Development of A Novel Micro Electromechanical Tunable Capacitor with a High Tuning Range

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Micro Electromechanical tunable capacitors are under active development recently [1-4]. The advantages for integrating MEMS (microelectromechanical systems) tunable capacitors on RF integrated circuits include: (1) higher quality factor compared with IC counterparts [1]; (2) lower interconnection- and parasitic-related loss; (3) reduced system complexity.

Among all the MEMS tunable capacitors developed so far, the parallel plate configuration is most commonly used. Conventional parallel-plate tunable capacitor consists of two fixed plates and one suspended plate (Fig. 1(a)) with a spacing denoted as (x + d), which can be changed by acting the DC bias (V) across the two plates. However, its performance is limited by the pull-in effect. When the spacing is reduced by 1/3 of d (original spacing), the pull-in effect will cause two plates to snap into contact. Thus the spacing can only be controllably adjusted from d0 to 2/3 of d0. The pull-in effect imposes a theoretical limit of 50% on the tuning range (C = eA/d).

Various applications require a tuning range greater than 50%. An earlier work [4] reported a tuning range of 200% achieved by using lateral combs (instead of parallel plate) created by deep reactive ion etching (DRIE) [4]. However, the monolithic integration of DRIE process with ICs is complicated.

We report a new parallel-plate tunable capacitor design with a tuning range greater than 50% limit imposed by the pull-in effect. The primary differences between this design (Figure 1(b)) and the conventional ones are: (1) the capacitance electrode (E1) and the actuation electrode (E2) are separated; (2) the spacing (d1) between E2 and the suspended top plate E1 is smaller than the spacing (d2) between E2 and E1. Applied voltage between E1-E2 changes spacing/capacitance between E1-E2. The unique design feature is d1 < 2/3 d. Then the top plate can be controllably moved by a maximum distance of d1/3. This allows the spacing between E1 and E2 to be controllably changed from its original value d1 to almost zero. A tuning range much greater than 50% thus can be achieved. This new design has been validated by FEA (finite element analysis) simulation using MEMCAD 4.0 (Figure 2).

The prototype tunable capacitor is fabricated on Pyrex® glass wafers (Fig. 3(a)(b)). A unique process to make the variable-height sacrificial layer (corresponding to d1 = 2μm and d2 = 3μm in Figure 1(b)) is developed. The two bottom plates (E1 and E2) are thermally evaporated gold film (5000Å) and the suspended top plate (E1) is electroplated permalloy film (2 μm). Copper is used as the sacrificial layer, which also serves as the seed layer for the permalloy electroplating.

The Si1 parameter of the tunable capacitor is measured using an HP 8510B network analyzer from 45 MHz to 5 GHz (Figure 4(a)(b)). The measurement result shows a near-ideal capacitative behavior in the tested frequency range with a return loss lower than 0.1dB. In the prototype device, the overlapping area of E2 and E1 is 90μm×90μm, which corresponds to a nominal capacitance of 0.0328 pF (obtained from the FEA simulation using MEMCAD4.0). The capacitance-voltage characteristic of five prototype devices fabricated in one batch is measured using HP 4284A precision LCR meter (Figure 5). The pull-in effect is observed at a DC bias of about 18 volts. The capacitance change is 0.024 ~ 0.028 pF, corresponding a tuning range of 73% ~ 85%.

References:

Figure 1. (a) Schematic side view of a conventional parallel-plate tunable capacitor (The overlapping area is $A$). (b) Schematic side view of the tunable capacitor with high tuning range.

Figure 2. Perspective view of the MEMCAD model for the tunable capacitor with high tuning range (the scale in the thickness direction is exaggerated).

Figure 3(a/b). SEM pictures of the tunable capacitor with high tuning range.

Figure 4 (a/b). The magnitude and phase of the $S_{11}$ parameter of the tunable capacitor with high tuning range measured using an HP 8310B network analyzer (45MHz-50GHz).

Figure 5. C-V curve of the tunable capacitor with large tuning range measured using HP4284A precision LCR meter.