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A−2−7 High Resolution Fabrication of Submicron Structures by Ion Beam Lithography

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An interest for scanning focused ion-beam-lithography has been stimulated by researches on high-intensity scanning ion-probe[1) and on ion-beam exposure of resist[2,3). Though the minimum linewidth which is used in VLSI and other device technology is decreasing, electron scattering effect both in resist and substrate severely limits the minimization of resist pattern-width achieved by electron beam lithography.

In ion beam lithography, the high resolution is expected because the lateral spread of deposited energy in resist is negligibly small compared with that of electron beam lithography due to small scattering angle of ions.

In this report, the exposure characteristics and resolution of resist matrial by 50 keV H^+ beam is studied to demonstrate the exellent exposing characteristics and the applicability to microfabrication of ion beam lithography.

A conventional ion-implanter was used to expose resist by 50 keV H^+ beam. PMMA film (0.34 μm thick) on Si substrate was mainly used as resist material for ion beam exposure. Figure 1 is the exposure characteristics of PMMA by 50 keV H^+ beam together with that for 20 keV electron beam from reference 2. The apparent sensitivity of PMMA resist is shown to be more than one order of magnitude higher for 50 keV H^+ beam than for 20 keV electron beam. The γ value corresponding to the slope of characteristic curve in Fig. 1 is 3.3 for a developer of MIBK:IPA=1:3 and 3.0 for that of MIBK and is almost the same as 2.7 for 20 keV electron beam. Figure 2 shows developed thickness of resist of which the initial thickness is sufficiently thick to stop the incident ions. The ion range in PMMA can be estimated about 0.7 μm from the saturated resist thickness removed in Fig. 2.

In order to investigated the resolution of ion beam lithography, Au free standing mask (0.2 ~0.4 μm thick) was used for the replication of patterns. The Au pattern mask with supporting rim of Si was fabricated by chemical etching of a part of Si substrate under the Au patterns. Figure 3 (a) shows the schematic arrangement of mask and wafer, and the mask and the wafer were in contact with each other. Figure 3 (b) and (c) show SEM photographs of top views of Au mask pattern and the replicated PMMA pattern, respectively. The thickness of Au pattern is 0.4 μm and is sufficient for the transfer of the pattern with high contrast. Fine structure (less than 0.1 μm) at the rough edge of the Au line pattern is accurately transfered to PMMA and high resolution of this method is confirmed. Figure 4 also shows a replicated PMMA pattern which is viewed obliquely to see the side wall of the pattern. The vertical walled edge of the pattern indicates that the scattering effect of incident ions has little effect on the replicated PMMA pattern. The little effect of back scattering of ions in ion beam lithography is also clearly seen in Fig. 5. Figure 5 compares SEM photographs of replicated PMMA patterns on Si and Au on Si substrate. Though width of the PMMA line pattern by electron beam lithography is different between that on Si substrate and that on Au substrate, but the difference in ion beam lithography is not observed in Fig. 5 (b).

In summary, 50 keV H^+ beam exposure technique of PMMA resist has excellent features of high resolution (less than 0.1 μm) and high sensitivity ($\sim 1\times10^{-6}$ C/cm^2) . At a modest H^+-current density of 1 μA/cm^2 at 50 keV, the time necessary for exposing PMMA is ~6 s. From those characteristics, ion beam lithography is expected to become useful technique for microfabrication of submicron structures.

References

1) R.L.Seliger et al.,Appl.Phys. Lett. 34 (1979) 310.
2) M.Komuro et al., J. Electrochem. Soc. 126 (1979) 483.
3) L.Karapiperis and C.A.Lee, Appl. Phys. Lett.,35 (1979) 395.

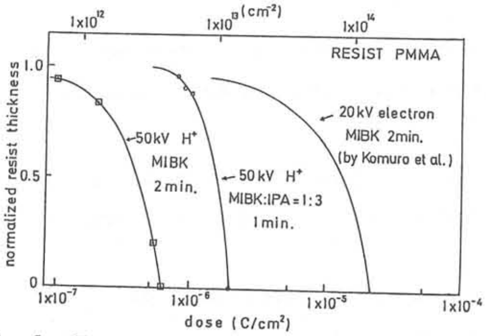

Fig. 1. Exposure characteristics of PMMA resist by H^+ beam. Data from ref. 2 for electron beam is also shown.

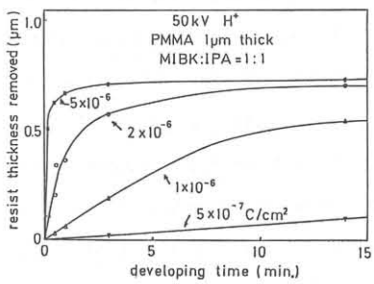

Fig. 2. Resist thickness removed v.s. developing time after irradiation of 50 keV H^+ beam.

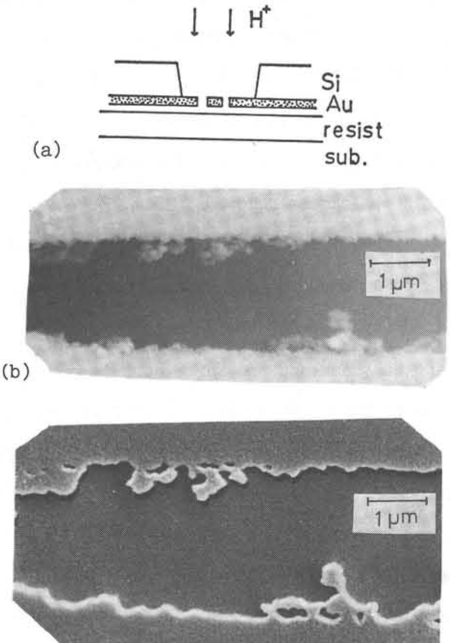

Fig. 3. (a) schematic arrangement of Au mask and wafer and SEM photographs of top views of (b) Au pattern (0.4 μm thick) and (c) the replicated PMMA pattern by 50 keV H^+ beam.

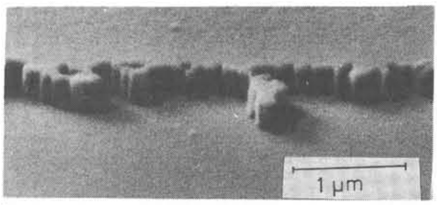

Fig.4. SEM photograph of replicated PMMA pattern of Au mask. The sample is tilted to see the side wall of the pattern.

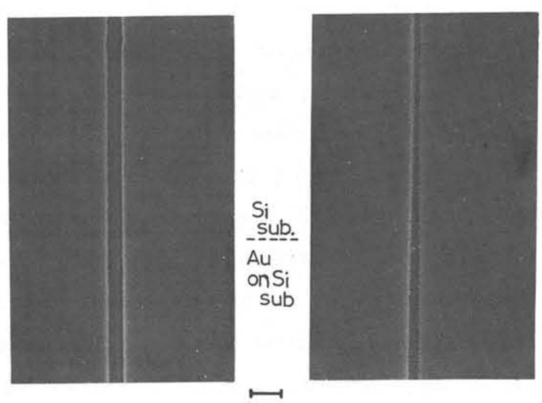

Fig. 5. Comparison of PMMA-pattern-width on Si and 0.1 μm-thick Au on Si substrates between (a) electron and (c) ion beam lithography.