Microfabrication of Hybrid Structure Composed of Rigid Silicon and Flexible Polyimide Membranes

Sunao Murakami*, Daisuke Ishihara, Masateru Araki, Tomoyoshi Horie, Naoto Ohira and Takahiro Ito
Department of Mechanical Information Science and Technology,
Faculty of Computer Science and Systems Engineering, Kyushu Institute of Technology (Kyutech)
Iizuka, Fukuoka, Japan

***Abstract*— We have designed and microfabricated millimeter-scale wing-shaped hybrid microstructures composed of rigid structures of single crystal silicon (SCS) and flexible polyimide (PI) membranes. The wing-shaped microstructures mimicking insect flapping flight have been designed using a fluid-structure interaction analysis, and have been microfabricated with the SCS substrates coated with photosensitive polyimide membranes. The wing-shaped hybrid microstructures fabricated have been observed, and the flexibility of the PI membrane was also confirmed using the bending test of the PI membrane.**

Keywords—microfabrication; hydrid structure; silicon; polyimide; flexible membrane

I. INTRODUCTION

Three-dimensional microstructures of single crystal silicon (SCS) have received much attention as the key structures of bulky movable micromechanical components, and have been already used in the technical applications such as the micromechanical resonators and microcantilevers [1, 2]. The SCS offers advantages as the structural material of the movable microstructure because of the high mechanical stiffness and the low internal loss. The SCS is also convenient to create microstructure using microfabrication technologies including deep reactive ion etching (D-RIE) process of silicon. Recently, the hybrid microstructures including silicon components and some organic polymers also have shown much potential for some applications such as micro-robots [3] and sensing devices on a flexible substrate [4]. In the fabrication of the hybrid structures, polyimide (PI) is one of the organic polymers widely used for many electrical applications as the flexible substances [5], which is known for high thermal stability, chemical resistance, and insulation performance. In this study, we have designed and fabricated millimeter-scale wing-shaped hybrid microstructures composed of the rigid silicon structures and the flexible polyimide membrane. The fabricated hybrid structures have been observed and the flexibility of the PI membrane part was also investigated.

II. DESIGN AND FABRICATION

A. *Design of the Hybrid Microstructures*

In this study, we have newly designed millimeter-scale wing-shaped hybrid microstructure mimicking insect flapping flight. Fig. 1 shows the structural image of the wing-shaped hybrid microstructure we have designed and fabricated in this study. The size and shape of the each part of the hybrid microstructure have been determined using a fluid-structure interaction analysis which we had reported [6]. In this study, we used SCS as a rigid material for the rigid part including the leading edge (beam structure) and the wing base, and used PI membrane as an elastic material such as the wing plate.

B. *Microfabrication of the Hybrid Microstructures*

For the microfabrication of hybrid microstructures described in Fig. 1, we need to think about the way to combine a wing plate of PI membrane with a SCS part of the wing. In this study, we used spin-coating of photosensitive PI solution on the SCS substrate. In detail, the wing-shaped microstructures composed of SCS and PI have been microfabricated using the process flow shown in Figs. 2. We used a SCS substrate of 100 μm thickness. At first, photosensitive PI spin-coated on the SCS substrate (Fig. 2 (a)) was patterned to the shapes of wing plate using photolithography process (Fig. 2 (b)), and cured at about 200°C under low oxygen condition. Then, a support substrate was temporarily bound to the upside (the side with the PI patterns) of the SCS substrate (Fig. 2 (c)). And, photosensitive resist (photoresist) spin-coated on the backside of the SCS substrate was patterned using photolithography process to prepare the protection mask pattern for the D-RIE process of the SCS substrate (Figs. 2 (d), (e)). After the D-RIE of the SCS substrate (Fig. 2 (f)), the residual photoresist pattern was removed (Fig. 2 (g)). And finally, the wing-shaped microstructures were released from the support substrate which had been temporarily bonded in step (c) (Fig. 2 (h)). The microfabricated microstructures were observed, and the flexibility of the PI membrane of the structure was also confirmed using the bending test of the PI membrane.

III. RESULTS

We have successfully fabricated wing-shaped hybrid microstructures as shown in Figs. 3. In the microfabrication process, we have investigated proper process conditions for the curing of patterned PI membrane and the D-RIE of SCS. Furthermore, we have added the load to the PI membrane (wing plate) of a fabricated hybrid microstructure to investigate

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the flexibility of the PI membrane. Figs. 4 show the results of the bending test. The PI membrane was deformed when the load was added to the membrane by the probe (Fig. 4 (a)), and the membrane kept the deformation while the load was added (Fig. 4 (b)). However the PI membrane returned to the original shape when the added load had been removed (Fig. 4 (c)). The flexibility of the PI membrane of the fabricated microstructure was confirmed using the bending test of the PI membrane.

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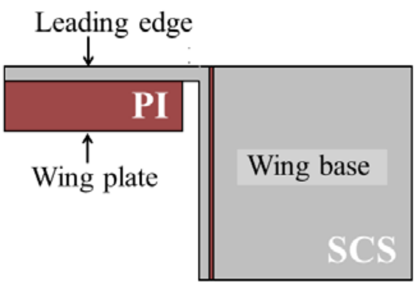

Fig. 1. Schematic diagram of wing-shaped hybrid microstructure.

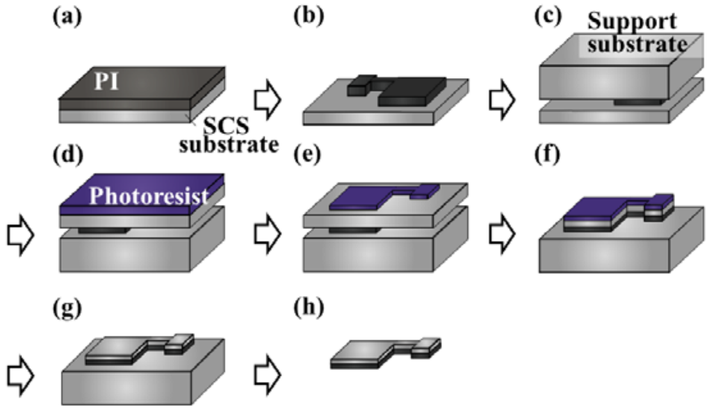

Fig. 2. Process flow of the wing-shaped hybrid microstructure: (a) spin-coating of photosensitive polyimide (PI) on a SCS substrate, (b) photolithography and curing of patterned PI membranes, (c) bonding of a support substrate on the side of PI patterns of the SCS substrate, (d) spin-coating of photoresist on the backside of the SCS substrate, (e) photolithography of photoresist, (f) D-RIE through the SCS substrate with photoresist mask patterns from the backside, (g) removal of residue of the photoresist patterns, and (g) release of wing-shaped hybrid microstructure from the support substrate.

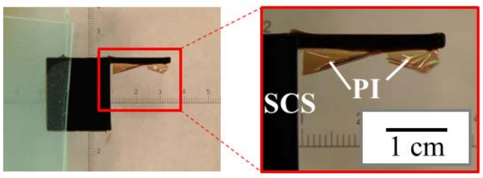

Fig. 3. Photos of a microfabricated wing-shaped hybrid microstructure.

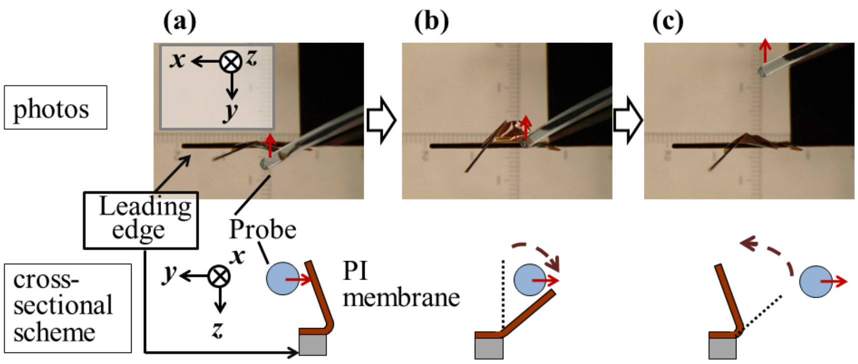

Fig. 4. Bending test of PI membrane part (wing plate) of the fabricated wing-shaped hybrid microstructure: (a) load was added to PI membrane by the probe, (b) PI membrane was deformed by the added load, (c) the shape of the PI membrane returned to the former state when the added load had been removed.