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Abstract

A Simple Method for Extracting Piezoelectric Coefficient d_{31} by Fitting Experimental Data with an Analytical Model †

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Abstract: This work presents a simple method to extract the piezoelectric coefficient d_{31} based on analytical model fitting. A theoretical circuit model is developed for a piezoelectric circular membrane actuator based on PZT thin film. The circular diaphragm consists of a 12 µm silicon layer, an 800 nm thick PZT layer, and a 200 nm Ti/Pt layer, featuring a single 50% inner top electrode coverage. The proposed model is validated by the finite element method with a 2D axisymmetric model of a PZT piezoelectric membrane. Further, piezoelectric coefficient d_{31} is extracted by fitting the Laser Doppler Vibrometer (LDV) experimental result with the analytical model.

Keywords: lumped element model; PZT actuator; piezoelectric coefficient

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1. Introduction

MEMS devices based on piezoelectric thin films have become ubiquitous in applications such as RF filters, acoustic devices, and energy harvesters [1]. The properties of the piezoelectric film play an important role in the performance of devices, especially the piezoelectric coefficient d_{31}. Several piezoelectric measurement techniques have been reported, including direct and indirect methods [2,3]. In this work, we propose a simple and easily accessible approach to measuring piezoelectric constants by fitting the Laser Doppler Vibrometer (LDV) experimental data with an analytical model.

2. Materials and Methods

Figure 1a shows a fabrication schematic consisting of a stack of Si/SiO2/Ti/Pt/PZT/Ti/Pt layers. Figure 1b shows the optical photograph of a fabricated PZT device. An equivalent circuit model is developed to predict the behavior of the piezoelectric actuator, including the influence of residual stress. The theoretical model is validated by a finite element simulation model, and the piezoelectric constant d_{31} is then extracted by fitting LDV experimental data with the theoretical model.

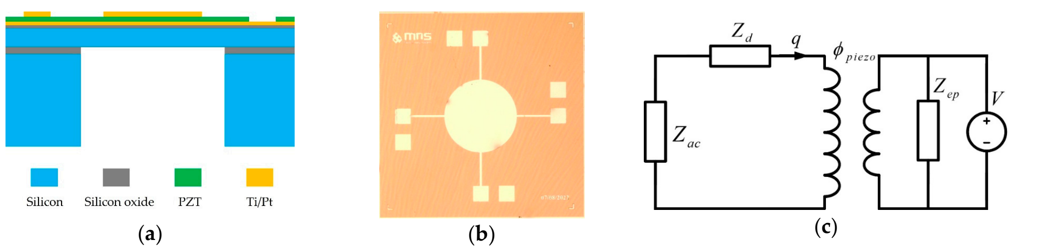

Figure 1. (**a**) Schematic of the piezoelectric actuator; (**b**) Optical photograph of the fabricated PZT device. (**c**) The equivalent circuit model of the piezoelectric membrane actuator.

3. Discussion

The equivalent circuit model is shown in Figure 1c, where Z_{ac} is the acoustic impedance; Z_d the diaphragm impedance; q is the membrane volume velocity; and Z_{ep} is the impedance collected from the piezoelectric film. $\varnothing_{piezo}$ is the transformer ratio related to volume velocity q and actuation voltage V. By analyzing the model, the piezoelectric constant d_{31} can be extracted by Equation (1) as follows:

$$\phi_{piezo} = \frac{j\omega 2\pi R E d_{31} Z_p F(k)}{D(1 - v_{piezo})} \tag{1}$$

where ω is the angular frequency; R is the radius of the membrane; E is the Young's modulus; Z_p is the distance from the mid-plane of the PZT layer to the neutral axis; D is the flexural rigidity of the membrane; v_{piezo} is the Poisson's ratio of PZT; $F(k)$ is the vibration mode-related function; and k is the radial mode shape number [4].

Figure 2a compares the theoretical and simulated results of the membrane displacement with a residual stress of 200 MPa, which match well. Figure 2b shows the displacement per voltage of a fabricated device measured by LDV and predicted by a theoretical model. The residual stress of the diaphragm is 200 MPa, as measured by a DektakXT stylus tool. To fit the experimental data, a measured quality factor value of 76 is substituted into the theoretical model. The theoretical and experimental results exhibit good agreement; the differences can be attributed to material parameters and fabrication tolerance. Subsequently, the piezoelectric constant d_{31} is extracted as 18 pm/V. Figure 2c shows the polarization vs. electric field hysteresis loop of deposited PZT film at 1 kHz.

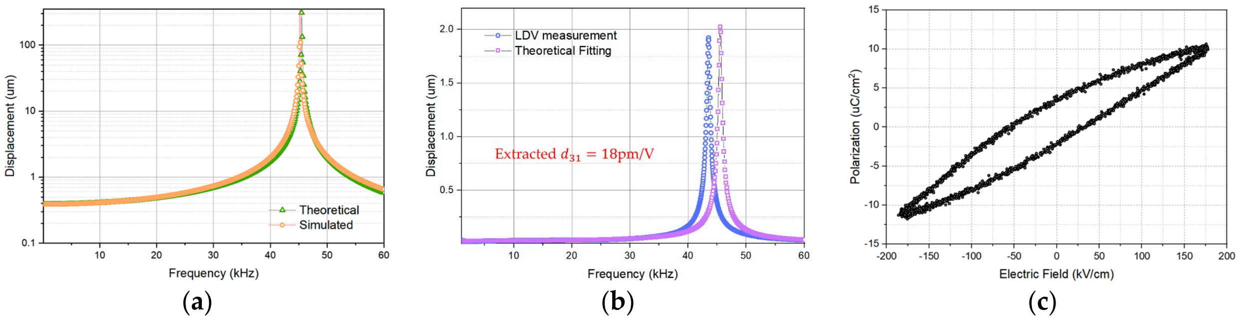

Figure 2. (**a**) Comparison of the theoretical and simulated results of the membrane displacement. (**b**) Results measured by LDV and predicted by the theoretical model. (**c**) P−E hysteresis loop of deposited PZT film at 1 kHz.

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