A novel route towards interface integrity in stretchable electronics

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A novel route towards interface integrity in stretchable electronics

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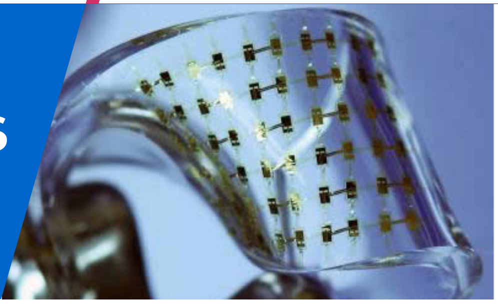


Introduction

Stretchable electronics is a new field aiming to enable a range of bio-compatible futuristic devices (Fig. 1,2). Interface delamination is a precursor to the failure of stretchable electronics made of elastically mismatched metal interconnects and rubber matrix materials.

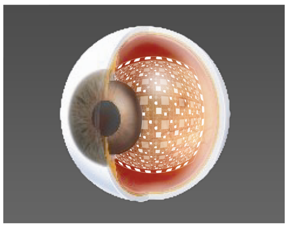


Figure 1: Intraocular retinal sensor array

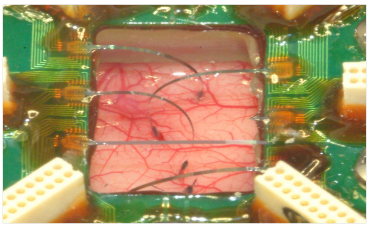


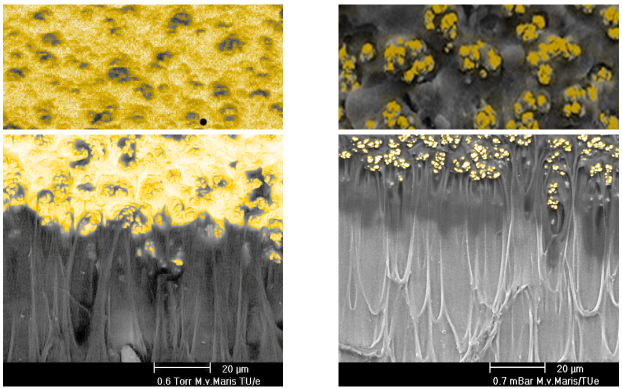
Figure 2: Neural activity monitoring array

Goals

1. Obtain insights in the macroscopic delamination mechanics of copper-rubber interfaces.
2. Develop a method to test and characterize these interfaces at microscopic scales.

Macroscopic interface testing

Real-time *in-situ* ESEM imaging of the progressing delamination front shows that (Fig. 3) interfaces that have the highest work of separation (G_C) do not have the cleanest surface. Showing that, delamination is a delicate balance between the forming, elongation and rupture of fibrils and interface debonding.



TPU, $A_r = 5.9\%, G_c = 3.7$kJ/m^2

PDMS, $A_r = 87\%, G_c = 1.3$kJ/m^2

Figure 3: (top) ESEM images of the rubber area fraction A_r on the copper after peeling, rubber is shown in black and copper in yellow. (bottom) Fibrilation of the progressing delamination front.

Microscopic interface testing

The bulge test is used as a loading platform for the stretchable electronics, originally designed to characterize thin films, it is enhanced with global DIC to capture local stress-strain information needed to measure inhomogeneous films.

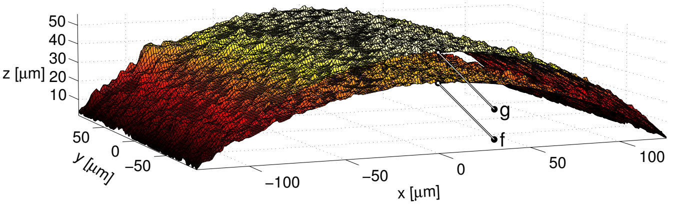


Figure 4: Two measured bulge test profiles f and g at 5% and 10% strain respectively. A pattern is applied on the surface using 80-500 nm Ag particles. In global DIC, the image g is mapped onto f by fitting its deformation $\boldsymbol{u}(\boldsymbol{x})$ by minimizing $\eta^2 = \int \left(f(\boldsymbol{x}) - g\left\{\boldsymbol{x} + \boldsymbol{u}(\boldsymbol{x})\right\}\right)^2 d\boldsymbol{x}$.

The quasi 3D data obtained from Confocal (or Atomic Force) Microscopy required a new DIC method because the pattern (Fig. 4), used to correlate with, also moves in the out of plane direction. The global DIC method is developed in cooperation with F. Hild.

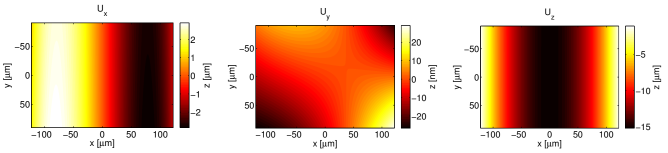


Figure 5: The displacement fields in x, y and z obtained from the global DIC method, using basis functions of the type $\varphi_n = x^a y^b$.

Conclusions

- Fibrilation of the rubber is observed, where $50\mu m$ long fibrils are formed.
- A delicate balance arises between the rupture of the fibrils and delamination of the interface.
- The rubber fraction on the delaminated Cu surface decreases with increasing rubber toughness and/or decreasing interface adhesion.
- A 2D$^+$ global DIC method is developed, useful for confocal, interferometry, and atomic force microscopy data.
- Which is very robust, even with 5% strain steps, yielding continuous full field displacement fields (Fig. 5), with sub pixel displacement resolution.