Development of a resonant asymmetric micro mirror using an electro active polymer actuation

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Abstract. In this paper we present the development of a resonant asymmetric micro mirror. In particular, we prove the possibility of using an Electro Active Polymer as actuation material. The working principle of the micro mirror and the design retained is first presented. Then the technological realization is summarized. We obtain micro mirror demonstrators and the first characterization results are given. These first promising results open the way of low cost and low temperature process actuators for Micro Electro Mechanical Systems.

1. Introduction

Micro Electro Mechanical System (MEMS) technologies lead to the development of miniaturized devices presenting high performances and low consumption [1]. In particular, micro mirrors are a key component for optical applications such as micro scanner, pico-projector or Light Detection And Ranging (LIDAR) systems. They consist in a movable electromechanical element, able to guide or deflect an optical beam or a laser. The actuation mechanism can be electrostatic [2], magnetic [3] or piezoelectric [4].

Among the various piezoelectric materials, Electro Active Polymers (EAPs), and in particular PVDF (Polyvinylidene fluoride) and derivatives fluorinated EAPs, are very interesting due to their ferroelectric properties, their low temperature processes and the possibility to be processed through standard printed electronic techniques [5]. They were already studied as actuator for example for haptic applications [6]. Our goal is to prove the possibility to use EAP as piezoelectric actuation material for a micro mirror.

In this paper, the work principle and the design of a resonant asymmetric micro mirror were presented. The main steps of the technological realization of demonstrator were also detailed. Finally, preliminary characterization results were given. The first promising measurement results proved the functioning of EAP actuators integrated in a silicon process flow. Further characterizations are in progress to evaluate the performances of this kind of innovative actuator for MOEMS devices.

2. Work principle and design

We aim to develop a resonant asymmetric micro mirror based on an Electro Active Polymer actuation.
As sketched in Figure 1, two piezoelectric actuator beams allow an out-of-plane displacement when an alternating actuation voltage is applied, thanks to the unimorph effect. It induces a rotation of the micro mirror due to the asymmetric position of the torsional springs which maintain the mirror.

The piezoelectric material is an Electro Active Pol-ymer (EAP) provided by Piezotech - Arkéma. PVDF (Polyvinylidenefluoride) and derivatives fluorinated electroactive polymers are subject to numerous developments. Thanks to their ferroelectric semi-crystalline structures, they exhibit piezoelectric, pyroelectric or even relaxor ferroelectric properties that open new perspectives in sensors and actuators applications. Among them, P(VDF-TrFE) (Poly vinylidenfluoride-co-trifluoroethylene) copolymers are of particular interest since they crystallize directly from solution in a ferroelectric phase and can be processed through standard printed electronic techniques and using low temperature processes.

The design was performed using the Finite Element Method (FEM) approach and CoventorWare® software. Figure 2 gives a schematic view of the beam actuator. Based on previous work [7], we selected $L_a=2/3 L_b$. We chose to realize devices with $L_b$ ranging from 3000 to 5000 µm which correspond to a theoretical resonant frequency ranging from 7.8 to 2.7 kHz. Then we adapt the actuator width ($W_a$) according to the beam width ($W_b$) to fulfill the EAP deposition requirements.

Due to the asymmetric position of the mirror ($\delta$), an angular rotation around torsional springs will result on the vertical displacement generated by the beam actuators. From [7], we select to study two different asymmetric positions of the mirror, $\delta = 50$ or 100 µm.

The torsion beam design is one of the main challenges for efficient resonant asymmetric micro-mirror design. We know that the torsion mode efficiency is higher if the torsion beam width ($w_t$) is...
equal or smaller than the torsion beam thickness (h). Nevertheless, for technological reasons, we chose larger torsion beam widths, from 5 to 50 µm. The smaller \( w_t \) will allow to obtain the best rotation angle, but presents the highest technological risk.

The following table gives a synthesis of the main dimensions of our demonstrator.

**Table 1.** Resonant asymmetric micro mirror main dimensions.

| Parameters            | Dimensions (µm) |
|-----------------------|-----------------|
| Mirror radius         | 250 - 1000      |
| Beam length           | 3000 - 5000     |
| Beam width            | 500             |
| Torsion beam length   | 400 - 500       |
| Torsion beam width    | 5 – 50          |
| Thickness of the device | 7.8            |

Using CoventorWare® and an arbitrary actuation voltage of 50 V, we obtain a mirror deflection of 48 µm (the lowest point at the end of the mirror) through harmonic simulations. It corresponds approximately to a rotation angle of about 5° using low actuation voltage. The simulated resonant frequency of the micro mirror with an actuation beam length of 3000 µm is 7.8 kHz, thus in good agreement with the theoretical resonant frequency of the single actuator beam.

![Beam Resonant asymmetric micro mirror deformation under 50V using FEM approach.](image1)

**Figure 3.** Beam Resonant asymmetric micro mirror deformation under 50V using FEM approach.

### 3. Technological realization

Figure 4 gives a schematic cross section of the device. Demonstrators were built using standard 8 inches silicon wafers and facilities.

![Schematic cross section of the resonant asymmetric micro mirror based on Electro Active Polymer actuation.](image2)

**Figure 4.** Schematic cross section of the resonant asymmetric micro mirror based on Electro Active Polymer actuation.
We first process the back side of the wafers to deposit and pattern the SiO\(_2\) hard mask which will allow to release the micro mirror at the end of the process. Then SiO\(_2\) and polysilicon layers were deposited in the front side of the wafer as structural layers and then etched to define the geometry of the MOEMS. A gold bottom electrode was deposited. This material is also used as reflective material, more suitable in IR spectral region, and it was deposited on the micro mirror part. The reflective properties of this gold material were evaluated using a multi wavelength ellipsometer. The measurement results indicate that the gold material used in our process presents a high reflectance value, in agreement with reference gold material (Figure 5).

![Figure 5. Reflective properties of the gold material above the micro mirror measurement using a multi wavelength ellipsometer, 9 points per wafer.](image)

The EAP layer was deposited using screen printing technology and in particular an automatic Screen Printer EKRA X5 tool. The EAP material is a Piezotech - Arkéma FC Ink H 25 P(VDF-TrFE) copolymer solution in Cyclopentanone (viscosity 3 Pa.S). After each deposition step, the layer is annealed during 15 minutes at 135°C in an infrared oven. It permits to evaporate the solvent and crystallize the PVDF-TrFE film. We obtained an acceptable alignment of the EAP actuator on the silicon device (±50µm). Figure 6 gives a view of the silicon wafer with the EAP layer above the bottom electrode.

![Figure 6. Photography of the resonant asymmetric micro mirror with the EAP layer deposited by screen printing above the bottom electrode. The EAP presents a misalignment of ±50 µm.](image)

We measured the EAP actuator thickness and we observed a curved profile of the actuator. This profile is not problematic for the operation of our device but can be improved in the future, for example by adjusting the viscosity of the EAP solution (Figure 7).
Figure 7. Photography Measurement using a mechanical profilometer of the profile of the EAP layer.

Top electrode and electrical lines in gold were then deposited on the top of the EAP layer, using a shadow mask. As shown in Figure 8, we obtain a quite good resolution and an acceptable alignment.

Figure 7. Photography of the resonant asymmetric micro mirror after gold deposition as top electrode, above the EAP, using a stencil.

Finally, the back side etching of the bulk silicon allows to release the MOEMS device can be seen in the Figure 9.

Figure 7. Photography of the resonant asymmetric micro mirror after back side etching of the bulk silicon. On the left the 200mm wafer and on the right a zoom on a single component.
4. Characterization

First, in order to activate the piezoelectric effect of the copolymer, actuators are poled with a square form signal (amplitude 160 V) at low frequency (1 Hz) during 120 s. This poling step induces the alignment of dipoles along the electrical field direction.

Then capacitance measurements were performed to check the EAP functioning, using an Agilent 4284A LRC meter. A capacitance value of 36 pF was measured on the actuators. It corresponds to a relative dielectric constant of 9, in good agreement with the expected value.

Electromechanical characterizations were also performed using a POLYTEC laser vibrometer MSA400. We used electrical probes to actuate our device as shown on Figure 10.

For this preliminary test, only 2 V_RMS were used to actuate the device. We focused on the first out-of-plane vibration mode of the beam actuator. A small dynamic deformation of the beam was measured (45 nm) using this low actuation voltage and it was unable to induce a notable vibration of the mirror. But a symmetric behaviour on the two actuators can be observed as expected (Figure 11). Higher actuation voltage should be used to actuate the mirror and evaluate the rotation angle which can be obtained using EAP actuators. Nevertheless, this first result proves the functioning of our innovative EAP actuator. The resonant frequency was measured at 15.97 kHz, thus higher than expected (7.8 kHz). It can be explained by residual stresses in the constitutive layers of the device.

Further measurements will be performed using higher actuation voltages to study our micro mirrors based on EAP actuators.
Figure 7. Laser vibrometer measurement on a micro mirror based on EAP actuators using an actuation voltage of 2VRMS.

5. Conclusion
In this paper the design of a resonant asymmetric micro mirror and the technological realization used to build demonstrator were presented. The electrical characterization of the actuators allows to extract a relative dielectric constant of 9, as expected. The preliminary electromechanical results prove the functioning of the actuators, which vibrate in their first out-of-plane resonant mode. Further characterization are in progress to obtain higher actuator displacement amplitudes, able to induce the rotation of the micro mirror.

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