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## Optimization of electrodes design for PZT thin-film actuated membranes

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### Abstract

This paper reports on the optimization of electrodes design for sol-gel  $\text{Pb}(\text{Zr}_{0.52}, \text{Ti}_{0.48})\text{O}_3$  (PZT) thin-film actuated-membranes. PZT can be used in many actuator applications such as micro mirror, RF MEMS, inkjet or loudspeaker due to its strong piezoelectric properties. We aim to design membrane-based actuators with the optimum electrode dimensions allowing the largest membrane displacement under a given actuation voltage. We present in this paper measurement results, in good agreement with the finite element modeling, proving that an actuator area between 50 and 60% of the membrane area exhibits the highest deflection.

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Keywords: PZT, actuator, design

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### 1. Introduction

$\text{Pb}(\text{Zr}_{0.52}, \text{Ti}_{0.48})\text{O}_3$  (PZT) is a good candidate for actuator applications such as micro mirror [1], RF MEMS [2], inkjet [3] or loudspeaker [4] due to its strong piezoelectric properties. Thus, we aim to design actuators with the highest efficiency. In particular, we want to determine the optimum electrode dimensions allowing the largest membrane displacement under a given actuation voltage. First, we present in this paper the actuation principle and the technological steps used to build PZT-actuated membranes.

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Then we present measurement results on PZT-actuated membranes presenting various actuator area over membrane area ratios. These results are in good agreement with the finite element modeling, proving that an actuator area between 50 and 60% of the membrane area exhibits the highest deflection.

## 2. Actuation principle and technological realization of demonstrators

Our actuation principle consists in stacking the piezoelectric layer and electrodes together with an elastic layer clamped on its four sides (Figure 1). When an electric field is applied between the top and the bottom electrode the PZT layer shrinks in-plane, due to the  $d_{31}$  coefficient effect, while the elastic layer is not affected. A bending motion of the membrane is therefore induced by the bimorph effect.

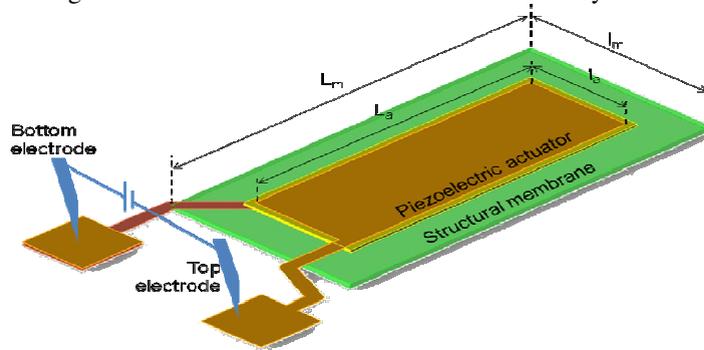


Fig. 1. PZT thin-film actuated membrane schematic view

We built devices from 8'' Silicon-on-Insulator (SOI) wafers with  $5\mu\text{m}$  thick top silicon. After a  $500\text{nm}$  thick silicon oxide layer deposition, we deposited and etched the piezoelectric stack as shown on the SEM cross section view in Figure 2 (a). It consists of a  $2\mu\text{m}$  thick sol-gel PZT layer sandwiched between the  $100\text{nm}$  thick Pt bottom electrode and the  $100\text{nm}$  thick Ru top electrode. Finally, we released the membrane by back side etching of the bulk silicon. Figure 2 (b) shows an optical view of an 8'' wafer including various PZT-actuated membranes sizes and various  $Y_{act}$ , namely the actuator area over membrane area. Note that the so-called actuator area corresponds to the top electrode area and that  $Y_{act} = (l_a \times L_a) / (l_m \times L_m)$  (Figure 1).

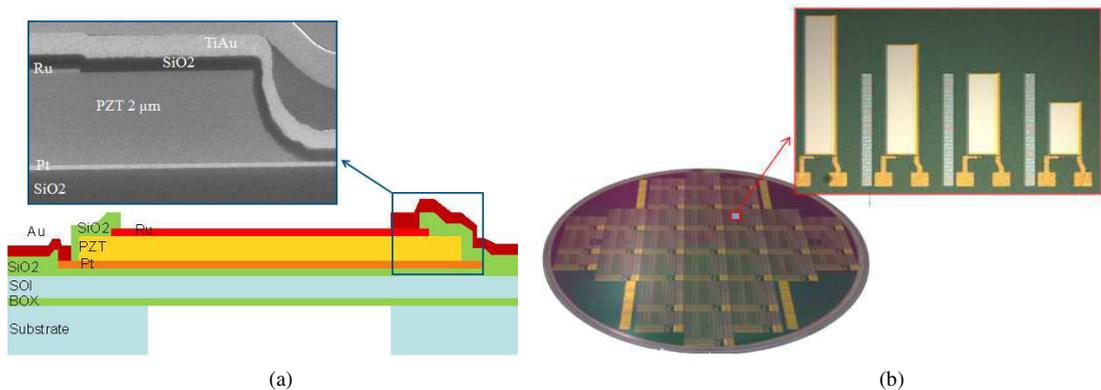


Fig. 2. (a)  $2\mu\text{m}$  thick (100) sol-gel PZT actuated membrane schematic and SEM cross section view; (b) Optical view of various sizes PZT-actuated membranes realized using 8 inches facilities

### 3. PZT-actuated membranes characterization and FEM simulations comparison

We measured the deflection of actuators for  $300 \times 600 \mu\text{m}^2$  membranes under a given bias voltage  $V$  for different values of  $Y_{act}$  ranging from 40 to 80%. The net deflection at  $V$  is the membrane displacement at  $V$  minus the membrane displacement at  $0V$ . This is performed in order to get rid of the initial deflection induced by the residual stress. We characterized these membranes with a white-light WYKO® interferometer. It gives the altitude of all the device points at the same time. Figure 3 gives an example of the interferometer profile measurement of a  $300 \times 600 \mu\text{m}^2$  membrane under  $-40V$ . Then we calculated the normalized net deflection, which is the net deflection normalized with respect to the maximum deflection value.

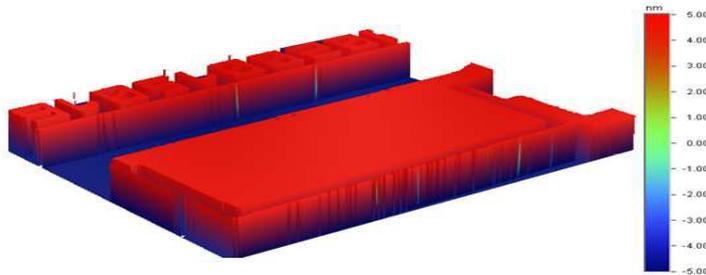


Fig. 3.  $300 \times 600 \mu\text{m}^2$  PZT actuated membrane WYKO profilometer view under  $-40V$

We therefore compared each maximum experimental deflection for different  $Y_{act}$  with finite element modeling using CoventorWare®. PZT  $d_{31}$  coefficient was extracted from measurements ( $150\text{pm/V}$ ) and was used as an input data [5]. Moreover, we used PZT Young's modulus extracted from picosecond ultrasonic measurements, namely  $110\text{GPa}$  [6]. The  $300 \times 600 \mu\text{m}^2$  membrane normalized net deflection versus  $Y_{act}$  variation is reported in Figure 4 (a).  $Y_{act} = 51\%$  exhibits the highest deflection. There is a very good agreement between measurements and modeling.

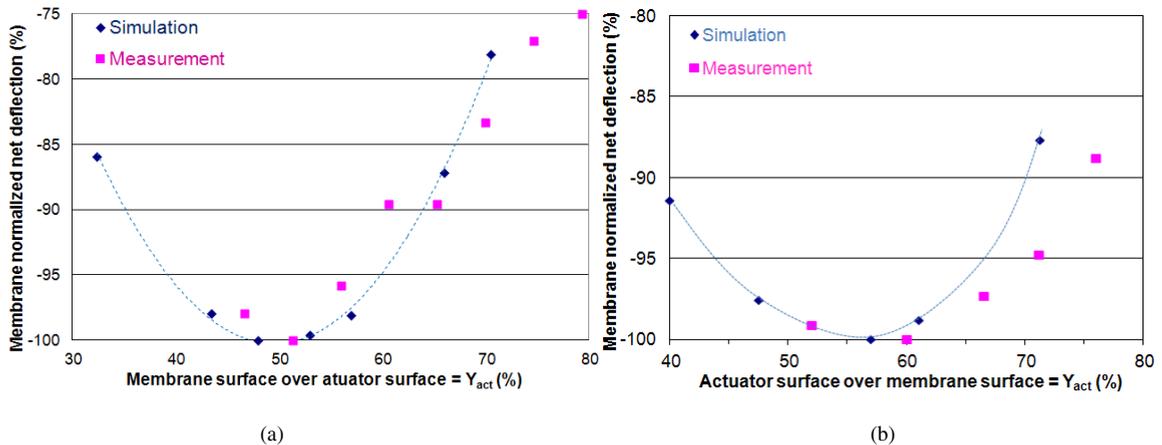


Fig. 4. (a)  $300 \times 600 \mu\text{m}^2$  and (b)  $300 \times 800 \mu\text{m}^2$  PZT actuated membrane normalized net deflection characterization and FEM modeling comparison

Besides, we investigated various membrane dimensions and shapes. As reported in Table 1,  $Y_{act}$  varies slightly according to the dimensions of the membrane, or its nature – rectangular or circular [7]. For example, the  $300 \times 800 \mu\text{m}^2$  membrane normalized net deflection versus  $Y_{act}$  variation is reported in Figure 4 (b).  $Y_{act} = 60\%$  exhibits the highest deflection. In this configuration, the highest deflection is reached when  $Y_{act}$  lies between 50 and 60%.

Table 1. Optimum actuator area over membrane area ( $Y_{act}$ ) FEM modeling and measurement comparison

Membrane shape and dimensions	$Y_{act}$ , FEM simulation (%)	$Y_{act}$ , Measurement (%)	Discrepancy (%)
			$\frac{Y_{act,FEM} - Y_{act,measurement}}{Y_{act,FEM}}$
Rectangular - $420 \times 240 \mu\text{m}^2$	55	50	9
Rectangular - $600 \times 300 \mu\text{m}^2$	48	51	6
Rectangular - $800 \times 300 \mu\text{m}^2$	57	60	5
Circular – Diameter $200 \mu\text{m}$	50	-	-

#### 4. Conclusion

As a conclusion, we showed experimentally in this study that the maximum deflection of a piezoelectric micro-membrane is reached for a given voltage once the ratio between the actuation area and the whole membrane area lies between 50 and 60%. Simulation and measurement results indicate that this ratio is valid both for rectangular and circular membrane shapes and for various membrane dimensions.

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