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Carbon nanotube based stretchable optically transparent electrodes for dielectric elastomer actuators

Contact e-mail:
dominik.nemec@
ipa.fraunhofer.de

Dominik Nemec (1), Serhat Sahakalkan (1), Gabriele Frediani (2), Ivica Kolaric (1), Thomas Bauernhansl (1), Federico Carpi (2,3)

(1) Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany; (2) University of Pisa, Interdepartmental Research Centre `E. Piaggio`, School of Engineering, Pisa, Italy; (3) Technology & Life Institute, Pisa, Italy

Abstract

Dielectric elastomer actuators (DEAs) show promise for a number of applications. Significant research and industrial interest lies in development of vibrotactile displays for consumer electronics. One of the most significant challenges in development is the lack of viable solutions to obtain stretchable optically transparent electrodes. **Carbon nanotubes (CNTs),** when used as electrodes, provide both electrical conductivity and transparency. Furthermore, high aspect ratio of the CNTs is essential as it allows the electrodes to be designed to comply with the deformations of the elastomer. However, as elastomeric films possess different surface characteristics than the typical substrates used to deposit CNTs, experimental investigations had to be undertaken to evaluate the compatibility of those materials. The goal of this work was to determine a preferred material combination for manufacturing of transparent electrodes on the VHB™ 3M™ film. Moreover, several coating methods with various process parameters were evaluated for preparation of electrodes and their influence on actuation properties.

Introduction

Transparent conductive films (TCFs)/electrodes are an important part of optoelectronic devices. The most TCFs in use are prepared by chemical or physical vapor deposition, electron beam evaporation and sputtering of metal oxides. These films can achieve excellent conductivity with high transparency. Some applications require also flexibility where substrates like polyethylene terephthalate (PET) or elastomers can be used. For such purpose TCFs based on metal oxides like indium tin oxide (ITO) are unsuitable due to their brittleness (Fig. 1). For this reason some other alternative materials like PEDOT (intrinsic conductive polymers) and carbon nanotubes were investigated, to be able to prepare transparent conductive films which are suitable for flexible and thermally non-stable substrates.

PEDOT can provide good electrical conductivity with high transparency. The one drawback of films based on PEDOT is poor UV stability. Over time the electrical conductivity of such films increases (Fig. 2) what is not acceptable for most of applications where the electrical conductivity is of prime importance.

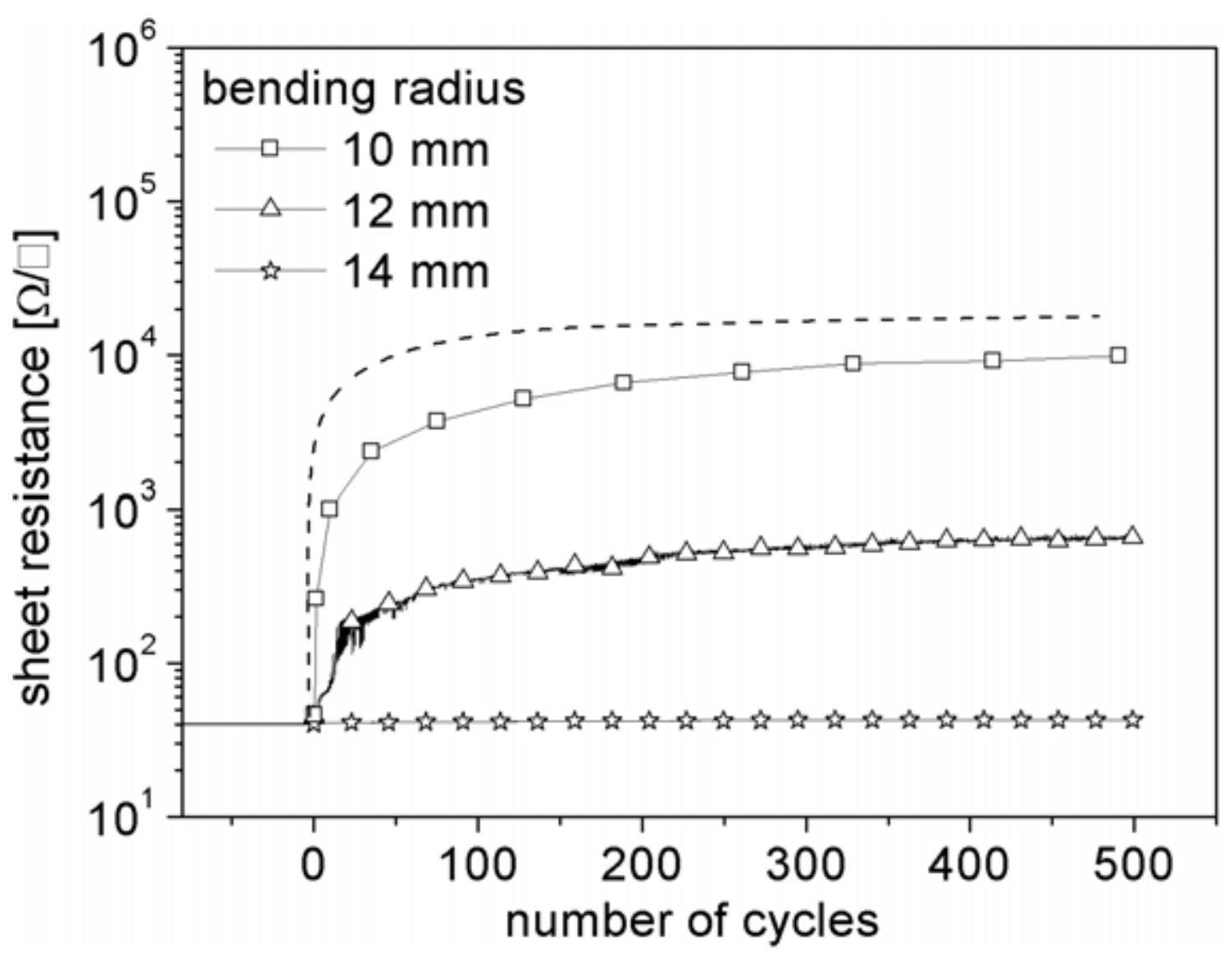

Fig. 1 Influence of bending radii on the electrical resistance of ITO-sputtered PET films [1]

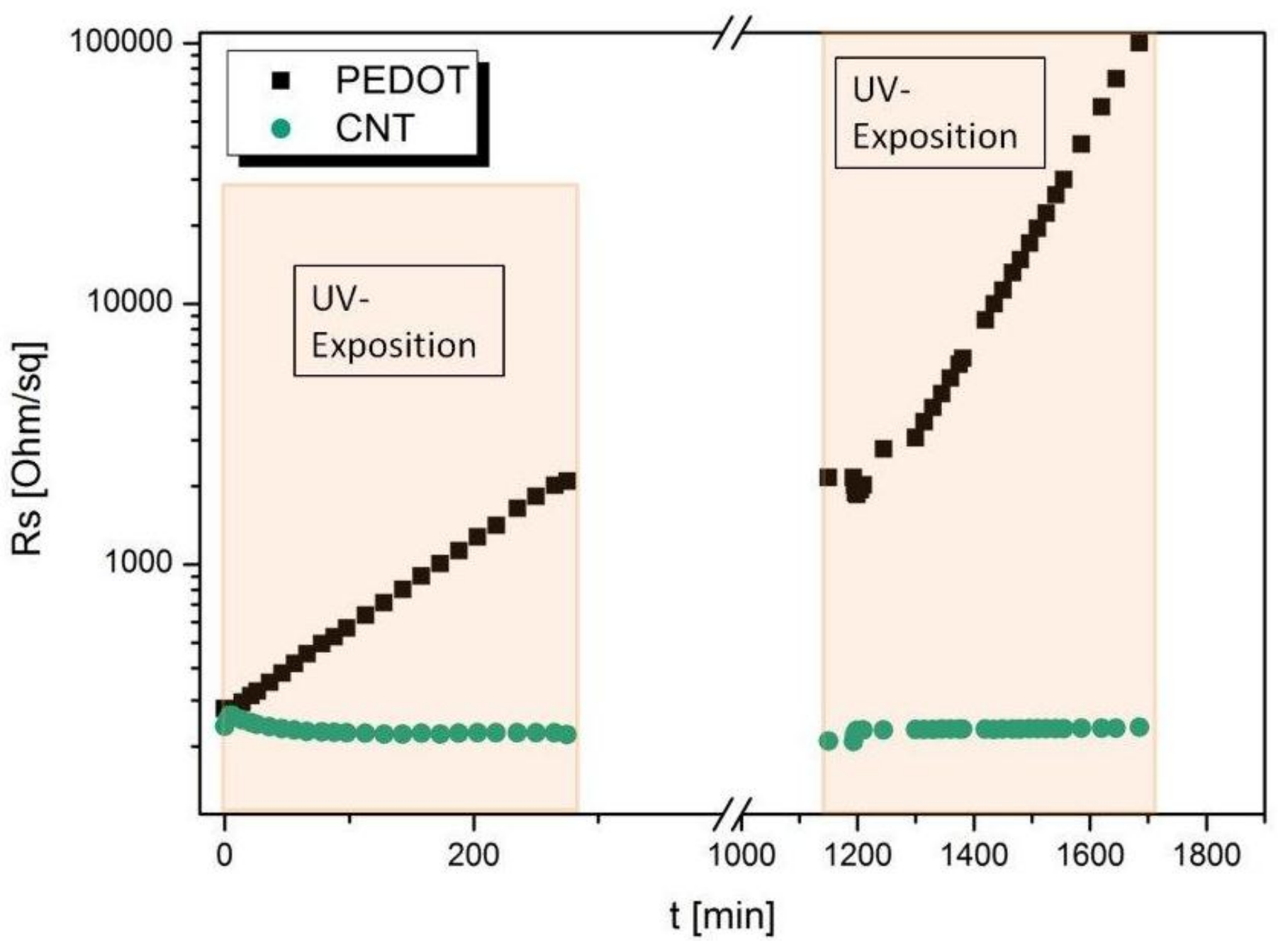

Fig. 2 UV stability CNT vs. PEDOT

Materials and methods

The transparent electrodes were prepared on the VHB™ (3M™) elastomer film substrate. The un-stretched film comes in rolls of 25 mm width. A square of about 25 mm was cut and stretched onto the ring frame with a diameter of 60 mm. Considering that the initial thickness of the film is 1 mm, the thickness after stretching is about 60 µm (Fig. 3), the films are stretched by a factor of 4 bi-axially.

To prepare the CNT dispersion single wall CNTs (KH Chemicals, Korea) were dispersed in water containing sodium dodecylsulphate by sonication. The dispersion was then centrifuged and deposited onto the pre-stretched elastomer substrate (on both sides) by spray coating and inkjet printing (Fig. 4). Additionally electrodes, made of carbon conductive grease (MG Chemicals, Canada) , were added on the edge of the deposited CNT film (Fig. 5).

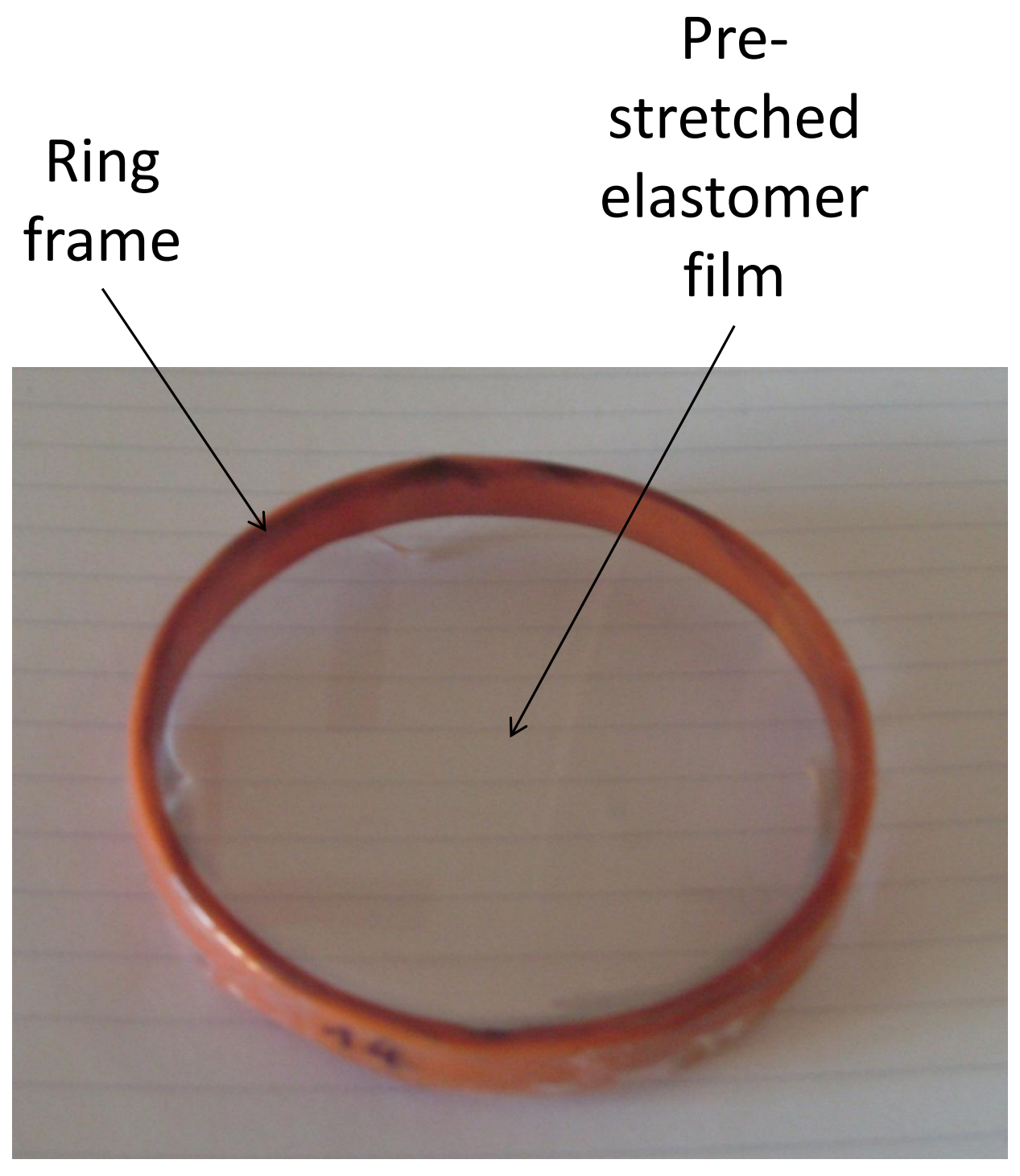

Fig. 3 Ring frame with pre-stretched elastomer film

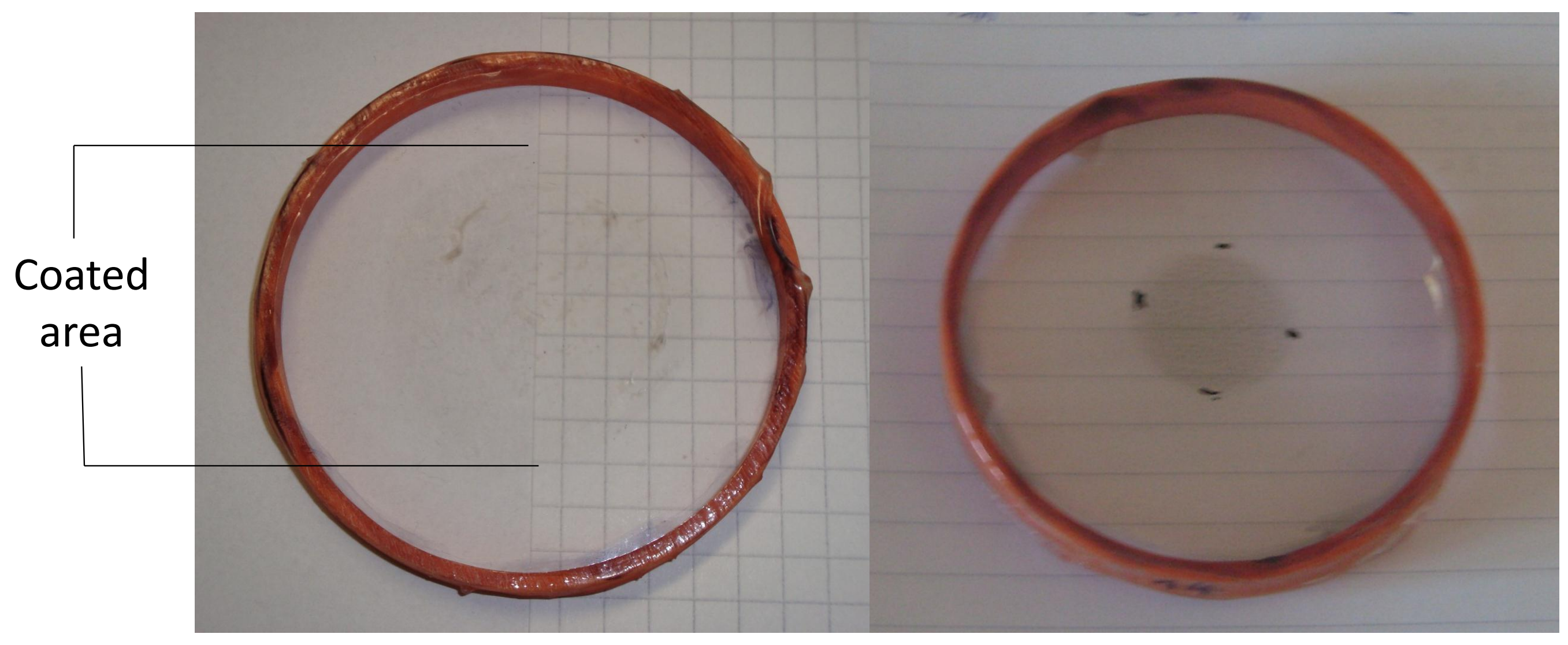

Fig. 4 CNT film deposited on elastomer substrate: (left) by spray coating; (right) by inkjet printing

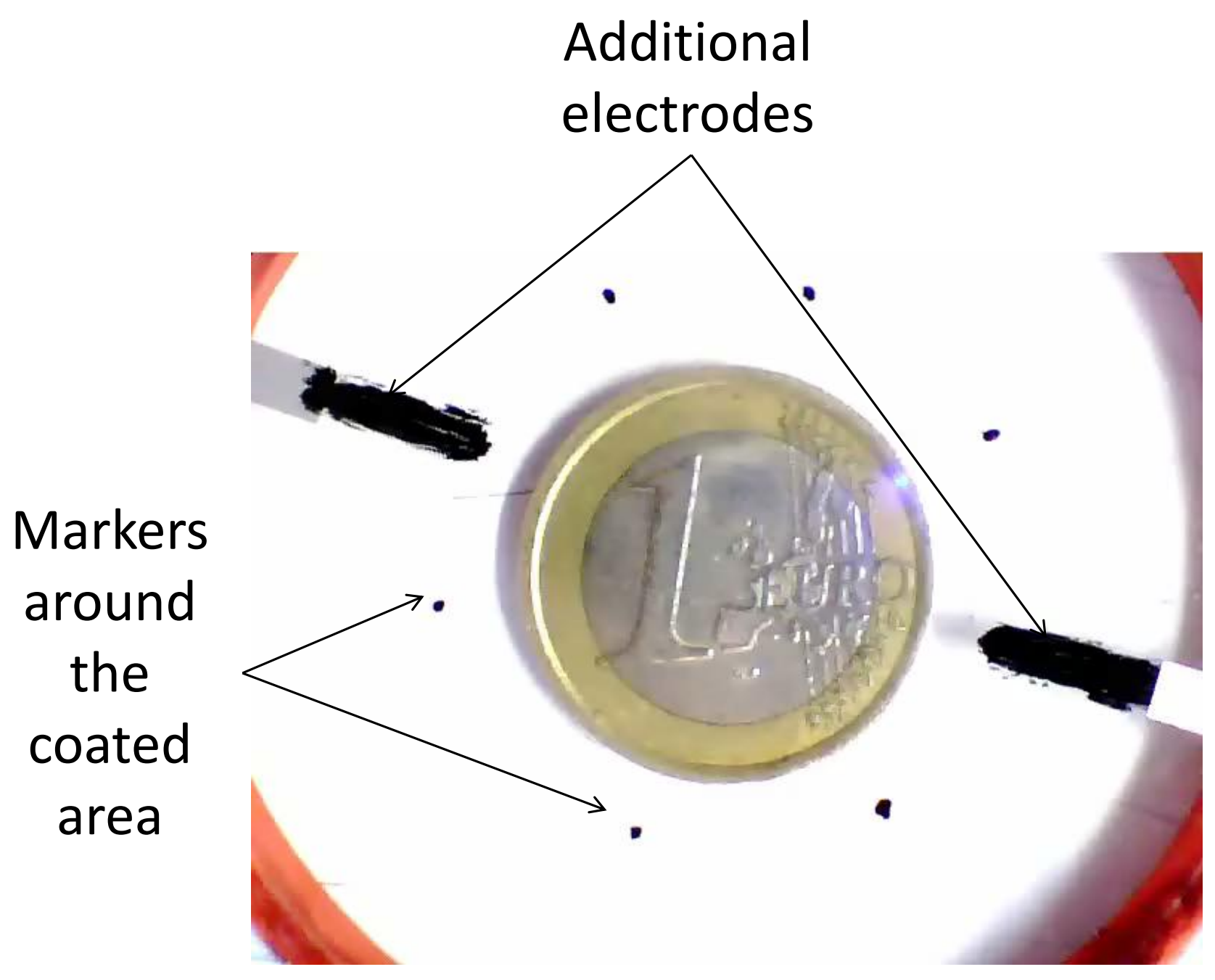

Fig. 5 Ready sample prepared for the actuation test

Results and discussion

Due to the stickiness of samples and difficult handling it was not possible to measure electrical conductivity and transparency of the complete system. Therefore performance was measured on single CNT layers deposited on glass substrate by spray coating (Fig. 6). This gave an indication on what results can be expect on elastomer substrates. The conductivity of the deposited electrodes on DEA was measured with an ohmmeter by tipping the surface with two electrodes at the distance of 10 mm (0.2 – 2 MOhm). To prove the functionality of the deposited CNT film onto elastomer substrate the electrodes were connected to a power supply as shown in Fig. 5. Then the voltage was changed between 2500 V and 5000 V and the expansion of the substrate was observed (Fig. 7).

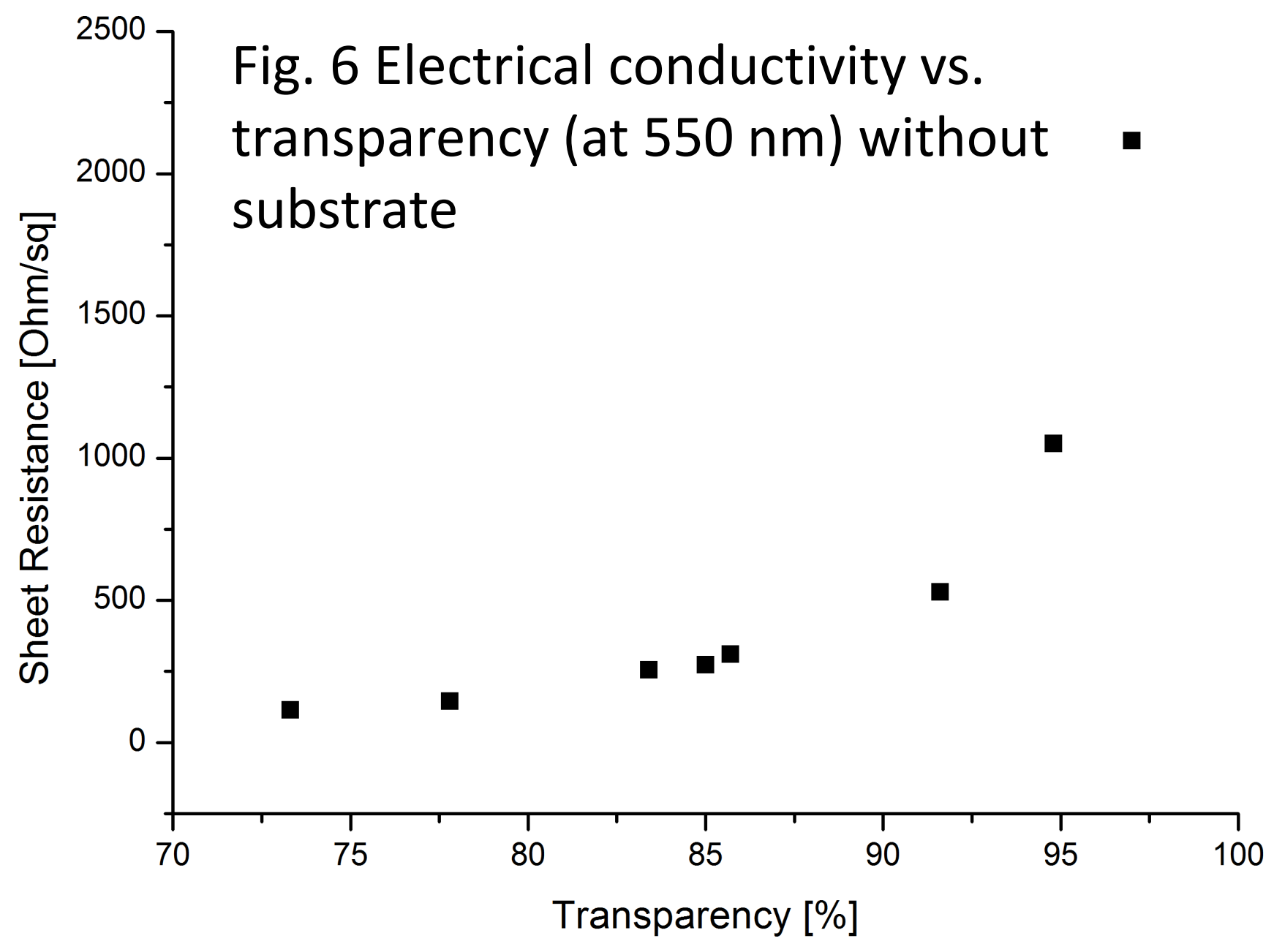

Fig. 6 Electrical conductivity vs. transparency (at 550 nm) without substrate

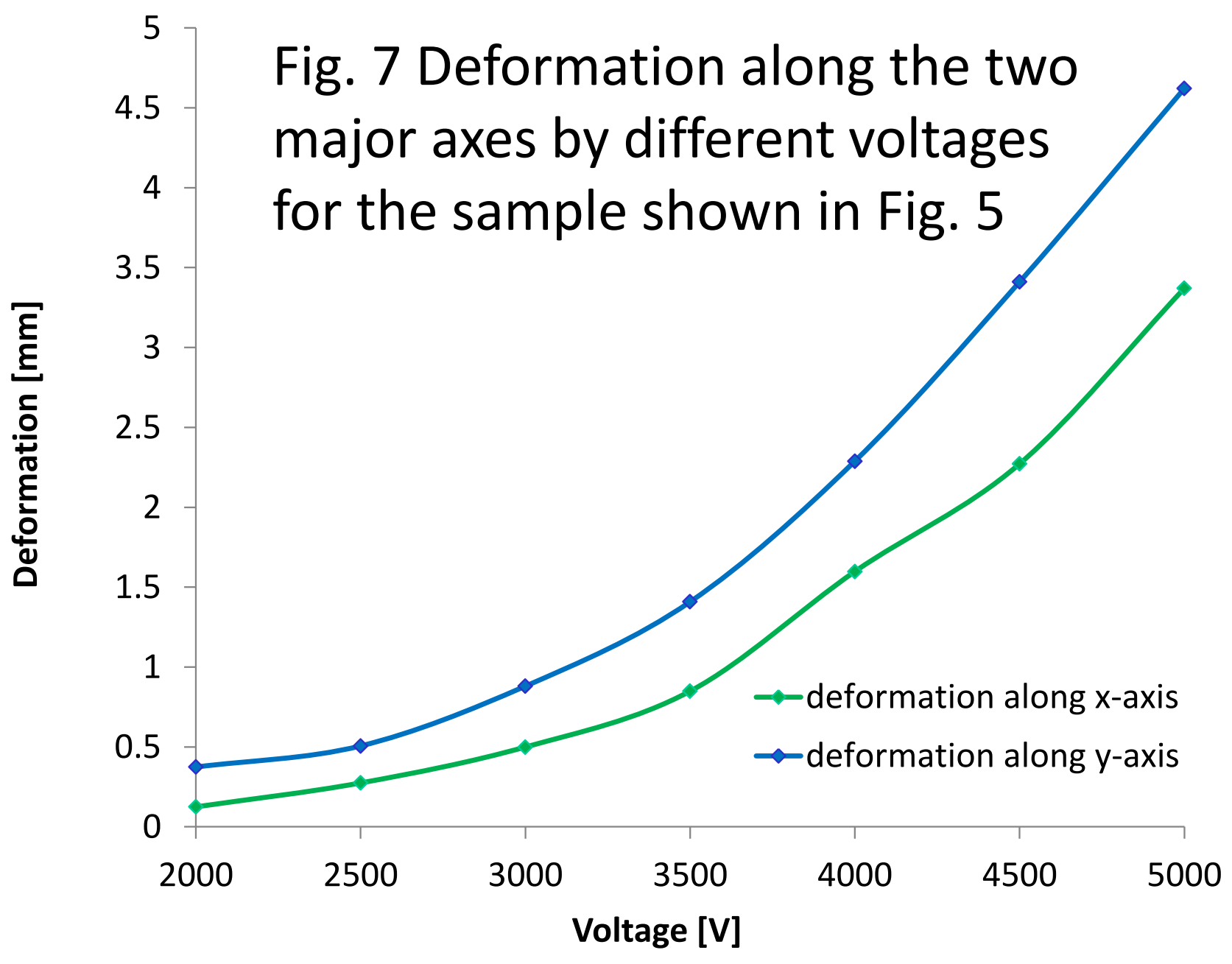

Fig. 7 Deformation along the two major axes by different voltages for the sample shown in Fig. 5

In the second experiment an elastomer film with the deposited CNT electrode (active membrane) and a elastomer film without electrode (passive membrane) were used to build up a lens, with an incompressible fluid between them (Fig. 8). Film stretching during actuation is visible via the change of logo under the lens (Fig. 9-10). With stretching of the two elastomer layers, the pressure on the silicone changes and as a consequence affects its form. This also influences the optical properties of the silicone lens and thus appearance of the logo.

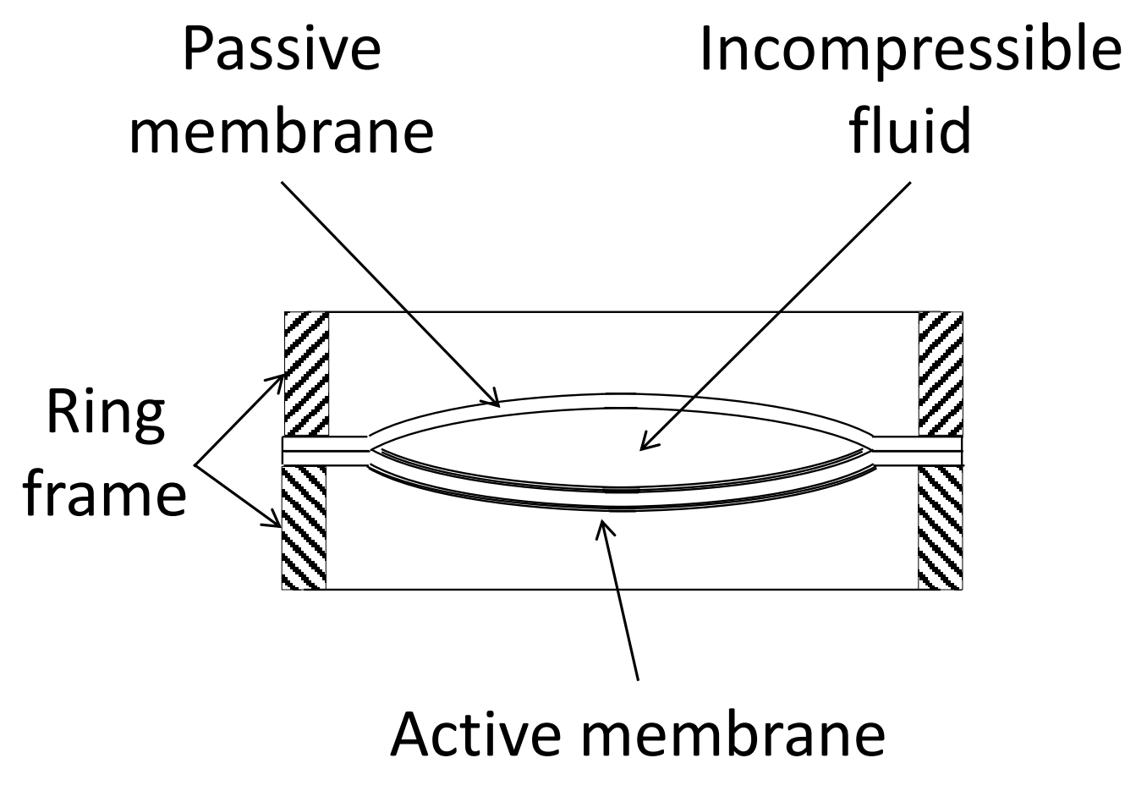

Fig. 8 Sketch of the DEA

Fig. 9 Lens before voltage application

Fig. 10 Lens while voltage application (5500 V)

Conclusions

It has been shown that coatings based on CNTs can be used as transparent electrodes for stretchable actuator systems. Additionally, investigations on various coating methods showed differences in the quality of the prepared electrodes. The superior performance of samples prepared by airbrush technique over those prepared by inkjet printing, in terms of actuation and optical quality, was demonstrated.

Further investigations on the CNT electrodes deposited by spray coating are worthy for future investigations and development. Except from the used processing methods, it is recommended to investigate utilization of other particles. It is anticipated that due to their spherical shape, such particles will be able to fill in the surface roughness of the elastomer, thus reducing the scattering and achieving electrodes of improved transparency.

Acknowledgments

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References

1. Koniger, T. and H. Munstedt, Advanced device for testing the electrical behaviour of conductive coatings on flexible polymer substrates under oscillatory bending: comparison of coatings of sputtered indium-tin oxide and poly3,4ethylenedioxythiophene. Measurement Science & Technology, 2008. 19(5)