Abstract

Electrostatic comb drive is one of the most widely used configurations for both sensing and actuation in a number of microsystems. For analysis of such popular comb drive, the lumped model is generally used considering parallel motion of individual comb. However, in practice, the ideal assumption of parallel motion may not be always valid and the beams may show undesired bending which affects the critical 'pull-in' characteristics considerably. Even slight overestimation of pull-in voltage may lead to severe structural damage during operation. So, the incorporation of the undesired bending prompts scope for contribution towards improvement of existing model and also proper pull-in analysis both theoretically and experimentally.

Accordingly, this work starts with a comprehensive modeling and analysis of the coupled electromechanical problems of reciprocated beam bending including the critical pull-in characteristics in a unit cell of an electrostatic comb drive system and gradually evolves toward the formulation of design guidelines to minimize the bending effect, supported by experimental results with a specific fabricated comb structure. In this direction, firstly an efficient semi-analytical approach is proposed to solve the coupled problem incorporating the effect of undesired beam bending under static condition. The effects of the bending phenomena on the critical performance parameters like pull-in voltage and capacitance change are studied thoroughly. The analysis is further extended to deduce important design guidelines to minimize beam bending in comb drive. Subsequently, a specific comb structure is fabricated and tested to establish the proposed design guidelines experimentally. In this regard, a single mask SOI-based cost effective fabrication process is established and a low-cost simple in-house experimental set-up is also developed for characterization of microstructures. Next, the dynamic characteristics of the reciprocated beam bending in double beam configuration of comb drive is analyzed and the theoretically predicted performance parameters like resonant frequency and dynamic pull-in characteristics are experimentally validated. It is shown that the proposed analysis predicts the critical pull-in characteristics of the microstructures more accurately than the conventional lumped model in specific cases.

Finally, the pull-in study for microstructures is extended for analysis on various electrostatic nanostructures. Simple generalized closed form expressions for the threshold determination of crucial design parameters and the critical pull-in voltages of three nanostructures like cantilever, fixed-fixed beam and tweezers are proposed incorporating the effect of van der Waals and Casimir forces. The main advantage of the proposed expressions is that they do not require any complex mathematical operations unlike reported in literature. Hence, they can serve as quick yet reasonably accurate predictor for the pull-in characteristics of nano-actuators.

The overall study will be thus useful for the designers to be sufficiently aware of the accurate design and analysis of the electrostatic micro and nano structures.

Keywords: *MEMS, Electrostatic actuation, Static and dynamic characteristics, Pull-in, Comb drive, Nano-actuator.*