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# Metal-Organic Dual Layer Structure for Stretchable Interconnects

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**Abstract**

This paper reports a novel method for obtaining stretchable interconnects using gold and organic material (PEDOT:PSS) in a dual-layer structure on PDMS substrate. With an appropriate design and carefully carried out microfabrication steps, the structure was successfully patterned into serpentine shape and highly stretchable interconnects were obtained. The fabricated interconnects can be stretched up to 170% of their original length while retaining an adequate level of conductivity.



*Keywords:* Organic polymer; Stretchable electronics

## 1. Introduction

The next era of electronics is expected to lead to flexible devices. The development of such devices would have an immense benefit for applications such as healthcare monitoring [1-2], wearable and consumer electronics [3] and robotics [4-5]. However, the development of such devices with existing technology is a challenge owing to the limited intrinsic elasticity and almost negligible stretchability of materials such as silicon, which is used as substrate. Therefore, numerous materials and techniques are currently being pursued to enable stretchable electronics. Among them stretchable interconnects is dominant as it they enable the use of traditional electronics while facilitating development of stretchable systems.

Initial progress in development of stretchable interconnects was made through metallic interconnects on stretchable substrate. This method resulted in a limited stretchability owing to high interfacial stress between the materials [6].

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Subsequently, smart structural engineering [7-9] and novel materials have been employed to improve the stretchability [10]. Some of the novel materials investigated for stretchable interconnects includes the nanocomposite [11], which utilize highly conductive fillers like carbon based material (e.g. Carbon nanotubes [12]. Graphite fakes [13], Graphene nanoplatelet [14] etc.) or metal-based materials (e.g. silver flakes [15], silver nanowires [16] etc.) embedded in soft polymer matrix and organic polymers [17].

Here, we report the development of hybrid stretchable system with a metallic and organic dual layer for development of stretchable interconnects. The dual layer comprises of conductive organic polymer poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) and metallic (Au) layer on a polydimethylsiloxane (PDMS) substrate. This structure enables high stretchability while retaining the acceptable conductivity. As illustrated in Fig.1, the PEDOT:PSS film is designed to provide the much needed continuity in the electrical path when Au layer fails because of typical cracks in it due to stretching. At the same time, the top Au film is regarded as an electrical conductivity promotion layer as well as a protection mask for PEDOT:PSS from chemicals and water.

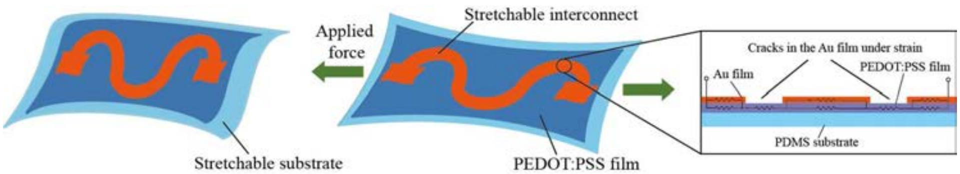


Fig. 1. Schematic representing the interconnect based on PEDOT:PSS. The cross section view illustrates the electrical path built by PEDOT:PSS layer under the Au film between the islands of Au film separated by the cracks generated under external strain.

## 2. Fabrication process

The geometries of proposed interconnects were designed into serpentine shape. Based on the degree of arc radius, the interconnects can be stretched to different level of elongations. The designs were composed of straight line and serpentine-shaped with an arc degree of 60º &180º as illustrated in Fig. 2 (Left).

The basic fabrication process is depicted in Fig. 2 (Right). First, the PDMS substrate was coated and cured on the carrier silicon wafer. Following this, about 700 nm-thick PEDOT:PSS film was deposited on PDMS using spray coating method. The spray-coated PEDOT:PSS film exhibits a resistivity around 0.0072 Ω·m. Following this step, a metal stack (10 nm Ti and 100 nm Au) was evaporated. The metal pattern was achieved through photolithography and etching. The interconnects were tested after releasing from the silicon wafer.

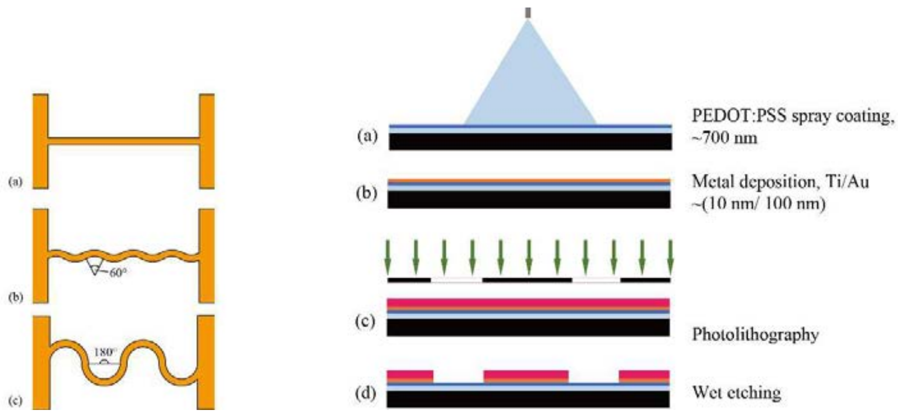


Fig. 2. Design of three different interconnects with respect to different arc radius (a) Straight line (b) Serpentine (60°) (c) Serpentine (180°) (Left); Schematic diagram of fabrication process of the interconnects (Right).

## 3. Electrical-Mechanical characterization

The electrical response of interconnects was measured under an applied strain with a custom-made stretching setup (Fig. 3 (Left)) and multimeter (Keithley 2700). The minimum step for one-end's stretch movement is 0.01 mm. The overall resistance is recorded through Labview program. The electrical response shown in Fig. 3 (Right) indicates that the deformation led cracks in Au film is the primary reason for the change in resistivity in the first phase (0-2.5%). However, this change in resistivity is significantly lower than the interconnects without PEDOT:PSS, as shown in Tab. 1. At certain stretching stage (~10%), the Au islands detach further and leave the PEDOT:PSS film to contribute more towards electrical continuity. As the conductivity of PEDOT:PSS film is limited, the overall resistivity is 10-50 times higher before stretched. When PEDOT:PSS film starts to break, the resistivity rises to around 0.022 **Ω**·m. The proposed interconnects remain conductive up to about 70% stretching from their original lengths.

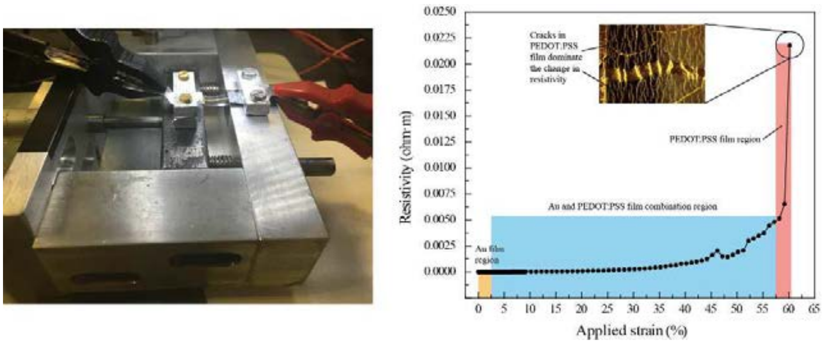


Fig. 3. Custom-made uniaxial stretching setup mounted with device under test, the device is connected to multimeter (Left); Electrical response of serpentine-shaped interconnect with PEDOT:PSS as underlying layer while under an external strain from 0% to 60% (Right).

Tab. 1. : Comparison of maximum possible elongation and the change in resistivity between three different designs of interconnect with/without PEDOT:PSS underlying layer.

| Design | Material | Maximum elongation | $\Delta\rho/\rho_0$ @ 1% applied strain | $\Delta\rho/\rho_0$ @ 10% applied strain |
|---|---|---|---|---|
| Straight line | Au film | 1% | 77.2% | - |
| | Au+PEDOT:PSS dual-film | 1.2% | 33.6% | - |
| Serpentine (60°) | Au film | 0.5% | 13.2% | - |
| | Au+PEDOT:PSS dual-film | 60.2% | 2.1% | 43.91 |
| Serpentine (180°) | Au film | 1.5% | 48.4% | - |
| | Au+PEDOT:PSS dual-film | 71.9% | 0.9% | 64.93 |

## 4. Conclusion and future work

The organic conductive polymer PEDOT:PSS film has a clear advantage of serving as an underlayer between the Au film and PDMS substrate. It successfully provides the electrical path when cracks generated in the Au film under external strain. Compared to the straight line design of the interconnects, the serpentine-shaped design helps to increase the elongation ratio from around 1% to more than 60%. The presence of PEDOT:PSS film also stabilizes the electrical response of the interconnects while under strain. The change in resistivity is dramatically reduced in the range of 1% external strain. Further improvements are required in the fabrication process to overcome challenges such as the wet etching process of Au film causing the delamination of PEDOT:PSS film from PDMS substrate. The overall process has to avoid any process containing water and solvent.

## Acknowledgements

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