AlN-actuated piezoelectric MEMS/NEMS resonators

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Piezoelectric MEMS/NEMS resonators have a great potential for a wide range of applications in fields such as telecommunications or biotechnology. In these two areas, devices like film bulk acoustic wave resonators, microplate resonators, microcantilevers and microbridges have been studied in detail [1-3]. High Q-factor and efficient electromechanical coupling are desirable figures of merit, which may be achieved in higher order modes [4]. Very often, piezoelectric films sandwiched between rectangular electrodes, on top of a deformable silicon layer, are used to excite these resonances.

In this work, we demonstrate an advanced design procedure to fabricate piezoelectric resonators based on flexible plates. Two design strategies are followed: i) optimized response (actuation or sensing) in a given mode; ii) filtering by excitation of a particular mode independently. Our procedure is based on the pioneering concept of modal sensors/actuators to control the vibrations of flexible piezoelectric laminates [5]. Excitation and detection by geometrically shaping the electrodes has been described previously, but it was restricted to one-dimension [5,6]. We have designed resonant piezoelectric sensors/actuators based on two-dimensional microplates by optimizing the surface electrode shape in both dimensions. A numerical finite element procedure, which considers the effective surface electrode covering the piezoelectric film as a binary function on each element, has been developed as in [7]. For the optimization goal, this binary function is assumed to be 1 (0) if covered (not covered) by the electrode; for modal filtering, a binary function accounts for differential excitation of different parts of the plate. Our calculations allowed us to predict, for a given mode in a plate with arbitrary boundary condition, the top electrode layout reaching higher displacement (and hence larger change in admittance) in resonance than any other electrode design for the same structure.

Fig. 1 shows three examples resulting from our calculations for a) optimization of a higher order mode in a microcantilever, b) filtering a torsional mode in a microcantilever and c) filtering a fundamental mode in a microbridge. In the case of optimization, the black part corresponds to the top metallization, whereas for filtering, both black and white areas have to be excited with opposite phase voltages. This ideal spatial distribution of the exciting signal, resulting from the FEM calculation, has to be implemented satisfying certain design rules, such as a minimum gap between metal areas. As an example, Fig. 2 shows some of the devices fabricated, in particular, those corresponding to filtering in Fig. 1; a conservative metal-metal gap of 5 µm has been used and the edges of the fabricated patterns, although close, do not perfectly match those deduced with the model. The AlN driven cantilevers and bridges (640 µm x 200 µm) were fabricated on p-doped (100) silicon substrate which served as bottom electrode. They were backside patterned down to a thickness of about 20 µm. Aluminium nitride, 1000 nm thick, was sputter-deposited and 500 nm thick Al electrode layer was placed on top, with the layout specified by the design goal and the optimization procedure.

The devices have been characterized by laser Doppler vibrometry and impedance measurements up to 6 MHz, to determine the resonant frequencies and out-of-plane displacements, and the corresponding admittance change for the first twenty modes. Fig. 3 shows the displacement spectrum measured on the bride-shaped structure of Fig. 2, designed to filter the fundamental mode (denoted as mode 2_0). Also included in this figure is the response of a reference microbridge, with exactly the same layers and geometry, except for the top electrode, which has two simple square electrodes. Although the filtering is not perfect in this particular device (some leak-through from other modes is present), a significant reduction of the response in the higher order modes, up to more than twenty resonances above the fundamental mode, can be demonstrated, showing that the implemented designs can suppress the contributions of different modes simply by shaping the surface electrodes.

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Figures:

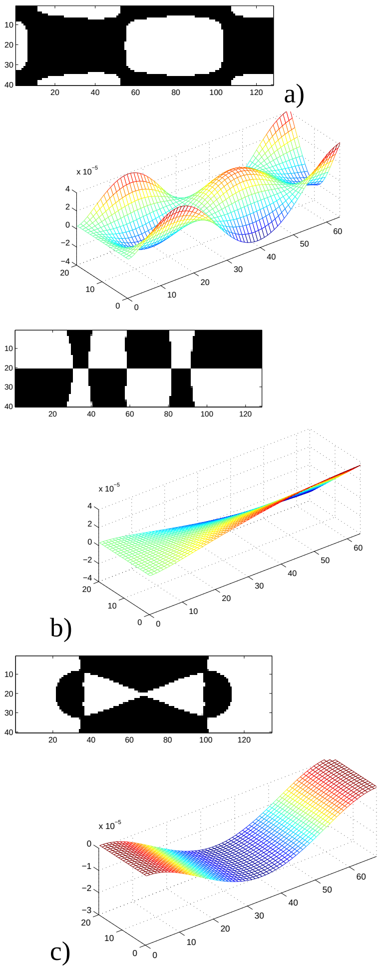

Figure 1. Calculated electrode shapes for a) optimization of a higher order mode in a microcantilever, b) filtering first torsional mode in a microcantilever and c) filtering fundamental mode of a microbridge.

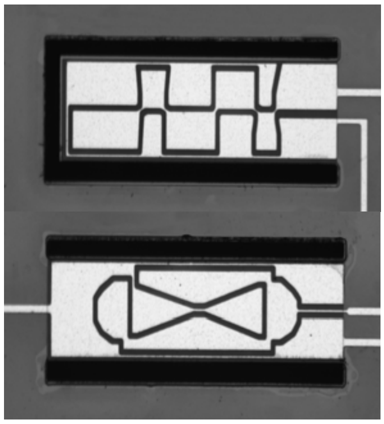

Figure 2. Implementation of the designs in figures 1 b) and c).

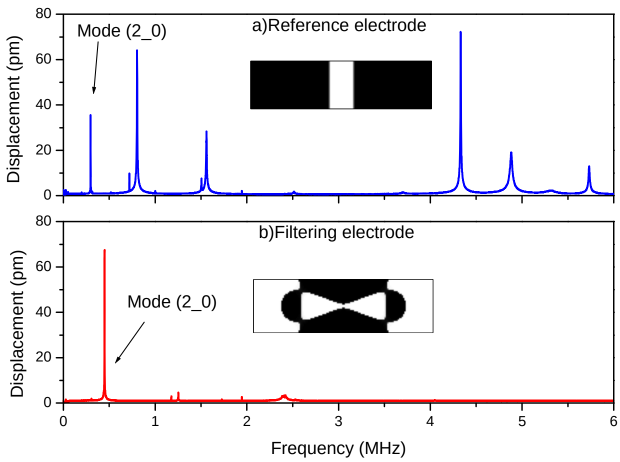

Figure 3. Displacements versus frequency for the same excitation in two microbridges differing only in the top metallization, a) with two lateral rectangular electrodes, and b)with tailored electrode layout.