Hitachi's Slimming System Using Ozone Process Technology

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OVERVIEW: While semiconductor manufacturers continue to express concerns about the limitations of photolithography, revolutions in lithographic techniques have led to the formation of patterns with dimensions smaller than the wavelength of the light source. Also, due to the increasing cost of exposure systems, equipment related to the lithography process is beginning to constitute the bulk of plant investment in the field of semiconductor manufacture. Meanwhile, there seems to be no end to the demands for fine gate lengths in logic devices such as MPUs (micro-processing units) and LSIs (large-scale integrations). Technical innovations are thus being made in fields such as lithography in an effort to meet these growing demands. Although gate lengths at the 90 nm node have already been developed, industry is now calling for a reduction to 70 nm or less. However, structures as small as this are difficult to form, even when using resolution enhancement technologies in conjunction with ArF excimer laser exposure techniques. To resolve this deadlock, Hitachi has developed and commercialized a slimming system, which can produce fine patterns below the resolution limit of exposure systems by precisely slimming a resist pattern formed by lithography. In combination with existing exposure systems, this slimming system can produce ultra-fine patterns that take the lead in next-generation exposure systems.

INTRODUCTION

ADVANCES in the performance and integration density of semiconductor devices are being helped on by innovative new lithography techniques, especially in exposure systems. To meet accelerating requirements of the ITRS roadmap[1)] the light source wavelength of exposure systems is being reduced from the *i* line (365 nm) to the wavelengths of KrF excimer lasers (248 nm) and even ArF excimer lasers (193 nm). Also, by combining these new light sources with resolution enhancement technologies using off-axis illumination, phase shift masks and so on, LSI patterns are being formed at dimensions smaller than the light source wavelength.

Hitachi has developed and commercialized a slimming system by applying it to ozone ashing process technology. The term "slimming" here refers to the technique for thinning out resist patterns formed by exposure systems. Here, we discuss this slimming system to which ozone process technology is applied.

EFFECTS OF SLIMMING AND METHODS FOR ACHIEVING IT

The effects of slimming techniques are shown in Fig. 2. This figure shows how line widths that cannot be formed even with exposure systems using ArF excimer lasers can be formed by the combination of slimming technology with exposure systems using a KrF excimer laser. With an ArF light source, even smaller dimensions can be achieved. Besides the KrF and ArF excimer lasers shown in this figure, similar effects can be obtained by combining slimming techniques with other light sources such as *g* line and *i* line sources, and with EB (electron beam) lithography systems (direct writing).

Fig. 3 shows how slimming can be used to produce fine gate electrodes. Slimming methods include those that involve ashing the resist pattern (called resist slimming), and those that involve etching the bottom anti-reflection coating (called BARC slimming)[2-4)]. In resist slimming methods, the lower layers (BARC, polysilicon, etc.) are etched after the resist pattern has

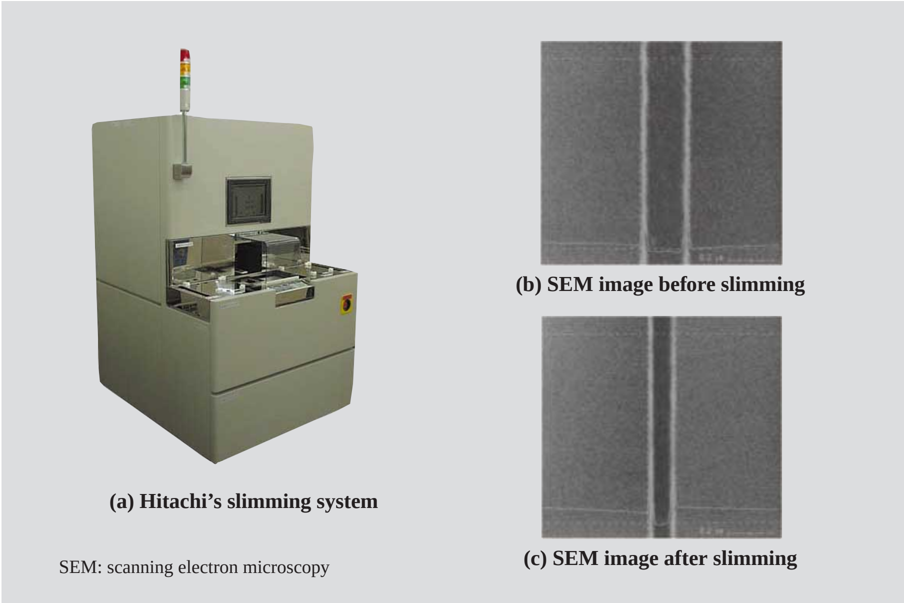

Fig. 1—A Slimming System Based on Ozone Process Technology and a Measuring SEM Image.
Hitachi'slimming system can produce ultra-fine patterns below the resolution limit of exposure systems by precisely thinning out a resist pattern formed by lithography.

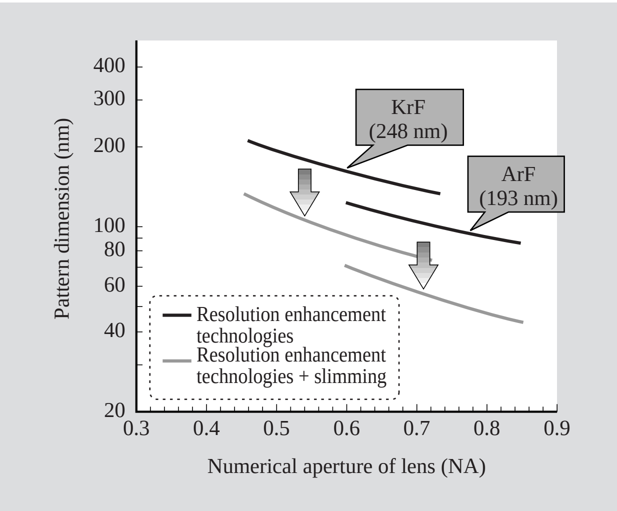

Fig. 2—Slimming Effects.
This figure shows how patterns formed using resolution enhancement technologies and patterns that have also been subjected to slimming vary with the numerical aperture of the lens. By combining a slimming process with KrF exposure, it is possible to form pattern dimensions equivalent to those obtained when using ArF exposure.

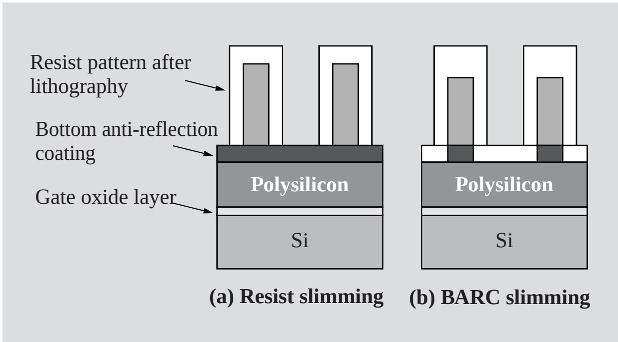

Fig. 3—Slimming Method.
A pattern formed by lithography is thinned out (slimming). After slimming, BARC and polysilicon can be etched to form an ultra-fine pattern.

been slimmed isotropically, allowing the formation of fine patterns with resolutions that have not been possible with existing exposure systems.

On the other hand, in BARC slimming it is possible to combine resist slimming with BARC etching. However, as the amount of slimming increases, the uniformity becomes worse and more of the resist film is lost. As a result, there are still problems to be overcome with this approach, such as limited slimming capability (no more than 40 nm for practical purposes), and poor reproducibility.

HITACHI'S SLIMMING SYSTEM PROCESS CHAMBER

In resist slimming with an ozone process, the constituent organic compounds of the resist pattern are broken down into carbon dioxide and water by oxygen radicals produced by thermal decomposition of the ozone, and the resist is thinned out as these reaction products evaporate off[5]. Since the amount of thinning varies according to the process temperature and the ozone supply rate, the slimming distribution is impaired by localized variations of the ozone supply and wafer cooling. In Hitachi's slimming system, the process is thus constructed in rate-controlling steps

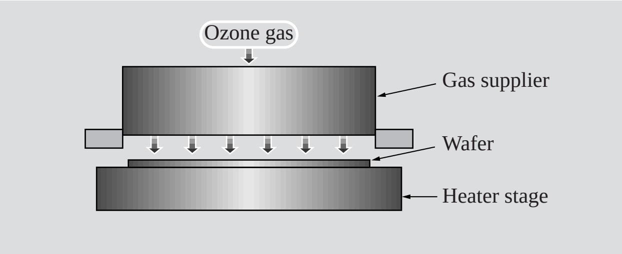

Fig. 4—Outline of Process Chamber Structure in the Slimming System.
Uniform slimming is achieved by providing a uniform supply of ozone and heating the wafer uniformly.

where the amount of thinning is independent of the ozone supply rate, and a configuration is employed where the slimming rate is kept constant by making the temperature distribution uniform across the wafer.

The structure of the process chamber in the slimming system is outlined in Fig. 4. Ozone gas, which is produced from a supply of oxygen gas by silent discharge, is introduced into a newly developed gas supplier. This gas supplier consists of multiple rectification plates, and can supply ozone gas uniformly without impairing the temperature distribution across the wafer. The wafer is uniformly heated by holding it against a hot plate by vacuum chuck. A structure is employed where particles on the back surface can be reduced by making the amount of contact between the wafer and hot plate as small as possible. The spent ozone gas is rendered harmless by an ozone decomposing system before it is released.

EVALUATION OF RESIST SLIMMING

High-precision Slimming Process

We compared the slimming distributions obtained when this system was used to perform resist slimming with the results obtained when BARC slimming was performed using a typical etching system. Fig. 5 shows the slimming distribution across a 200-mm wafer. As this figure shows, BARC slimming occurs preferentially at the outer parts of the wafer, and has a greater tendency for variation (3σ, 9.6 nm). This is thought to be because there is more etchant at the outer parts of the wafer, causing the etching rate to increase. On the other hand, resist slimming with the ozone process occurs uniformly across the entire wafer surface (3σ, 3.9 nm). Since the measurement reproducibility of CD-SEM (scanning electron microscopy) used in this evaluation is about 3 nm, we can conclude that good uniformity was obtained.

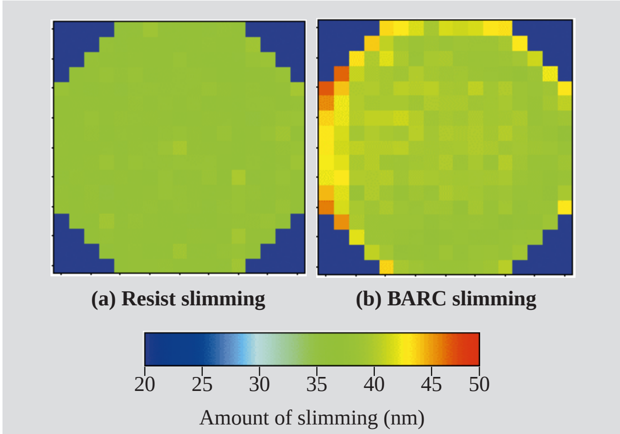

Fig. 5—Slimming Distribution.
In the case of BARC slimming, the amount of slimming is greater at the outer parts of the wafer and the variation tends to increase (b). *On the other hand, in the case of resist slimming with an ozone process, it can be seen that it is possible to achieve a uniform slimming process across the wafer surface* (a).

Formation of Ultra-fine Patterns

Fig. 6 shows a cross sectional SEM image of a 190-nm line formed on the BARC after it has been subjected to resist slimming. As this figure shows, even after the slimming process has been performed for 1

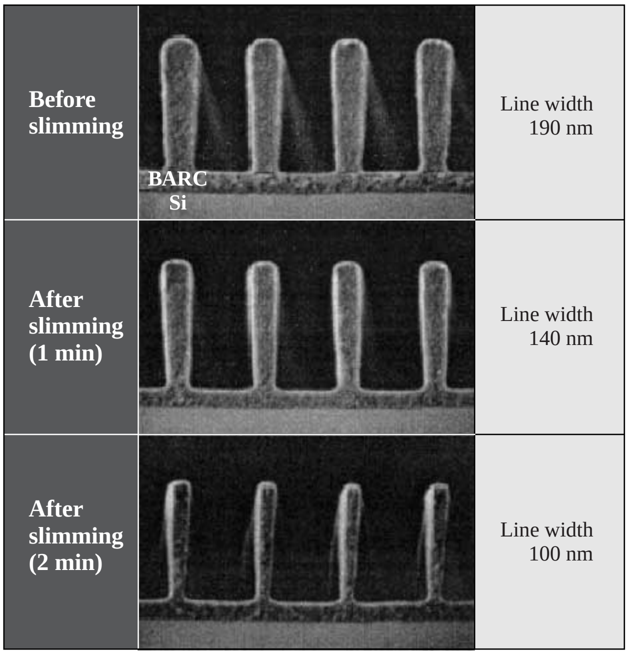

Fig. 6—Pattern Profiles.
This figure shows resist patterns formed by lithography and the change in cross sectional profile after slimming. The profiles are kept intact during slimming, even in patterns having a reverse taper profile. This shows that it is possible to achieve isotropic slimming results with an ozone process.

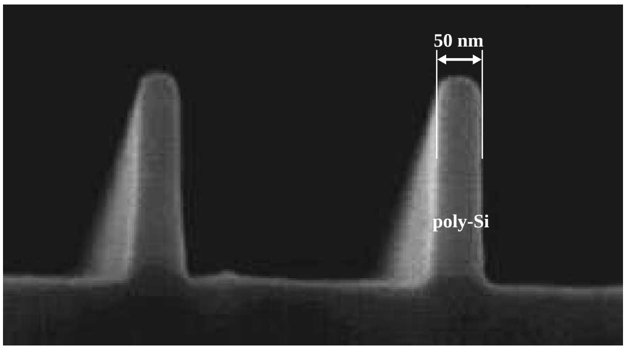

Fig. 7—Formation of a 50-nm Gate.
This figure shows an example of a 50-nm gate electrode formed with Hitachi's slimming system. A 130-nm line width was reduced to 70 nm by slimming, and then the BARC and polysilicon were etched to produce a polysilicon gate electrode with a line width of 50 nm.

or 2 minutes, the reverse taper profile left after the lithography is left intact. It can also be seen that the ozone slimming process is isotropic.

Fig. 7 shows a cross sectional SEM image of an ultra-fine gate electrode formed using resist slimming. This was formed by slimming a 130-nm line width to 70 nm and then etching the BARC and polysilicon to form a gate electrode with a line width of 50 nm. This shows that by using a slimming system, it is possible to realize ultra-fine gate electrodes with good uniformity across the wafer surface. This would not have been possible using current mass production lithography techniques alone.

CONCLUSIONS

We have discussed a slimming system developed by Hitachi and to which ozone process technology has been applied.

Significant benefits can be achieved by combining the slimming system with existing exposure systems, which makes it possible to achieve ultra-fine patterns. Although this report has concentrated on the needs of the semiconductor business field, slimming systems are also expected to make important contributions to the field of magneto-resistive heads, where dimensions are decreasing at an even faster rate than in the semiconductor field. In the future we aim to improve the performance of this system and address the needs of a wide variety of fields.

REFERENCES

(1) International Technology Roadmap for Semiconductors (http://public.itrs.net)

(2) Wei W. Lee, et al., "Fabrication of 0.06 μm Poly-Si Gate Using DUV Lithography with a Designed SixOyNz Film as an ARC and Hardmask," 1997 Symposium on VLSI Technology Digest of Technical Papers, pp. 131-132 (1997)

(3) J. Chung, et al., "Deep-Submicrometer MOS Device Fabrication Using a Photoresist-Ashing Technique," *IEEE Electron Device Letters* **9**, No. 4, pp. 186-188 (1988)

(4) H. Kawakami, et al., "A Method for the Formation of Sub-100 nm Patterns Using an Ozone Asher," Collected Lectures of the 54th Symposium on Semiconductor/Integrated Circuit Technology, pp. 60-65 (1998) in Japanese.

(5) S. Tsunekawa, et al., "Ozone Asher Realizing Damageless Ashing Process," *Hitachi Hyoron* **79**, pp. 799-802 (Oct. 1997) in Japanese.

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