Non-Contacting Deformation (NCD) of Line Resist Pattern due to Interaction Force with AFM Tip

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It is entirely fair to say that the minute resist pattern should be deformed due to interaction force without any contact force, that is, non-contacting deformation (NCD). The NCD of a resist pattern can be analyzed based on the interaction investigation using atomic force microscope (AFM). An EB chemically amplified line resist patterns from 60 to 115 nm width and 210 nm height were used as the test patterns. In the force measurement, the AFM tip approaches to the top corner of line resist pattern, then, the AFM tip begins to bend toward the resist pattern due to the interaction force. We calculated the amount of NCD of the line resist pattern by 3D-finite element method (FEM). As decreasing the resist pattern width, the interaction force decreases but the NCD of resist pattern increases. The NCD less than 50nm design rule is also discussed quantitatively.

Keywords: non-contacting deformation (NCD), interaction force, resist, Hamaker constant, atomic force microscope, finite element method (FEM)

1. Introduction

Recently, as increasing the integration density of micro electronic devices, the resist pattern size less than few tens nanometer should be required. In general, the surface properties of minute solid material are enhanced comparing with its cohesion property. As well known, the line edge roughness (LER) has been recognized as a serious problem to be solved.[1] Meanwhile, as the another serious problem in future, we found out the non-contacting deformation (NCD) of a resist pattern, that is, deformation of the minute resist pattern due to interaction force without any contact force.[2] It seems reasonably to suppose that the NCD of a resist pattern should affect to an accuracy of line width after etching procedure. Meanwhile, in order to quantify various weak interactions acting on a condensed matter, atomic force microscope (AFM) [3] is utilized. In this paper, we focus on NCD of the line resist pattern due to interaction force with an AFM tip in non-contacting stage. Based on the deformation measurement, the amount of NCD less than 50nm width pattern can be discussed quantitatively.

2. Experiment

In the force measurement, the AFM tip approaches to the resist pattern from the resting position at which no interaction force acts on the tip apex. Then, both the AFM tip and the local area of line pattern begin to bend toward resist pattern surface due to interaction force as shown in Fig.1.

Fig.1 Schematic illustration of the NCD acting between AFM tip and line resist pattern.
3. Results and Discussion

3.1. Interaction between AFM tip and resist line pattern

Figure 3 shows the interaction curves between the AFM tip and the resist patterns. The plots as shown in Fig.3 indicate the measurement data for various line width patterns. It is clearly observed that the attractive force starts to act less than 5nm distance. From these results, the attractive interaction force $F$ before making a contact is defined as the maximum force in each interaction curve, and they can be clearly detected. In this way, the NCD occurs surely between the AFM tip and the resist patterns. Therefore, we can fare certain state that the NCD should occur in the practical resist patterns which are closely formed on a substrate each other. Figure 4 shows the interaction force $F$ depending on the line pattern width $w$.

\[
\frac{1}{k} = \frac{1}{k_T} + \frac{1}{k_R} \quad [N/m] \quad (1)
\]

The interaction distance $d$ between the AFM tip and resist pattern is also defined. A commercially available AFM was used for the interaction measurement. The calibration measurements of the spring constant correlated well with the manufacturer's given value of $k_T = 1.2$ N/m. The radius of curvature $R_T$ of the tip apex is approximately 8 nm as shown in Fig.2a. An EB chemically amplified line resist patterns from 60 to 115 nm width and 210 nm height were used, as shown in Figs.2b and 2c. The curvature radius in cross section of the pattern top corner can be measured with the AFM. Both the curvature of tip apex and the resist pattern top are used for analyzing Hamaker constant of this system. Hamaker constant can be calculated by utilizing the optical constants of materials and the interaction force.[4] The local deformation occurred of the line pattern can be estimated by 3D-FEM.
By fitting with the theoretical data to the measurement one, Hamaker constant $H$ in this system can be determined as $8 \times 10^{-20}$ [J], as shown in Fig.4. For the comparison, Hamaker constants are $6.5 \times 10^{-20}$ [J] for Polystyrene-Air-Polystyrene system, $7.5 \times 10^{-20}$ [J] for PVC-Air-PVC system and $14 \times 10^{-20}$ [J] for Alumina-Air-Alumina system. Therefore, the obtained value is reasonable comparing with the practical interaction systems.

Then, we will discuss the amount of NCD obtained by the FEM simulation in the next section.

3.2. Analysis of NCD by FEM simulation

The amount of pattern deformation due to NCD can be estimated by the 3D-FEM simulation. Figure 6 shows the pattern mesh model for the 3D-FEM analysis. The resist pattern shape is divided into approximately 1000 elements in this case. The symbols $h$, $L$ and $w$ represent pattern height, length and width, respectively. As previously mentioned, the pattern width $w$ corresponds to $2R_2$. By changing the pattern width $w$, the NCD of the resist pattern less than 50nm width can be analyzed. The basic assumptions made in performing FEM analysis are as follows. (1) The physical properties of material are linearly related to interaction force. (2) The resist/substrate interface is defined as a fixed point, that is, no deformation occurs at the substrate. Young's modulus and Poisson ratio of resist material used for the calculation are 1.2 GPa and 0.34, respectively.

Figure 7 shows an example of the simulation result of the pattern deformation by the 3D-FEM. The pattern deformation $x$ at the center of the line pattern can be estimated.
Fig. 7 Pattern deformation due to interaction force.

In this regard, the pattern deformation $x$ for various height and width is shown in Fig. 8. The pattern height 210nm corresponds to the experimental condition. As decreasing the pattern width $w$, the pattern deformation $x$ increases gradually. Particularly, in the case of resist pattern less than 50nm width, the deformation extremely increased. Moreover, it is clearly observed that the pattern deformation has close correlation to the pattern height. In order to control the pattern deformation $x$ less than 1nm, the aspect ratio of resist pattern should design less than 4. As the integration density of micro devices increases, the NCD should be recognized as one serious problem.

4. Conclusion

We discussed the mechanism of NCD of the minute resist pattern due to interaction force with the AFM tip. As decreasing the resist pattern width, the interaction force decreases, but the pattern deformation less than 50nm extremely increased. Hamaker constant is determined to be $8 \times 10^{-20}$ [J]. It can be considered that the NCD is recognized as one serious problem to be solved as similar to LER in the future device fabrication.

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References