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Low-Voltage Operated Piezoelectric Tunable Capacitor for Reconfigurable RF Systems

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1. Introduction

As there is great demand for RF tunable capacitors with wide tuning range and high Q-factors for reconfigurable RF systems, much research is being performed to develop RF MEMS tunable capacitors. Most researches have focused on the electrostatic types, which are free from restrictions of materials and processes, but operate at very high voltages of over 20 V [1]. Moreover, the “pull-in” phenomena limit the continuous tuning range to below 50 %. Other types of RF MEMS actuation mechanisms, such as electro-thermal or electromagnetic drives have also been developed, but have the serious drawback of large power consumption.

Piezoelectric actuation is a promising mechanism for realizing RF MEMS tunable capacitors with a low operation voltage and a wide tuning range [2]. We proposed a piezoelectric actuator using CMOS compatible aluminum nitride (AlN), and demonstrated that a continuous tuning ratio of more than 3 is possible with an operation voltage of 3-5 V and high Q-factors [3,4]. The capacitors were applied to wideband built-in tunable antennas for digital terrestrial broadcasting as an example of reconfigurable RF systems.

2. Design philosophy

One of the most serious issues in the piezoelectric MEMS actuators is curling of the actuator beams due to residual stresses. Piezoelectric AlN actuators are composed of thin and long multiply stacked layers, tend to suffer from a large curling effect due to unbalanced residual stress in the stacked AlN layers.

Novel folded bimorph structures have been introduced to cancel the curling effect as shown schematically in Fig. 1. Using symmetrically designed forward and backward beams can compensate the curling. Further, the piezoelectric actuation is doubled when reversed voltages are applied to the forward and backward bimorphs.

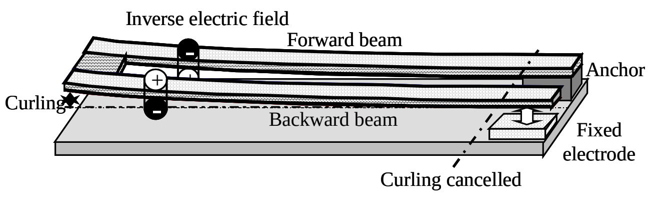


Fig. 1. A schematic drawing of proposed folded structure piezoelectric tunable capacitor having forward and backward bimorph actuator beams.

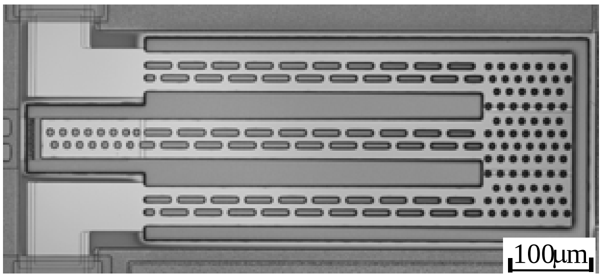


Fig. 2. Laser microscope image of tunable capacitor, with singly clamped folded bimorph actuators.

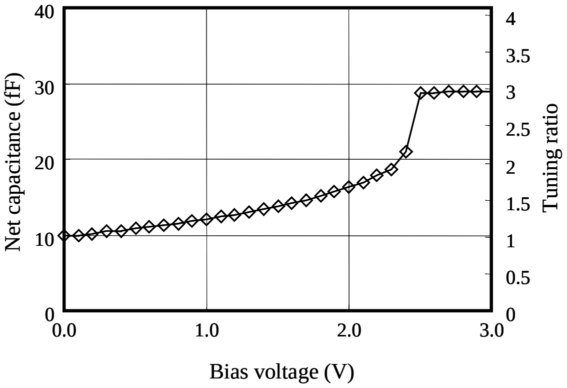


Fig. 3. Measured net capacitance changes of the fabricated piezoelectric RF MEMS tunable shunt capacitors with singly clamped folded beams.

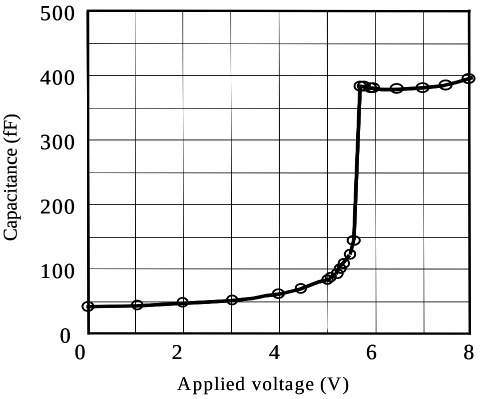
The fabrication process is fundamentally CMOS compatible with process temperatures of no more than 200 C.

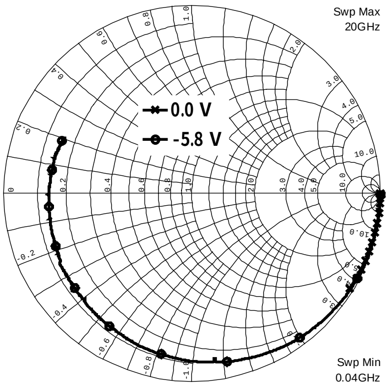
3. Performance of the tunable capacitor

An optical image of the RF MEMS tunable capacitor with a singly clamped folded bimorph actuator is shown in Fig. 2. Height measurements using laser microscopy revealed the curling at the actuation point was suppressed to less than a few microns while curling at the folding point reached a few tenth microns.

Smooth continuous capacitance changes were observed with a hyperbolic relation up to the contact point of the movable and fixed electrodes of the tunable capacitors. The lowest operation voltage of 2.5 V was obtained with a tuning ratio of 3, for the first time as shown in Fig. 3. The Q-factor of the tunable capacitor was less than 10 at 2 GHz because of a low-resistivity Si substrate.

To increase the Q-factor and decrease parasitic ca-





pacitance around signal pads, piezoelectric tunable capacitors were also made on insulating quartz substrates. Figs. 4 and 5 show capacitance changes and the S_{11} plot of the capacitor. A very large capacitance change was observed from 40 to 385 fF at an operation voltage of 5.5 V, along with a minimum Q-factor of 40. The performance indicators, such as tuning ratio/operation voltage and Q show our results exceed these of previously published works.

4. Application for Tunable antenna

Currently developed tunable capacitors will likely be key components in the reconfigurable RF front-ends as tunable antennas, tunable filters, impedance machers, and wide range VCOs. One of the largest advantages of the MEMS tunable capacitors is their very high IIP3 characteristic compared with varactor diodes. A wideband built-in tunable antenna for digital terrestrial broadcasting has been targeted for the first application. It is difficult to realize a built-in antenna because the system requires a wideband antenna in a UHF band and its frequency bandwidth gets narrower as the antenna's size is reduced.

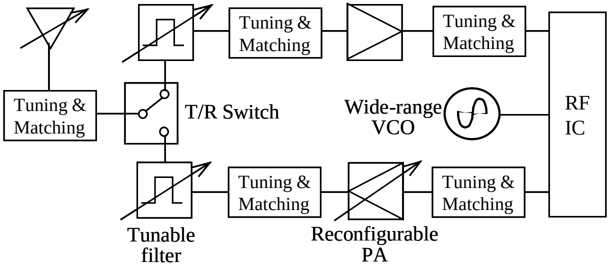


Fig. 6 Reconfigurable RF front-end using MEMS.

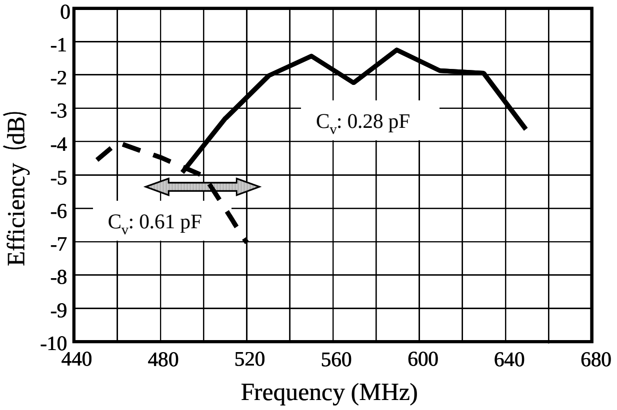


Fig. 7 Efficiency of the tunable antenna using piezoelectric MEMS tunable capacitor.

The shape of the antenna element is a meander structure, and one point of the antenna connects to the PCB board through the tunable capacitor. Figure 7 shows efficiency of the tunable antenna. A wide tuning range from 450 to 650 MHz was realized at an efficiency of more than –5dB under a tuned capacitance from 0.28 to 0.61 pF.

5. Conclusion

A novel RF MEMS tunable capacitor with a folded beam piezoelectric bimorph actuator has been developed. Its continuous wide tuning ratio of more than 3 was realized at operation voltages of 3-5 V for the first time. These piezoelectric RF MEMS tunable capacitors are promising as key components for adaptive antenna systems and multi band/mode reconfigurable RF systems. Our process that uses CMOS compatible materials and temperatures makes it possible to easily adopt RF MEMS into RF CMOS processes.

Acknowledgements

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