# Buckling waves in aluminum on a polyimide sea

## In situ analysis towards a reliable design strategy for stretchable electronics

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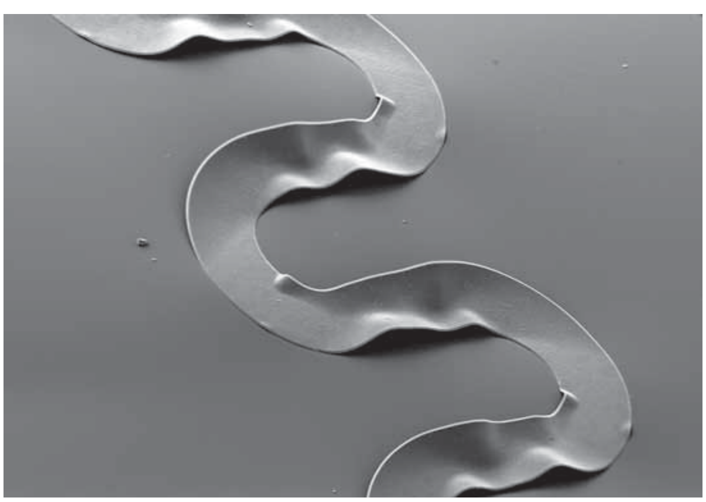

'Stretchable electronics' refers to highly deformable devices in which compliant polymeric substrates support micron-size sensor units; these may provide spatially distributed measurements over complex surfaces. Stretchable sensors have opened new perspectives and applications in many fields, among which biomedicine is one of the most promising: instrumentation for tools which need to withstand significant bending or stretching during service has been demonstrated via balloon catheters and implantable patches [1–3], enabling a totally new generation of smart devices.

Stretchability and bendability of such systems are achieved by selecting a compliant substrate for the sensing units and by granting sufficient deformability to the electrical interconnects.

Several approaches have been developed with the purpose of realizing elastically stretchable and bendable interconnects; among others, co-planar patterned metal conductors are one of the most effective options. Conductive thin metal coatings are patterned onto an intrinsically deformable substrate with a suitable design, in order to provide the interconnects with structural integrity and constant electrical conductivity during extreme deformations ($\gg$10%). Different structural designs have been proposed, among them, an S-shape geometry has been widely used [4,5].

However, even if metal/polymer systems allow for device stretchability and flexibility, matching the mechanical response of the metal film and the polymeric substrate still creates some issues related to mechanical and functional failure. Fracture of the metal films and interface delamination phenomena represent the most critical mechanical issues for such systems. In particular, previous studies [6,7] have shown that in metal/polymer systems subject to stretching, the metal film will first develop cracks perpendicular to the tensile direction at low strains. Upon further loading, compressive transverse stresses arise in the film strips due to a Poisson's ratio mismatch between the substrate and the film, causing delamination and buckling in a direction perpendicular to the tensile direction.

The freestanding delaminated metal films lose the benefits of mechanical confinement provided by the compliant substrate; indeed, experiments have shown that a freestanding thin metal film usually fractures at smaller strain with respect to thin metal films bonded to polymeric substrates [8,9].

The cover image shows the buckling delamination observed in S-shape stretchable interconnects upon stretching. This image was taken by means of a Scanning Electron Microscope (Zeiss EVO 50

EP, $LaB_6$ cathode electron gun) at the SAMM Laboratory, Department of Chemistry, Materials and Chemical Engineering, Politecnico di Milano. Buckling of the metal film along the rectilinear arm is induced by the compressive stress of the metal owed to lateral contraction of the polymeric substrate upon axial stretch. Buckling delamination of the polymer/metal interface is a failure mode of practical relevance in the field of deformable interconnects. Delamination will cause loss of the confinement effect granted by the substrate, leading to a freestanding metal film, which is more prone to fracture onset and propagation.

The sample was prepared on Si 4″ substrates, single side polished. In order to provide a repeatable adhesion of layer on wafers, a thin oxide layer (30 nm) was grown by thermal dry oxidation and treated with plasma oxygen before coating with the structural layer. The substrate (structural layer) was implemented with a polyimide film, Durimide® 115A with a target thickness of 10 μm. In order to reduce the layer adhesion and allow the removal of devices from the substrate at the end of the process, wafers were treated with a primer before deposition, since the composition DI115A already includes a primer and further priming is reported to reduce the adhesion in the resist datasheet. The metal layer was deposited by evaporation of 1 μm of Al and defined by lift-off in a planar S-shape design. For this purpose, the deposition of the layer was performed after coating the wafer with Ma-N 1420 negative resist with a thickness of 2100 nm, followed by layer lithography and development. In order to enhance the Al adhesion to the substrate, the surface was activated before Al deposition with further plasma oxygen treatment just before evaporation.

To address the associated challenges in materials science, it is instrumental to improve the mechanical reliability and hence the electrical functionality of deformable interconnects. In this perspective, the study of the mechanical behavior at small scale is mandatory. A design strategy based on focused insight of the mechanical issues at a small scale represents a step forward for the future of deformable electronics applications. Five different layouts have been investigated by varying three main geometric parameters: the radius, the amplitude, and the width of the meander. Micro-tensile testing with simultaneous imaging of the samples has been performed by means of an in-house developed micro-tensile equipment (featuring a 5 N load cell and a displacement actuator with a resolution of 50 nm) with vacuum proof components; thus suitable for the use in SEM chamber. Deformation mechanisms of metal/polymer interconnects have thus been investigated through a combination of micro-tensile testing and in-situ optical and SEM imaging.

The results of this study provided an insight into the local mechanics involved in the onset of the delamination and buckling in S-shape deformable interconnects. In particular, a correlation was found between the interface failure phenomena and the geometrical parameters that define the design of deformable interconnects, allowing the identification of unexpected drawbacks related to specific S-shape design features.

This study provides useful indications on the correlation between geometrical features and relevant deformation mechanisms that can jeopardize the mechanical and hence electrical reliability of the deformable interconnects, therefore setting the basis for a systematic approach to optimize the S-shaped design of electrical interconnects in deformable electronics devices.

**Further reading**


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