Electronic Supplementary Material (ESI) for Journal of Materials Chemistry

Self-healing electrodes for dielectric elastomer actuators

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Description and validation measurements for the test set-up used for the resistivity measurement.

The test set-up is shown in Fig.1 and consists of:

1) Measurement platform with 4 magnetically fixed pin electrodes
2) Switchbox
3) Current source and voltmeter
4) Laptop

Remark: This test set-up can also be used for a two-point measurement or an original Van-der-Pauw-measurement (see http://en.wikipedia.org/wiki/Van_der_Pauw_method).

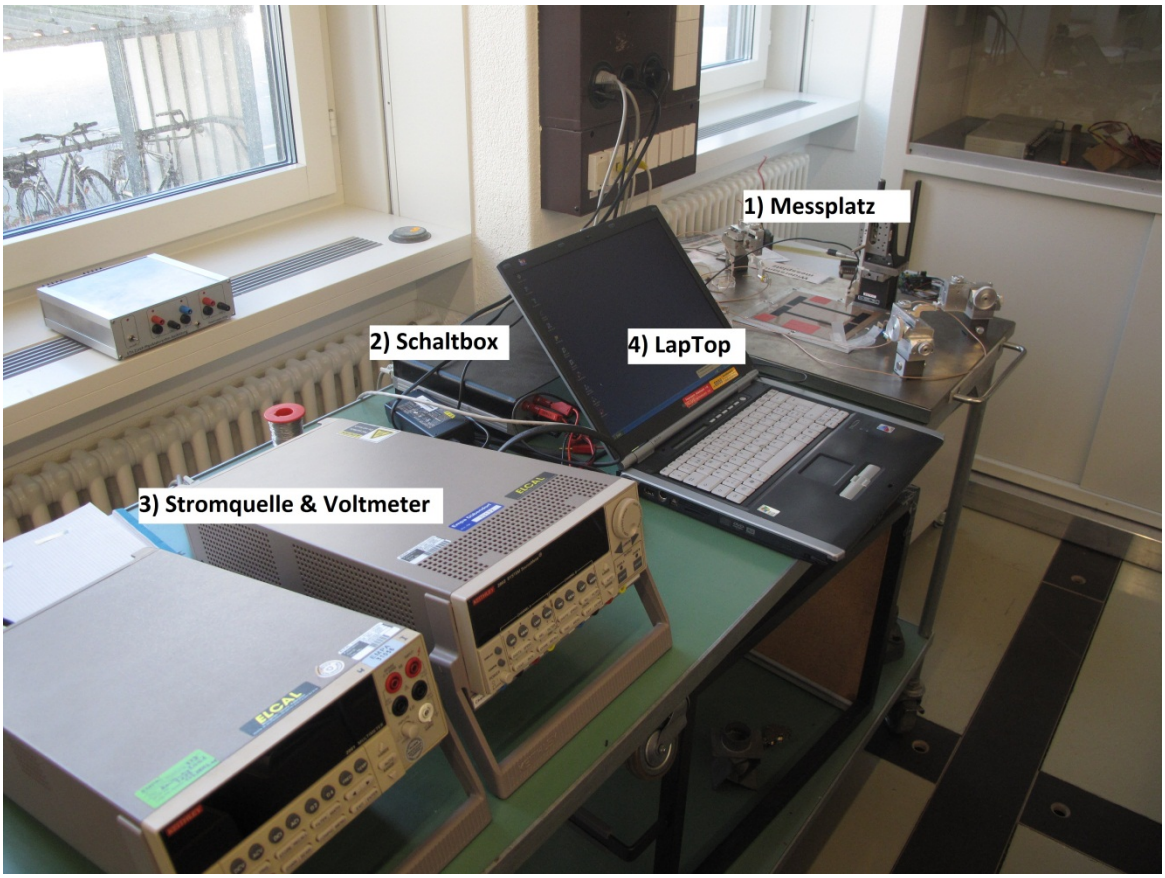


Figure 1. Overview of the four-point measurement set-up

The measurement platform (see Fig. 2) allows to measure flat specimens of about 300 mm x 200 mm in area. As the current source a **Keithley 2602** System Sourcemeter is used and for the validation measurements a current of always 4 [µA] was applied. With this current the voltage over the strip of approx. 10 cm × 0.75 cm is about 700 mV. With the help of a **Keithley 2001 Multimeter** the voltage drop between the third and the reference pin electrode was measured (typical values are between 100 mV and 700 mV. The switchbox can be used as an option to connect the pin electrodes with the current source and the voltmeter. The switchbox is controlled by a LabView-VI called „RelaisKing“ on the Laptop.
For safety reasons the current source should be electronically limited to 40 V output voltage maximum. The reaching of this limit during the measurement gives wrong data and should be avoided therefor.

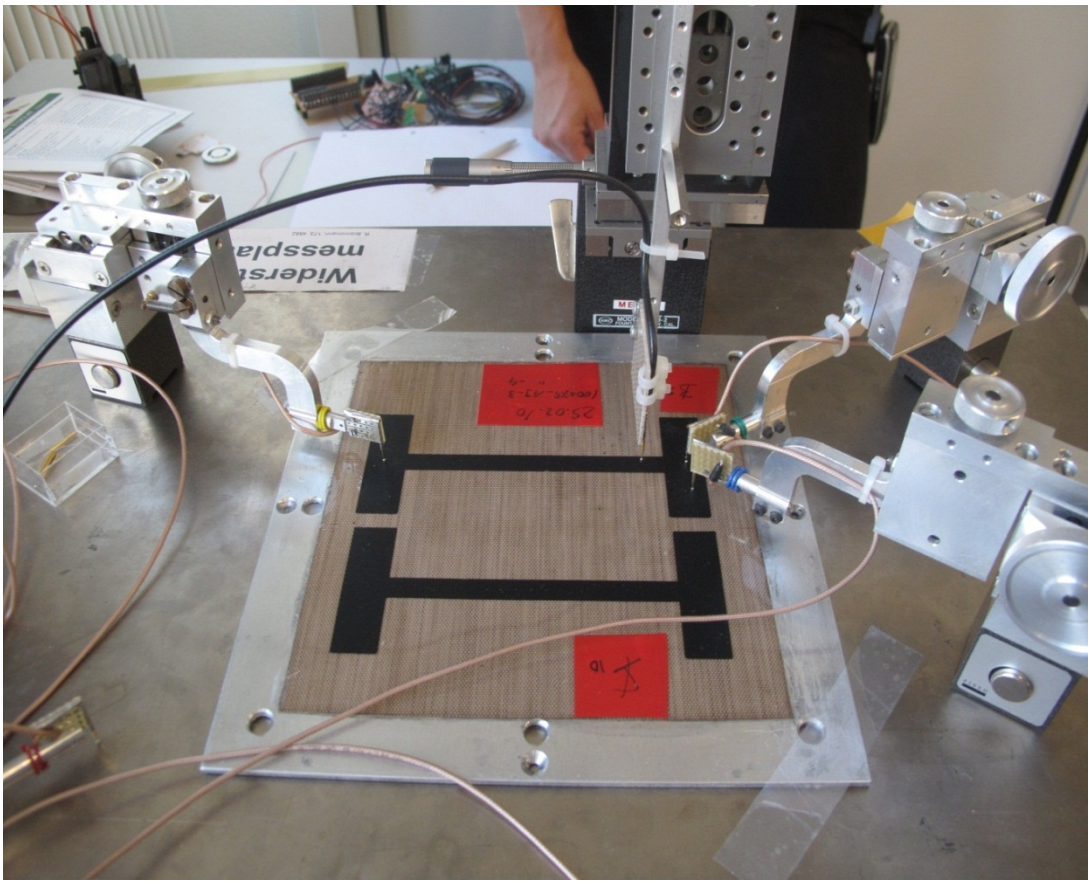
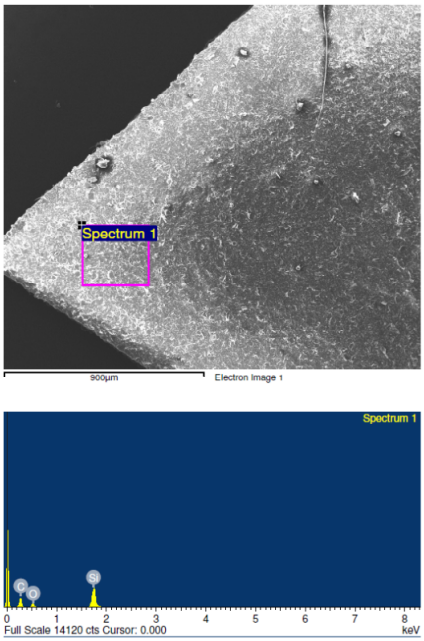


Figure 2. Measurement platform with pin electrodes and a typical specimen (H-shape)

XPS analysis of the electrode surface before and after the breakdown



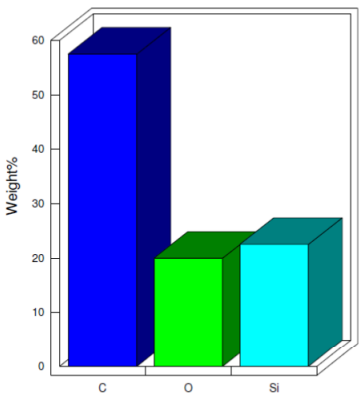


Figure 3. SEM image of the intact electrode where the XPS characterization was done together with the absorption peaks of the detected elements (left) and the elemental composition (right).

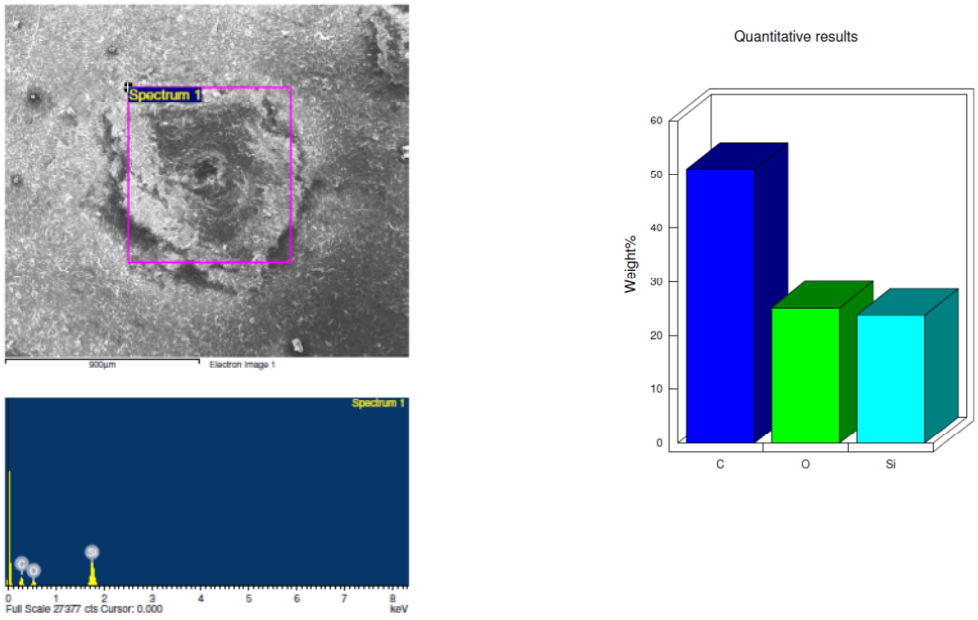


Figure 4. SEM image of the electrode surface containing both unaffected and burnt electrode where the XPS characterization was done together with the absorption peaks of the detected elements (left) and their elemental composition (right). Please remark that a little increase in the amount of oxygen was observed.

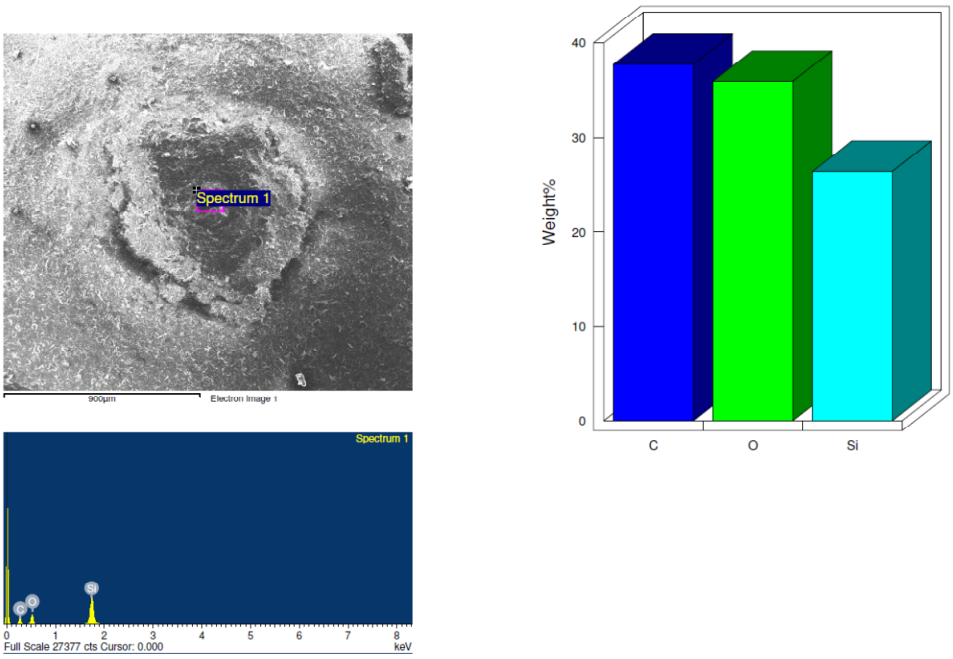


Figure 5. SEM image of the electrode surface where the breakdown occurred and where the XPS characterization was done together with the absorption peaks of the detected elements (left) and their elemental composition (right). Please remark that an increase in the amount of oxygen was observed which is expected since the polydimethylsioloxane is burnt to silica during the self-healing process.

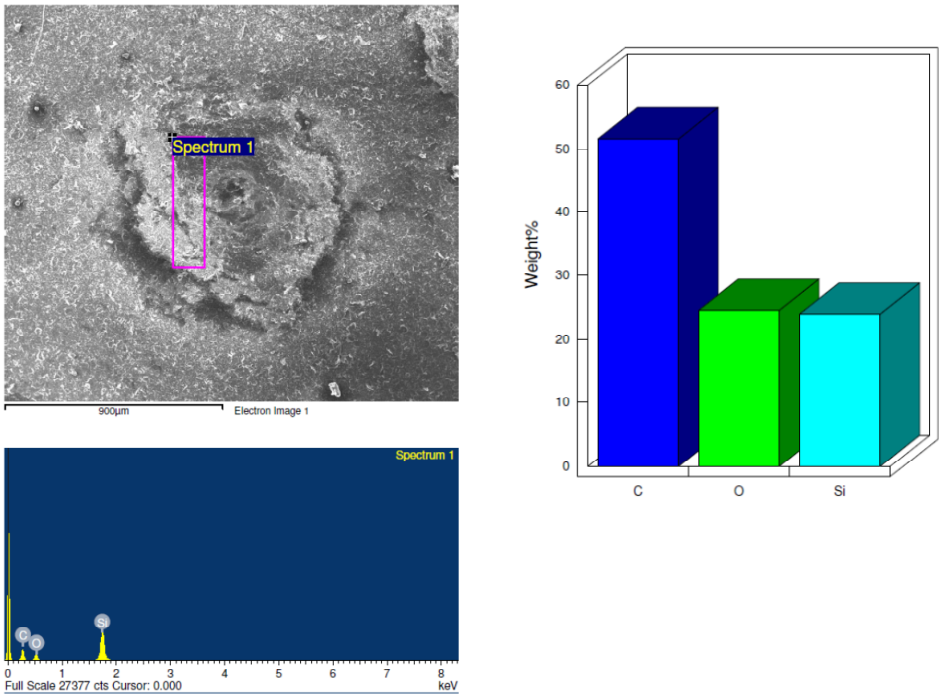


Figure 6. SEM image of the electrode surface near the place where the breakdown occurred where the XPS characterization was done together with the absorption peaks of the detected elements (left) and their elemental composition (right). Please remark that the proportion of the detected elements is similar to that of the intact electrode (Figure 3).

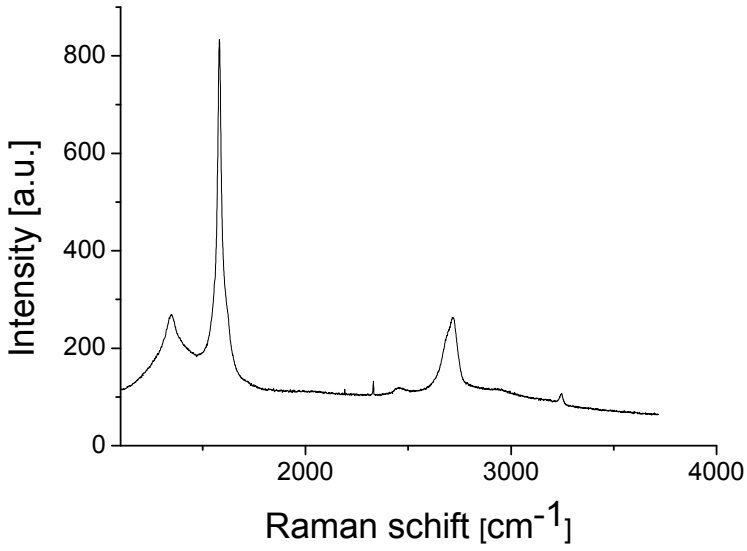


Figure 7. Characterization of the starting material xGnP-M-25 and the one reduced by hydrazine.

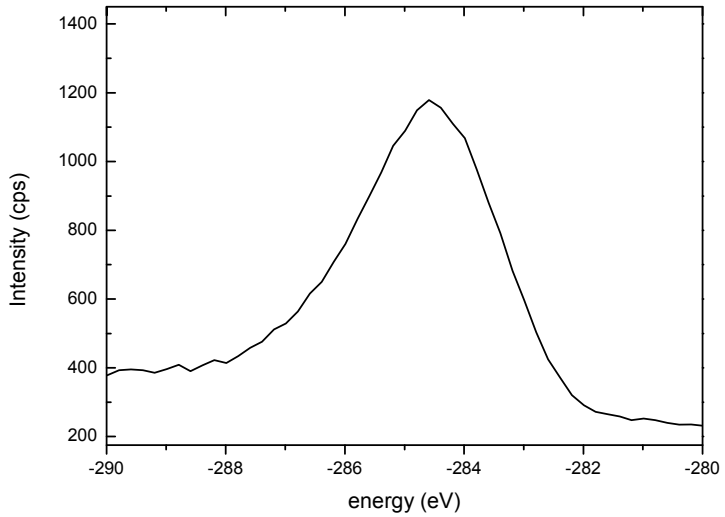


Figure 8. XPS analysis of the treated xGnP-M-25. The spectrum looks similar to that presented for reduced graphite oxide from the literature.[S. Stankovich, D. A. Dikin, R. D. Piner, K. A. Kohlhaas, A. Kleinhammes, Y. Jia, Y. Wu, S. T. Nguyen, R. S. Ruoff, Carbon, 2007, 45, 158-1565.]

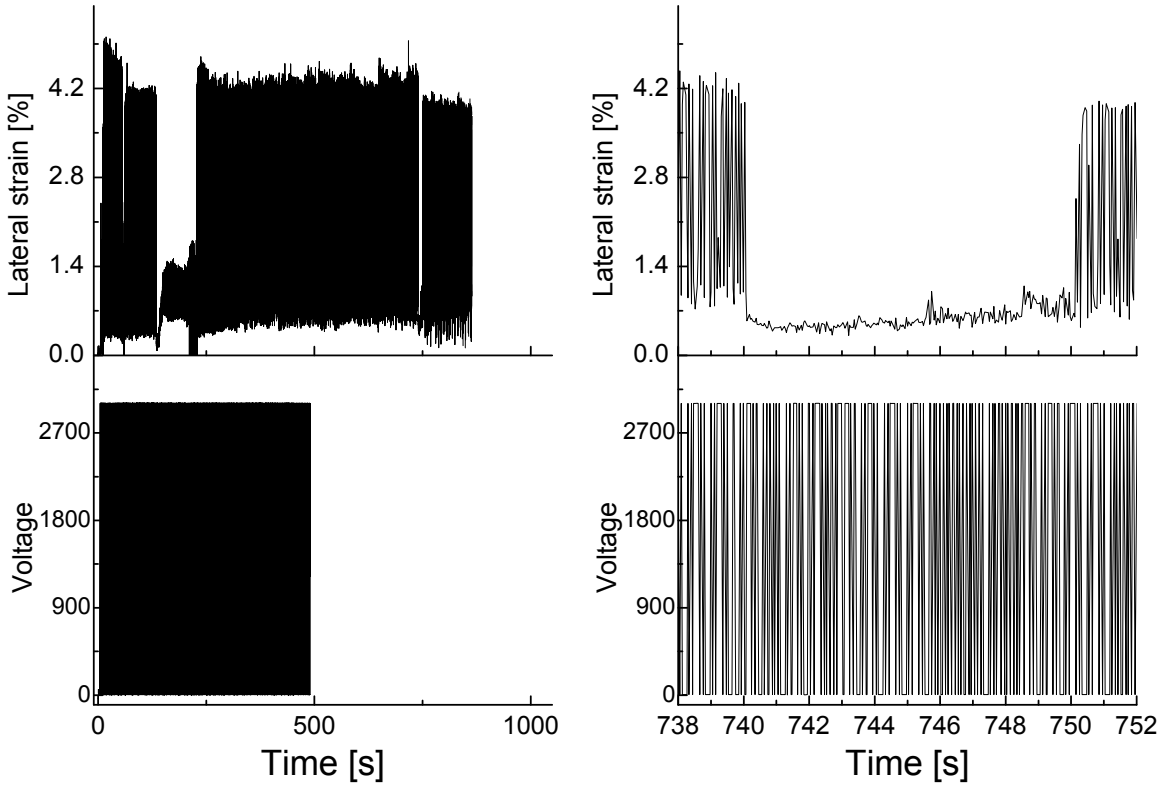


Figure 9. An actuator tested at a frequency of 0.01 s for 100000 cycles at 3000V. The actuator suffered some damages which reduced its performance by about 25%. On the right side an enlargement of the left part from 738 s to 752 s is given.