Aluminum Microstructures on Anodic Alumina for Aluminum Wiring Boards

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ABSTRACT The paper demonstrates simple methods for the fabrication of aluminum microstructures on the anodic oxide film of aluminum. The aluminum sheets were first engraved (patterned) either by laser beam or by embossing to form deep grooves on the surface. One side of the sheet was then anodized, blocking the other side by using polymer mask to form the anodic alumina. Because of the lower thickness at the bottom part of the grooves, the part was completely anodized before the complete oxidation of the other parts. Such selectively complete anodizing resulted in the patterns of metallic aluminum on anodic alumina. Using the technique, we fabricated microstructures such as line patterns and a simple wiring circuit-board-like structure on the anodic alumina. The aluminum microstructures fabricated by the techniques were embedded in anodic alumina/aluminum sheet, and this technique is promising for applications in electronic packaging and devices.

KEYWORDS: aluminum • patterning • selective anodizing • wiring board

INTRODUCTION

Microscale metallic patterns on various types of surfaces are of prime importance in many fields of technology, and enable the rapidly progressing miniaturization of components. The potential applications of metallic microstructures include microelectronics, lab-on-chips, sensors, medical technologies, etc. Metallic microstructures on nonconducting surfaces, such as polymers, plastics, glasses, and ceramics are the topic of keen interest in both the scientific research community and microelectronic industry. Various methods based on masking, direct writing processes, and electrochemical techniques have been successfully applied for microscale metallic structures of insulator surfaces (1−4).

Printed wiring boards are the backbone of the electronic packaging and manufacturing. The market of the electronic packaging is more diverse, growing, and functionally more demanding. It can be characterized by a generic set of requirements that encompasses the prevailing trends of “cheaper, faster, and better”. Traditionally, aluminum interconnect has been widely used for the fabrication of different types of wiring circuit boards and in integrated circuits. However, demand of the higher density and lower resistive interconnects for PCBs and ICs technologies greatly displaced the use of aluminum by copper-based interconnects. However, considering several factors such as lightweight, heat dissipation, low cost, ease of fabrication, etc., aluminum is still a best choice for the suitable applications in electronic packaging industries. Though aluminum has about half the specific conductivity than copper and about one-third the density of copper, taking wires with the same mass and length, aluminum is a better conductor because of the higher cross-sectional area (5). In addition, better heat dissipation in the case of aluminum reduces the thermal stress on the components that increase durability and reliability of the components (6). Because of the mentioned properties and lower fabrication cost, aluminum seems promising for the less-complex wiring boards with highly reduced cost (7). Furthermore, several recent reports suggest that the aluminum interconnect has lower resistance than that for copper when scaling below 100 nm; this also indicates the future possibility of aluminum based interconnects in advanced technologies (8, 9).

Aluminum, when polarized anodically in some acidic electrolytes develops porous type oxide film on the surface, in a process known as anodizing (10, 11). When anodizing is carried out under suitable conditions, the oxide layer can grow up to a few hundreds of micrometers with self-organized uniform pores. Anodic alumina is an insulator with good mechanical strength, high temperature, and chemical stability. Compared with the epoxy resin wiring boards, alumina exhibits several times higher thermal conductivity and has significantly less thermal expansion. Taking advantages of these properties, various applications of anodic alumina are reported, such as in electronic packaging, microdevices fabrication, hybrid integrated circuits, etc. (12−16). In these contexts, fabrication of microstructures of aluminum on anodic alumina surface with cost-effective techniques is worthwhile for the further development of the aluminum−anodic alumina-based technologies.

In this article, we have demonstrated a simple technique to fabricate aluminum microstructures in anodic alumina by

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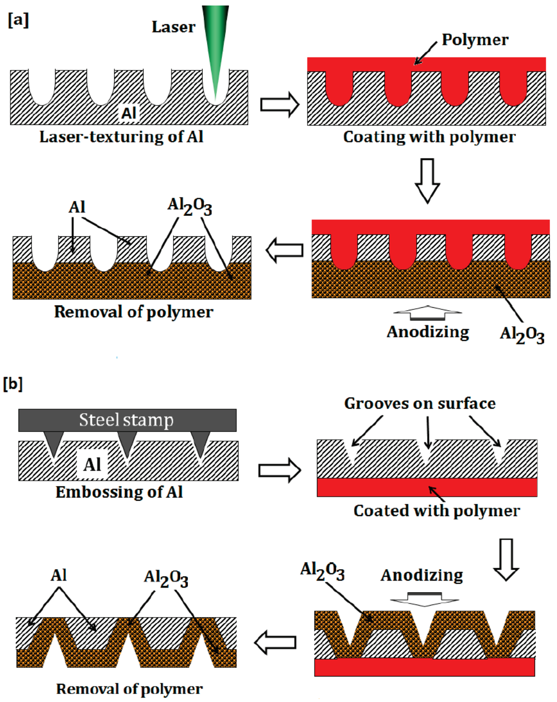

FIGURE 1. Schematics of various steps for fabrication of aluminum microstructures on anodic alumina: (a) using laser micromachining method; and (b) by stamp engraving method (not to scale).

anodizing of patterned-aluminum using laser ablation and metal embossing and tried to employ it to fabricate a prototype of wiring board with Al interconnects embedded in the porous anodic alumina.

EXPERIMENTAL METHODS

Pure aluminum (99.99%) sheet with a 125 μm thickness was cut into 15 mm × 20 mm pieces and ultrasonically cleaned in ethanol for 5 min. The aluminum surface was patterned (or carved) by two different methods: laser micromachining and embossing. For the laser micromachining, the aluminum specimens were irradiated with focused laser beam, and the specimens were moved against the beam using 3D stage controlled by a PC to carve the surface with desired microstructure. The power of the beam was 5mW, pulse width 8 ns, and the frequency 50 Hz. After the laser micromachining, the micromachined surface was coated with polymer, i.e., commercial nail polish or wax to mask the surface, as shown in Figure 1a. The one-side coated specimens were then anodized in 0.22 M oxalic acid solution for about 4 h with constant current of 10 $\mathrm{mA/cm^2}$ at 20 °C. Finally, the coating on the laser-machined surface was removed by peeling and cleaned with acetone. The detail schematics of the procedures are shown in Figure 1a.

For the embossed specimens, first the aluminum sheets were annealed at 450 °C for 30 min and then left inside the furnace for about 12 h, for slow cool down to room temperature to soften the aluminum sheet. The annealed specimens were then embossed by specially designed steel master. About 35 MPa force was applied for the embossing the aluminum specimens to transfer the line pattern to the surface. Then the rare-face (back side of the embossed face) of the specimen was coated with the polymer and anodized as explained above. The schematics of the procedures are shown in Figure 1b.

The specimens were characterized by using confocal scanning laser microscope (CSLM, 1SA21, Lasertec) and optical microscope (SW-700TD, ARCH Company) fitted with digital camera.

RESULTS AND DISCUSSION

Aluminum surface can be micromachined by using laser beam. The present authors reported that irradiation of a focused laser beam on the aluminum surface can precisely ablate the irradiated part resulting in the "groove" on the surface. The shape and size of such grooves can be controlled by adjusting the laser power, scanning speed, and other parameters (17). In the present investigation, the aluminum sheet was micromachined by a laser beam so that the resulting grooves have depth more than a half of the total thickness of the sheet. Figure 2 shows the laser micromachined surface of the aluminum sheet and its depth profile. The depths of the grooves were measured about 80 μm, and the width of the aluminum lines formed on the surface were about 90 μm, however the distance between the any two grooves may changes with different structures. The micromachined surface is then coated with polymer as mentioned in Figure 1a, leaving the opposite side (back side) of the sheet exposed to the anodizing electrolyte. However, this coating step can be omitted if one uses a special anodizing cell with one-face exposure to electrolyte only.

Anodizing of the specimen was carried out in oxalic acid solution, which results in the porous type of aluminum oxide film. During the anodizing the oxide formation front moves toward the micromachined surface, i.e. toward the laser formed grooves. Finally, aluminum beneath the grooves was anodized, leaving aluminum only toward the micromachined surface as diagrammatically shown in step 3 of Figure 1a. In our experimental setup, about 4 h anodizing was sufficient to reach the state; however, the time can be reduce by adjusting the experimental conditions. After anodizing, the polymer coating peeled-off and washed with acetone, resulting in the aluminum microstructure on anodic alumina as shown in Figure 3.

Figure 3 shows the images of aluminum microstructures on porous anodic alumina substrate. Figure 3a shows the surface view of aluminum microstructure (line pattern) on the anodic alumina substrate, and its cross-sectional CSLM image in Figure 3b. The blue color of the anodic alumina between two adjacent lines is due to the rear illumination of the specimen. The microstructure shows long-range uniformity and good separation of the lines on the anodic alumina surface. The width of the aluminum lines are about 60 μm and separated with adjacent line by about 50 μm. Adjusting the laser scanning separation, the width of the microstructures can be decreased or increased as shown in Figure 3c, where the width of the line is about 90 μm (also see Figure 2). However, the distance between the two metallic lines merely depends on the size of the laser formed groove. Moreover, it can be seen that the sides of the aluminum lines (toward the base) are also anodized to some extent. This is due to the penetration of the electrolyte inside the polymer coating after the anodizing front reach to the oxide-polymer interface. Similarly, to demonstrate the capabilities of the technique, a simple wiring board patterned on aluminum surface by laser-micromachining process, and subjected for anodizing after polymer coating as stated above. The optical image of the resulting wiring board is

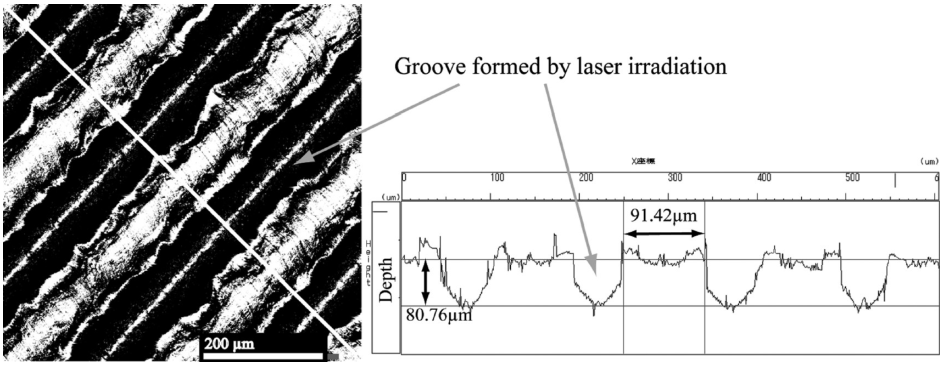

FIGURE 2. CSLM image of laser micromachined aluminum substrate and depth profile of the grooves along the white line on the surface.

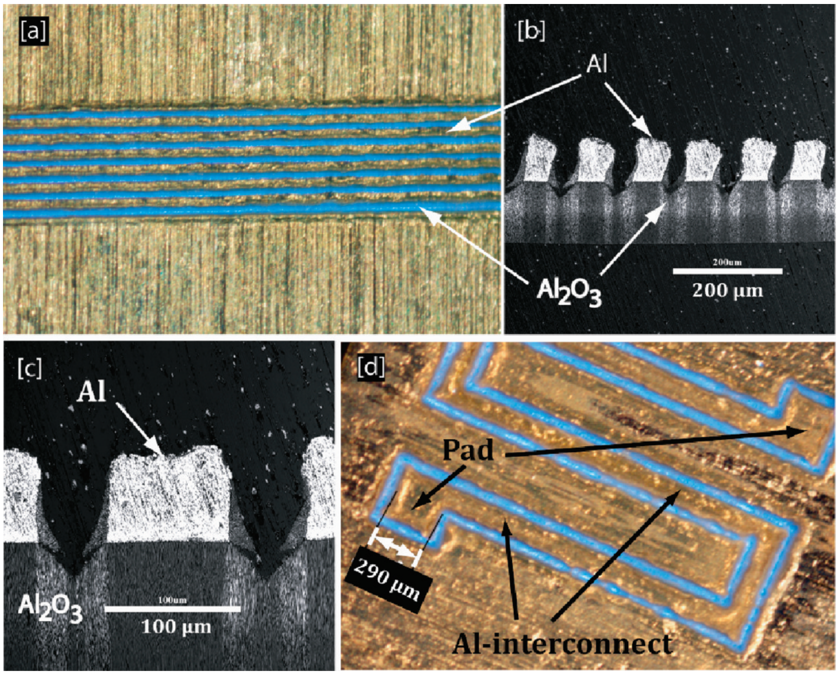

FIGURE 3. Images of aluminum microstructures on anodized aluminum substrate fabricated by partially anodized laser micromachined aluminum sheet: (a) showing closely spaced lines about 60 μm in width, and (b) its cross-sectional view; (c) magnified view of 90 μm wide aluminum line separated from the neighboring metallic structure by a completely anodized part (i.e., by anodic alumina); (d) simple pad-interconnect microstructure for perspective Al-wiring boards. (Note: the blue color of the aluminum oxide in optical microscope images a and d are due to the back-side illumination.)

shown in Figure 3d, where two Al pads are connected through Al interconnect. The width of the interconnect line here is about 200 μm, and the whole structure is well-isolated from the aluminum sheet by aluminum oxide.

In order to make the technique simpler, instead of laser micromachining, a prepatterned steel stamp (master) was used to form the groove on the aluminum surface by embossing as described in Figure 1b. Here, the steel master had designed so that the grooves formed on the aluminum surface (after embossing) was about 1 mm. After coating the polymer on the back surface, then aluminum specimen was anodized through the embossed surface. Figure 4 shows the confocal scanning laser microscope images of such aluminum specimen where the bottom part of the groove completely oxidized. It can be seen that aluminum lines are well separated from each other, and no metallic contact between them. Though the space between the grooves in the present case is about 1 mm it is also possible to make an embossing stamp for the closer grooves that result in the finer metallic structure.

Although, to demonstrate the technique, we used laser micromachining and simple embossing techniques for patterning the aluminum surface; however, several other techniques can be employed to get more defined and fine patterns. Techniques such as electrochemical micromachining, molding (LIGA), and hot embossing will be more viable for the mass production. To achieve the higher aspect ratio and close-spacing aluminum microstructures, LIGA based techniques may be the good choice. Furthermore, other metals such as copper or nickel (18−20) can subsequently be plated on the metallic aluminum microstructure for more extended applications.

The technique described here is simple, fast, and environmentally friendly, as it does not require several steps and harmful chemicals like in lithography based techniques. In

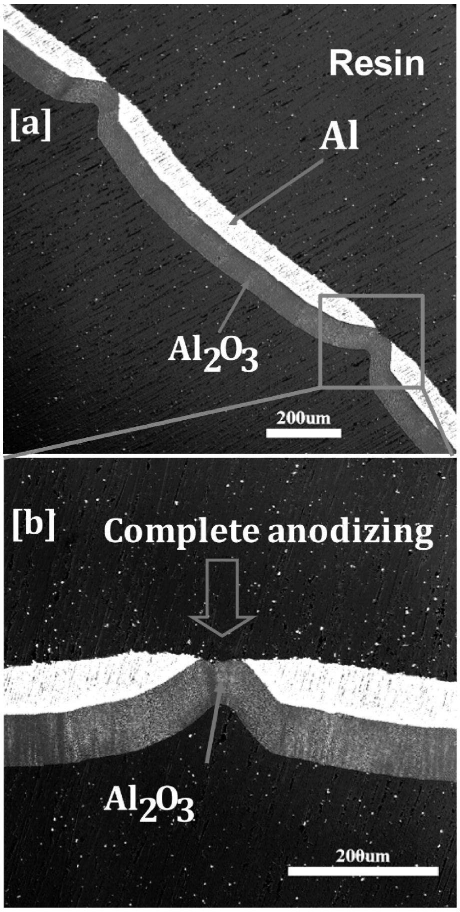

FIGURE 4. (a) Cross-sectional image of aluminum lines on anodic alumina formed after anodizing of embossed aluminum, and (b) magnified view of the completely anodized embossed part.

addition, as the whole structure is embedded in aluminum/aluminum oxide, it has good mechanical strength, high adhesion to the substrate and has high thermal conduction. These are among the most concerning features to design a circuit board. However, further studies and optimization are needed for its potential applications in the industries, such as feature size of the metallic patterns; faster anodizing condition and thickness of the aluminum oxide, etc., can be optimized as needed. Considering its simplicity, flexibility, and cost-effectiveness, we hope the technique will be promising for designing the microelectronic components and devices.

CONCLUSIONS

Aluminum microstructures on anodic alumina are fabricated by patterning the aluminum followed by anodizing. The size and shape of the microstructure can be obtained by patterning the aluminum surface with suitable dimensions. The aluminum microstructures are in good shape and are embedded in aluminum oxide/ aluminum sheet. Because of its simplicity, cost-effectiveness, and physical properties, the technique is promising for the fabrication of the aluminum-based wiring circuit boards.

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