Fabrication of multilayer ordered metallic nano-dot arrays by nano plastic forming and thermal dewetting process

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Abstract
A new fabrication method of multilayer ordered nano-dot array structures with low cost is developed in this paper. As for the first layer, ordered Au nano-dot array is fabricated by nano plastic forming and thermal dewetting, and then it is coated with a SiO₂ spacer layer. Multilayer nano-dot structures are produced by repeating Au coating, dewetting and SiO₂ coating process. Effective parameters influencing formation of the second layer dots including Au layer thickness and SiO₂ spacer layer thickness are investigated. Mechanism of second layer dots formation is also studied. It is confirmed that regular 3D nano-dot array can be obtained by optimizing the thickness of SiO₂ spacer layer and Au layer.

Keyword: Nanofabrication, Nano Plastic Forming, Nano-dot

1 Introduction
Three dimensional nano/quantum dot array structures have attracted more and more attention due to their broad range of applications in optical and electrical fields such as laser and solar cell devices. Currently, it is difficult to control the size and alignment of the dots in three dimensional by conventional self-organization process such as epitaxial growth, annealing and other chemical methods. In order to address the problem of the conventional methods, a new fabrication method of multilayer ordered nano dot array with low cost is developed in this paper. This process is combination of Top-down and Bottom-up approaches: Nano Plastic Forming (NPF) patterning of metal layer coated on the substrate as Top-down approach and self-organization by dewetting as Bottom-up approach. Experimental results show that multilayer ordered nano dot array structures with good alignment can be obtained by optimizing the thickness of metal layer and silicon dioxide spacer layer.

2 Experimental setup
2.1 The proposed experimental procedures
Figure 1 shows the fabrication process of a multilayer nano dot array examined in this paper. (1) A quartz glass substrate was coated with Au by a DC sputter coater after it was cleaned by ultrasonic in an acetone bath. The sputtering gas was argon, and pressure was 15Pa. Thickness of Au layer was 10nm. The distance between the specimen and the Au target was 35mm. (2) Nano Plastic Forming (NPF) was performed to fabricate a square grid of nano grooves on the coated layer. (3) The specimen was annealed in ambient atmosphere in an electric furnace at 700 degree for 10 minutes. Thin gold film was aggregated into a nano dot array by self-organization mechanism. (4) A SiO₂ spacer layer was then coated by a RF-sputter coater. The sputtering gas was argon. The pressure was 10 Pa. RF power was set to be 150 W and distance between the substrate and the target was 50mm. An Au layer was coated on the SiO₂ layer, and then it was annealed without NPF grid patterning. Nano dots on the second layer were fabricated. (5) Multilayer was fabricated by repeating (1) Au coating, (3) annealing, and (4) SiO₂ coating.

2.2 Nano Plastic Forming
Figure 2 illustrates a schematic diagram of a nano plastic forming equipment used for the experiments. It has computer controlled X-Y stages and a Z stage. The complete process of imprinting involves the indentation of the diamond tool and the movement of the stages. First, a serious of parallel nano grooves was fabricated on the gold layer. Then the specimen was rotated on the stage for 90 degree. A serious of parallel grooves was indented again, and nano groove grids were fabricated on the coated Au layer.

Fig. 1 Schematic diagram of the whole process

Fig. 2 Nano Plastic Forming Equipment

3 Results and discussions
In Fig. 3 (a) the SEM image of the ordered nano-dot array fabricated with NPF is shown. The size and position of the dots is predefined on the substrate. The dots show uniformity and regularity. Fig. 3 (b) shows the nano-dots formed without NPF. The disordered dots have broad distribution in size and alignment. It is clear that uniformity of dot size and regularity of dot alignment are improved by grid patterning by NPF [1]. The specimens with ordered nano-dot array were used for the following experiments to...
fabricate double layer and multilayer dots array structures. To investigate the dots formation on second layer, effective parameters such as SiO\(_2\) spacer layer thickness and Au layer thickness are studied independently.

![Fig. 3 FE-SEM image of ordered nano dot array fabricated by NPF (a) and random dots without NPF (b)](image)

Figure 4 shows the SEM micrographs of second layer Au dots generated on SiO\(_2\) layers of various thicknesses. In Fig. 4(a), where the spacer is 30nm, the dots formed at troughs are slightly smaller than the dots on mounds. While increasing the spacer thickness, the size difference between dots at troughs and dots on mounds is becoming larger as shown in Fig. 4 (c, b). The thickness of spacer influences the topography thus affecting the morphology and alignment of second layer dots. The cross section of double layers ordered nano-dot array is shown in Fig. 4(d). It is demonstrated that the 3D well-aligned ordered nano-dots structures are successfully fabricated by utilizing this method. By repeating the processes several times, multilayer 3D structure can be achieved.

![Fig. 4 FE-SEM images of morphology of second layer dots on SiO\(_2\) layer of various thickness and cross section. Thickness of Au layer is 17nm. Annealing at 700°C for 10min.](image)

Figure 5 shows the second layer Au dots formed from Au films of various thicknesses on the spacer layer. For the 10nm Au layer in Fig. 5(a), multiple little dots are formed randomly on mounds and troughs. For the 15nm Au layer shown in Fig. 5(b), larger dots are formed on mounds and relatively smaller dots are formed at troughs. The regularity of dots is improved. As shown in Fig. 5(c, d), when the thickness of Au layer increases to 20nm, much larger dots are formed on the spacer layer. The uniformity and regularity of dots is reduced.

![Fig. 5 FE-SEM images of morphology of second layer dots from Au layer of various thickness. Thickness of SiO\(_2\) spacer layer is 100nm. Annealing at 700°C for 10min.](image)

The variation of average diameter and RAE (relative arrangement error) [1] of second layer nano-dots on mounds against the thickness of second Au layer are summarized in Fig. 6. It is confirmed that the mean diameter increases with the increase of Au layer thickness. Standard deviation (error bar) decreases with increase of Au thickness when the thickness is smaller than 15nm. However, the deviation increases a lot when the Au layer becomes thicker than 20nm.

![Fig. 6 Variation of average diameter and RAE of second layer nano-dots on mounds against the thickness of second Au layer](image)

The RAE parameter is calculated to compare the degree of regularity quantitatively. It is found that good regularity is obtained when the thickness is between 15nm to 20nm. From the results above, the precisely regular nano-dot array can be achieved by optimizing the thickness of the second Au layer.

**4 Conclusion**

In this paper, a new fabrication method of multilayer ordered nano-dot array is developed. Effective parameters such as SiO\(_2\) spacer layer thickness and Au layer thickness are studied. The thickness of spacer influences the topography thus affecting the morphology of second layer dots. Precisely regular nano-dot array can be obtained by optimizing the thickness of the second Au layer.

**5 References**