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Characteristics of Nanoscale Lithography Using Atomic Force Microscope with Current-Controlled Exposure System

Masayoshi Ishibashi, Seiji Heike, Hiroshi Kajiyama, Yasuo Wada and Tomihiro Hashizume

Advanced Research Laboratory, Hitachi, Ltd.
Hatoyama, Saitama 350-03, Japan
Phone: +81-492-96-6111, Fax: +81-492-96-6006, e-mail: isibasi@harl.hitachi.co.jp

1. Introduction

Downscaling of electronic devices requires a higher resolution capability in lithography. However, the resolution in optical lithography is limited essentially by the wavelength of the source light and it is believed to be difficult that the resolution becomes less than 100 nm. Hence, several types of new lithography techniques, such as electron-beam (EB) lithography, X-ray lithography, and focused ion-beam lithography, have been studied as post-optical lithography techniques.

Scanning probe microscopy (SPM) is one of the powerful tools for fabricating nanoscale structures. SPM fabrications using electron exposure of the resist [1]-[4] and selective oxidation of the substrate [5] have been reported. In AFM (atomic force microscopy) lithography, the tip position is controlled by a cantilever of AFM and the exposure of the resist is performed by field-emission and/or resistive current between a conductive substrate and a metal coated tip. An advantage of this technique is that the resist patterning can easily be applied to current lithography techniques.

We have modified the AFM lithography technique by controlling the exposure current by means of an extra feedback system. We fabricated the line and space (L&S) patterns in negative resists and found improved characteristics of nano-lithography.

2. Experimental

We used a negative-resist RD2100N (Hitachi Chemical Co.) in thickness from 15 to 100 nm. The tip-sample spacing was controlled by a commercial AFM control system. A commercial cantilever with a tip was coated with Ti by sputtering deposition. A positive dc bias of 10 to 90 V was used to form resist patterns. The exposure dose was controlled by constant-current feedback.[6]

3. Results and Discussion

Figure 1 shows a SEM (scanning electron microscope) picture of a typical L&S resist pattern with a 40 nm-thick resist and an exposure doses of 2.6 nC/cm. The L&S resist pattern using a regular constant bias control resulted in a modulated width of the L&S pattern because of the current modulation by the ununiformity of the resist surface.

Figure 2 shows the sensitivity curves of RD2100N. The sensitivity increased with resist thickness. The sensitivity values at resist thicknesses of 15, 40 and 100 nm were approximately 1.0, 2.9 and 8.8 nC/cm, respectively. The value of the constant γ was about 5, which is copmarable to that of EB lithography.

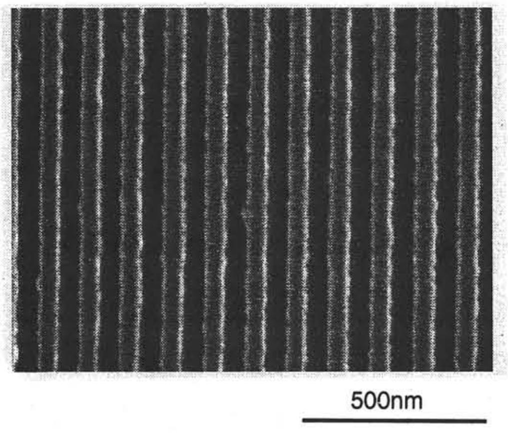

Fig. 1 SEM picture of line and space resist pattern at 40nm.

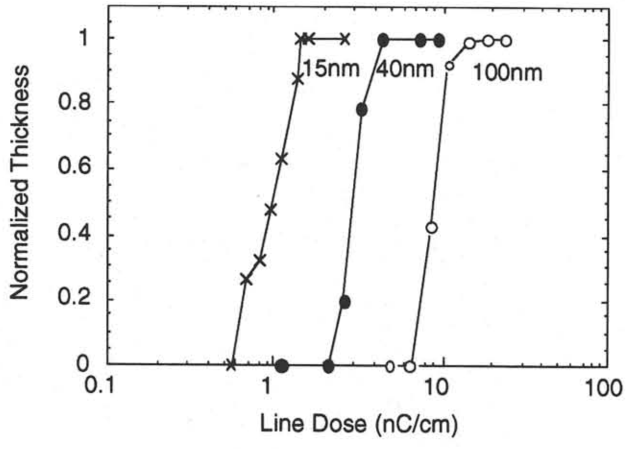

Fig.2 Sensitivity curve of MRS using AFM.

Figure 3 shows cross-sectional SEM pictures of the resist patterns at the exposure doses of (a) 105, (b) 28 and (c) 13 nC/cm. The thickness of the resist is 100 nm in all cases. The resist profiles are steep although the top of the resist surface has concave shape. The AFM images of the resist surface after patterns were written but before development also revealed deformed resist lines. These results indicate that indentation by the tip deformed the surface of the resist because of the strong Coulomb force supplied with the bias voltage between the tip and the substrate. From Fig. 3 it can also be seen that the linewidths of the patterns depend on the exposure dose. Here, the linewidths decreased as the resist thickness decreased. Thus, the resolution depends on the resist thickness. For the resist thickness of 15, 40, 100 nm, the minimum pattern sizes we obtained were 27, 55 and 110 nm, respectively. The dependence may possibly be explained by the current distribution inside the resist.

Figure. 4(a) and 4(b) show a locus of the scanned tip and a SEM picture of a sharp-angle resist pattern with the 40 nm-thick resist and the exposure dose of 10 nC/cm. As shown in the figure, the widening of the pattern is very small, and the radius of the angled corner (arrow), whichwas doubly exposed, is less than 20 nm. These results indicate that the proximity effect, which is one of the major factors limiting the resolution of EB lithography, is small in the case of AFM lithography.

The maximumn line scan speed used in our present system, 100 μm/s, still gives a very low throughput as a lithography technique. However, the throughput problem will be solved by using a set of parallel and by increasing the line scanspeed up to 1 to 10 mm/s.

4. Conclusion

In conclusion, we fabricated resist patterns in negative resist and investigated the characteristics of nanolithography using AFM with a current-controlled exposure system. The cross-sectional shape of the resist is steep and the proximity effect is small, which suggest that SPM lithography has a potential as a powerful technique for nanomater-scaled device and file fabrication.

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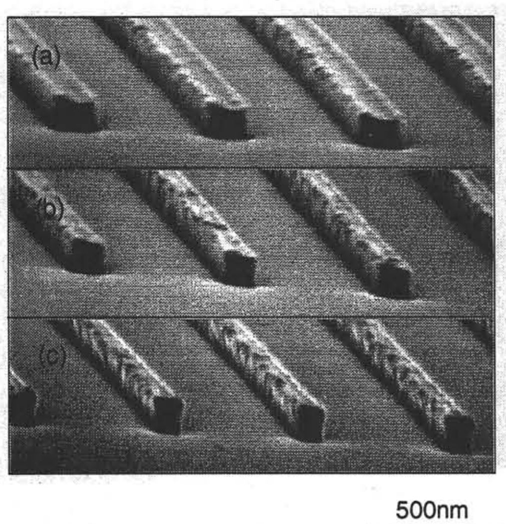

Fig. 3 Cross-sectional SEM pictures of the resist patterns.
Exposure dose of (a) 105nC/cm, (b) 28nC/cm, (c) 13nC/cm.

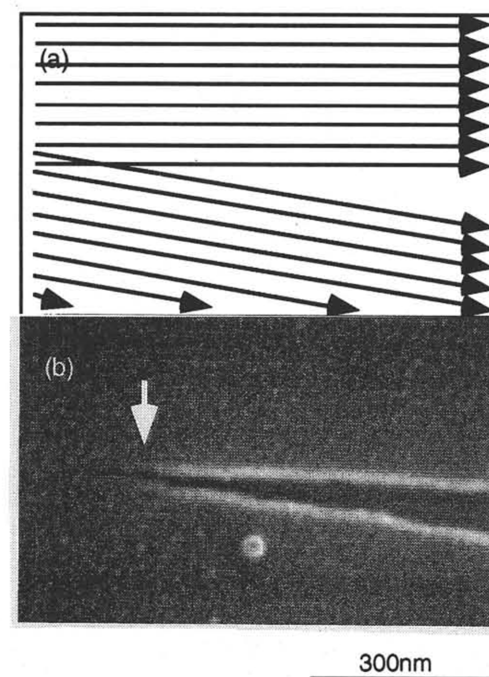

Fig.4. Sharp angle resist pattern .
(a) Locus of scanned tip, (b) SEM picture.

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