IEA Sensing for Corner Coupled Square Plate MEMS Resonators Array

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MEMS resonators have been used for wide range of sensing applications, including mass sensor, force sensor and accelerometer. To enhance the functionality and sensitivity, large sensors array can be fabricated on the same die. Meanwhile, the connectivity issue becomes prominent as more interconnections and bond pads are required. One solution is to mechanically couple these resonators together and utilize their collective behaviour, which makes it possible to readout all the eigenvalues of the system by actuating only one element. Inverse eigenvalue analysis (IEA) can therefore be performed to extract the system matrix that contains useful sensing information such as the mass and stiffness of all resonators.

We report an IEA-based sensing approach for coupled square plate MEMS resonators array with ultra-high sensitivity and single-input-single-output actuation capability. The resonator is designed using multi-user MEMS process (MUMPs). As shown in Fig. 1(a), the first polysilicon layer of PolyMUMPs technology shapes the driving electrodes and interconnections at the bottom. The second polysilicon layer is used as the centre-stem square plate that vibrates at transverse-mode. The thickness of the square plate (1.5um) and the gap distance between the top plate and bottom electrode (0.75um) are fixed. The side length is designed to be 100um to provide ~1.2MHz resonance frequency. Fig. 1(b) depicts the actuation scheme and electrical connections. Electrode 1,3 provide dc bias and readout the output ac current generated by capacitance change due to plate vibration. A small ac drive signal is applied to electrode 2,4 as well as the top square plate. Fig. 2(a) shows the dc displacement of the resonator using finite element method (FEM) simulation. The pull in voltage is estimated to be 50V when the displacement is around 1/3 of the gap distance, as shown in Fig. 2(b). The design also benefits from high quality factor (~10000 under vacuum) and low impedance (17.36kΩ under 20V bias).

Adjacent resonators are coupled through a small mechanical beam in between the corners of two square plates. The beam has a length and width of 10um and 5um respectively, giving a weak coupling ratio of 7%. Fig. 3 reveals the spring mass model and eigenmode analysis of 5 corner coupled square plate resonators. If we only readout the output current of a single resonator, some resonance modes can be hardly identified (e.g. the third resonator at M2). Such effect can be alleviated by driving all the resonators with the same ac signal and readout their output current summation. It is worth noting that this actuation scheme works only if there is device mismatch. Fig. 4 demonstrates how 1% frequency mismatch can substantially enhance the identifiability of all 5 eigenvalues. Hence, the seemingly undesired process variability introduced by the fabrication error now turns into an advantage for IEA sensing. Apart from these 5 eigenvalues, another set of eigenvalues is needed to derive the system matrix via external perturbation. Hence we perturbed the first resonator slightly by changing its dc bias, and recorded 5 new eigenvalues. Based on these two distinct sets of eigenvalues, Gladwell’s inverse problem theory was applied to determine the system matrix. Results suggest a 0.6% relative error for mass/stiffness determination of each resonator.
Fig. 1. (a) PolyMUMPs fabrication process of one resonator and (b) the actuation circuit

Fig. 2. (a) FEM simulation of the displacement under dc bias and (b) pull-in effect

Fig. 3. An example of 5 corner coupled resonators: (a) spring mass model and (b) eigenmode analysis

Fig. 4. Frequency response of the coupled array considering frequency mismatch