Residual Stress and Electrical Resistance Characterization in Copper Films on Polyethylene terephtalate (PET)[1]

Introduction

Flexible electronics, the assembly of electronic circuits on polymer substrates, is an emerging technology field. This is due to the many advantages compared to classical electronic boards, like mechanical flexibility, light weight and the possibility to fabricate large areas.

The understanding of the mechanical and fracture properties of such composites is essential before bringing this technology to mass production. In the case that the electrical connection between the elements of the electronic device is achieved by the metallization with copper layers, stability of these layers, bonded to the polymer is a key issue. In this study Cu thin films on PET were characterized during loading and unloading experiments in order to understand the relationship between applied strain, stress and electrical properties.

Experimental

The electrical resistance was characterized in laboratory conditions and stresses were determined by in situ X-ray diffraction at the BESSY II synchrotron source using end station KMC-2 and the sin2 Ψ method[2]. The setup was in the reflection geometry using a beam wavelength of 0.17714 nm. The (111) Cu peak was measured at four different psi (Ψ) angles using a detector exposure time of 5 s during the entire loading and unloading of the sample. In the case of the in situ XRD experiments, an Anton Paar TS600® straining stage was utilized using a continuous loading function (no stopping) and a strain rate of 0.00001 s^{-1}.

Results and Discussion

It has been demonstrated that the resistance of the Cu thin films on PET increases significant upon loading and, due to the viscoelastic relaxation of the PET substrate[3,4], recovers not only during unloading but also during the next 24 hours in fully unloaded samples (Fig. 2). In the case of stress, one can observe elasto-plastic behavior which can be correlated well with the applied strain.

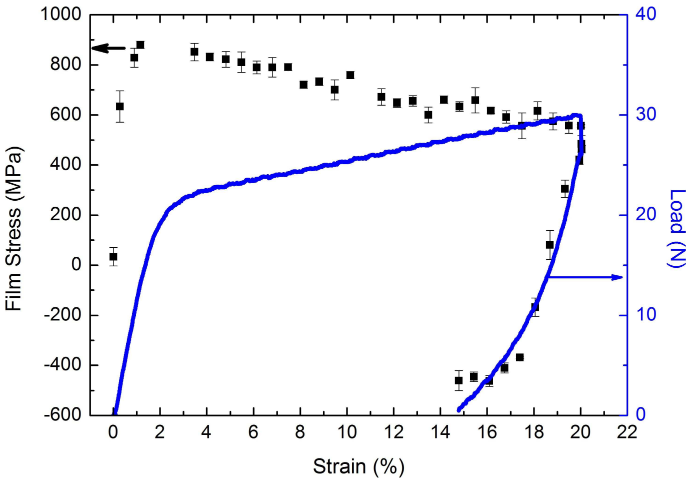

Fig. 1 In-situ measured stress in the Cu film (squares, left Y-axis) and external load applied to film/substrate system (solid line, Y-axis) as a function of strain.

Residual stress from a PET substrate in combination with a 200 nm thin film of copper on top were characterized in-situ. The loading results at first in the formation of tensile stresses of about 900 MPa. Then the stress decreases due to plastic deformation and crack formation. Finally, upon unloading, the film stress changes from tensile to compressive with a final stress of -400 M Pa at zero load (Fig. 1).

These compressive stresses are responsible for the decrease of the electrical resistance after unloading the sample as shown in Fig. 2.

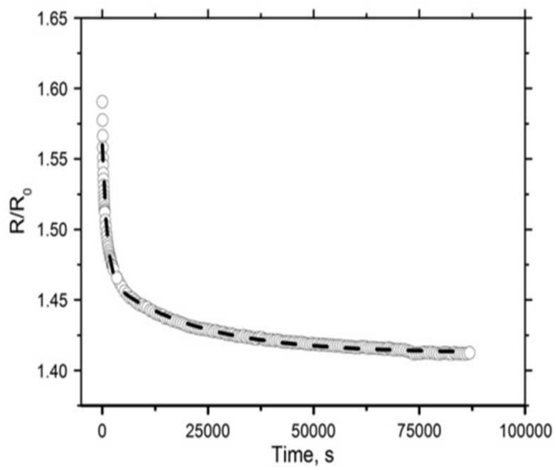

Fig. 2 Relaxation of resistance in an unloaded sample measured for 24 h.

A reason for this behaviour of the resistivity is the decreasing crack density. Direct observation of this assumption can be found in the corresponding SEM micrographs (see Fig. 3) taken during the relaxation process of the composite structure.

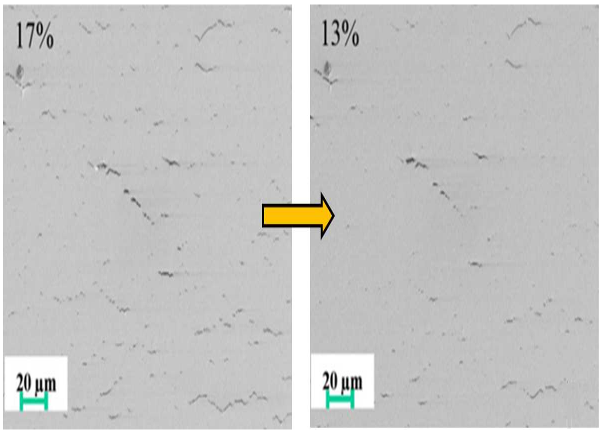

Fig. 3 SEM micrograph of the same area of surface of Cu film taken in situ during unloading stage of the tensile test. The straining direction is vertical. Corresponding values of global strain are shown in the top left corner of the micrographs.

Summary

With the TS 600 Tensile Stage it was possible to investigate the influence of strain on a composite material consisting of PET with a deposited Cu film. It has been demonstrated that the material responds with an increase of resistivity upon exposure to strain. This increase was attributed to the formation of cracks within the Cu film. During the relaxation of the material and also within the following time period (up to 24 h), the resistivity decreases substantially. This very important finding is caused by the viscoelastic properties of the PET substrate, which results in a closure of the cracks.

References

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Data provided by:

Keckes, J.; Glushko, O.; Marx, V.M.; Kirchlechner, C.; Zizak, I.; Cordill, M.J.