<Technical Report>

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Analysis of Pattern Collapse of Electron Beam Resist Ranging from 60 to 152 nm Width with Atomic Force Microscope Tip

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Abstract

Quantitative analysis of collapse property of an electron beam (EB) resist pattern ranging from 60 to 152 nm width and 220 nm height is demonstrated experimentally. By directly applying a load to a top corner of resist pattern with a micro-cantilever tip, resist line pattern adhering on a substrate can be collapsed easily accompanying slight residue formation. The load required for collapsing pattern decreases linearly with decreasing the pattern width of the resist pattern. The pattern collapse occurs in the cause of insufficient cohesion of the resist material.

In recent years, nanofabrication technique has become important to realize electronic micro devices such as high density memory, liquid crystal display and quantum effective devices. In the lithography process, particularly, resist pattern is regarded as an important mask material for dry or wet etching processes. However, improvement of the adhesion strength of the resist micropattern has been recognized as one serious problem to be solved, because the pattern collapse during water rinsing in the pattern development process occurs drastically due to Laplace force^{1,2)}. In this regard, Namatsu et al. demonstrated that the supercritical drying process as one of the effective solution in order to prevent pattern collapse²⁾. In these days, various studies on adhesive phenomena of resist material have been accomplished by several researchers³⁻⁵⁾. A great deal of effort has been made on monitoring the adhesive property. What seems to be lacking, however, is quantitative and direct analysis physically. Meanwhile, with the invention of the atomic force microscope (AFM)⁶⁾, we have been equipped in good time with the appropriate tools to understand the physi-

cal properties of condensed matter on a nanometer scale⁷⁻¹⁰⁾. Understanding these collapse property is of crucial importance for development not only microelectronic device but for designing polymer material.

Electron beam (EB) resist, chemically amplified negative type, consisting of hydroxystyrene as a base polymer was used. The resist film of 220 nm in thickness was coated onto a Si (100) wafer by a spinning method. The pre-baking treatment was carried out at 110°C for 90 s on a proximity hot plate. The silane-coupling treatment with hexamethyldisilazane (HMDS) as an adhesion promoter was performed at 80°C for 60 s. The line pattern ranging from 60 to 152 nm in width and of 6 mm length were imaged to the resist film by using an EB stepper (HITACHI-HL-750D) with the acceleration voltage of 50 kV. The charge density of EB exposure was approximately 5 $\mu\text{C}/\text{cm}^2$. Post exposure baking was conducted at 120°C for 90 s. Then, the resist films were developed by dipping into tetramethylammoniumhydroxide (TMAH) 2.38% aqueous solution for 60 s. Subsequently, the resist patterns were rinsed in the deionized water for 30 s, and dried by the spin method. In order to observe the resist patterns, a scanning electron microscope (SEM; S-5000 made by HITACHI Ltd.) was used. Fig. 1 shows AFM images of EB resist patterns fabricated on the Si (100)

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substrate.

An AFM (SPA-300, Seiko Instruments Inc.) integrated with a cantilever tip was used for the collapse investigation. The conical shape tip was made of Si single crystal by lithography technique. The curvature radius of tip apex is approximately 9 nm. The spring constant of cantilever was 0.75 N/m. The cantilever torsion by contacting to the resist pattern was detected experimentally using a laser reflection system. The force applied to the resist pattern is determined by multiplying the measured cantilever displacement by the spring constant of the cantilever. The scanning speed of

Fig. 2 Schematic explanation of collapse process. Tip movement was controlled in vector scan program and monitored simultaneously.

(a) 60 nm width

(b) 115 nm width

Fig. 1 AFM images of the line patterns of EB resist. (800 nm square)

the tip was $1 \mu\text{m}/\text{sec}$. Fig. 2 shows the schematic explanation of the collapse process. (a): Prior to the collapse experiment, the pattern shape was imaged in the non-contact mode by which no pattern collapse occurs. (b): The tip traversed the resist pattern under the vector scan control. By directly applying load F to the top corner of resist pattern with the cantilever tip, the resist pattern adhering on the substrate can be collapsed easily. Fig. 3 shows the force-distance curve of the cantilever for resist pattern of 60 nm width. The maximum force F_m corresponds to the load required for collapsing the pattern. As the causes of the background difference before and after reaching the maximum force F_m , it can be considered that the collapsed pattern adheres on the tip apex and that the tip run onto the collapsed pattern. This load F_m can be regarded as the meaningful value which reflects the adhesion and cohesion properties. In this study, the line width dependency of collapse property of EB resist pattern is focused. In Fig. 2 (c): The pattern collapse and residue formation can be reconfirmed by imaging the sample in the non-contact mode. Neither the AFM tip nor the resist pattern appeared to be damaged as a result of the surface imaging procedure. Five pieces of line patterns were used for collapse investigation for each size. All investigations were carried out in a dry atmosphere (21°C , 4 %RH), because water vapor is known to coat surfaces with several monolayers after a brief exposure to ambient conditions.

Fig. 3 The load applied by cantilever tip during vector scan. Negative sign of load indicates deformation direction of cantilever opposite to the scanning direction.

Fig. 4 Dependence of load required for collapsing on the pattern width of resist pattern.

Fig. 4 shows the data from the load required for collapsing pattern F_m at various line width. The load F_m decreases linearly as pattern width decreases. The standard deviation of the load F_m is relatively low. By using the AFM, size dependency of adhesion property of micro-condensed matter can be detected clearly. Moreover, by imaging the substrate surface

after pattern collapse, a slight residue of resist material, approximately 20 nm height, can be observed. Therefore, one can safely state that the pattern collapse occurs in the cause of insufficient cohesion of the resist material. This method in this study can be applied to F_2 excimer resist patterns and synchrotron radiation resist patterns less than 100 nm in width. Moreover, this technique will give useful information to other fields, for example, condensation control of nano-size particles and structural design for quantum effect devices and so on.

In order to improve the measurement accuracy of the collapse investigation, the following issues should be taken into consideration: (i) Plastic deformation and friction resulting from the contact between the cantilever tip and the resist pattern surface should be clarified. (ii) The actual contact area between the tip and the resist pattern surface should be estimated quantitatively. In order to analyze the results in this paper on the point of energy dimension, discussing above two items is also important.

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<研究速報>

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原子間力顕微鏡を用いた線幅 60~152nm の
電子線用レジストパターンの倒壊特性の解析

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要 旨

線幅 60~152nm で高さが 220nm である電子線 (EB) 用レジストパターンの倒壊特性の定量解析を行った。微細なカンチレバー探針を用いて、レジストパターン上部の角に荷重を加えることにより、レジストラインパターンを容易に倒壊することができる。その際、基板上に僅かながらレジスト残さを形成していた。パターン線幅の減少に伴って、倒壊が生じる荷重も線形的に減少する。パターン倒壊は、レジスト材料の凝集力不足が原因で生じる考えられる。

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