Cochlear implant improved by highly conductive and bio-compatible ion gel adhesive

Beom Hee Park, Jihong Kim, and Bokyung Kim

***Abstract*— At interface of cochlear implant, lack of adhesion to the induces resistance for transmission of signal. In this work, we introduce biocompatible GelMA-ion-gel-based adhesive with compatibility to the lithographic process and beneficial mechanical and electrochemical properties for cochlear implant. It was concluded that the ion gel has low strain. The broad area of electrochemical window enables the stable injection of the electron. The lithographic process has been applied to build conductive interface patterns covering alloy-based electrodes. Separated coverage for each electrode was compared with coverage over entire electrodes.**

***Index Terms*— cochlear implant, ion gel, lithographic process**

I. INTRODUCTION

Apparent improvement in charge transfer was found by using conductive hydrogel[1]. However, it covers entire patterns, causing crosstalk between electrodes, and the hydrogen air generated due to charge, and the morphology of metal electrode breaking hydrogel [2], and has low adhesion to neural tissues.

In this paper, ion high charge injection, low interference between channels, minimal damage by soft interface morphology was investigated in research of GelMa ion gel.

II. Materials

A. Synthetic method

Towards the optical cochlear implant: optogenetic approaches for hearing restoration

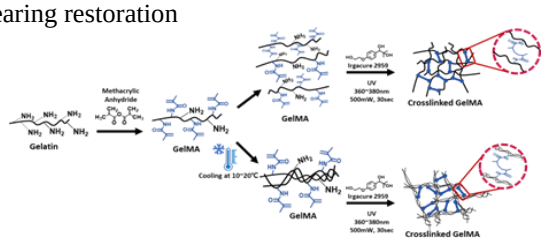


Fig 1. Synthetic method of crosslinking GelMA

Fish GelMA was synthesized as described previously Gelatin was mixed at 10% (w/v) in phosphate-buffered saline(50°C) and stirred until fully dissolved. Methacrylic anhydride was added until the 20% (v/v) of MA was reached at a rate of 0.5 ml/min to the gelatin solution with stirring at 50°C and allowed to react for 2 h. The reactive amine and hydroxyl groups of the amino acid residues were modified by changing the amount of MA present in the initial reaction mixture. After dilution (5×) with warm (40°C) PBS to stop the reaction, the mixture was dialyzed against distilled water using dialysis tubing for 1 week at 40°C to remove low-molecular-weight impurities (including unreacted MA and methacrylic acid byproducts which are potentially cytotoxic. To enable photopatterning, photocrosslinking using photo initiator is necessary. Lyophilized GelMA macromer was dissolved in PBS containing 0.5% (w/v) Irgacure 2959 as a photoinitiatior at 80°C, and subsequently used for fabrication of hydrogels.

B. Patterning method

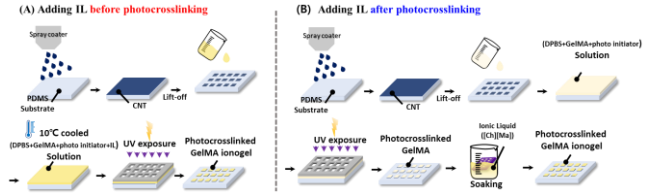


Fig. 2. Patterning process by two methods (A) Adding ionic liquid before photocrosslinking, (B)Adding ionic liquid after photocrosslinking

Patterned iongel is formed by two different methods which are distinguished by sequence of adding Ionic liquid.

1. Adding IL before photocrosslinking

Crosslinkable GelMA solution are poured on the substrate. The crosslinkable GelMA solution includes DPBS, GelMA, Photoinitiator(Irgacure 2959), and Choline-Malate Ionic liquid. In this case, Ionic liquid is included in solution. Then, coated solution was covered by photo mask, and 360nm UV expose to the solution.

2. Adding IL after photocrosslinking

Crosslinkable GelMA solution are poured on the substrate. The crosslinkable GelMA solution includes DPBS, GelMA, and Photoinitiator(Irgacure 2959). Ionic liquid is not included in solution. Then, coated solution was covered by photo mask, and 360nm UV expose to the solution. After photopatterning, patterned gel was soaked in Ionic liquid.

C. Long-term stability

In terms of bio devices, device stability is necessary. In the case of hydrogel, water evaporation is the critical issue to apply commercial electrical devices. Our iongel-based patterned stimulator is using ionic liquid, so that it has lower vapor pressure than water which can prevent from evaporation of iongel[3]. Ionic liquid, also has wide range of electrochemical window which means it has electrical stability without redox

reaction over a wide range[4]. Moreover, our materials has biocompatibility with no inflammation.

D. Energy efficiency

voltage gradient occurs from the stimulation. Further nerves have difficulty to be stimulated from the electrodes[5]. So high adhesion to tissue and high resolution patterned electrode is needed. In addition, since operating voltage is much lower compared with operating voltage of metal electrode, iongel patterned iongel stimulator can prevent crosstalk effect.

E. Charge injection method

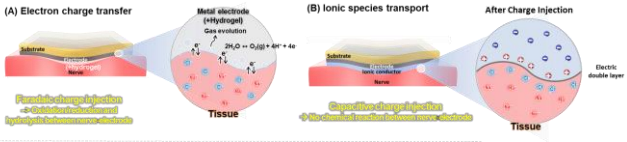


Fig. 3. Charge injection mechanism (A) Electron charge transfer, (B) Ionic charge tranport

Without iongel, stimulation occur directly at the electrode surface. It stimulates by faradaic charge injection[6]. If we use metal electrode, electrode occurs redox reaction. At this step, hydrogen ions and hydrogen gas evoke. Hydrogen ion changes body pH, and this evoke calcium ion influx which causes cell apoptosis and tissue injury. And produced gas(hydrogen gas) presses tissue, and it can increase contact resistance. Even electrode coated with hydrogel, those phenomenon appears. Compare with electron charge transfer, our system, ionic species transport stimulates by capacitive charge injection. There is no any chemical reaction between nerve and electrode. when voltage apply, ion transport to the nerve iongel interface and EDL is formed. it can attract bio ions and stimulate nerves.

F. Energy efficiency

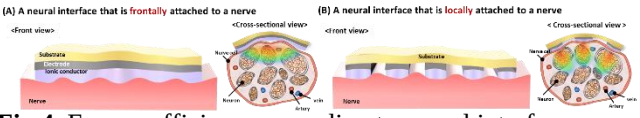


Fig 4. Energy efficiency according to neural interface adhesion (A) Frontally attached (B) Locally attached to a nerve

The existing cochlear implant neurostimulator, it is completely attached to the nerve. In this method, stimulation is applied to the entire adhesive interface between the nerve and the neurostimulator, rather than accurately delivering stimulation to a specific area. Since this method is applied to areas that do not require stimulation, it can cause side effects and reduce efficiency due to energy dispersion. However, if stimulation is delivered locally to a specific nerve bundle through patterning, only the desired response can be elicited, and energy efficiency can also be increased.

Ⅲ. Results and Discussion

Through cytotoxicity test, we can confirm GelMa iongel has better cell viability than PEDOT:PSS, which is well known to be biocompatible.

GelMa iongel has transparent and stretchable properties and also has a modulus of 82 kPa when the amount of ionic liquid is increased to 80 wt%. Due to this low modulus, nerve damage can be prevented by being mechanically matched with soft tissue.

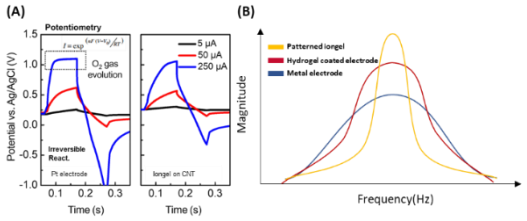


Fig 5. Electrical performance (A) potentiometry (B) stimulation efficiency

When only the Pt electrode was used, there was the redox reaction through the flat part of the graph, and it can be confirmed that the redox reaction did not proceed because there is no flat part in our system using iongel and CNT. The patterned GelMa iongel electrode can locally stimulate only the desired cochlear frequency area, and it can be confirmed that it shows better efficiency and selectivity than existing metal and hydrogel coated electrodes[7].

IV. Conclusion

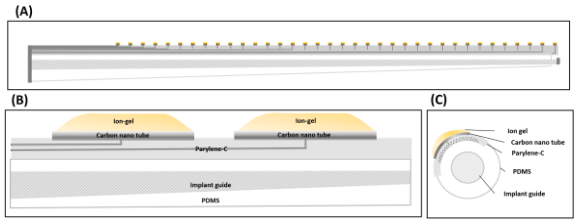


Fig. 6. Design of cochlear implant array (A) Side view, (B) Closer view, (C) Cross view

Considering investigated advantages, Improved cochlear implant electrode array with 36 channels was designed. Pattern of conductive GelMA-ion-gel-based adhesive by lithographic process enabled the design of separate electrode in Fig.6. The microwire consisted with spin-coated Carbon nano wire. The electrode was attached to PDMS substrate for the flexibility.

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