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REGULAR PAPER

Preparation of self-supporting Au thin films on perforated substrate by releasing from water-soluble sacrificial layer

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A self-supporting thin film is useful as a target material for laser-driven ion acceleration experiments. In this study, 100-nm-thick sputtered gold (Au) thin films were released from substrates using water-soluble sacrificial layers, and the released films were subsequently scooped up on perforated substrates. Au thin films were deposited by DC plasma sputtering on the sacrificial layers. In the releasing test, sodium chloride (NaCl) was shown to be most suitable as a sacrificial layer for Au thin films. In addition, sputtered Au thin films with thicknesses of 50 and 150 nm were deposited onto NaCl sacrificial layers, released on water, and scooped up on perforated substrates. Self-supporting Au thin films were obtained for all film thicknesses, but wrinkles and cracks appeared in the 50 nm film.

1. Introduction

Self-supporting thin films made of diamond-like carbon (DLC)[1–3] and gold (Au) have attracted increasing attention as film targets for laser-driven ion acceleration experiments.[4–8] One of the methods of manufacturing self-supporting thin films is to use a soluble sacrificial layer.

A thin film can be released from a substrate by dissolving the substrate. Usually, a powerful acid is required for dissolving a typical substrate, such as metal (copper, tungsten, and nanostrands) and silicon (Si).[9–13] However, the use of strong acids is unfavorable for industrial production processes. One of the good approaches to avoid this process is to use a sacrificial layer between a typical substrate and the objective film. The objective film is released from the substrate by removing the sacrificial layer. Water-soluble materials, such as sodium chloride (NaCl), nickel chloride, and betaine, were used as the sacrificial layers.[14–25] The releasing process of the thin film using a water-soluble material as a sacrificial layer is considered to be safer for humans and the environment than methods using a strong acid with the exception of nickel chloride, which is a carcinogenic material.[26]

Gold leaf is a self-supporting Au film; however, it is too rough and insufficiently pure to be a suitable target for laser-driven ion acceleration experiments.

The plasma sputtering method[27] has been widely used in industry for forming thin films. By this method, the control of film thickness is relatively easy, and the purity of the film material is high. High-purity and flat Au thin films with a thickness of several tenths of nanometers thinner than gold leaf films can be obtained on a substrate by the sputtering method.

In this paper, the releasing and self-supporting processes of Au thin films using a water-soluble sacrificial layer are presented. 100-nm-thick Au thin films were deposited by the plasma sputtering method on substrates possessing a variety of sacrificial layers. The release of the Au thin films from the substrates was attempted by removing the sacrificial layer. Self-supporting Au thin films were then fabricated by transferring the released Au thin films onto perforated substrates.

Gelatin, oblate, silk fibroin, and NaCl were used as water-soluble sacrificial layers owing to their low environmental load. Gelatin[28] and oblate are water-soluble materials derived from collagen and made from gelatinized starch, respectively. Silk fibroin is a natural protein composed of raw silk with sericin.[29]

2. Experimental methods

Gelatin, which becomes a thick film through drying, was used as a sacrificial substrate functioning as a sacrificial layer and a supporting substrate. The gelatin thick film was fabricated as follows: (1) gelatin granules (cooked gelatin, Morinaga) were mixed with purified water at a ratio of 2 : 1, (2) the mixed gelatin solution was cooled at 5 °C for 12 h in a refrigerator, and (3) the clotted gelatin solid was dried at room temperature for 24 h.

Oblates were used as sacrificial substrates in the case of the gelatin substrate. Two different manufacturers' oblates (produced by Niigata Oblate and Takigawa Oblate) were used.

A silk fibroin sacrificial layer was coated onto a glass substrate by a spin coater (Mikasa Spinner IH-D3) after dissolving in purified water at a concentration of 10 wt %. The silk fibroin solution was obtained by maintaining it at 5 °C for 30 min in a refrigerator without stirring after the addition of the silk fibroin powder (Matsuda Silk Farm) to purified water. The silk fibroin solution was set at 300 µl on a glass substrate. The glass substrate was rotated by the spin coater for 30 s at 300 rpm and additionally for 30 s at 2000 rpm.

The NaCl sacrificial layers were deposited onto Si substrates using a vacuum vapor deposition system (Ulvac VPC-260F). NaCl powder was heated to 1000 °C by resistive heating on an evaporation boat. The deposition duration of NaCl was 5 s.

Au thin films were deposited on sacrificial substrates and layers by a DC sputtering system (Sanyu Electron SC-701) as shown in Fig. 1. An annular mask was placed on a substrate in the sputtering process. The distance between a target and a substrate was 25 mm. A pure Au target (99.99%) with a size of φ49 mm × t0.05 mm was used as the sputtering target. The chamber was vacuumed using a rotary pump. The discharge current was 2.5 mA and the atmosphere gas was air during

