Dependence of De-molding Force on Process Conditions in UV Nanoimprint

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The de-molding force between a UV resist and a Si dioxide surface is measured for various UV light intensities and exposure times. Typical UV radical polymerization resists are examined without any surface treatment of the Si dioxide surface for releasing. The result shows that the de-molding force increases in as increments of the UV light intensity, however it does not depend on the UV dosage. But the de-molding force depends on the product of the square root of the light intensity and exposure time, which is nearly consistent with the UV curing characteristics of the polymer.

Keywords: UV nanoimprint, UV curable resist, de-molding force, light intensity, dosage

1. Introduction

Nanoimprint lithography [1] is expected to produce fine patterns for advanced devices at efficient costs. UV nanoimprint is especially applied for such industrial applications as subwavelength optical elements or patterned media because the total turnaround time is shorter than for the thermal nanoimprint process.

In the UV nanoimprint process, one issue is the de-molding process that affects the defect yield. Even though the UV curing properties, including the polymer's adhesive characteristics, are essential for de-molding, there are few reports on de-molding characteristics related to UV curing characteristics, such as UV light intensity or exposure time.

Our previous report investigated the relations between the UV curing characteristics of radical UV resists and exposure light intensity [2]. Monomer consumption and modulus modification are fairly expressed by the product of the square root of the light intensity and the exposure time.

This paper investigates C-TGC-02 and

C-TGC-03 resists (Toyo Gosei), which are pilot UV radical resists. The de-molding force between the resist and the SiO₂ surface is measured for various UV light intensities, and the results are compared to such UV curing characteristics as the monomer conversion ratio.

2. Experiment

There are two types of UV curable resists for nanoimprint lithography: a radical polymerization type and an ion polymerization type. In this study, we examined C-TGC-02 and C-TGC-03 resists, which are pilot UV radical resists that consist of acrylic acid adduct of propyleneglycol diglycidyl ether/2-methyl-1-(4-methylthiophenyl)-2-morpholino-propane-1-one produced by Toyo Gosei.

Figure 1 shows the schematics of the sample. On a quartz plate, the UV resist is spin-coated using a primer to strongly adhere it to the plate. Then a Si tip with a SiO₂ thin layer is put on the resist, where the SiO₂ layer is grown by piranha boiling (H₂SO₄ + H₂O₂) for 30 minutes. The Si tip is 10 mm

squared and gulled on an Al base.

Then UV light is irradiated to the resist through the quartz plate to cure it. To eliminate the effects of a release agent and the friction between a resist and a mold pattern, a flat SiO₂ surface on a Si substrate is used. The arial distribution of the UV light intensity is measured, and the deviation is kept less than 10% of the 10 mm squared.

Figure 1 Schematic of sample preparation

Figure. 2 Schematic of de-molding force measurement

Figure 2 show the schematic of the measurement of the de-molding force. The force gauge is connected to the Al base through a flexible joint and its position is fixed. The quartz plate is pulled down by a stepping motor at 0.1mm/s. The de-molding force is measured by the force gauge when the resist is released from the SiO₂ surface. The de-molding force per unit area of the Si tip is evaluated as the de-molding pressure.

3. Results and discussions

3.1 De-molding force measurement

Figures 3 and 4 show the measured de-molding force per unit area in variation with UV light intensity I for C-TGC-02 and C-TGC-03 resists. The intensities of the UV lights are 1, 3, and 30 mW/cm². As the UV irradiation time increases, the de-molding force also increases. As the increment of the UV intensity increases, the increment of the de-molding force is accelerated.

3.2 Relation to polymerization of resists

To investigate the relations between the de-molding force and the polymerization of resists by UV irradiation, we evaluated the dependence of the de-molding force on the exposure dosages. Figures. 5 and 6 show the relations between the de-molding force per unit area and the exposure dosages for various UV light intensities. The de-molding forces not only depend on the UV exposure dosages but also on the UV light intensity.

The chemical reaction speed of the UV radical polymerization resist depends on the products of the square root of UV intensity I and exposure time t [2]. Figures. 7 and 8 show the relations between the de-molding force per unit area and $\sqrt{It}$ for various UV light intensities. The de-molding forces are fairly expressed by the value of $\sqrt{It}$. This means that the de-molding force is nearly related to the polymer's UV curing characteristics.

To compare these phenomena with the chemical reactions of the resists, monomer conversion ratios were evaluated by FTIR (Figs. 9 and 10). The increment of the de-molding forces was delayed more than the monomer conversion by UV radical polymerization.

4. Conclusion

The de-molding force on various UV light intensities and exposure times was experimentally investigated using UV radical polymerization resists. The de-molding force is related to the product of the square root of the light intensity and the exposure time, which is related to the monomer conversion of the resists.

Figure 3 De-molding force for C-TGC-02

Figure 4 De-molding force for C-TGC-03

Figure 5 Dependence on dosage for C-TGC-02

Figure 6 Dependence on dosage for C-TGC-03

Figure 7 Dependence on $\sqrt{I}t$ for C-TGC-02

Figure 8 Dependence on $\sqrt{I}t$ for C-TGC-03

Figure 9 Monomer conversion for C-TGC-02

Figure 10 Monomer conversion for C-TGC-03

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