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High Frequency 1D piezoelectric resonant microscanners with large displacements

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Abstract

This paper presents design, fabrication and measurements for two single-axial resonant driven microscanners with apertures of 1.2 mm and 1 mm diameter, which achieve large $\theta_{\text{opt}}$ D-products of 73.2°·mm and 40°·mm at high frequencies of 27 kHz and 60 kHz, respectively. Unipolar rectangular signals with different amplitudes of 15 V and 10 V have been used for driving. The attainment of large tilting angles and high frequencies are resulted from the high torque delivered by the thin-film PZT driving layer and mechanical leverage amplification. To study the influence of geometrical parameters on the static and dynamic performance and optimize the designs, FEM simulations have been applied. In order to realize closed-loop actuation one actuator has been used as piezoelectric sensor delivering corresponding feedback signals for position detection. The simulation and characterization results will be presented and discussed.

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Keywords: PZT; microscanner; high frequency; large $\theta_{\text{opt}}$ D-product; leverage amplification

1. Introduce

Micromirrors are gaining high interest for versatile applications due to their miniature size, low power consumption and cost efficiency. Among the main driving principles (thermal, electromagnetic, electrostatic and piezoelectric) piezoelectric materials offer considerable advantages, because of the large electromechanical coupling coefficient and low operating voltages. In accordance with the development of the processing technology PZT actuated micromirrors are showing increasingly attractive performance [1]. Researches on different 1D PZT driven

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micromirrors have been performed and reported in [2]. Based on the earlier results, two designs have been developed and fabricated.

At first this paper introduces the design development, where FEM simulation results are shown. Then the fabrication process of these microscanners is presented. They are followed by the characterization results, where the static and dynamic performance of the microscanners and the signals corresponding to the motions of the microscanners are included. At the end an outlook of the work is given.

2. Design development

For the presented mirrors the concept of using leverage amplification is applied, which has been reported in [2]. The microscanners possess a mirror in the center, an outer actuator frame consisting of two PZT bimorph actuators (I and II) as well as connecting bars and torsion bars (Fig. 1). In Design A meandering connecting bars are applied reducing the mechanical stress within the bars during the torsion motion of the micromirror and enabling high scanning angles. In Design B the microscanner possesses double torsion bars, which allow high eigenfrequencies and serve as levers leading to mechanical leverage amplifications.

![Design schematics and wire bonded micromirrors: (a) and (c) Design A and B; (b) and (d) Micromirror with design A and B.](image)

![FEM simulated maximal shear stress (= 1.3 GPa) of Design A at 15° mechanical tilting angle; (b) FEM simulated maximal shear stress (= 3.6 GPa) of Design B at 15° mechanical tilting angle.](image)

The FEM simulation results shown in Fig. 2 demonstrate a comparison between the meandering connecting bars in Design A and the straight connecting bars in Design B with regard to the maximum material stress. While Design A achieves a mechanical tilting angle of 15° showing a maximum shear stress of about 1.3 GPa within the torsion bars, the shear stress within the thin double torsion bars of Design B is up to 3.7 GPa at the same mechanical tilting
angle. This comparison shows that the stress can be reduced significantly by using meandering bars. On the other hand, design B with double torsion bars shows the advantages of enlarged eigenfrequencies of more than 60 kHz.

Moreover, the connection bars in both designs also serve as the lever enabling mechanical leverage amplification. The mechanical amplification leads to the phenomena that the mirrors have much larger motion amplitudes than the actuators in resonant torsion mode, where the first amplitude peaks appear (in Fig. 3).

3. Fabrication process

Based on the shown designs, microscanners have been realized by means of bulk silicon micromachining processing. The actuators feature 2 μm thin-film PZT with high piezoelectric coefficients of up to -21 C/m² [3]. The complete process flow is shown in Fig. 4, which has been previously described in detail [4].

4. Characterization results and conclusion

The measured θopt·D-product of devices with design A achieves 73.2 °·mm at 27 kHz driven by a 15 V unipolar-rectangular-pulse-signal, whereas devices with design B achieve a θopt·D-product of 40 °·mm at 10 V and 60 kHz. In the torsion mode of the micromirror, the mirrors reach amplitudes of up to 30 times larger than the actuators’ amplitudes, which is in accordance with the effect indicated in Fig. 3. This reveals the good mechanical efficiency of the micromirrors. For the fabricated devices high Q-factors of about 1800 have been calculated from the measured oscillating decay time of micromirrors (Fig. 5).
Because of the good mechanical efficiency, only PZT actuator I is needed for the driving so that actuator II can be used for sensing the actuators’ motion due to the direct piezoelectric effect (see Fig. 1). To avoid electric crosstalk both actuators have separated ground electrodes. Fig. 6 (a) shows the sinusoidal driving signal (green), the motion amplitudes of the micromirror (blue) measured by a Photo-Sensitive-Device (PSD) and the electric signal delivered by the PZT sensor (purple). The agreement on the frequency between the three signals has been shown. Fig. 6 (b) shows the amplitudes comparison of the PSD signal and the sensed actuator signal, where slight linearity can be observed.

In order to realize closed-loop operation, controlling electronics utilizing the piezoelectric response signals are currently being developed. Moreover, first studies on long term stability of PZT actuators have been performed and further characterization with the closed-loop controlling for the micromirrors has been projected. Besides the presented resonant 1D micromirrors, 2D and quasi-static driven micromirrors are also being investigated.

References