Integration of Polydimethylsiloxane Polymer in Interdigitated Electrode for Enhanced Biosensing Aided by Optical Analyses

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ABSTRACT: The current work predominantly demonstrates the fabrication of interdigitated electrode (IDE) using effortless and cost saving photolithography technique for enhanced biosensing. The morphology of IDE was well examined with optical analyses, high power microscope and 3D nanoprofilometer. IDE was characterized by field emission scanning electron microscope justified errorless fabrication technique as a clean IDE with sharp electrodes and junction were observed. Polydimethylsiloxane polymer assist in modulation of mechanical and physical pressure on sensor integrated on IDE. The results proved that optical characterization enables the imaging of preliminary morphology of polymer coated IDE. The surface morphology of IDE with and without the presence of polymer successfully examined with optical analyses.

Keywords: *Interdigitated electrode; PDMS; Optical Characterization*

1. INTRODUCTION

Interdigitated electrode (IDE) is one of prominent examples of biosensor used in electrical and electrochemical in biosensing system. IDE consist of two electrodes interlocking, separated by electrode channels and thereby multiplying IDE fingers array which are connected to main electrode pads appears as comb-like structure, resembles the microfabricated capacitors [1]. The sub-micron IDE dimensions are encouraged in detection of DNA hybridization [2]. However, nano-scaled IDE fabrication is least preferred due to its complication in high precision fabrication and accurate handling of experimental procedures. Commonly, IDEs are fabricated using silicon substrate as its base material, and different types of metals are used as its electrode material.

Polydimethylsiloxane (PDMS) is a highly biocompatible silicone elastomer that facilitates extracellular deposition of the matrix. Its suitability for fabrication of microporous scaffolds has been well demonstrated in previous literatures [3]. The resistance of PDMS to mechanical loads such as pressure or outside force is minimal. Moreover, the PDMS mechanical properties can be improved by adjusting the curing temperature and mixing ratio of polymer and its curing agents. In the present work, the engineering of PDMS polymer layer on IDE was studied. The presented approach complements prior work that was focused on the basic surface morphological analyses in developing PDMS polymer engineered IDE.

2. METHODS

2.1 Photolithographic Technique for IDE and PDMS Coating

Photolithography technique was performed to develop IDE with Al electrode as explained [4]. The device was then analyzed under scanning electron microscope (SEM, Hitachi, S-4300 SE, Japan), high power microscope (HPM) and 3D profiler (Hawk 3D Profiler). PDMS polymer prepared in 10:1 weight ratio by combining PDMS prepolymer with curing agent. On the surface of the IDE a uniform layer of PDMS was coated by spin coating for 50 seconds at 3000 rpm. The PDMS-coated IDE was kept on hot plate for 4 hours at 70 ° C. 3D nanoprofilometer and HPM were examined for the PDMS coated IDE, to investigate its characterization.

3. RESULTS AND DISCUSSION

3.1 Development of IDE

Figure 1 shows the images of silicon at each process in developing IDE. The image of silicon wafer is shown in Figure 1a, where a 4-inch wafer cut into 4 quadrants using a wafer cutter. The blue-black surface of silicon wafer transforms into dark purplish blue (Figure 1b) after undergone wet thermal oxidation, creating a 300 Å thickness of oxide layer. Figure 1c and 1d represents the uniform deposition of aluminium metal through physical vapor deposition and the uniform coating of positive resist developer (RD+) using a spin coater. As the photoresist coated substrate allowed to pass through UV with patterned chrome mask, the IDE pattern was developed on silicon wafer using RD+ developer solution (Figure 1e). After the final step of etching the aluminium, the developed IDE through simple photolithography fabrication technique is shown in Figure 1f.

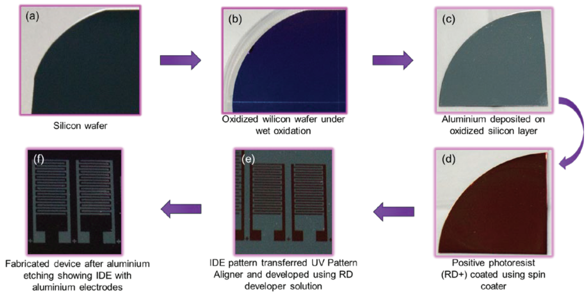

Figure 1 Development of IDE using conventional photolithography technique.

3.2 Characterization of IDE

Figure 2 shows the electron microscopic image of fabricated IDE under FESEM. Figure 2a shows the electrode and gap between it, whereas Figure 2b shows the joint end of electrode junction. The uniform and clear image affirm the precision of photolithography technique as the device fabricated with least foreign particles on it and least variation from the patterned chrome mask. Figure 3 shows the optical images of IDE analyzed under HPM and 3D nanoprofilometer. Figure 3a and 3b represent IDE under HPM at 5X magnification scale. Aluminium electrode visible with grey comb-like structure and the blue gaps between it indicate oxidized silicon substrate. Figure 3c shows the optical image obtained under 3D profilometer. The 3D image clearly depicts the IDE structure with color variation and also thickness of different surfaces as shown in Figure 3d (Red-electrodes; Green-gaps).

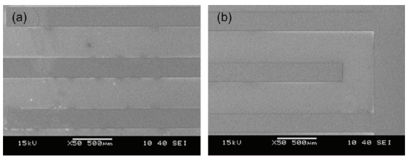

Figure 2 Electron microscopic images of IDE under FESEM

3.2 Characterization of PDMS Coated IDE

Figure 4a and 4b show the optical image of polymer coated IDE under HPM. The color of electrode (red-yellowish) and gap (blue) varies compared to the one without PDMS layer under HPM. Moreover, an adhesive surface is observed reflects the presence of polymer on IDE surface. Figure 4c shows the optical image of PDMS coated IDE under 3D profilometer. A smooth polymer layer observed under 3D view and the variation in thickness in the PDMS layer also indicated by the change of color on IDE electrode and gap.

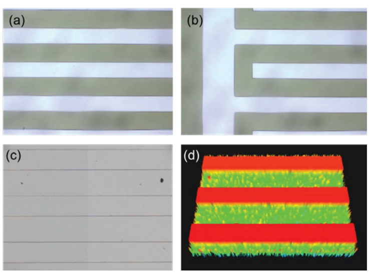

Figure 3 Optical images of IDE under HPM and 3D profilometer

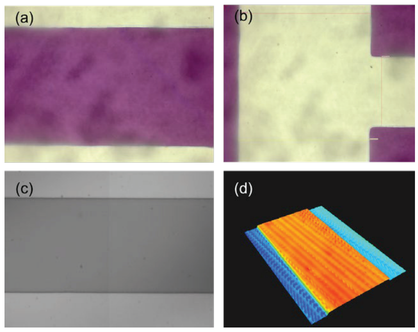

Figure 4 Optical images of PDMS coated IDE under HPM and 3D profilometer indicating the presence of polymer layer (red-yellowish) on the capacitance.

4. CONCLUSION

The aluminium IDE was well developed through the effortless photolithography technique with least errors. The morphology of IDE was examined under FESEM, HPM and 3D nanoprofilometer, which affirmed the precision of IDE fabrication. The results have convinced that optical analyses are highly acceptable for fundamental morphology examination of IDEs. As the PDMS polymer widely applied in biomedical fields, the integration of the polymer on IDE is highly encouraged through a straightforward drop casting and baking technique. The PDMS coated IDE morphology is also well examined through the preliminary optical analyses which could assist researchers for primary analyses of polymer coating on IDE.

REFERENCES

[1] S. MacKay, P. Hermansen, D. Wishart, and J. Chen, "Simulations of interdigitated electrode interactions with gold nanoparticles for impedance-based biosensing applications," *Sensors (Switzerland)*, vol. 15, no. 9, pp. 22192–22208, 2015, doi: 10.3390/s150922192.

[2] J. Martinez, A. Montalibet, E. McAdams, M. Faivre, and R. Ferrigno, "Effect of electrode material on the sensitivity of interdigitated electrodes used for Electrical Cell-Substrate Impedance Sensing technology," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, pp. 813–816, 2017, doi: 10.1109/EMBC.2017.8036948.

[3] A. W. Auner, K. M. Tasneem, D. A. Markov, L. J. McCawley, and M. S. Hutson, "Chemical-PDMS binding kinetics and implications for bioavailability in microfluidic devices," *Lab Chip*, vol. 19, no. 5, pp. 864–874, 2019, doi: 10.1039/c8lc00796a.

[4] S. Ramanathan *et al.*, "Assorted micro-scale interdigitated aluminium electrode fabrication for insensitive electrolyte evaluation: zeolite nanoparticle-mediated micro- to nano-scaled electrodes," *Appl. Phys. A*, vol. 125, no. 8, p. 548, 2019, doi: 10.1007/s00339-019-2833-0.