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Presentation and characterization of novel thick-film PZT microactuators

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ABSTRACT

We propose in this paper the characterization of a new generation of piezoelectric cantilevers called thick-films piezoelectric actuators. Based on the bonding and thinning process of a bulk PZT layer onto a silicon layer, these cantilevers can provide better static and dynamic performances compared to traditional piezocantilevers, additionally to the small dimensions.

1. Introduction

PZT (lead, zirconate, titanate) material is widely used in the microworld for the design of highly performant actuators and sensors. Thanks to their high displacement resolution and high bandwidth, pizoelectric actuators are prized for several applications such as in microrobotic domain (cantilevers for micro-tweezers [1,2], AFM piezo-scanner [3], etc.) or biomedical applications [4]. Despite their high resolution, piezoelectric actuators present several well known nonlinearities, such as hysteresis or creep. Many studies are currently trying to overcome these nonlinearities by using compensation techniques [5–14], or through feedback control strategies (see [6,16] and references herein).

One of the mainly used piezoactuators is the unimorph cantilever, it is made of one piezoelectric active layer bonded onto a passive elastic layer, resulting in an out of plane displacement when an electric field is applied between the two sides of the piezoelectric layer. Different technologies are used to create PZT piezoactuators. The first one uses bulk PZT layer resulting in thick cantilevers (>200 μm) allowing the generation of large bandwidth but with small displacements. In counterpart, another fabrication process consists in the deposition of thin layer of piezoelectric materials (in the range of some micrometers), resulting in thin film cantilevers generating high displacements but with small bandwidth. In [15], we proposed a new fabrication approach resulting in the generation of thick-film piezoactuators, with novel performances both in the static and dynamic domains. In fact, the actuators developed with this technology exhibit performances that are taken from the advantages of the classical bulk PZT (large bandwidth) and from those of the thin films (large displacements). Linear assumption and modeling of the actuators have been given for that. In this paper, we deal with the characterization of this novel generation of piezoelectric actuators, for both static and dynamics aspects in order to demonstrate that at the optimal operating range, they also exhibit hysteresis nonlinearities similarly to classical piezoelectric cantilever actuators.

2. Proposed piezoelectric actuator

The fabrication process of the piezoelectric actuator, detailed in [15], is based on the gold bonding (at room temperature) of a PZT bulk layer (200 μm thickness) onto a SOI (Silicon On Insulator) wafer. The SOI composed of a 5 μm device silicon layer, a 1 μm buried oxide layer (insulator), and a 500 μm handle silicon layer. Mechanical thinning and polishing of the PZT layer is then performed. A thin gold film is then deposited on the top surface of the PZT layer, which serves as a top electrode for the cantilever actuation. The gold layer used for the bonding is also used as the bottom electrode. Cantilevers are then sliced into beams with a saw, and the handle layer of the SOI wafer is etched through DRIE (Deep Reactive Ion Etching) process.

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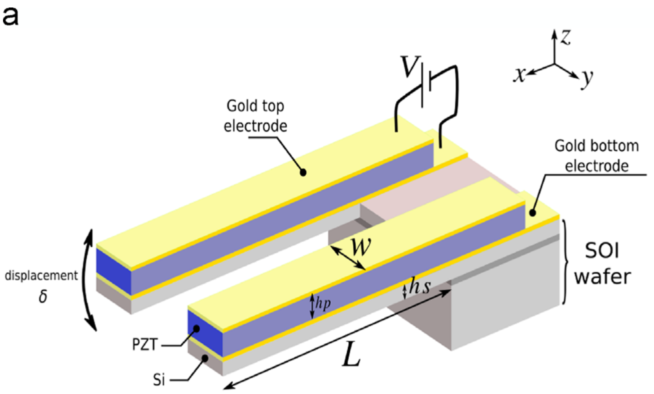

Design of the cantilever.

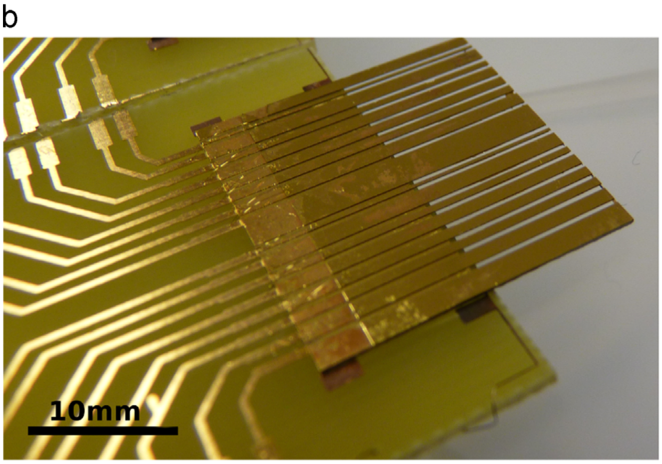

Photo of a set of cantilevers.

Fig. 1. Thick-film PZT unimorph cantilever. (a) Design of the cantilever. (b) Photo of a set of cantilevers.

The realized unimorph cantilevers had a PZT layer of $h_p = 25$ µm thick and a silicon elastic layer of $h_s = 5$ µm. The length of the cantilevers is $L = 4$ mm, and the width w varies from 150 to 750 µm (Fig. 1).

3. Characterization of the piezoelectric actuator

In the sequel, we use a piezoelectric cantilever actuator of 150 µm of width. The characterization setup is composed of:

- the piezoelectric actuator,
- an optical sensor (LC2420 from Keyence companyn) capable of measuring the deflection of the cantilever (displacement) with a resolution of tens of nanometer and bandwidth in excess of 5 kHz,
- and a computer and a dSPACE board used to generate the input voltage and to acquire the measurement. The sampling time is tuned to be 50 µs.

3.1. Hysteresis characterization

In [15], the modeling used to estimate the performances of the actuator was linear. Here, we provide deeper characterization of the actuators which demonstrate that they are nonlinear when increasing the operating range. First, a sine input voltage of amplitude 10 V is applied to the cantilever actuator used for the experiment. The frequency is chosen to be low relative to the resonant frequency in order to avoid the phase-lag effect and thus to avoid a distorted curve. However, the frequency should not be too low in order to avoid the creep effect which is another nonlinearity found at very low frequency or very low rate [16]. In this case, we choose 0.1 Hz which is sufficiently low face to the first resonant frequency of the cantilever and sufficiently high relative to the creep frequency domain. Fig. 2 depicts the output displacement obtained from the actuator versus the input voltage. As depicted, the actuator strongly exhibit hysteresis whose amplitude exceeds $h/H \approx 14\%$. We can also see that the gain obtained with the novel actuator is in excess of 3.7 µm/V which is much larger than that of traditional piezoelectric cantilever actuators based on PZT. The gain of these latters are generally less than 1.5 µm/V [16].

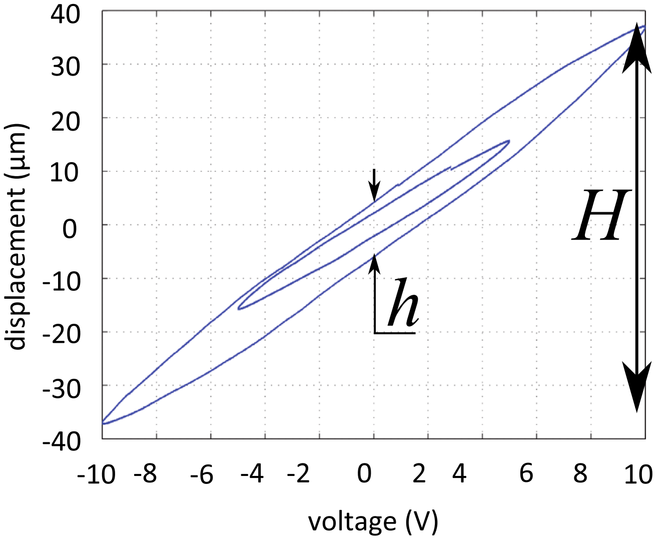

Fig. 2. Experimental characterization of the hysteresis nonlinearity.

To go further on the characterization of the gain of the novel actuator, we apply higher amplitude than 10 V for the input voltage. Fig. 3 depicts the gain which corresponds to the ratio between the amplitude of the output displacement and the amplitude of the input voltage. In the same figure, we also plot the linear model that is used to estimate the displacement in [15]. As we can observe, the gain increases substantially with the input voltage amplitude. Furthermore, the static performance of the actuator is underestimated with the linear model. These experimental characterization results highlight the static performances of the novel actuator.

3.2. Creep characterization

Classical piezoelectric cantilever actuators are also known to

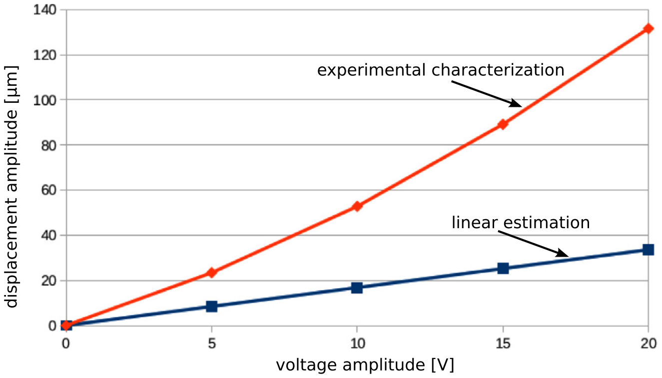

Fig. 3. Experimental characterization of the gain of the actuator.