Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 573-575

High-Reliability Lithography Performed by Ultrasonic and Surfactant-Added Developing System

T. Iwamoto[1)], H. Shimada[1,2)], S. Shimomura[1)], M. Onodera[1,2)] and T. Ohmi[1)]

1) Department of Electronics, Faculty of Engineering, Tohoku University,
Aramaki Aza-Aoba, Aoba-ku, Sendai, 980 Japan
Fax: 022-224-2549, Phone: 022-224-2649
2) Laboratory for Microelectronics, Research Institute of Electrical Communication,
Tohoku University, Katahira 2-1-1, Aoba-ku, Sendai, 980 Japan
Fax: 022-227-8989, Phone: 022-227-9066

Formation of high-precision fine resist patterns has been achieved by an effective removal of dissolved resist polymers, that is, the reaction products of the developing process. For this purpose, two techniques have been employed, namely physical method using ultrasonic agitation and chemical method of adding surfactant to the developer. By combining these two methods, the dissolved polymers have been effectively removed, thus allowing the resist to reveal its inherent patterning performance.

1. Introduction

Advanced lithography technology is required to achieve highly reliable resist patterning, which guarantees perfect uniformity, reproducibility, and wide process margins as well as ultrafine resist patterning. In practice, the dimensional accuracy of resist patterns fluctuated throughout a single wafer or from a wafer to a wafer. Because a large amount of resist polymers are dissolved in a very short time, the reaction products form a stagnant layer (gel layer[1)]), resulting in the suppression of the resist-developer reaction. Therefore, the existence of a stagnant layer leads to large fluctuations in the resist dissolution rate. And also, it gives rise to the degradation of the resist performance. The purpose of this paper is to describe highly reliable resist patterning process by quickly removing the reaction products by ultrasonic developing and the addition of surfactant in the developer.

2. Experimental

Novolac photoresist coated on a Si wafer, which was 1.26μm or 1.08μm in thickness after pre-bake (90°C/90sec), was exposed with a g-line or an i-line stepper system, respectively (FPA-1550MII, FPA-2000iI :Canon). After exposure, the samples were subjected to post-exposure bake (110°C /90sec). In the development process we employed a dipping method. The dipping time was 70 seconds in the developer,

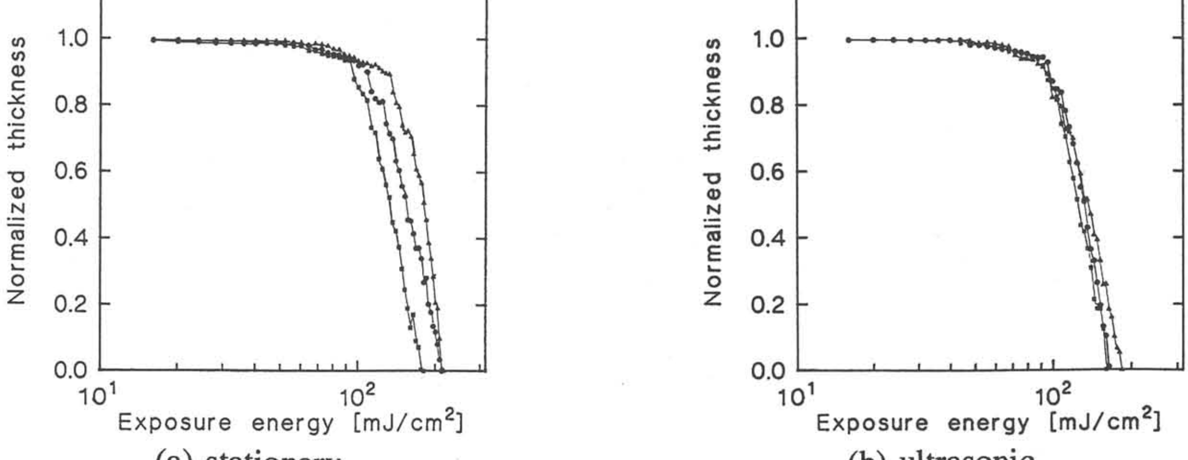

Figure 1. Contrast curves of resist developed by means of (a)stationary and (b)ultrasonic developing under the same conditions.

which was 2.38wt% tetramethylammonium hydroxide solution (TMAH). In this experiment ultrasonic waves (38kHz) were applied to the developer, and the samples were set perpendicular to the propagation of ultrasonic waves. And the surfactant, a nonionic hydrocarbon type, was added to the developer. The amount of the surfactant into the developer is 200ppm. Then the rinsing time was 60 seconds in the ultrapure water. Contact hole patterns and line-and-space patterns were observed by a scanning electron microscope (SEM). The resist thickness was measured by a surface profiler (α-step : Tencor).

3. RESULTS AND DISCUSSION

3.1 Ultrasonic developing

Figure 1(a) and (b) show the contrast curves of the resist prepared in the same manner which were developed by stationary and ultrasonic developing, respectively. For stationary developing, the developing characteristics fluctuated from run to run. In the case of ultrasonic developing, the same contrast curve is obtained for all runs. The result suggests that the reaction products cause the fluctuation in the developing process. Therefore, in order to obtain a stable development process, it is essential to remove the reaction products from the resist surface to the bulk developer.

Figure 2 shows the contrast curves for thicker resist films developed with or without ultrasonic waves. The resist thickness is 2.7μm. The resist contrast and sensitivity are both enhanced[2] by using ultrasonic developing. It is obvious that the thicker the resist film is, the larger the influence of the reaction products becomes. Namely, the resist-thickness dependence of the resist performance becomes less significant by using ultrasonic developing. In practice, since the thickness of a resist film varies on a textured surface, it is quite essential that the resist performance is insensitive to the resist thickness variation.

Figure 3 shows the SEM images of 0.6μm contact hole patterns as a function of exposure energy. The contact hole patterns are formed under lower exposure energies by using ultrasonic developing than by using stationary developing. Figure 4 shows the defocus characteristics of 0.6μm contact hole patterns developed with or without ultrasonic waves. A wider focus margin is obtained by using ultrasonic developing. Since the exposed resist portions perfectly dissolve in ultrasonic developing, the inherent resist performance can be revealed.

3.2 The addition of surfactant in the developer

Figure 5 exhibits the SEM image of 0.3μm contact hole patterns formed by an i-line stepper and a developer with or without surfactant. The contact hole pattern formed by the surfactant-free developer fails, while that formed by the surfactant-added developer is perfectly clear. The addition of surfactant to developer enhances its wettability[3)-6)], and the developer can be

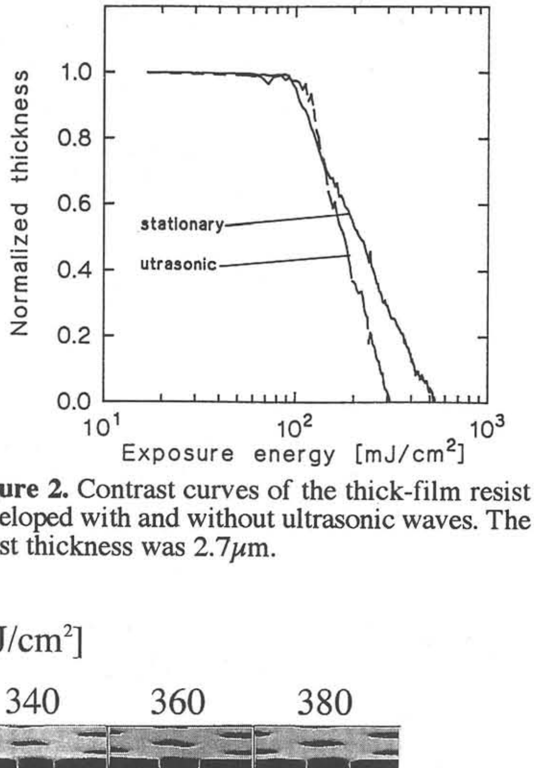

Figure 2. Contrast curves of the thick-film resist developed with and without ultrasonic waves. The resist thickness was 2.7μm.

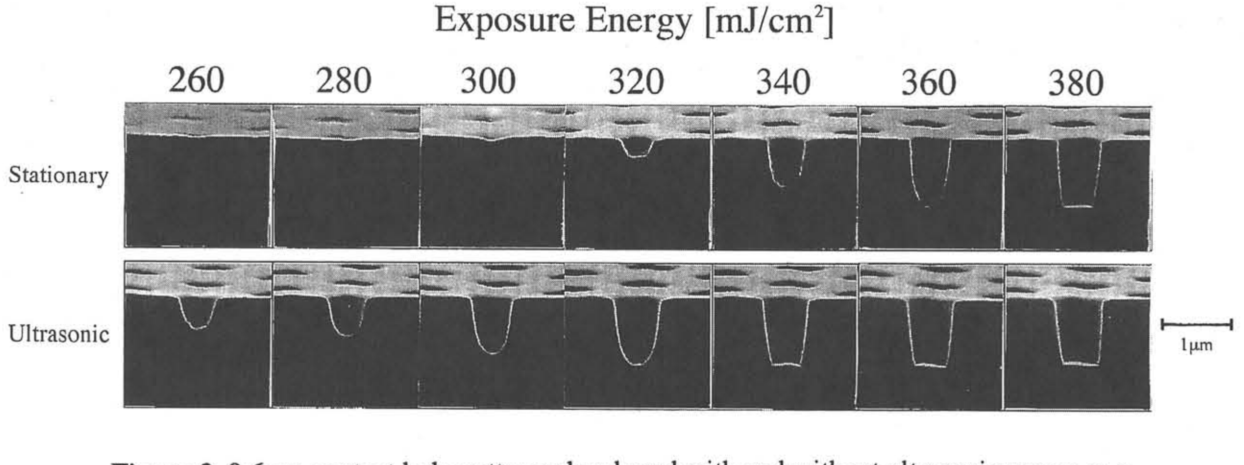

Figure 3. 0.6μm contact hole patterns developed with and without ultrasonic waves as a function of exposure energy. A g-line stepper was employed. The focus was +0.5μm.

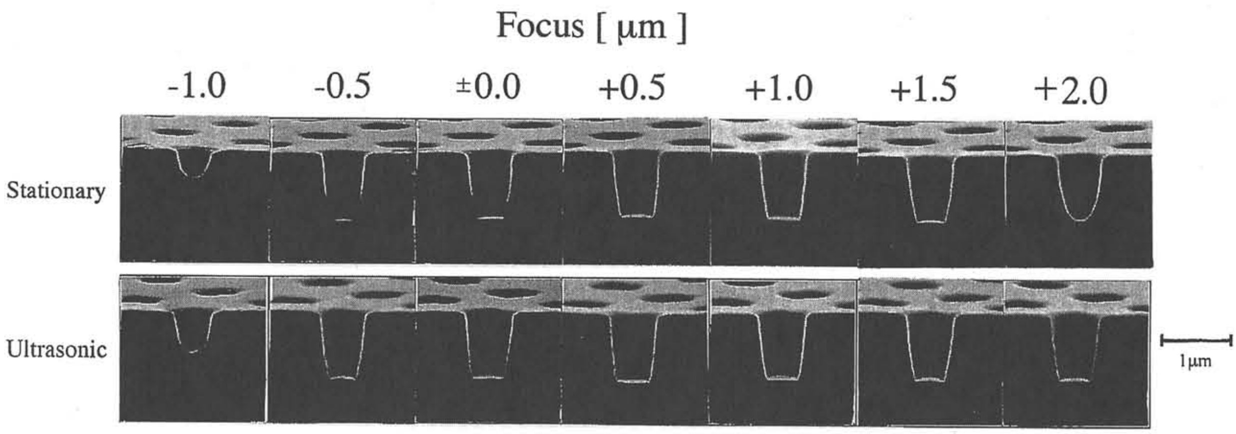

Figure 4. Defocus characteristics of 0.6μm contact hole patterns developed with and without ultrasonic waves at an exposure energy of 380 mJ/cm^2 and 360 mJ/cm^2, respectively. A g-line stepper was employed.

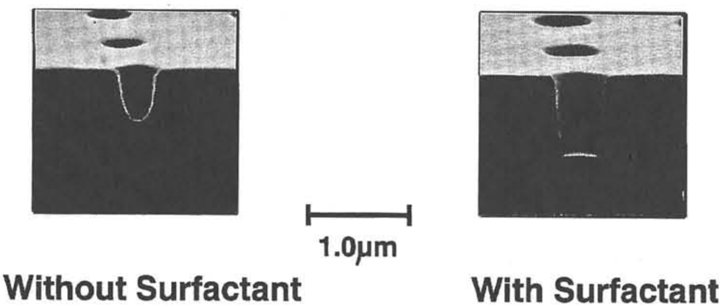

Figure 5. 0.3μm contact hole patterns formed by the developer with and without surfactant and an i-line stepper (410mJ/cm^2).

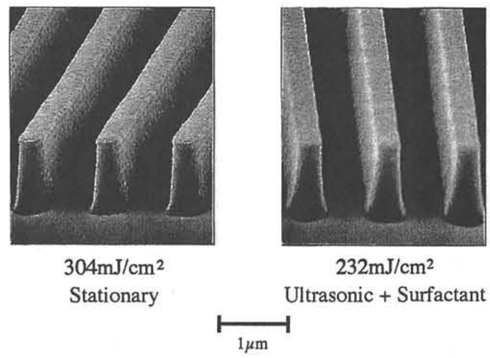

Figure 6. 0.6μm line-and-space patterns by using ultrasonic developing with surfactant.

easily supplied to resist surface by effectively making reaction products diffuse into the bulk developer.

3.3 Their combined effects

Figure 6 shows 0.6μm line-and-space patterns by means of the combined effects of ultrasonic developing and the addition of surfactant to developer on resist performance. The exposure energy necessary for forming 0.6μm line-and-space patterns is reduced by 23.7% when employing surfactant-added ultrasonic developing. The combination of both physical and chemical forces for the quick removal of the reaction products leads to superior resist performance.

4.SUMMARY

We have found that the reaction products cause the large fluctuations in the developing process. Highly reliable resist patterning is achieved due to quickly removing reaction products in the interface between resist surface and developer. And, employing ultrasonic developing and the addition of surfactant in the developer, the inherent resist performance has been revealed.

Acknowledgment

This study was carried out at the Super Clean Room of Laboratory for Microelectronics, Research Institute of Electrical Communication, Tohoku University.

References

1) Moreau W.M, "Semiconductor Lithography," Chapter 10, Plenum Publishing Corporation, New York(1988).

2) Cynthia Zee et.al., Proc. SPIE, 920, pp154-161, (1988).

3) H.Shimada et.al., J.Electrochem.Soc., Vol.139, No.6, pp.1721-1730, (1992).

4) S.Shimomura and et.al., Proc. SPIE, 1925, (1993) to be published.

5) H.Shimada et.al., Ext. Abstr. Int. Conf. SSDM, Tsukuba, pp440-442, (1992).

6) H.Shimada et.al., Jpn.J.Appl.Phys.Vol.32 pp.347-351, (1993).