Flexible Wire Based on Silver Nanowires and Elastomer

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Abstract. In order to solve the problem that the wire is difficult to have both elasticity and conductivity, a novel method for producing flexible wires based on silver nanowires (AgNWs) and elastomer has been proposed. This type of flexible wire is fabricated using a pre-stretching process and a glass sheet transfer process. Stretching test shows that after 50 times 0-30%-0 cycles of tensile test, the resistance growth rate relative to initial resistance is only 510%. The flexible wire can be widely used in flexible electronic devices.

1. Introduction
Flexible wires are the key components in flexible electronic devices such as intelligent manufacturing, pension service, disability assistance and so on. The flexible wires required to be both elastic and conductive. In recent years, the research of flexible wires has become a hotspot [1, 2].

At present, research on flexible wires is progressing rapidly after decades of development. There are three main methods for making flexible wires: mechanical buckling, multidimensional metal wires, composite material of conductive material and elastomer. Suo et al. deposited a gold membrane on a pre-stretched ultra-thin elastomer to make wires [3]. Stretching rate of the wire can reach 100%, but it is easy to wear. M. Jablonski et al. make curved metal wires buried into elastomer to improve the flexibility of the wire, but it is only suitable for single direction stretching [4]. The composite material of conductive material and elastomer has attracted intensive attention of researchers due to its good flexibility and conductivity. Feng Xu [5] and Haopeng Wang [6, 7] et al. produced stretchable conductors by the way of embedding AgNWs in the surface of PDMS. And the conductive composites are conductive and flexible. Based on the work of predecessors, this paper explores new methods to further improve the flexibility of wires.

Here, starting from the selection of materials and the new manufacturing process, the new method for manufacturing flexible wires was explored. The novel AgNWs/PDMS composites were selected, and a pre-stretching process and a glass sheet transfer process were used to produce flexible wires. The flexibility and elasticity of this new type of wires are improved greatly.

2. Experimental Details
2.1. Materials
The flexible wire is made by the method of mixing conductive fillers into elastomer. The conductive composite material not only maintains the excellent conductivity of conductive fillers, but also has excellent flexibility of elastomer. Therefore, it is an ideal material for making flexible wires.

The conductive properties of this conductive composites are determined by the conductive filler mainly. Here, AgNWs are selected for their excellent conductivity, good mechanical flexibility and
well transparency. Currently, AgNWs have demonstrated application value in solar cells, touch screen, tactile sensor and other areas [8]. Though experiments, it’s found that the size, concentration, and solvent of AgNWs all have effects on the flexible wire. In order to ensure the conductivity and flexibility of the flexible wire, the size and concentration of AgNWs should be with a diameter of 90 nm, a length of 2 ~ 20 µm and a concentration of 10 mg/mL. In addition, the water solvent is selected to obtain a uniform thickness during the production process of flexible wires.

Elastomer mainly affects the flexibility of conductive composite material. Here, well-known PDMS is chosen for its outstanding physical and chemical properties. PDMS film has excellent flexibility and transparency, so it is an extremely suitable material for making flexible wires as substrates. In this paper, the type of PDMS is Dow Corning Sylgard 184.

Therefore, the flexibility of the wire is guaranteed from the perspective of materials.

2.2. Method

The flexible wire is fabricated by using a pre-stretching process and a glass piece transfer process. The specific steps are as follows:

First, a PDMS film needs to be prepared in advance. The preparation method comprises the following steps: mixing the main agent and the binder of the liquid PDMS in a certain ratio; stir the composite uniformly and pour it on a glass plate; allow the liquid PDMS to naturally flow to the required thickness; then remove the bubbles inside the liquid PDMS; at last, heat and cure the PDMS film.

Second, cut the prepared PDMS film into a strip with a width of 5mm and a length of 100 mm. Stretch the strip PDMS film and fix it on a glass plate.

Third, drop AgNWs solution on a glass piece with a width of 3 mm and a length of 60 mm. Wait for the AgNWs solution dried leaving AgNWs on the glass piece, then repeat the dropping process three times.

Fourth, make the side of glass piece coated with AgNWs adhered to the pre-stretched PDMS film by thin liquid PDMS. Remove bubbles inside the middle between AgNWs and liquid PDMS, then heat and cure the entire structure.

Finally, remove the glass piece, then the flexible wire is obtained as shown in Figure 1.

3. Results and Discussion

In order to test the flexibility of the flexible wire, a stretching test is designed using a tensile tester provided by Shanghai Hualong Testing Instrument Co., Ltd. The flexible wire was fixed in the middle of the clamps of the tensile tester and was repeatedly stretched to 130% at a constant speed during the stretching test. The stretching speed would have effects on the conductive stability of the flexible wire. Here, the stretching speed selected in this experiment is 3 mm/min. The method of stretching test is to make fifty times 0-30%-0 stretching cycles on the flexible wire.

![Figure 1. Physical photo of the flexible wire](image-url)
Figure 2 shows the relationship between resistance and stretching cycles of the flexible wire. The initial resistance of the flexible wire is 3.2Ω, and the resistance value increases slightly with the number of stretching increases. At the state of fifty times stretching to 130%, the resistance of the flexible wire is just 19.5Ω, and the resistance growth rate relative to initial resistance is only 510%. The stretching test proved that the flexible wire produced by a pre-stretching process and a glass sheet transfer process has good conductivity and elasticity.

Figure 3. The relationship between the resistance and the stretching cycles

Figure 4 shows the SEM image of the flexible wire after repeated stretching cycles. It is found that, the surface of the flexible wire has no obvious cracks. Therefore, good electrical conductivity of the flexible wire is maintained after repeated stretching.
4. Conclusion
In summary, the novel flexible wire based on AgNWs/PDMS composites produced by a pre-stretching process and a glass sheet transfer process exhibits excellent flexibility and elasticity. Therefore the flexible wire has potential applications in flexible devices such as bionic robots, medical instruments, health monitoring equipment, and so on.

5. Acknowledgments
The authors would like to acknowledge the financial support provided by Innovation Method Fund of China (2016IM010300) and the Fundamental Research Funds for the Central Universities (FRF-GF-18-010B).

6. References
[1] Wang Guobiao, CHEN Diangsheng, CHEN Kewei, et al. The current research status and development strategy on biomimetic robot [J]. Journal of Mechanical Engineering, 2015, 51 (13): 27-44.
[2] CAO Jianguo, ZHOU Jianhui, MIAO Cunxiao, et al. Research progress and development strategy on tactile sensors for e-skin [J]. Journal of Harbin Institute of Technology, 2017, 49 (1): 1-13.
[3] S. P. Lacour, J. Jones, S. Wagner, T. Li, Z. Suo. Stretchable interconnects for elastic electronic surfaces. P IEEE. 93 (8): 1459-1467, 2005.
[4] I. Chtioui, F. Bossuyt, M. de Kok, J. Vanfleteren, M. H. Bedoui. Arbitrarily Shaped Rigid and Smart Objects Using Stretchable Interconnections. IEEE T COMP PACK MAN. 6: 533-544, 2016.
[5] F. Xu, Y. Zhu. Highly conductive and stretchable silver nanowire conductors. Adv. Mater. 24 (37): 5117-5122, 2012.
[6] Wang H P, Zhou D B, Cao J G. Development of a skin-like tactile sensor array for curved surface [J]. IEEE Sensors Journal, 2014, 14 (1): 55-61.
[7] Wang H P, Zhou D B, Cao J G. Development of a stretchable conductor array with embedded metal nanowires [J]. IEEE Transactions on Nanotechnology, 2013, 12 (4): 561-565.