Interface roughness improves stretchable electronics reliability

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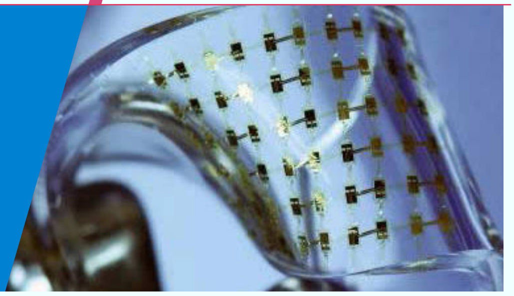

Introduction

Stretchable electronic devices enable a range of futuristic bio-compatible applications (Fig. 1-2). The designs of these devices usually consist of off-the-shelf electronic components, interconnected with metal lines made stretchable by design, (Fig. 3a) embedded in a stretchable (rubber) matrix material.

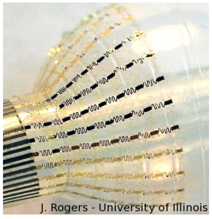

Figure 1: Hart ablation catheter

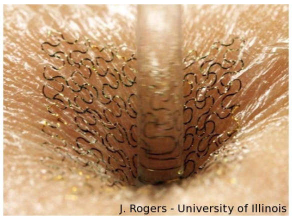

Figure 2: Smart skin

Many design solutions can be found in literature, one of which is the horseshoe shape interconnect. However, interface delamination is a common precursor to failure in all designs (Fig. 3c).

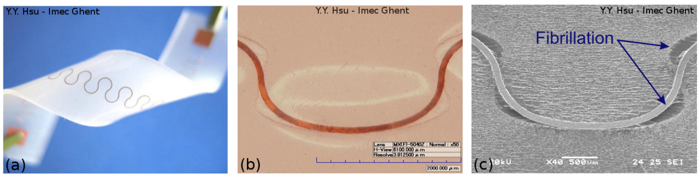

Figure 3: (a) Horseshoe shaped interconnect sample, (b) uni-axially stretched under a microscope, (c) showing fibrillation at the interface failure position, when imaging in-situ in an ESEM.

Goal

Understanding the delamination micro-mechanics responsible for the interface toughness. This knowledge can be applied to all interconnect designs to increase their stretchability.

Experiments

Four types of peel-test experiments are performed to investigate the characteristics of interfaces, i.e., two types of roughness in two opening modes. Moreover, the delamination front is visualized with in-situ ESEM imaging.

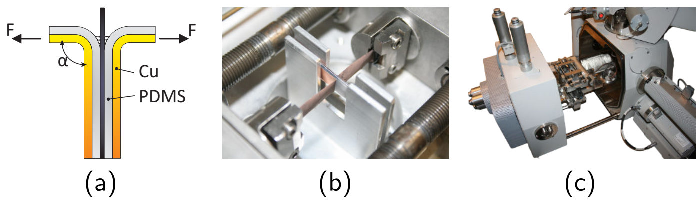

Figure 4: (a) Schematic of a 90° peel-test (b) 90° peel-test sample mounted in a tensile-stage, (c) which is mounted in the ESEM,

Figure 5 shows that the roughness morphology dictates the shape of the fibrils. Moreover, the interface of the rougher sample is more tough, this is due to the extra energy dissipation in the longer fibrils.

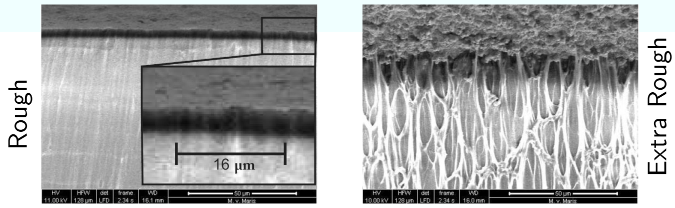

Figure 5: in-situ visualisation of the delamination micro-mechanics, i.e. the forming, stretching and ultimately rupture of fibrils.

Figure 6 shows that the area fraction of rubber left behind on the new metal surface is greater for the rougher sample indicating an increase in rubber fracture, again showing that the rougher sample is more tough.

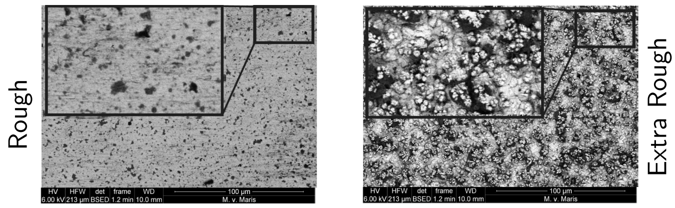

Figure 6: The new metal surfaces for both roughness types, for a 90° peel test, i.e. crack opening mode.

Figure 7 shows an increase in rubber fracture for the less rough sample, showing some sensitivity to the crack opening mode. Yet, the rougher sample shows no mode dependency.

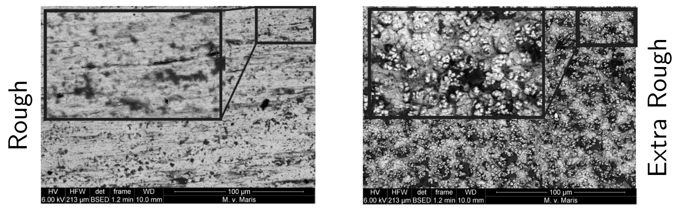

Figure 7: The new metal surfaces for both roughnesses, for a 0° peel test, i.e. crack shearing mode.

Conclusions

- In-situ ESEM imaging revealed a complex mechanism, which is the dominating dissipation mechanism
- The roughness initiates and controls the fibrillation process
- The fibrils and large surface roughness cause these interfaces to be insensitive to the crack opening mode, due to the "local" mode-mixity in the roughness morphology and the orientational freedom of the fibrils
- Future designs of stretchable electronic devices should aim to initiate the fibril process, with an artificial "tailored" roughness