Gokan, S. Esho, and Y. Ohnishi, “Dry etch resistance of organic materials,” J. Electrochem. Soc., vol.130, p.143, 1983.

[11] W. Shnabel and J. Kiwi, Aspects of Degradation and Stabilization of Polymers, ed. H.H. Jellinek, p.195, Elsevier, Amsterdam, 1977.



Hisakazu Miyatake was born in Osaka, Japan on February 25, 1952. He received his B.E. degree in electrical engineering from Nagoya Instate of Technology in 1975, and received M.E. degree in applied physics in Tohoku University in 1977. He joined Sharp Corporation in 1977 and was engaged in the research and development of process technology of DRAM, Flash memory and the other kinds of integrated circuits. In 1999, he was on loan to Selete (Semiconductor leading edge technologies, Inc.) for the purpose of planning and implementing the 130 nm/300 mm program. During the program, he managed the collaboration of 300 mm diameter Si process technologies with International SEMATECH. In 2002, He returned Sharp Corporation and has been participating in Semiconductor Technology Roadmap Committee of Japan, some kinds of technology committees of JEITA (Japan electronics and information technology industry association), and EUV process technology committee of ASET (Association of Super-Advanced Electronics Technologies).

Takashi Ito received the B.S., M.S., and Ph.D. degrees in Electronics Engineering from Tokyo Institute of Technology, Tokyo, Japan in 1969 and 1971, and 1974, respectively. He joined Fujitsu Laboratories Ltd. in 1974, and has been engaged in research and development of semiconductor technologies for high-performance LSIs. He was assigned as Head of Silicon Technology Laboratory, Fujitsu Laboratories Ltd. in 2001 and Chief Scientist and Director of Akiruno Technology Center, Fujitsu Ltd. in 2003. He moved to Tohoku University as Professor of Graduate School of Engineering in 2004. Dr. Ito is a member of the Japan Society of Applied Physics, the IEEE and the Electrochemical Society. He received the Teshima Memorial Award, Watanabe Memorial Award, Ohm Technology Award, Ohkouchi Memorial Award, and Yamazaki Award in 1975, 1981, 1999, 2000, and 2006, respectively.