Smart Skin Display の要素技術研究 II: PDMS 上に形成する二層配線の曲げ特性強化手法の検討
Integration Technology for Smart Skin Display II: Bendability Enhancement of Multi-level Metallization on a PDMS Elastomer

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1. Introduction

This study is motivated by the stress control of top wires for Smart Skin Display. Regarding double layer wiring, the stress applied to bottom wires of Smart Skin Display when bending can be decreased by positioning its stress neutral axis, but the bending stress of the top wires cannot be lowered. A structurally new wiring design is proposed to enhance the bendability of Smart Skin Display as an FHE device based on fan-out wafer-level packaging (FOWLP) [1].

In this work, first, the magnitude of the stress applied to the FOWLP-based FHE is simulated using a finite element method (FEM) to know the optimized wire structure for the subsequent experimental work. Second, this study proposes non-prestrain 3D wavy wires interconnecting the embedded components used in Smart Skin Display. The fan-out wires are fabricated on a corrugated layer photolithographically formed with a photosensitive dielectric. With the simulation verifying the feasibility of corrugation designs, we fabricate 3D corrugated interconnections, characterize the bendable properties, and compare them to 2D planar wires.

2. Simulation study

The 3D corrugated wires are advantageous for high-density flexible interconnection, compared with conventional 2D serpentine wires. At the top of PDMS substrates, a 1-µm-thick Parylene as a stress buffer layer (SBL) was formed. SU-8 was employed for a corrugation layer formed on the SBL. The following two configuration are designed, as shown in Fig. 1.

Fig. 1. Two configurations of inter-chip wires formed on a corrugated layer: trapezoid (a) and serpentine (b).

The main concern is the disconnection of inter-chip metal (gold) wires resulting from highly induced stress when bending with small curvature radius or large displacement. Several parameters are simulated to derive the most dominant one influencing the stress in the wires to solve this issue.

One of the critical parameters is the thickness of metal wires. Here, two types of single-wiring layers are compared: trapezoid and serpentine wires. As shown in Fig. 2(a), the simulation demonstrates that thinner wires lower the stress in both the configurations. However, from a practical use point of view, relatively thick wires are needed due to their high mechanical reliability and low electrical resistance. It is a trade-off to balance the required specification between minimizing the bending stress and enhancing the mechanical and electrical performance of the wires.

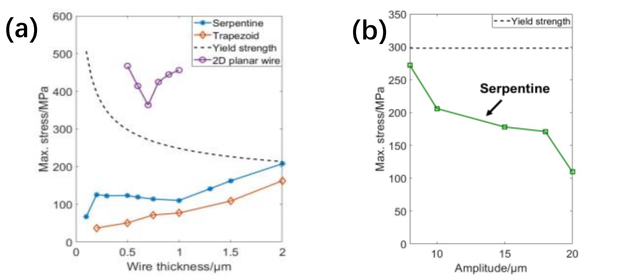

Fig. 2. Correlation between wire thickness (a)/corrugation amplitude (b) and maximum Von-Mises stress in 3D corrugated wires. (b) only shows the simulation result of serpentine configuration. Black dash lines plot the yield strength of gold [3]. The amplitude in (a) is 20 µm, and the thickness in (b) is 500nm.

Fig. 2(b) shows the impact of the wire amplitude on the maximum stresses. This figure suggests that the stresses applied in the 3D corrugated wires tend to decrease with an increase in the amplitude of the wires. The fabrication of the 3D corrugated wires with an amplitude of 20 µm is technologically possible using the advanced photolithography processes we have demonstrated [2].

3. Experimental method and Results & Discussion

A 3D corrugation layer was fabricated with SU-8 to verify the feasibility of 3D corrugated wire formation. A 20-µm thick SU-8 was spin-coated. Then, the SU-8 was photolithographically patterned on Parylene-C deposited a PDMS wafer. The 3D corrugations are successfully formed on Si wafer as shown in Fig. 3. (a) and (b), and their sidewall profiles would be changeable by controlling photolithography conditions such as exposure dose and proximity gap for trapezoid configuration and overlaying a thin additional SU-8 film for serpentine configuration. The formation of 3D serpentine corrugated wires on PDMS substrate is shown in Fig. 3(c).

Fig. 3(d) shows the I-V characterization of interconnections with a Ti/Au/Ti thickness of 30/500/30 µm formed on a 3D serpentine corrugation before and after 100-cycle bending test in which the curvature radius is 5 mm. The 3D corrugated wires show excellent bendability in comparison with conventional 2D wires. After the bending test, the resistance of interconnections formed on 3D corrugation with a L/S of 20/20 µm and 30/30 µm increased by approximately 150% and 94%. In contrast, the resistance increase of the conventional 2D plane wires reaches beyond 2,000%. The stress control of the 3D corrugated wires should be further enhanced, but high bendability is obtained in this experimental study.

References

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[3] Y. H. Huh, *et al.*, Engineering Against Fracture (2009), pp. 339-346.

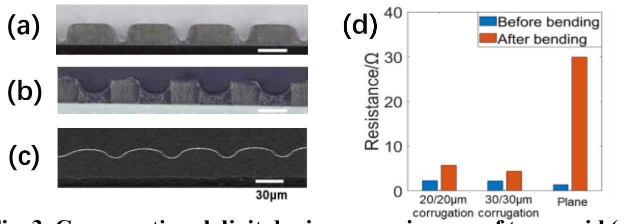

Fig. 3. Cross-sectional digital microscope images of trapezoid (a) and serpentine (b) corrugation formed on a Si wafer. SEM 3D corrugated wires formed on PDMS (c). Resistance increase of 3D corrugated wires (serpentine) and conventional 2D plane wires before and after 100 times bending (R: 5 mm) (d). Scale bar: 30 µm