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Hydrogel-based Flexible Hybrid Electronics Technology for Biomedical Application

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Abstract

A new flexible hybrid electronics (FHE) approach using advanced wafer-level packaging (WLP) technologies with hydrogel substrates is proposed. Hydrogels mainly consisting of water have excellent biocompatibility and substance permeability, and they are expected for biomedical applications. Various microchips can be embedded in the hydrogels and high-density inter-chip wirings can be formed in the FHE system. In this work, we integrate the fabrication process of Au wirings on a hydrogel substrate at the wafer level and characterize their electrical properties.

1. Introduction

Polymeric materials are widely used as flexible substrates. Table 1 shows comparison between the flexible substrates. Although polyethylene terephthalate (PET) and polyimide (PI) are well known to be a typical flexible substrate, they cannot perfectly fit curved surfaces due to their rigidity. In contrast, polydimethylsiloxane (PDMS) has high ability to follow complicated three-dimensional shapes, and thermomechanical internal stress is less accumulated due to the low glass transition temperature (Tg) of -200°C. The three polymers have low permeability of substances such as water, tissue fluid, and gases (oxygen etc.), and thus, skin will be steamed by sweat when these flexible substrates are attached to the skin for a long time. On the other hand, hydrogels including a lot of water molecules are a network polymer and reveal high flexibility and substance permeability. However, metallization on the hydrogels is very challenging because heating and vacuum processes cannot be applied for the water-based hydrogels. Nishizawa *et al.*, have reported conductive polymer wirings on a hydrogel [1] and Shimamoto *et al.*, have described the formation of Au micro-patterns on a hydrogel [2]. We have previously formed fine-pitch Au or Cu interconnects on PDMS without microcracks and wrinkling by WLP technologies [3]. Here, we will replace the PDMS with hydrogels. Figure 1 shows the conceptional structure of a proposed hydrogel-based FHE, where heterogeneous microchips can be embedded in the hydrogels and connected with inter-chip wirings formed on the hydrogel. In this paper, we demonstrate interconnect formation on a hydrogel substrate using WLP technologies.

2. Experimental

A hydrogel “Wizard gel” used in this study was from Yushiro Chemical Industry Co., Ltd. Figure 2 shows a process flow to form Au wirings on the hydrogel. First, polyvinyl alcohol (PVA) as a sacrificial layer was spin-coated on a Si carrier wafer. Next, Ti/Au was deposited by sputtering, and Au wirings were formed by wet etching. 1-μm-thick parylene as an insulator between the metal and hydrogel was vapor-deposited on the wirings, and then, a silane coupling treatment was performed after the surface modification with a 172-nm excimer ramp. Thereafter, the hydrogel was compression-molded while being UV-cured through a quartz substrate. After that, the PVA was dissolved with warm water at 60°C, and finally, the Au wirings were transferred to the hydrogel substrate from the Si wafer. The adhesion between the parylene and hydrogel was evaluated by a cross-cut test (ASTM D 3359-87 Method B). 4-point probe patterns were used for the resistance evaluation.

3. Results and Discussion

Figure 3 shows the top view of hydrogel/parylene/SiO_2 films with and without surface modification on the parylene surfaces. The adhesion strength of the former one with surface modification exhibits higher than the latter one without surface modification. As shown in this figure, the hydrophilization by Vacuum Ultra Violet (VUV) with a silane coupling treatment on the parylene surfaces gives good adhesion enhancement between the parylene and hydrogel. Figures 4 (a) and (b) show the schematic of evaluation samples for electrical measurement: (a) for top view and (b) for side view. Figure 4 (c) shows photomicrographs for 500-nm-thick Au wirings formed on a hydrogel. It can be said that Au wirings with widths of 50 and 100 μm are successfully formed on the hydrogel. By enhancing the adhesion between the hydrogel and parylene, the Au wirings can be transferred from the Si carrier wafer to the hydrogel. As shown in the bottom picture of Fig. 4, no wrinkling and microcracking are observed just after the transfer process. This is because the UV curing process for the hydrogel is done at some interval in order to keep the hydrogel temperature at below 60°C. The measured resistances are shown in Fig. 5. As seen in this figure, the average resistances of the 10-mm-long Au wirings with widths of 50 and 100 μm are 4.7 and 2 Ω, respectively.

4. Conclusion

We proposed a heterogeneous integration methodology with hydrogel-based FHE for biomedical applications. Inter-chip Au wirings were photolithographically formed on a hydrogel for the first time and relatively low resistances were obtained by the advanced WLP technologies. Good adhesion between the hydrogel and insulator parylene was also obtained.

Acknowledgment

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References

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Table 1 Comparison among flexible substrate candidates.

Material	Cost	Tg (°C)	Flexibility	Biocompatibility	Permeability
PET	◎	50	○	×	×
PI	×	>350	○	△	×
PDMS	○	-200	◎	○	×
Hydrogel	○	-	◎	◎	◎

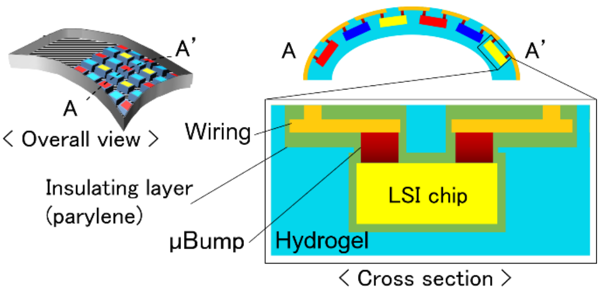

Fig. 1 Schematic structure of hydrogel-based flexible hybrid electronics.

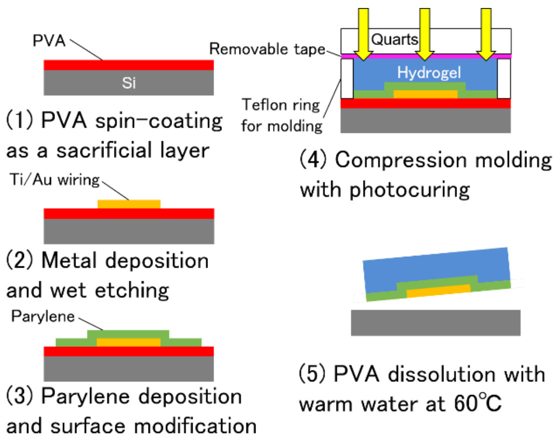

Fig. 2 Process flow of wiring formation on hydrogel.

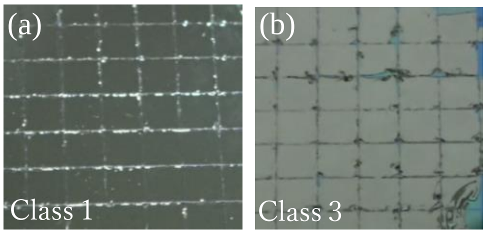

Fig. 3 Adhesion strength between parylene and hydrogel with (a) and without (b) a silane coupling treatment.

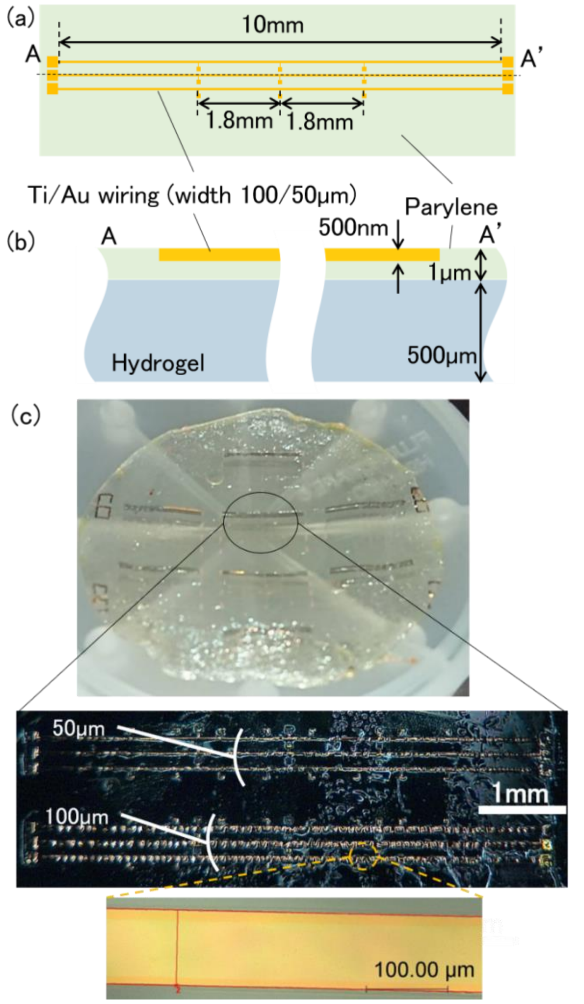

Fig. 4 Top (a) and side (b) views of wire design and photograph of Au wirings formed on a hydrogel (c).

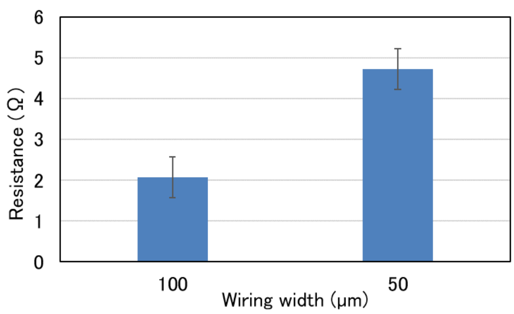

Fig. 5 Resistance measurement of Au wirings formed on hydrogel.