Deformation Analysis of ArF Resist Pattern by using AFM

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1. Introduction
Resist lithography is a representative technique of printing a minute pattern on a silicon wafer. In the lithography process, it is well known that Laplace force affects strongly on the resist pattern deformation during the pattern development. Therefore, it is necessary to analyze the cohesion property of resist pattern quantitatively. In this regard, direct peeling method with AFM tip (DPAT) is proposed as an useful technique to evaluate directly the mechanical properties of the resist pattern.[1] In this paper, we analyze deformation and Young’s modulus of an isolate resist pattern by the DPAT method.

2. Experiment
2.1 Sample preparation
An ArF excimer resist consisting of acrylic resin as a base polymer was used. The pattern width, length and height were 100, 700 and 200nm. As the BARC materials consisting of acrylic resin were used. The thickness of the BARC layers after the hard baking at 205°C was 80-100nm. A commercially available AFM, integrated with a micro cantilever tip, was used for the DPAT investigation. The curvature radius of tip apex was approximately 8nm. The spring constant of the cantilever (k_c) was 0.6719N/m. The applied force to the resist pattern is determined by multiplying the measured cantilever displacement by the spring constant k_c of the cantilever.

2.2 DPAT Method
Measurement of Young’s modulus of resist pattern was conducted in drying air (less than 5%RH). The experimental setup is as shown in Fig.1. The cantilever deformation was detected in bending and distortion directions. The deformation was detected by the four divided photo detector.

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2.3 Calculation

The spring constant of the resist pattern ($k_R$) is derived from the chain spring constant model as shown in Fig.2. Based on the model, the spring constant of resist pattern ($k_R$) was calculated by the Eq.1 [2].

\[ k_{tot} = \frac{k_c k_R}{k_c + k_R} \]  \hspace{1cm} (1)

In this case, the Young’s modulus $E$ of resist pattern was calculated by Eq.2.

\[ E = \frac{4h^3 k_R}{wl^3} \]  \hspace{1cm} (2)

where symbol $h$ is height of the resist pattern, $w$ is width of the resist pattern, $l$ is the width of the resist pattern. The total spring constant composed with the resist pattern and the cantilever $k_{tot}$ can be obtained by the deformation profile in Fig.3.

![Peeling profile of resist pattern by DPAT.](image)

3. Estimation of Young’s modulus

The $k_{tot}$ value is measured by the deformation profile of the resist pattern on the BARC. Table 1 summarizes the calculation results. The average of Young’s modulus of the resist pattern on the BARC can be estimated as 4.28MPa. In general, Young’s modulus of a minute resist pattern was estimated experimentally to be 1.2GPa [1]. Table 2 shows Young’s modulus of various polymers. Young’s modulus estimated in this paper is too small to compare with the other data. The reason why the resist pattern couldn’t be deformed uniformly is that the cantilever applies force on the local point of the resist pattern. Thus, the strain is concentrated to the center of the resist pattern. To modify Eq.2, data fitting with deformation analysis by finite element method (FEM) is necessary to estimate the distribution of strain of the resist pattern.

4. Conclusion

By the DPAT method, it is possible to deform the isolated resist pattern directly. The Young’s modulus is estimated but it is important to support with the local deformation analysis by FEM.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polystyrene</td>
<td>2.7 ~ 4.2GPa</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.4 ~ 1.3GPa</td>
</tr>
<tr>
<td>Nylon</td>
<td>1.2 ~ 2.9GPa</td>
</tr>
<tr>
<td>Elastic rubber</td>
<td>1.5 ~ 5.0MPa</td>
</tr>
</tbody>
</table>

Table 2 Young’s modulus of various polymers.

![Peeling force vs. PZT stage displacement](image)

![Calculation result of Young’s modulus.](image)

![Table 1](image)

References