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Development of 3d micro–nano hybrid patterns using anodized aluminum and micro-indentation

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Abstract

We developed a simple and cost-effective method of fabricating 3D micro–nano hybrid patterns in which micro-indentation is applied on the anodized aluminum substrate. Nano-patterns were formed first on the aluminum substrate, and then micro-patterns were fabricated by deforming the nano-patterned aluminum substrate. Hemispherical nano-patterns with a 150 nm-diameter on an aluminum substrate were fabricated by anodizing and alumina removing process. Then, micro-pyramid patterns with a side-length of 50 μm were formed on the nano-patterns using micro-indentation. To verify 3D micro–nano hybrid patterns, we replicated 3D micro–nano hybrid patterns by a hot-embossing process. 3D micro–nano hybrid patterns may be used in nano-photonic devices and nano-biochips applications.

Keywords: Micro–nano hybrid pattern; Anodized aluminum; Micro-indentation; Hemispherical nano-pattern

1. Introduction

Recently, micro electro mechanical systems (MEMS) and nano-technologies are being used in various applications such as electrochemical nano-biochips, nano-photonics, ubiquitous sensors and nano-patterned displays. All of these applications require micro- and nano-patterns. In some special cases, micro–nano hybrid patterns are demanded to improve their performance.

Micro-patterns are easily fabricated by MEMS technologies or precision mechanical machining. Sometimes, these micro-patterns with various sizes and shapes are used as the mold for the injection molding and hot-embossing process for the multiple replications [1–5]. In addition, nano-patterns fabricated by e-beam lithography, hologram lithography and nano-probe lithography are also variously applied to the bio and optical applications [6–8].

For fabrication of the micro–nano hybrid patterns, the method of using the block copolymer was suggested by Choi et al. [9]. However, this method was limited only to the 2 dimensional patterns on the flat substrate. In order to improve the resolution of nano-bio sensors and optical brightness of nano-optical elements, 3D micro–nano hybrid patterns were taken into account seriously. However, the conventional approaches such as e-beam lithography and block copolymer for the fabrication of the 3D micro–nano hybrid patterns are not only expensive but also locally fabricated and limited to the flat substrate.

This paper presents a simple method of fabricating 3D micro–nano hybrid patterns using micro-indentation on the anodized aluminum substrate. The aluminum substrate with hybrid patterns was used as the mold for replication on the polycarbonate (PC) substrate by a hot-embossing process.

2. Fabrication of 3D micro–nano hybrid patterns

In the conventional fabrication methods of the micro–nano hybrid patterns, micro-patterns were first fabricated and then nano-patterns were formed on the micro-patterns. Therefore, 3D hybrid patterns were hardly fabricated because the surface morphology of micro-patterns obstructs the fabrication process of nano-patterns. Moreover, these hybrid patterns have been

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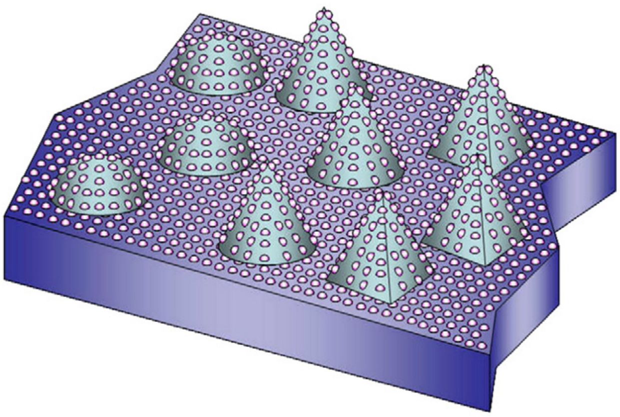

Fig. 1. Schematic illustration of 3D micro–nano hybrid patterns.

limited to the 2D patterns. For the fabrication of 3D micro–nano hybrid patterns as shown in Fig. 1, we used the method by which nano-patterns were first built up, and then micro-patterns were fabricated on the nano-patterned substrate using a micro-indenter with the micro-scale tip.

2.1. Nano-patterns

For the fabrication of nano-scale patterns, e-beam lithography and hologram lithography based on laser have been generally used. These two methods are not only expensive approaches but also are limited to a local region of around several millimeters. In this research, a simple and cost-effective fabrication method for hemispherical nano-patterns was used. The hemispherical nano-pattern array can be easily obtained by anodizing pure aluminum and removing the anodized aluminum oxide (AAO) layer [10–14].

Fig. 2 shows the fabrication process of 3D micro–nano hybrid patterns using the anodized aluminum and the micro-indentation process. When pure aluminum is anodized in the electrolyte, a nano-porous AAO structure is formed (Fig. 2—step2). The interface between AAO and the base aluminum layer is kept up with the hemispherical nano-patterns owing to the self-assembly characteristics of the anodizing process (Fig. 2—step3). Furthermore, the diameter of hemispherical nano-patterns can be easily controlled from tens of nano-meters to several hundred nanometers by changing the applied voltage and the composition and temperature of the electrolyte.

In the experimental study, pure aluminum (99.999% purity) was anodized in a 0.3 M oxalic acid solution at 70 V and 17 °C for 20 min. Thin Pt plate was used as a counter electrode for the anodizing process. The AAO layer was removed in the etching solution composed of 1.8 wt.% chromic acid and 6 wt.% phosphoric acid at 65 °C for 1 h, and then the nano-hemispherical patterns were fabricated on the base aluminum layer after cleaning. Fig. 3(a) and (b) shows the field emission scanning electron microscope (FE-SEM, S-4300, HITACHI, 0.5–30 kV) image and atomic force microscopy (AFM, Nano Scope Multimode, Digital Instrument, Contact mode) image of the base aluminum layer with the hemispherical nano-patterns, respectively. The diameter of the fabricated hemispherical nano-pattern ranged from 100 nm to 150 nm.

2.2. 3D micro–nano hybrid patterns

In order to fabricate 3D micro–nano hybrid patterns, hemispherical nano-patterns were first built up through the anodizing process, and then micro-patterns on the nano-patterned aluminum substrate were formed by deforming the substrate. The micro-indentation process was used to fabricate

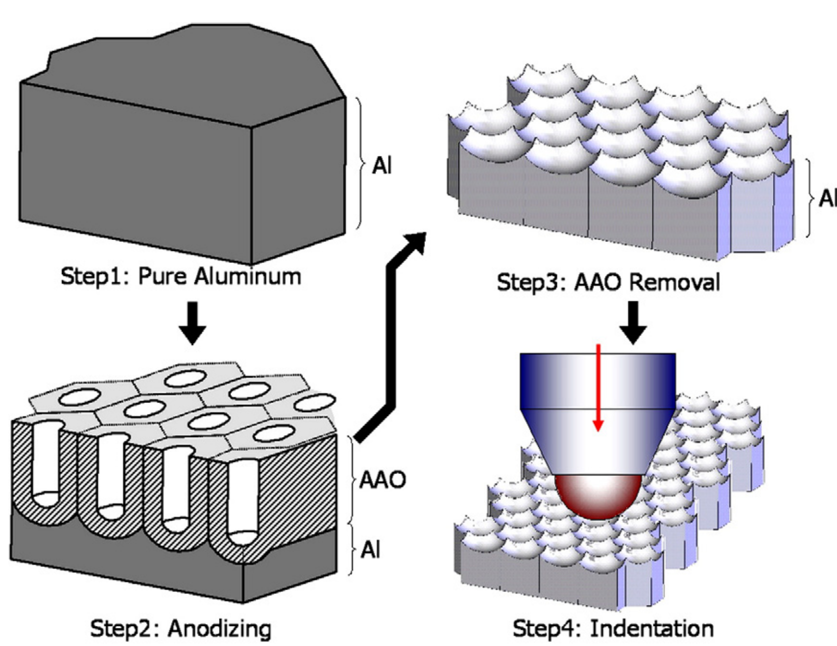

Fig. 2. Fabrication process of 3D micro–nano hybrid patterns using anodized aluminum substrate and micro-indentation.