Extremely Stretchable Electrode based on Combination of Inkjet-Printed Silver and Conductive Composite for Stretchable Lighting Applications

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ABSTRACT

We have studied stretchable electrode based on combination of inkjet-printed silver electrode and conductive composite materials for stretchable lighting device application. We combined conductive composite materials with inkjet-printed metal thin film for high conductivity for both low and high elongation conditions. Our approach has advantages of simple patterning capability, high intial conductivity, and compensated low resistance sustaining under tremendously high tensile strain conditions when compared with previously reported methods. Our stretchable electrodes showed high condudctivity from the inkjet-printed silver electrode and maintained similar level of conductivity when they are elongated over 100%.

Keywords: stretchable electrode, conductive composite, inkjer-printing

1 INTRODUCTION

Last 10 years, stretchable electrodes have shown great progress. It has many potentialities for future electronics such as flexible display, wearable electronics and biomedical application.[1,2] The stretchable electrodes require high conductivity and high stretchability. Previous stretchable electrodes were mainly realized by either vaccum deposition or inkjet-printing of conductive materials on stretchable substrates.[3-7] Those stretchable electrodes can well sustain electrical performance at relatively low tensile strain condition (typically under 30% elongation). In order to realize stretchable electrode that can well sustain electrical performance at higher tensile strain condition (over 30% elongation), conductive composite materials have been also widely used. Recently, CNT-based conductive composite materials have been reported for stretchable electrode application.[8] However, CNT-based conductive composite materials has cost issues and it needs a complex fabrication prodcess for having high conductivity and stretchability.

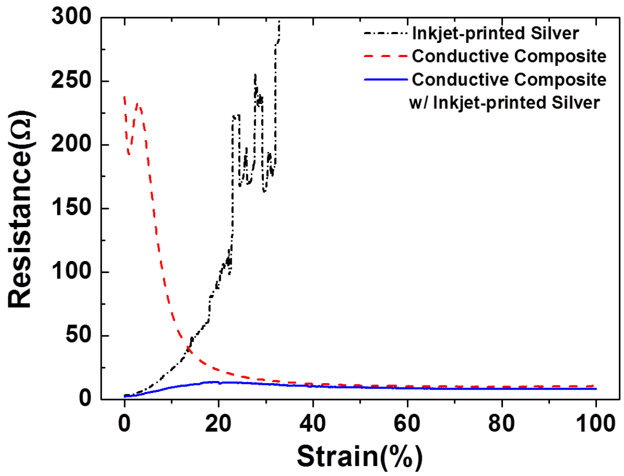
In This study, we combined highly stretchable conductive composite materials with inkjet-printed silver thin film to obtain high conductivity under both low and high elongation conditions.

2 EXPERIMENTAL

We prepared three types of stretchable electrodes, inkjet-printed silver electrode on elastomeric PDMS substrate, nickel powder based conductive composite and inkjet-printed silver on the nickel based conductive composite, respectively. For three electrodes, poly(dimethylsiloxane) (PDMS; Sylgard 184 from Dow Corning) was used for insulating and stretching matrix of stretchable electrodes.

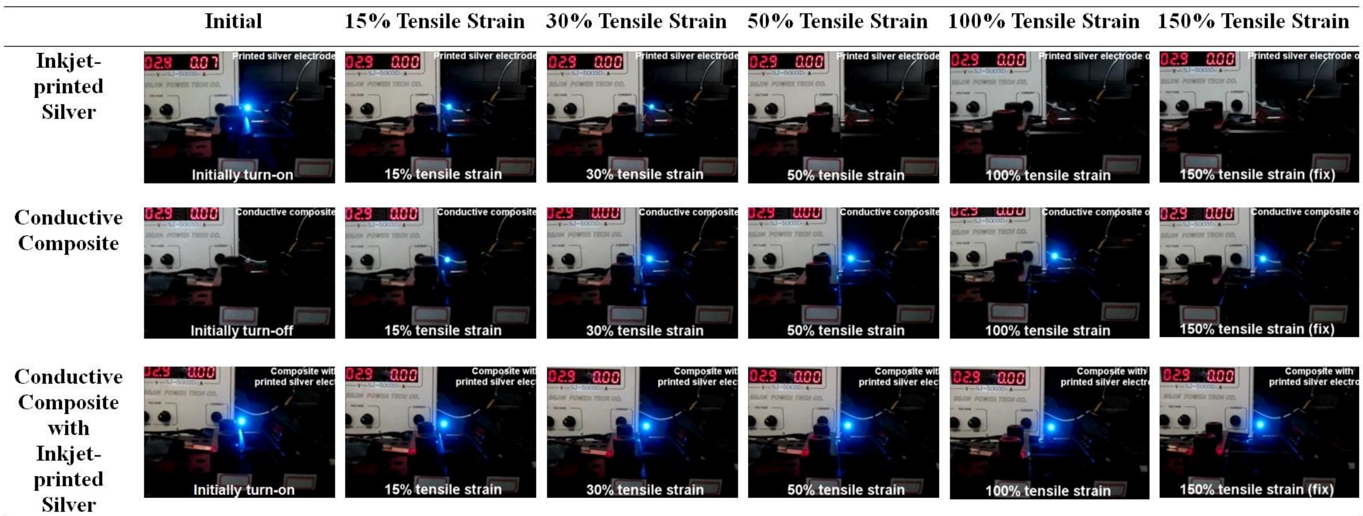
To fabricate inkjet-printed silver electrode, we fabricate elastomeric PDMS substrate which has intentionally roughened surface which was shown at our previous publications.[5-7] The roughened surface can provides releasing the film stress for the inkjet-printed silver electrode under tensile strain. 10:1 weight ratio mixture of PDMS base and curing agent was cast onto a roughened flat aluminiu mold. The aluminium mold surface was intentionally roughened by wire-electro discharging machining (wire-EDM). The casted PDMS mixture was cured on a hot plate at 150 ℃ for 10 min in air ambient. For silver electrode printing, nanoparticle type silver ink (DGP-40 from ANP Corp.) was used. Originally, adhesion property between PDMS substrate and silver ink is very poor, because, while silver ink was soluted in polar solvent, PDMS has hydrophobic property. For making good adhesion property between the PDMS substrate and the silver ink, the PDMS surface was treated by UV ozone treatment. The silver electrode with 10-mm length and 1-mm width was printed on to the UV ozone treated roughened PDMS substrate by using a piezo electric inkjet-printer (DMP-2831 from Dimatix Corp.). Detail inkjet-printing process was shown at previous publication.[7]

To fabricate conductive composite, nickel powder (<150 μm, 99.99% from Sigma Aldrich) was used for conductve filler. 10 : 1 weight ratio mixture of PDMS base and curing agent mixed with 14.3 vol% nickel powder by blender mixer for 10 min and then it was put in desiccator for degassing air bubbles in the mixture for 1 hour. Degassed mixture was cast on to the flat aluminium mold.



(a)

Figure 1 : **(a)** *In situ* measurement of resistance change in terms of applied tensile strain for inkjet-printed silver, conductive composite and conductive composite with inkjet-printed silver. **(b)** Luminance change of LED which was connected inkjet-printed silver, conductive composite and conductive composite with inkjet-printed silver, respectively as applied tensile strain



(b)

The casted PDMS with nickel powder mixture was cured on a hot plate at 150 ℃ for 10 min. Fully cured conductive composite electrode has 10-mm length, 1-mm width and 1-mm thickness.

To fabricate inkjet-prited silver on to nickel based conductive composite, the conductive composite was used as subsrate for inkjet-printed silver and also used as electrode itself. All fabrication process is same with the aforementioned inkjet-printed silver electrode on PDMS substrate except that the conductive composite was used as substrate.

Mechanically stretching test was performed by using homemade stretching equipment, and the electrical property of the stretchable electrodes was measured by using Keithley 2420 that is controlled by a computer.

3 RESULTS AND DISCUSSIONS

Figure 1. (a) shows comparison of electrical resistance variation with applied tensile strain for three kinds of stretchable electrodes. Tensile strain was applied at 16.7 μm/s, and electrical resistance was measured every 0.2 sec.

The initial resistance of inkjet-printed silver, conductive composie and conductive composite with inkjet-printed silver were 3.2, 237.4 and 2.2 Ω respectively. The inkjet-printed silver electrode shows good electrical performance at low tensile straion condition (under 20% elongation). However, its electrical resistance was rapidly increased at higher tensile strain condition (over 20% elongation). The inkjet-printed silver shows electrically open characteristic at above 38% tensile strain condition. This resistance increasing was originated from increasing of metal cracks as tensile strain.[5,7,9] The conductive composite shows poor electrical performance at low tensile strain condition. However, its electrical resistance was decreased as strain increase. The resistance was reached 20 Ω at 21% tensile strain and it remains under 20 Ω until 100 % tensile strain condition. On the other hand, the inkjet-printed silver on to conductive composite shows high conductivity at low to high elogation condition. This combined stretchable electrode shows resistance lower than 20 Ω at all range of performed tensile strain condition. Its resistance was increased gradually until 20% strain condition, mainly due to crack formation of the inkjet-printed silver electrodes. As the tensile strain further increases, the resistance decrease, saturates to be around 10 Ω, and maintain its value even up to 100% tensile strain, because conduction occurs through the conductive composite materials at high strain. Figure 1. (b) shows comparison of Light Emitting Diode (LED) operating experiments at various tensile strain conditions. The three types of stretchable electrode was connected to power generator and conventional blue LED, and luminance was monitored with applied tensile strain. For the inkjet-printed silver, LED was turned-on at initial stage. However its luminance was gradually decreased, and finally turned-off at over 30% tensile strain. For the conductive composite, LED was turn-off at initial stage. However its luminance was gradually increased, and fully turned-on around 30% tenile strain condition. The luminance was maintained at even up to 150% tensile strain. Similar with resistance variation, LED that was connected to the combined stretchable electrode shows fully operating luminance from initial to 150% tensile strain.

4 CONCLUSION

In conclusion, we have fabricated an extremely stretchable electrode based on combination of inkjet-printed silver and conductive composite. The resistance of the extremely stretchable electrode was maintained below 20 Ω even up to 100% tensile strain. We believe that combination of our stretchable electrodes can be used for interconnection of stretchable lighting device.

5 ACKNOWLEDGEMENTS

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