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Compound Nanoimprint Processes and Their Applications for Functional Nanodevices

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1. Introduction

The basic UV-NIL process recently has become well known. The UV-NIL process is different from conventional lithography technologies, because thin residual resin remains on the printed area in the UV-NIL process. Once the residuals are removed by O_2 RIE, it is possible to fabricate nanopatterns on the substrate by etching with resin mask patterns. Since nanometal patterns are formed by electroplating with resin patterns, UV-NIL can be combined with electroplating to yield a compound nanoimprint process. Section 2 introduces the newly developed photocurable resins. Section 3 describes applications of the UV-NIL compound nanoimprint process for LEDs and High-Density Patterned Media.

2. Photocurable Resins

It is expected that UV-NIL will be applied to nanometal structures by the chemical or electrochemical wet processes of plating, etc. Chemical durability and adhesiveness to the substrate will be required in these applications. A new resin, TR-11, was developed for this purpose. Fig. 1 shows the results of our evaluation of the durability of both PAK-01 and TR-11 against the wet process. Line and space resin patterns of 10um in width and 350nm in height were made as an experimental sample. The resin was spin coated onto the silicon substrate that was 20mm square and had a film thickness of 2um, and then UV of 1000mJ/cm^2 was irradiated to the resin. The plating durability was evaluated by referring to the electrodeposition condition in the magnetic pattern on the substrate used in our experiment. Table 1 shows the conditions of our experiment. The PAK-01 patterns flaked off from the substrate when it had been immersed in the plating liquid for 20min. On the other hand, there was no change in the TR-11 pattern. In addition, even though PAK-01 shows better adhesion to the Si substrate than TR-11, the swelling of PAK-01 poses a problem for actual applications.

Table 1 Experimental condition

Solution	Trisodium citrate
pH	6
Imemersion time	20min
Drying method	Deionized water

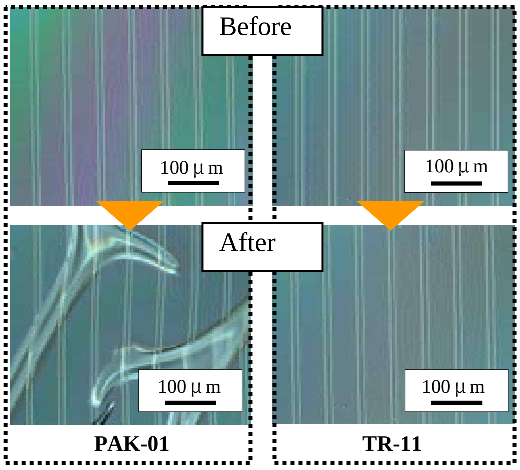

Fig. 1 Resin patterns before and after durability

3. Applications of UV-NIL

3.1 LEDs

Light-extraction efficiency is an important factor for higher-luminescence LEDS. Light-extraction efficiency is increased by reducing the reflection of light on the LED surface. There have been reports that nanostructures on the LED surface prevent reflection [1][2]. We were able to make a metal nanoscale mask for etching in a large area by using UV nanoimprint in combination with electrodeposition.

By using this mask and reactive ion etching (RIE), we fabricated nanostructures of GaN for antireflection. The fabrication process consisted of five steps, as shown in Fig. 2. First, photocurable resin was used to form replicated patterns having resistance to electrodeposition by UV-NIL. The mold had dots of 225nm in depth, 200nm in diameter, and 500nm pitches. Next, Ni nanopatterns were electrodeposited to the holes using the seed layer. Ni was used as an etching mask because it has high resistance to Cl_2 RIE. Then, the photocurable resin was removed. Subsequently, the GaN substrate was etched by Cl_2-based inductive coupled plasma (ICP) RIE. Finally, the Ni mask and the seed layer were removed. As a result of this process, nanostructures of 600nm in depth, 300nm in diameter, and 500nm pitches were formed on the surface of the GaN substrate. When measured by a photodiode, the light output from the front surface of this fabricated LED was 1.5 times higher than that from a conventional LED (see Fig. 3).

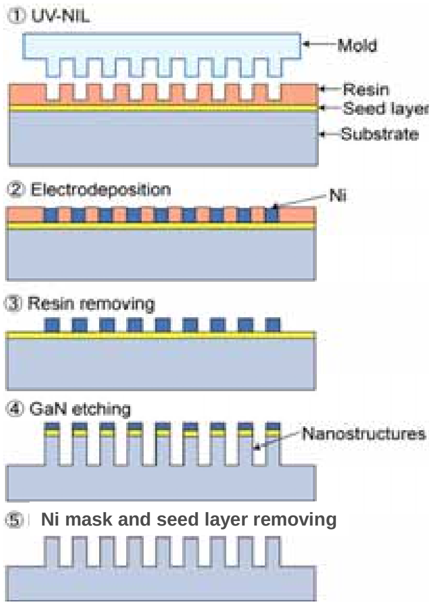

Fig. 2 GaN nanostructure fabrication process

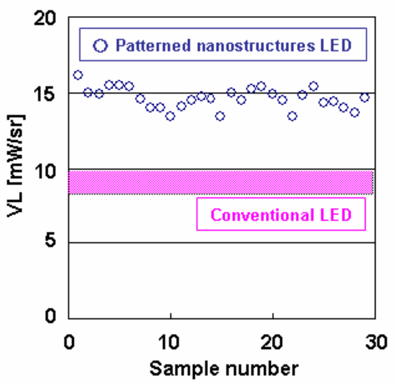

Fig. 3 Light-output from front surfaces of experimental and conventional LEDs

3.2 High Density Patterned Media

Patterned media are attracting considerable attention as a next-generation magnetic recording medium [3]. The process used to fabricate this medium is as follows. Photocurable resin (TR-21 from Toyo Gosei Co., Ltd.) was spin-coated onto the silicon substrate. The UV-cured resin, which had a thickness of 90nm, showed high durability against the electrodeposition and oxygen of dry etching. Then, the nanohole pattern was formed by UV imprinting equipment (ST-50 from Toshiba Machine Co., Ltd.). The force applied to the quartz mold was 3 kN. UV was irradiated at a wavelength of 365 nm to solidify the resin. To remove the micro/nano air bubbles, the imprint process was carried out under reduced pressure (30 hPa). After the mold was released, the residual layer was removed by oxygen reactive ion etching. The etching condition was optimized to reduce the side etching. By using a rotating disk electrode (RDE) apparatus, CoPt was electrodeposited at a constant potential onto the surface of the seed layer. Finally, the CoPt nanodots array and the resin surface were planarized by chemical mechanical polishing (CMP) equipment (MA-400D from Musashino Denshi Co., Ltd.). Fig. 4 shows the results of electrodeposition onto the actual hole pattern. As measured from the SEM images, the CoPt nanodots were 120 nm in diameter and 120 nm in height. Fig. 5 shows an AFM image in the track area and the corresponding MFM image. These two images indicate that magnetic domains were formed that corresponded in position to the nanodots array.

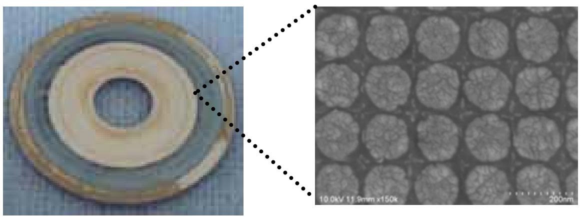

Fig. 4 Result of electrodeposition.
Left: Photograph of disk. Right: Magnified SEM image.

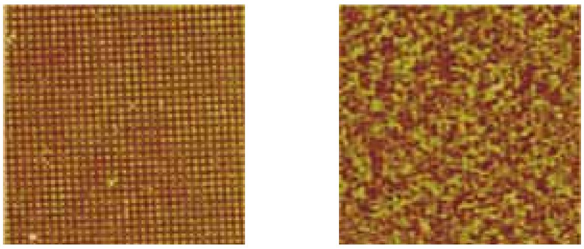

Fig. 5 Result of electrodeposition.
Left: AFM image. Right: Magnified MFM image

4. Conclusions

A magnetic nanodots array fabrication method using UV nanoimprint lithography (UV-NIL) and electrodeposition was developed. Since the photoculable resin patterned by UV-NIL was directly used for the electrodeposition mask, a simple and high-throughput fabrication process was realized. If NIL technology progresses rapidly over the next several years at the appropriate technological level, it will become useful for practical applications. It is expected that NIL technology could contribute greatly to industry if new resins are developed that are appropriate for various applications.

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