Scientific summary

Introduction

This project aims at the fabrication of miniaturized dielectric elastomer transducers. These transducers are made of silicone polymers sandwiched between compliant metallic electrodes. A voltage applied to the electrodes produces a change in the shape of the elastomer layer between the electrodes (see fig. 1).

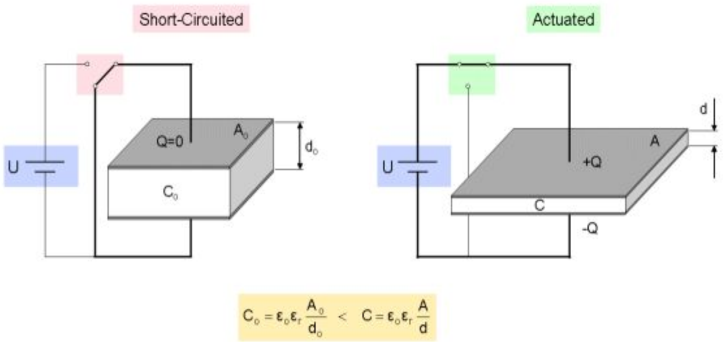

Fig 1. Actuation of an elastomer transducer

An important parameter of the actuator is the electromechanical pressure it is able to provide: $P_{eq} = \varepsilon_0 \varepsilon_r \left(\frac{U}{d}\right)^2$, with ε_0 the vacuum permittivity, ε_r the relative permittivity of the material, U the voltage between the two electrodes and d the thickness of the elastomer layer.
The goal of this work is to develop a manufacturing process producing very thin layers to reduce operating voltage while keeping efficient electrostatic pressure. This process will run under high-vacuum, as magnetron sputtering is used to deposit the metallic electrodes. This clean procedure also avoids any dust contamination that could be fatal for actuators operation.

Method

The elastomer layers are deposited using a roll-to-roll process. The silicone (elastomer) is transferred from a cylinder to a rotating steel belt. The layer is then partially cured using an infrared heater. Then, the silver electrodes are deposited by sputtering (≈ 50 nm) through a mask belt onto the elastomer layer. Both belts run simultaneously at the same speed.
One important point is to be able to deposit **compliant** electrodes onto the polymer. Indeed, electrodes need to follow the movements of the elastomer layers (when stretched) while keeping their electrical conductivity. To do so, we aimed at depositing silver layers with small grain size (10-15 nm) allowing formation of a crack network between undeformable grains. When the layer is stretched, this crack network is formed along grain boundaries; the cracks are so narrow that due to electron wave function overlap, the conductivity is not hindered. When the grain size increases, cracks are fewer as well as much bigger and can go through individual grains, preventing very quickly any conductivity (see fig. 2).
The continuous process is a repetitive sequence of deposition of a new elastomer layer onto the freshly deposited electrodes and then repeats with another elastomer layer.. The heater finishes curing of the first layer and partially cures the second one, creating a crosslinking at the edges between the two elastomer layers, ensuring a good sealing of the structure. By this process we aim at depositing a large number of layers (> 1000) with a reduced number of defects in a fully automatic method.

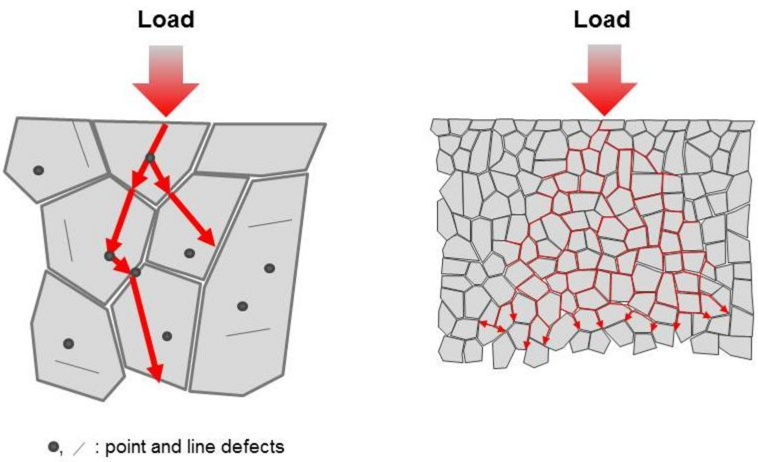

Fig 2. Influence of grain size reduction on cracks formation

Results

The most important result we obtained is the deposition of silver electrodes able to sustain well more than 10% stretching with a limited increase of the resistivity.

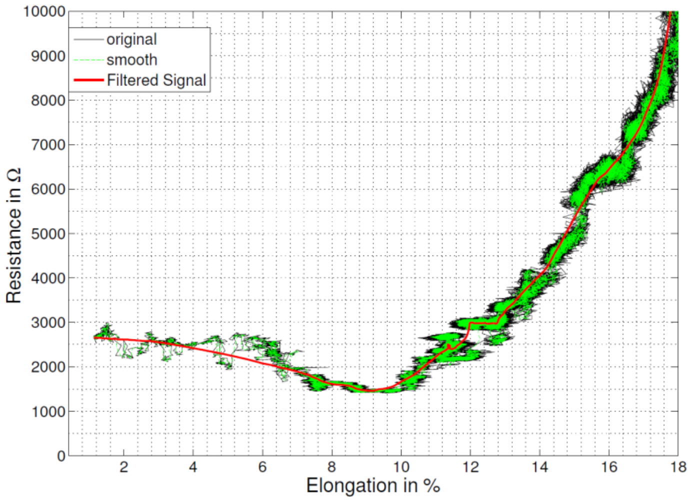

Fig 3. Resistance versus elongation of a silver electrode

To the best of our knowledge, it is the first time sputtered metallic film can achieve more than 10% stretching without losing conductivity. Up to now, electrodes were made of carbon or silver grease, not suited for a controlled and industrial process; ion implanted layers or using corrugated morphology, giving compliant electrodes but only in the direction of corrugation.

Challenges

There are still some challenges to overcome in this project. First, we still have to transfer from the Ultra-High Vacuum laboratory set-up with a 2"-circular magnetron to our large (1 m^3) chamber and 10" x 4" magnetron, the experimental conditions we determined for compliant silver electrodes deposition. We also have to study the behavior of the silver layers deposited on non-fully cured silicone.

The main challenge lies in the settings of the stepper motors running the two belts. The belts being of different lengths, we need to determine the driving parameters (speed, stepping) allowing us to keep a precise alignment of the electrodes after each layer. A slight misalignment can result in an important discrepancy after few hundred layers. We could be forced to integrate a positioning system with a feedback loop to readjust the position of the belts after each turn or to use synchronized DC motors.