Deformable Structure Design for Stretchable Biomedical Epidermal Flexible Electrodes

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Abstract: In this paper, deformable structures used for stretchable biomedical flexible electrode are designed. The presented cross curves in the deformable structures promote the reliability of the flexible electrode. To show the strain distribution of the structures when stretched, three-dimensional FEM analysis models are established. The FEM analysis results illustrate that the designed structures can be stretched to 20% with the maximum principal strain less than 0.3% which adapt to the deformation of the skin.

1. Introduction

With the rapid development of flexible materials, researches relevant to flexible electrodes for biomedical signals measurement are increasing. The conformal contact between the flexible electrodes and human skin leads to lower skin-electrode impedance, thus, it can acquire better bioelectric signals by the flexible electrodes [1]. The flexible electrodes can also attach to the skin for a long period of time, which can be used in long-term bioelectric signals monitoring.

Currently, there are mainly three ways to fabricate flexible electrodes. The first way is to apply deformable structures to realize the flexibility of the electrodes [2]. The second way is to utilize the flexible conductive polymers as the raw materials of the electrodes [3]. The third way is to combine the conductive nanomaterial with flexible silicon material [4].

On the first method which realizes the flexibility of the electrodes by deformable structure, to achieve high stretchability of the electrode by pattern design is the most important matter, for the electrodes are required to contact and stretch with human skin. Self-similar Peano curves are proposed for electrode structure design [5]. The advantage of this kind of structure is that it can achieve good stretchability in different directions. All vertical Peano curve can maximize stretchability in longitudinal axes of the electrodes and half-and-half Peano curve have the ability to balance stretchability of the electrode in all directions. However, the Peano curve electrodes possess

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low reliability, for the Peano curve is single curve and the electrode is in no conducting state if any part of the curve breaks along the complicated fabrication process and the contact to the skin.

In this paper, we put forward two kinds of deformable structure unit for stretchable biomedical epidermal flexible electrodes based on the flexible electrode model. The interspersed curve in the structures we presented ensure the reliability of the whole electrode. By FEM analysis, the strain distribution of the electrode in the condition of uniaxially and biaxially stretching is analyzed to simulate the deformable of the electrode along the human skin.

2. Methods

2.1 Materials and structure of the flexible electrode model

As illustrated in Fig.1, the flexible electrode model composes electrode layer and elastomer substrate. The electrode layer includes a layer of Polyimide (PI) and a layer of Au on the top of PI. The flexible substrate is made of Ecoflex (Smooth-on, 0030) which is a kind of ultra-low modulus silicon. All the material parameters are shown on Table 1. The flexible electrode contact and deform with the skin when measuring the bioelectric signals. As the average human skin deformation is 10%~20%, the design principle for the structure of the electrode is that the electrode layer should be stretched by at least 20% with the maximum principal strain of Au layer less than 0.3% (the elastic limit of Au is 0.3%).

Table 1 Parameters of the materials in flexible electrode

	Au	PI	Ecoflex
Density (kg/m^3)	19320	1300	1070
Poisson's ratio	0.42	0.499	0.370
Young's modulus	79.5 GPa	3.1 GPa	125 kPa

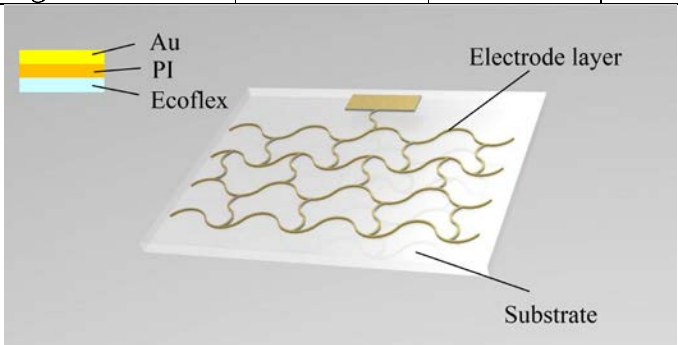

Fig. 1 The flexible electrode model

2.2 Fracture condition in single curve electrode

The fabrication process of the electrode illustrated in Fig. 1 is complicated including spinning coating, magnetron sputtering, lithography and transfer printing. The success rate of the fabrication is about 30%, mainly because of the fracture of the electrode layer during fabrication process. When attached to the skin for a period of time, the electrode may also break.

Fig. 2 shows the photos of part of the single curve electrodes. Fig. 2A displays a complete electrode part, however, the electrode in Fig. 2B is completely disconnected because of the fabrication process. After a period of time of contact to the skin, the electrode breaks as shown in Fig. 2C.

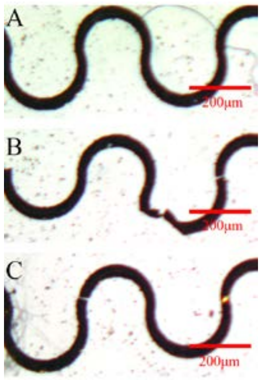

Fig. 2 The fracture condition of single curve electrode

2.3 Deformable structure units design

To avoid the affection of the broken electrode curves to the conductivity of the whole electrodes, we put forward two deformable structure units for the electrode layer as present in Fig. 3. The cross lines ensure that the electrodes keep conductive when part of the electrodes break. In addition, the curves improve the stretchability of the electrode effectively.

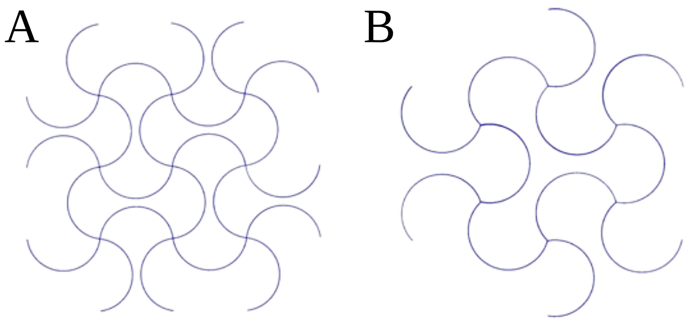

Fig. 3 Structure units design for stretchable flexible electrode

3. Results

To verify whether the presented structure units can be stretched by at least 20% with the maximum principal strain of Au layer less than 0.3%, the FEM analysis was conducted. The model is shown in Fig. 1 with Au layer (300nm), PI layer (2μm) and Ecoflex layer (25μm) and the figure is shown in Fig. 3 with the width of 10μm of each curve. The 20% uniaxial and biaxial displacement was added on the edge of the electrode layer respectively and then the FEM results was conducted by ABAQUS.

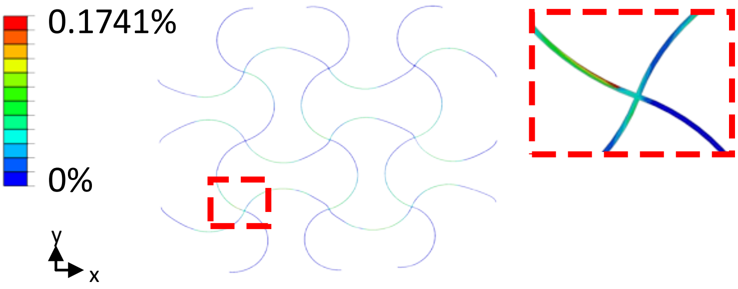

Fig. 4 Uniaxial stretching FEM result of structure A

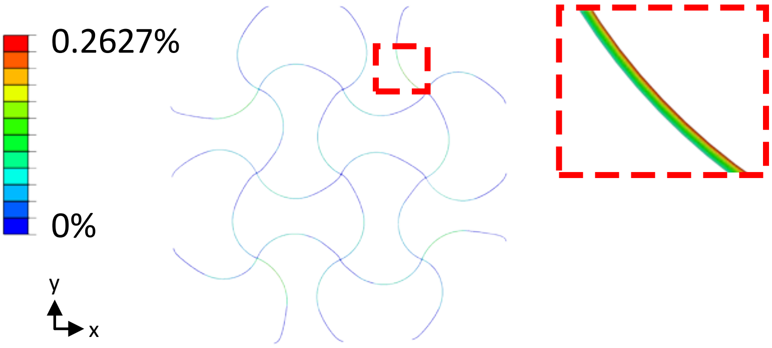

Fig. 5 Biaxial stretching FEM result of structure A

The results show that when stretching by 20% in x-axis, the maximum principal strain of the Au layer is 0.1741% (Fig. 4) and the maximum principal strain of the Au layer is 0.2627% when stretching by 20% in both x-axis and y-axis (Fig. 5). The position of the maximum principal strain of the metal layer is labeled on the FEM results in particular. The results indicate that the structure A can meet the requirement of stretching with human skin.

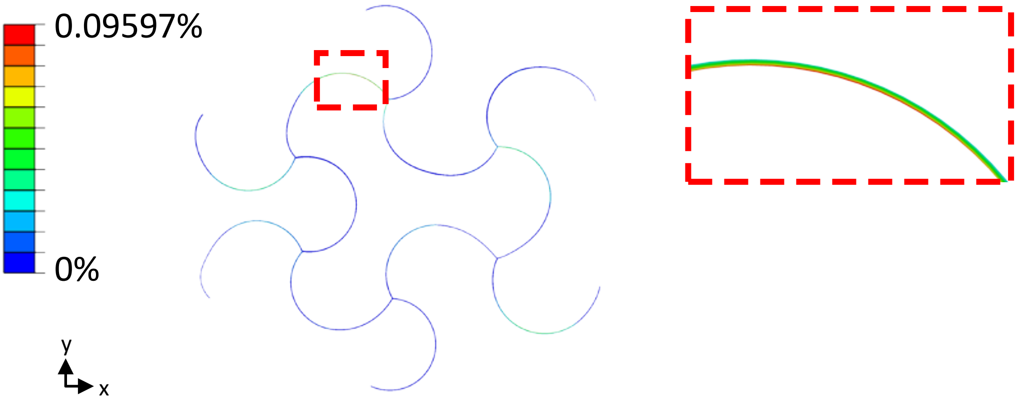

Fig. 6 Uniaxial stretching FEM result of structure B

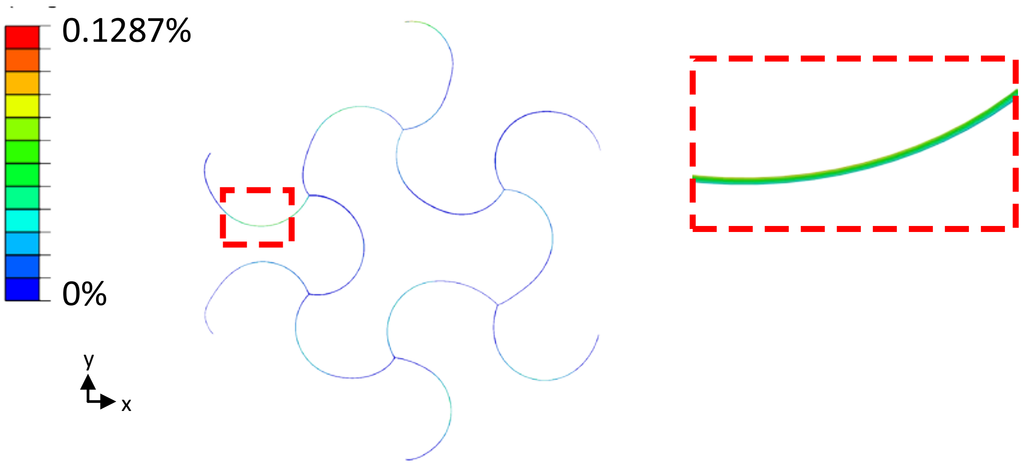

Fig. 7 Biaxial stretching FEM result of structure B

When stretching by 20% in x-axis, the maximum principal strain of the Au layer is 0.09597% (Fig. 6) and the maximum principal strain of the Au layer is 0.1287% when stretching by 20% in both x-axis and y-axis (Fig. 7). The position of the maximum principal strain of the metal layer is labeled on the FEM results in particular. From the results of FEM, we can verify that the structure B can meet the requirement of stretching with human skin.

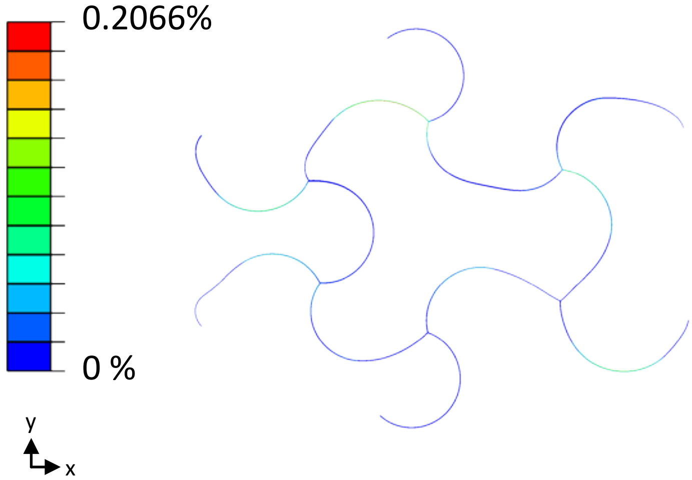

Fig. 8 Uniaxial stretching FEM result of structure B

When stretching the structure B by 40% in x-axis, the maximum principal strain is still lower than the elastic limit of Au and the structure is greatly deformed, which shows the good stretchability of structure B.

4. Conclusion

In this paper, we put forward two kinds of deformable structures for the stretchable biomedical flexible electrode. The interspersed electrode curves ensured the reliability of the electrode, which solved the actual problems. By FEM, we verified that the good stretchability of the structures. The structure B can even be stretched by 40% with maximum principal strain less than 0.3%. By arraying the structure further, we can get a whole pattern of flexible electrode which can achieve high reliability and stretchability.

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