Functional Liquid-Crystalline Elastomers in Microsystems

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Functional liquid-crystalline elastomers (FULCE) are a new class of smart materials that show a reversible change of shape when heated or irradiated with UV light. These materials have a high potential for use as actuators with large deformation and small forces in micromechanical systems. Within an EU project, we investigate the possibility of integration of the materials in MEMS. We did show compatibility with standard MEMS technologies, and tested a method for hybrid assembly of FULCEs on silicon and glass substrates without the use of adhesives. All these processes were found suitable for application.

A new material for actuators

The search for new, innovative materials plays an important role in microsystem technology research. There are various micro actuators containing piezoceramics or shape-memory alloys. However, those materials are often difficult to integrate or do not show a substantial ability for large deformations that are needed especially for use as artificial muscles. A promising approach could be compliant materials that contain mechanically active components like elastomers, enhanced by liquid-crystalline molecules (mesogens). Those molecules show a more or less uniform alignment when they are in a liquid-crystalline phase. This alignment is lost when the LC undergoes a phase transition into the liquid state; the order of the molecules becomes isotropic. In combination with uniformly aligned elastomer networks, this effect can lead to a significant change in the shape of the elastomer.

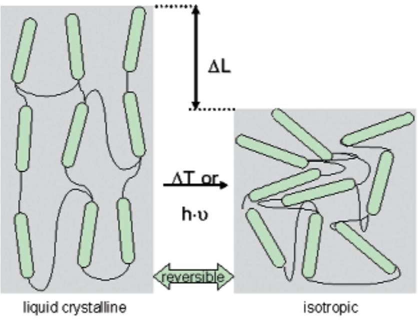

Figure 1: Phase transition induced by temperature change or irradiation

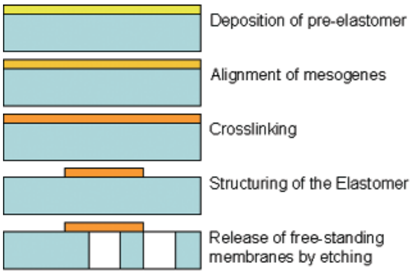

Figure 2: Required processes steps for monolithic integration

The synthesis and development of this kind of material, called "functional liquid-crystalline elastomer (FULCE)", has been a field of research in organic chemistry in recent years. The University of Freiburg has developed elastomers that are able to reversibly change their length by 400% due to a change of the phase of the LC molecules, whereby stresses up to 27 kPa have been measured. Depending on the LC used, this change of phase can be caused by heating or irradiation with UV light. These properties make FULCEs a promising material for use in MEMS with large deformations and small forces.

Integration into MEMS

Besides the evaluation of the mechanical properties and the long-term stability of the materials, it is necessary to show compatibility with standard materials used for MEMS, such as silicon or glass substrates, and the processes used to manufacture the system.

The first approach is to integrate the manufacturing of the elastomer into the production of MEMS, i.e. on the wafer level. This can be done using a pre-elastomer solution and photosensitive crosslinking of the polymer after formation of a film on the wafer surface. In this case, one needs to perform the alignment of the mesogens on the wafer level, too. As the pre-elastomer can be used in a liquid form, this monolithic approach has advantages in the handling of the materials. If this is not applicable, the second method to integrate the material would be the hybrid assembly of preformed elastomer films, e.g. by using bonding processes or adhesives. In our experiments, this pre-elastomer solution is a dichloromethane solution of polymethylsiloxane polymer with side-chain units like phenyl benzoate derivative, as mesogenic molecule, and benzophenon crosslinker. The preformed films consist of a similar material.

Experiments

A typical bending beam structure was chosen to demonstrate the process steps for the utilisation of FULCE as an actuator. Even for this rather simple example, at least five different technology steps had to be adapted for the use of FULCEs (Fig. 2). The alignment of the mesogens within the network is a crucial step, because the ability of the material to function as an actuator relies on a uniform alignment with a high degree of order. Usually, mechanical stretching is employed to align the network. However, this method cannot be used with a film deposed on a rigid substrate. For our tests, we deposed films of a pre-elastomer on glass substrates and exposed them to strong electric and magnetic fields of 300 kV/m and 11 Tesla, respectively. Using XRD and polarisation microscopy, an effect on the alignment of the network was shown, but not yet quantified. The results bear out that alignment of the material on the substrate is possible.

Essential for the integration is the deposition and structuring of thin films. We spin-coated a pre-elastomer containing a photoreactive crosslinker on a substrate and crosslinked it after complete evaporation of the solvent using a photomask. The parts exposed to UV light were crosslinked to an unsolvable elastomer, while the rest of the pre-elastomer could be solved in

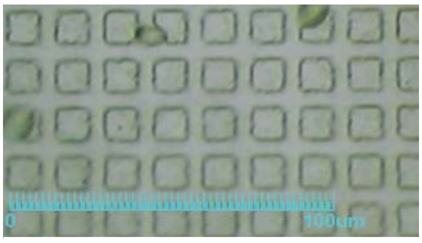

Figure 3: FULCE patterned using standard photolithography

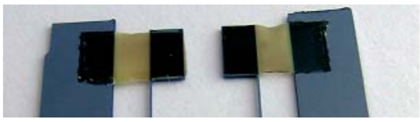

Figure 4: Free standing elastomer membranes released by ASE

toluene after the exposure. As we show in figure 3, structures down to 5µm could be patterned using this method. The film is about 500 nm thick. The biggest problem while increasing the film thickness is the swelling of the elastomer structures due to the developing in toluene, which can affect the mechanical properties.

To be able to use the contraction of the material as displacement, we also needed to release free-standing elastomer membranes by etching. We chose advanced silicon etching (ASE) for this step because of its mechanically advantageous etching geometry, selectivity, and low process temperatures. The tests were carried out using a non-aligned elastomer that had been applied to the surface in a solution and was crosslinked using the mask aligner AL 6-2 prior to etching (Fig. 4).

Figure 5: Deformation of a silicon structure due to the shrinking of FULCEa

To test the hybrid integration of preformed films, we needed to find a low-temperature method for assembly. As adhesives are likely to have negative effects on the elastomer, we adapted a technique for the assembly of polydimethylsiloxane on silicon. The elastomer and the silicon surface were activated in oxygen plasma and brought in contact with each other. The oxidised FULCE sealed immediately and irreversibly to the silicon surface. Using this approach, we were able to manufacture a demonstrator that shows the remarkable actuator properties of the materials (Fig. 5).

Summary

We were able to show that all the necessary processes for manufacturing a micromechanical system containing FULCE are compatible with existing technologies and materials. Full integration into batch processing and hybrid assembly was investigated and found suitable for application. Possible applications for FULCE are artificial muscles, or probes for biomedical applications. The compatibility of materials and manufacturing processes makes them ideal as actuators for fully compliant systems, too.

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