Mass-balanced through-wafer electrostatic *x*/*y*-scanner for parallel probe data storage

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Introduction

In this work we describe the design, fabrication and testing of a mass-balanced planar *x*/*y*-scanner designed for parallel-probe storage applications (see Fig. 1a). We explore electrostatic actuation as an alternative to the electromagnetic actuation used in [1]. To increase the shock resistance, mass-balancing is used and the scanner is fabricated by deep reactive ion etching through a complete wafer. To move the scan table in both positive and negative x and y directions, four comb drives are used. The comb-drive fingers are tapered to increase the generated force without decreasing the minimum trench width.

Design

Shock resistance is an important requirement for probe-storage applications. A mass-balancing concept is adopted from [1] for shock resistance in the planar x and y directions while being compliant for actuation. The comb-drive actuators are coupled to the scan table through pivoting elements, so that the scan table and comb-drive translator move in opposite directions. When the table and translator masses are matched, the system is mass-balanced for enhanced linear shock resistance. A large out-of-plane stiffness for passive vibration rejection is achieved by etching the device, including the spring suspension, through the full thickness of the wafer (400 μm). This large etch depth necessitates the use of a relatively large gap between fingers, resulting in a reduced actuator efficiency. We investigated different finger shapes; here we present results from a design based on a tapered finger shape as shown in Fig. 1b. When the translator and stator move closer together, the gap between the fingers decreases because of the tapered shape, which increases the force generated.

Fabrication

The scanner is fabricated from a 400-μm single-crystal silicon wafer using a deep-trench-etching process that etched through the wafer in 165 min with an aluminum etch stop. The minimum trench width after etching is 25 μm, which is used as the gap distance between fingers. After etching, individual scanner chips are separated from the wafer and glued to base plates. Then several break-out pieces (see Fig. 1b) are removed to provide electrical isolation between the stator and the translator of the comb drives.

Results

The applied voltage waveform was the square root of an offset sine ($=\sqrt{\sin(t)+1}$) to ensure that the driving force, which is proportional to the square of the voltage, is a sine wave without higher-order harmonics. The measured resonance frequencies for the x and y axes were 147 and 133 Hz, respectively (Figs. 2a and 2b), in good agreement with the values of 148 and 130 Hz predicted by finite-element (FE) simulations. These simulations estimated effective spring constants for the x and y axes of 100 and 70 Nm^{-1}, respectively. A stable displacement of 38 μm at 156 V was measured for the x axis, whereas the y axis moved 38 μm at 119 V, also in good agreement with FE simulations shown as dotted curves in Figs. 2c and 2d. The calculated maximum generated force was 3.8 mN (at 156 V) and 2.7 mN (at 119 V) for the x and y axes, respectively. A comparison with an electromagnetic scanner and the results of finite element analysis of several comb finger shapes will also be discussed.

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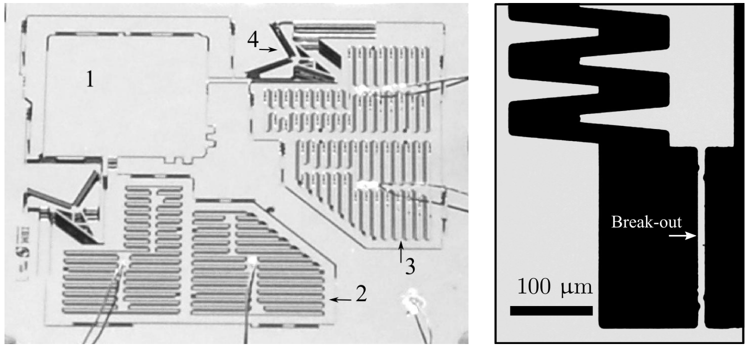
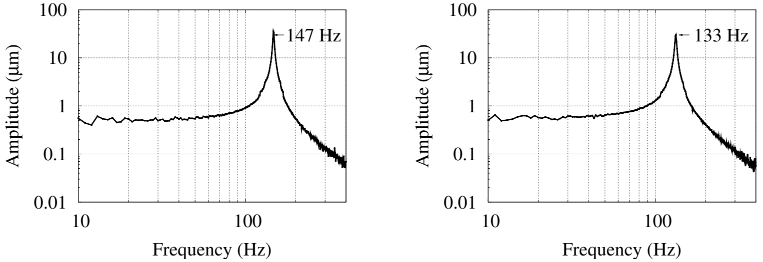
[1] M.A. Lantz, H.E. Rothuizen, U. Drechsler, W. Häberle, M. Despont, J. MEMS 16(1) (2007) 130–139



(a) Assembled scanner: 1 = scan table, 2 = x comb drives, 3 = y comb drives, 4 = pivoting element

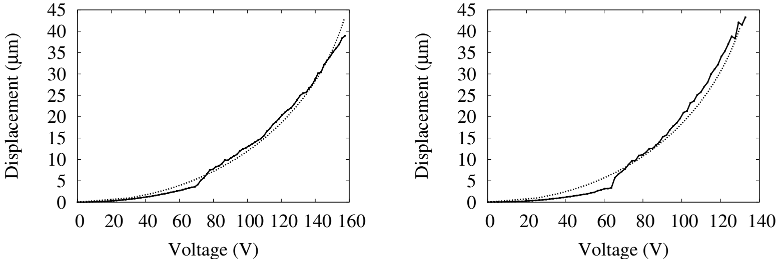
(b) Break-out piece.

Figure 1. Overview and closeup of the device realized.



(a) x-axis frequency response

(b) y-axis frequency response



(c) x-axis displacement vs. voltage

(d) y-axis displacement vs. voltage

Figure 2. Actuator frequency response (drive voltage equals $\sqrt{\sin(2\pi f t)+1}$) and displacement versus voltage (dotted curve is FE simulation).