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Durability of Quartz Mold and Failure Mode Analysis in Imprint Lithography

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1. Introduction

Miniaturization has been achieved recently in electronics, optics, and micro-electromechanical systems. The demand for the fabrication at low cost has evolved. Fine patterns with accurate alignment are indispensable for the small and functional devices. However the very expensive equipments such as the steppers and the dry etching equipments are needed to form fine patterns in micro fabrication.

Imprint lithography has been developed as a candidate to solve such an issue[1]. This technique has been recognized as a micro-fabrication technique that can be used as an alternative to conventional photolithography. This technique makes it possible to fabricate the micro patterns at high resolution and high-throughput without expensive equipments.

Two kinds of methods in imprint lithography have been previously reported, thermal imprint lithography[1] and photo curing imprint lithography[2]. Thermal imprint lithography, with a heat cycle, had considerable amount of pattern placement errors because of the thermal expansion and shrinkage[3]. Photo-curing imprint lithography, at room temperature, is suitable for the fabrication of fine patterns with accurate alignment.

Figure 1 shows the process flow of the photo-curing imprint lithography. A mold which has micro ditches of designed micro shape is prepared and the resin is coated on the substrate. The resin is pressed by the mold, and is photo-cured. The mold is released from the resin. Then the structures of the ditches in the mold are transferred to the resin.

In order to use this technique for the mass production, it is necessary to examine the durability of the mold. In photo-curing imprint lithography the mold has to be made of the material which transmits the light. The quartz is generally used as the mold material because quartz mold, which has high transmittance of the light, can be made by the conventional semiconductor fabrication technology. However the press and the release in the process give rise to the brittle fractures of the quartz mold. Making the causes of the failures clarified, the durability should be improved to be at the level that it can be used for the mass production.

Although the repeatability of the mold use for decades of times were reported by Chou et al.[1] and Zacharatos et al.[4], there are few reports on the durability of the mold and the failures in the repetitions of the photo-curing imprint lithography process. In this article, we examined the durability of the quartz mold in the repetitions of the photo-curing imprint lithography process for a thousand times, and the failure modes were analyzed.

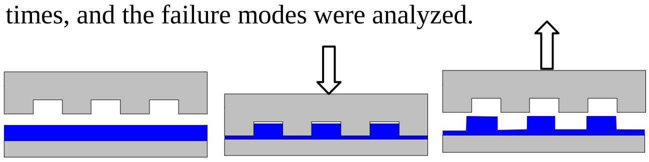

Fig.1 Schematic diagram of photo-curing imprint lithography process.

2. Experiment

We formed a quartz mold by reactive-ion etching using patterned metal mask. Table 1 shows the properties of the mold. The mold has two kinds of width patterns, 5-μm width and 10-μm width, of 7-μm depth. We treated the mold with a surfactant, the silane-coupling agent of the fluorinated polymer, in order to assist the release of the mold.

The mold was pressed to the photo-curable acryl resin coated on the glass substrates. Then the mold was released from the resin after the exposure. We processed them for a thousand times. The process conditions are shown in Table 2. In repetitions of this process, the mold was cleaned with acetone and treated with the surfactant every forty times.

The mold was observed to clarify whether the following failures take place; 1) Cracks in the base material, 2) Adhesion of the resin, and 3) Breakage of the patterns. We studied the cause of failures by using weibull analysis.

Table 1. Mold properties used in this work

Material	Quartz
Thickness	0.5mm
Size	100mmϕ
Patterns	L/S=5/12μm (length=2mm, length=3mm)
	10/12μm (length=2mm)
Depth	7μm

Table 2. Process conditions

Resin thickness	7 μm
Pressure	5 MPa
Holding time	5 min
Exposure	500mJ/cm^2 by Metal halide lamp

3. Results

Figure 2 shows the photographs of the quartz mold and the cross sectional images of patterns after a thousand times repetitions of the process. We couldn't observe, in the mold, any cracks in the base material and adhesion of the resin (Fig. 2(a)). We could not observe the 10-μm wide pattern broken (Fig. 2(b)). However the breakages of the 5-μm wide patterns were observed (Fig. 2(c)). The breakage of the 5-μm wide pattern took place in the root of the cross sectional pattern profile.

Figure 3 shows the incidence of the breakage of 5-μm wide pattern against the number of the repetitions of the process. The incidence of the breakage had been gradually increasing as repeating the process.

Figure 4 shows the weibull plot of the breakage of 5-μm wide patterns. The weibull plot could be optimized to two lines. The shape parameters m, known as the weibull slope which shows the behavior of failure distribution, were m=0.4 and m=0.06.

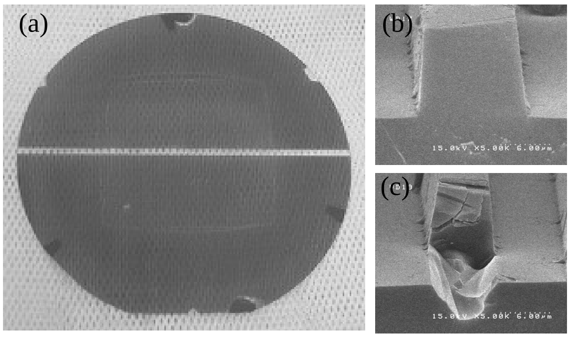

Fig.2 The mold after a thousand times repetition of the process. (a)Photograph of the whole mold. (b)Cross sectional image of a 10-μm wide pattern. (c)Cross sectional image of a 5-μm wide pattern.

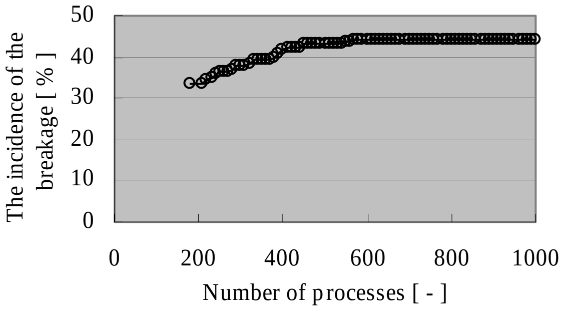

Fig.3 The incidence of the breakage of 5-μm wide patterns against the number of processes.

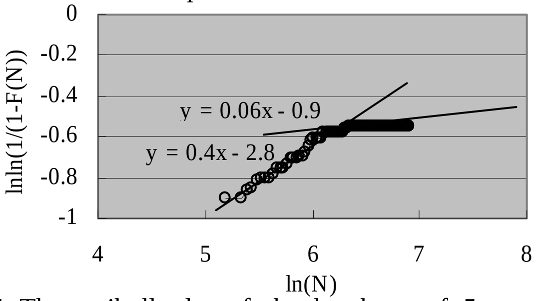

Fig.4 The weibull plot of the breakage of 5-μm wide patterns.

4. Discussion

It was made clear that the durability of the quartz mold depended on the width of the patterns. Wide patterns are hard to break compared to fine patterns. The cracks of the base material and the adhesion of the resin can not be detected on the mold. These represent that the mold with only the wide patterns can be used for one thousand times.

The breakage in the fine patterns was observed in the root of the cross sectional pattern profile. This reveals that the breakage was caused by the stress concentration in the root of the pattern profile. The press and release of the mold apply the stress to the patterns. The leverage enhances the stress in the fine patterns whose aspect ratios are high.

The weibull plot of the breakage was optimized to two lines. This suggests that there are two kinds of tendency of the failure incidence. This results from the existence of two kinds of length in 5-μm wide patterns. The different length of patterns gives the different incidence of the breakage.

Since the shape parameters obtained by the weibull plot were smaller than 1, the breakage rate are decreasing as progressing the repetitions of the process. This indicates that the failures were in the initial failure period. The failures derive not from the storage of the stress but from the phenomena in the weak point of the patterns. Strengthening the root of the pattern profiles, the durability of the mold even with fine patterns is improved. To make the cross sectional shapes of the root dull can be a way to strength the root of the patterns.

5. Summary

The durability of the quartz mold in photo-curing imprint lithography was examined. The cracks of the base material, the adhesion of the resin, and the breakage of the wide patterns could not be observed after a thousand times repetition of the photo-curing imprint lithography process. The mold with the wide patterns can be used for one thousand times.

However the breakage of the fine patterns occurred. The breakage was caused by the stress concentration in the root of the cross sectional pattern profile. The weibull plot indicated the breakage was in the initial failure period. Strengthening the root of the cross sectional pattern profile, the durability of the mold even with fine patterns is improved.

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