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Micromachined SU-8/PMMA Sandwich Electrodes with Functional Graphene Coatings for Biopotential Monitoring

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Summary:

Dry electrodes with high human biopotential signal recording quality is the promising future for wearable long-term health monitoring devices. Here, we present an ultrathin and flexible textile-like electrode composed of double-layered SU-8/PMMA microstructure fabricated using lithography-based microfabrication techniques featuring structures as fine as 100μm. Graphene oxide (GO) is introduced to the electrodes as an electrically conductive material using a single-step dip-coating method. To improve the electrical conductivity of the coated GO and hence, the performance of the electrodes, a reduction step using eco-friendly vitamin C (L-ascorbic acid) was carried out to transform GO to reduced graphene oxide (rGO). Our experimentation involved recording lead-I ECG signal acquisition using the fabricated electrodes, demonstrating their superior performance compared with Ag/AgCl wet electrodes with similarity up to 98.84% with distinguishable QRS peaks. The results pave the way towards a clinical-grade ECG signal performance.

Keywords: dry electrode, ECG, graphene oxide, microfabrication, vitamin C.

Introduction

Cardiovascular monitoring using electrocardiography (ECG) is an established technique to monitor the activity of the heart [1]. Typically Ag/AgCl wet electrodes are used to acquire biopotential signals such ECG [2]. Although these wet electrodes show highly accurate performance, they have various issues like the conductive gels drying out over time and problems with skin irritation [3]. In this study we propose a novel fabrication flow with the use of a hard mask (protection layer) avoiding the use of electron beam lithography (EBL). This work utilized industrial acrylic-based PMMA and SU-8; an epoxy-based material, to create textile-like mesh. The mesh arrangement of textile weaves makes these electrodes suitable for biopotential measurements on the skin, as this structure inherently guides signal energy in the "*z*" direction, perpendicular to the skin surface. To functionalize the electrode, graphene oxide was utilized, taking advantage of the superior capabilities of a simple, eco-friendly green reduction method using L-ascorbic acid.

Electrode fabrication

The fabrication (Fig. 1a) starts with depositing a 200 nm of SiO_2 as sacrificial layer. Then as supportive material 50 um negative photoresists SU-8-50 was spin coated at 3000 rpm then soft-baked at 65 °C for 7 min and 95 °C for 20 min then exposed to a dose of 140 mJ ultraviolet (UV) to produce a square-type microarray, post-exposure bake was then performed at 65 °C for 1 min and 95 °C for 6 min. The sample was then immersed in SU-8 developer. The next layer was PMMA, 495K MW PMMA-C4 was spin coated at 4000 rpm and was baked at 180° C for 10 min to produce 300nm. To selectively etch the PMMA, a layer of copper (Cu) was deposited on top of it. The copper layer was then patterned by spin-coating AZ5214 photoresist (PR) and exposed to UV light. Then O_2 plasma was performed for 3 minutes to etch the exposed regions of PMMA. After patterning the PMMA the Cu layer was removed by an etchant mixture of acetic acid and hydrogen solution. Finally, the electrode was released by immersion inside buffered oxide etch BOE 7:1 for 5 h. The released SU-8/PMMA sample was drop-casted by diluted GO graphene oxide suspension (4mg/mL) on a hydrophobic Teflon surface to confirm a uniform coating and dried at room temperature for one day. Next, the sample was immersed in 0.5 g/ml L-ascorbic acid and deionized water for three days at room temperature. After the reduction, the sample was washed by deionized water and left to dry (Fig. 1b). The electrode internal layers after wiring are demonstrated in Fig. 1c.

ECG signal recording

Data acquisition utilized an open-source unit (Cyton Board, OpenBCI) and recorded signals were processed using MATLAB. Electrocardiogram signals were recorded and compared with microfabricated electrodes against clinical-grade wet Ag/AgCl electrodes in a single-lead setup. The placement and an image of the microfabricated electrode during signal acquisition were illustrated in Fig. 1d.

Results and Conclusion

The resistance of the textile-like electrode was measured by a desktop multimeter and showed a relatively low resistance of 0.5 kΩ upon reduction. The flexibility of the electrodes was demonstrated in Fig. 1e, and their microscope images with and without rGO. The correlation function between the signals over a 10-second period was calculated to be 98.84%, indicating a strong correlation. This high correlation serves as validation for the high performance of the TPM electrode in capturing biopotential signals. Fig. 1f displays the two signals recorded over 10-second intervals.

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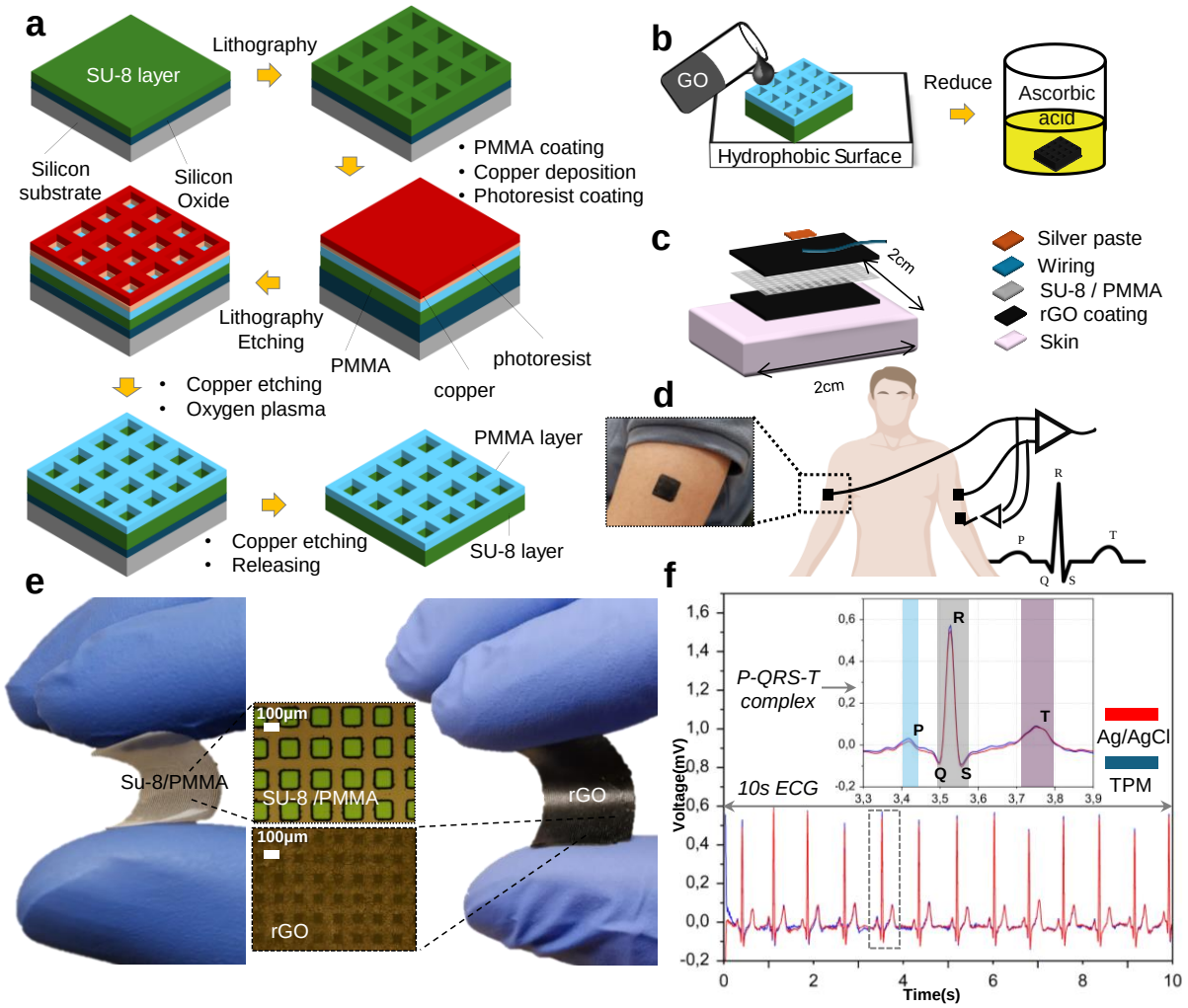

Fig. 1. (a) Fabrication steps of TPM electrode, (b) GO coating-reduction process, (c) exploded view of a TPM electrode showing its inner layers, (d) images of the electrode placed on the upper arm, (e) flexibility test applied by manually bending the electrode with under microscope images, and (f) Simultaneous ECG recording with textile-like electrodes and Ag/AgCl electrode