Fabrication of stretchable transparent electrode with high porous conductive carbon inducing vacuum force

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1. Introduction

Stretchable electrode has been paid attention as the demand on flexible and stretchable devices such as artificial skin and muscle, smart clothing, and electronic textile. [1, 2] One of many challenge on the stretchable electrode is fabricating the electrode has high stretchable ability. Owing to the stretchable ability and bio-compatibleness, PDMS has been widely used as the electrode substrate [3]. The main challenge on the stretchable electrode using PDMS as electrode substrate is transferring stretchable

conductor on the substrate. The stretchable conductor pattern is prepared by photolithography method [4]. Also, other methods have been proposed such as growing the pattern with proposed chemical etching or deposition with masking [5, 6]. On the order hand, there are other methods that inject or spay the conductor on an elastomer substrate directly. For example, gravure-offset method has been highlighted for cost efficiency and rapidity of the process. However, the aforementioned methods need transferring the electrode patterns to elastomer. The printed electronics method is simple so that can reduce the manufacturing cost while the photolithography method needs multi step process for preparation. Nevertheless, lithography methods is still in development stage since the adhesive force is not sufficient between transferring conductor and substrate resulting in poor durability of the stretchable electrode.

In this study, we proposed fabrication method transferring electric conductor in engrave pattern on a stretchable substrate. In order to transfer the electric conductor material on the substrate completely, we induced vacuum force resulting in full permeation of elastomer into the electric conductor. Here, vacuum force is induced by itself

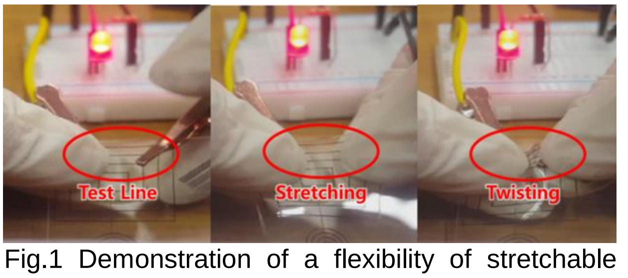

Fig.1 Demonstration of a flexibility of stretchable electrode fabricated under proposed process.

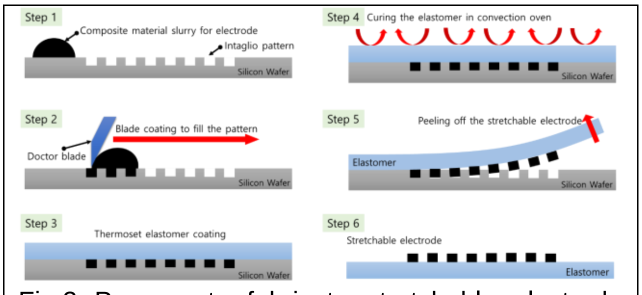

Fig.2 Process to fabricate stretchable electrode under wet condition. Vacuum force induced during curing step.

without extra vacuuming under solvent evaporation. This auto vacuuming phenomena can be achieve only under wet transferring process which is proposed in this study. Also, extra process to dry electric conductor could be skipped since the transferring process is carried under wet condition and this can reduce cost for the electrode fabrication.

2. Body of abstract

The curing method using vacuum force on a fabrication of stretchable electrode is proposed in this study. Unlike conventional methods, thermosetting elastomers is cured when the electrode slurry is still wetted. In this method, it was expected that volatile solvent in the slurry evaporates before the elastomer is fully cured and escapes the intaglio pattern during the curing

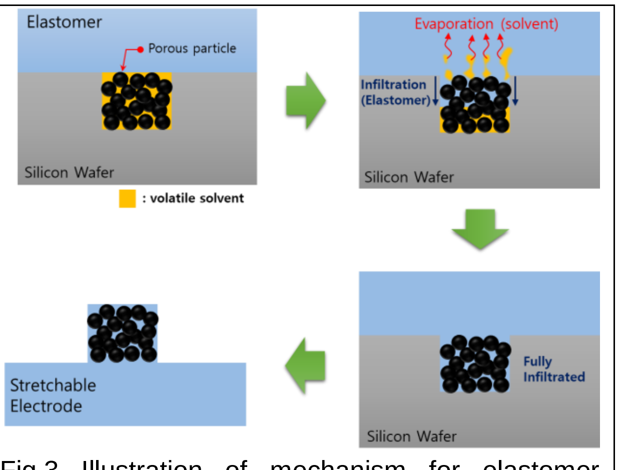

Fig.3 Illustration of mechanism for elastomer permeation into electric conductive material in the engrave pattern.

process. Consequently, vacuum force built inside the electrode conductor leads full infiltration of elastomer into the electrode pattern. For a demonstration of the proposed method, electrode slurries were synthesized with volatile solvents and porous carbon-blacks carrying the solvent. Also, the effect of adsorption/desorption ability of the porous carbon was studied. Here, two particles such as Denka-black and Ketjen-black were chosen for the demonstration. In this test, complete infiltration of elastomer into the intaglio pattern was observed only for the electrode fabricated with Ketjen-black having superior adsorption/desorption ability. Also, the fabrication shows extraordinary transfer ration of the electrode conductor from silicon substrate to elastomer. While, in the case using electrode slurry synthesized with Denka-black having low adsorption/desorption ability, the elastomer could not permeate the particles completely. This result attributes to fact that the particle carries insufficient solvent due to the poor adsorption/desorption resulting in weak vacuum force. Additionally, the effect of volatility of solvent on the proposed method was investigated. Here, three solvents such as Acetone, Tetrahydrofuran, and Ethanol were considered. In the test using Ethanol solvent having inferior volatility compared with the others, bubble defects in cured elastomer were observed. This result elucidated from the fact that Ethanol couldn't fully evaporate before

elastomer is cured due to the inferior volatility so that the gasified solvent (Ethanol) captured in the elastomer. However, clear transparent electrode was obtained by using Acetone and Tetrahydrofuran since the solvents shows higher evaporation rate. Lastly, the curing methods were explored to improve the fabrication quality.

According to the evaporation and curing

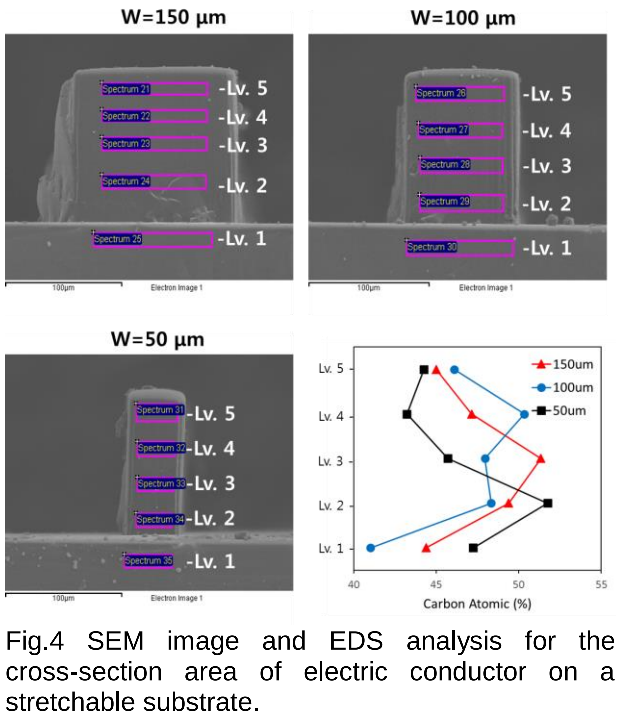

Fig.4 SEM image and EDS analysis for the cross-section area of electric conductor on a stretchable substrate.

mechanism, it is desired to heat the solvent in the intaglio pattern prior to elastomer. From this motivation, the curing process was carried out on the hot plate and the results were compared with an electrode cured in convection oven. Here, to clarify the comparison, the curing tests were carried out with inferior electrode slurry synthesized with Denka-black or excessive solvent. First, the full infiltration of elastomer into the particles was observed by curing the electrode on a hot plate even with the inferior slurry using Denka-black. This fabrication quality couldn't be obtained by curing the elastomer in a convection oven. Furthermore, the bubble defects which are observed in elastomer cured in convection oven couldn't be found in the electrode cured on a hot plate. This result indicates that curing on hot plate provokes evaporation of solvent prior to thermosetting of the elastomer so that induce infiltration of the elastomer more. Based on the results, it can be conclude that vacuum force is key factor for high transfer ratio of the electrode conductor. Furthermore, the infiltration can be enhance by adsorption/desorption ability of particle, volatility of solvent and curing method.

Acknowledgment

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References

[1] S. Hong et al., "Highly stretchable and transparent metal nanowire heater for wearable electronics applications," Advanced materials, vol. 27, no. 32, pp. 4744-4751, 2015.
[2] T. Sekitani and T. Someya, "Stretchable, large-area organic electronics," Advanced Materials, vol. 22, no. 20, pp. 2228-2246, 2010.
[3] D. Fuard, T. Tzvetkova-Chevolleau, S. Decossas, P. Tracqui, and P. Schiavone, "Optimization of poly-di-methyl-siloxane (PDMS) substrates for studying cellular adhesion and motility," Microelectronic Engineering, vol. 85, no. 5, pp. 1289-1293, 2008.
[4] T. Adrega and S. P. Lacour, "Stretchable gold conductors embedded in PDMS and patterned by photolithography: fabrication and electromechanical characterization," Journal of Micromechanics and Microengineering, vol. 20, no. 5, p. 055025, 2010.
[5] X. Li et al., "Transfer of large-area graphene films for high-performance transparent conductive electrodes," Nano letters, vol. 9, no. 12, pp. 4359-4363, 2009.
[6] K. S. Kim et al., "Large-scale pattern growth of graphene films for stretchable transparent electrodes," nature, vol. 457, no. 7230, pp. 706-710, 2009.
[7] D. McCoul, W. Hu, M. Gao, V. Mehta, and Q. Pei, "Recent advances in stretchable and transparent electronic materials," Advanced Electronic Materials, vol. 2, no. 5, 2016