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Miniaturized Electric Field Mill based on Lorentz Force Actuation

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Summary: In this paper we report on electric field sensors based on MEMS technology and the field mill concept with interdigitated combs. To achieve high sensitivity, the movable comb is excited by the Lorentz force in the out-of-plane direction. The sensor can be supplied with voltages below 1 V, resulting in a low internal crosstalk.

Keywords: MEMS, electric field mill, Lorentz force, sensor, simulation

Introduction

Although the strength of an electric field is one of the fundamental physical quantities, it is very difficult to measure, despite a long history of knowledge. This applies mainly to DC fields or low-frequency AC fields. The typical measuring device, the electric field mill, chops the field to be measured with a mechanical shutter. This creates varying charges on the electrodes below the shutter. By measuring the currents to the electrodes, the electric field strength can be calculated. However, these sensitive devices are quite bulky and require rotating parts that are prone to wear.

The corresponding miniaturized concept is based on shutters that move back and forth. The most common variant uses interdigital combs, one stationary and one grounded, which vibrates in the plane of the combs. The vibration in the electric field changes the charges on the combs and the current to the electrodes (combs) is in turn measured ([1, 2, 3]). Since the active area of the sensor is in the square millimeter range, the current is only a few pA. Therefore, noise is a common limitation.

The shutter is driven by an electrostatic actuator at half the frequency of the mechanical resonance f_r with relatively high voltages U of several tens of volts, resulting in high crosstalk. Since the excitation force is proportional to U^2, the frequency of the crosstalk is $f_r/2$, while the useful signal is at f_r. However, remaining relevant drawbacks of in-plane vibration are the squeeze film damping between the fingers, which limits the quality factor of the vibration, and the vibration amplitude, which directly affects the size of the output signal.

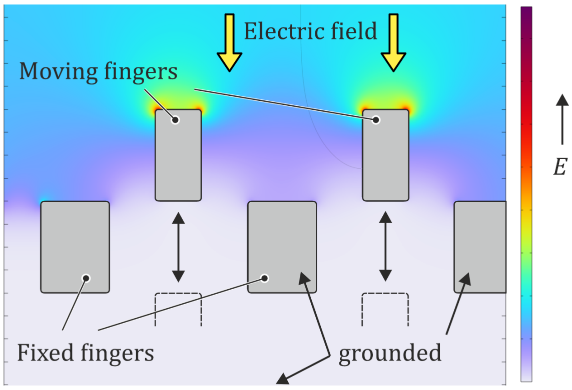

Fig. 1: The electric field sensor consists of two combs, fixed fingers and moving fingers that vibrate out of the comb plane.

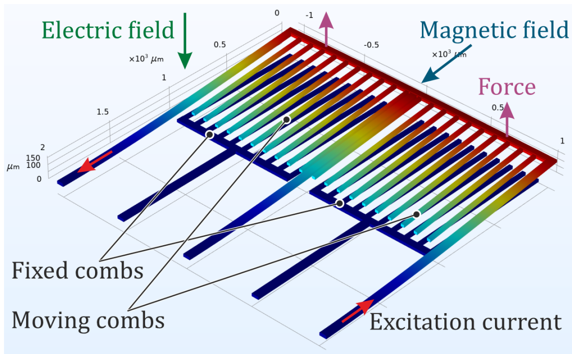

Fig. 2: Excitation and deflection of the moving structure by the Lorentz force due to the electric current and the magnetic field.

Sensor Concept

The structure studied in this work overcomes these disadvantages by vibrating the movable comb out of the plane (Fig. 1) and by using the Lorentz force for actuation (Fig. 2 and 3). Here, the mechanical amplitude is no longer limited by the distance between the fingers, and squeeze film damping is not relevant as long as there is a sufficiently large air gap under the structure. In addition, the density of the fingers is greater than for in-plane vibration sensors. Lorentz force excitation was achieved by applying an alternating current to the line on the moving structure at the frequency of mechanical resonance and by applying a magnetic field from a permanent magnet under the chip.

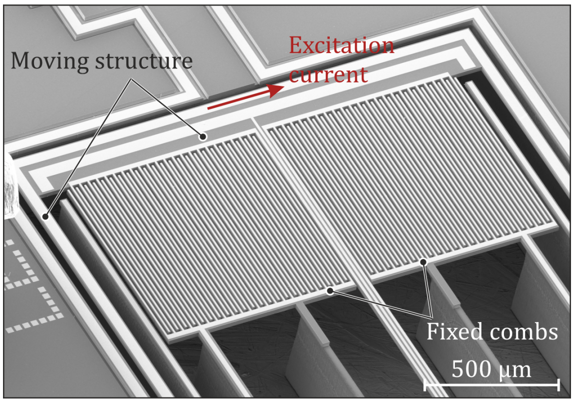

Fig. 3: Scanning electron microscope image of the MEMS electric field sensor. The moving structure is E-shaped with an array of fingers on the inside. The outer bars of the E carry the excitation current and the middle bar is for the signal paths.

Chip fabrication

The devices have been fabricated on 100 mm SOI wafers with a 20 µm thick device layer. The structures have been defined by deep reactive ion etching (DRIE) from the front and back, creating a gap of 8 µm between the combs. The buried oxide was removed by wet etching. The lines for the excitation current and the signal paths are made of 20 nm chromium and 250 nm gold.

Measurement Setup and Results

The sensor chip and permanent magnet are bonded and grounded in a DIL28 package. This part forms the bottom electrode of a parallel plate capacitor to generate the measurement field.

The moving structure was driven with a current of 2 mA in a field of about 200 mT at the resonant frequency of 2.03 kHz, resulting in a mechanical amplitude of about 20 µm and a quality factor of 40. The currents to the fixed and moving combs are converted to voltages using transimpedance amplifiers with a feedback resistance of 100 MΩ. The two signals are then added and measured at the excitation frequency by a lock-in amplifier. Figure 4 shows an offset-corrected sensor characteristic.

Conclusion

MEMS electric field mills with out-of-plane vibration, excited by the Lorentz force, present a promising alternative to in-plane devices with electrostatic actuators. A salient benefit of these devices is that, due to the low excitation voltage, internal crosstalk is negligible, thereby enabling

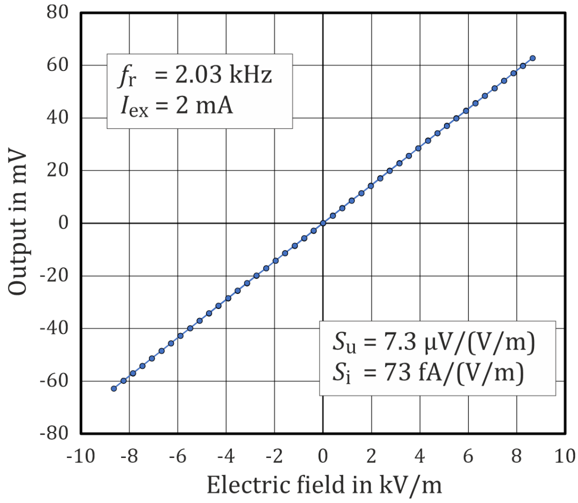

Fig. 4: Cyclic measurement starting and ending at 0 V/m. Each point is the average of 50 readings, the standard deviation for all points is less than 50 µV.

high-resolution measurements. The substantial size of the sensitive area and vibration amplitude has enabled a sensitivity level that exceeds 70 fA/V/m. It must be noted that further development is still feasible.

References

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