Mesh Patterned High Tunable MIM Capacitor

Young Chul Lee

Division of Marine Electronics and Communication Engineering, Mokpo National University(MMU)571 Chukkyo-dong, Mokpo, Jeonnam, Korea 530-729

E-mail : leeyc@mmu.ac.kr

ABSTRACT

In this work, a novel tunable MIM capacitor with the meshed electrode is proposed first in order to improve the tunability characteristics using fringe fields. The capacitors were fabricated on a low-resistivity Si substrate employing lead zinc niobate (PZN) thin film dielectric. The fabricated capacitor with the meshed electrode, whose line width and spacing was 2.5㎛, achieved the effective capacitance tunability of 31 % that is higher value of 18.5 % than that of the conventional capacitor with the rectangular-type electrode.

Key words

Tunable capacitor, fringing fields, tunable dielectric

Ⅰ. Introduction

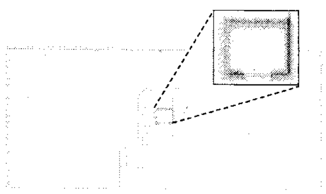
In the recent wireless communication market, a great diversity of networks such as cellular network, personal area network (PAN), wireless local area network (WLAN), etc. coexist. In order to enable "seamless roaming"reconfigurable intelligent devices are needed to be compatible with various communication standards [1]. Therefore, a compact and low-cost tunable device is indispensable for reconfigurable RF applications satisfying multi-band or multi-mode standards. Tunable dielectric based tunable RF device technology is one of the viable solutions for reconfigurable RF applications, because of a high tunability, compact size, and low cost. In order to realize various reconfigurable devices, tunable capacitors as their basic element have been implemented by using several electric-field tunable dielectrics such as ferroelectric materials or paraelectric materials [2-5].

Representative electric-field tunable dielectrics such as barium-strontium titanate (BST) [6, 7] and bismuth zinc niobate (BZN) [8-10] have been successfully demonstrated for the possibility of the tunable circuits. Using these dielectrics, high-performance capacitors, matching networks, band pass filters [11], and phase shifters [12] have been implemented for tunable system applications. However, although high tunable characteristics were achieved, their operation frequencies were as low as below ~100 MHz and the applied bias voltage ranged 20~50 V. Therefore, only limited applications are available for low-frequency circuits or high-power systems. Moreover, most research efforts have focused on dielectric materials, metallization [9, 12, 13], or buffer layers [14] for high tunable and low-loss characteristics.

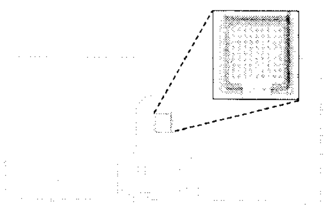
In this work, a tunable capacitor with a mesh-type electrode is reported firstin order to improve its tunability and DC bias characteristics. This capacitor was fabricated on a general low-resistivity Si substrateusing $PbO-ZnO-Nb_2O_5$ (PZN) cubic pyrochlore thin film dielectrics. The capacitor is analyzed in terms of the effective capacitance and tunability compared to the conventional one with the rectangular-type electrode.

II. Design and Fabrication

In general, tunable MIM capacitors operate using electric (E)-fields and their distribution is linear and uniform between the electrodes and fringes out at the edges. For devices with larger electrodes, the energy of the fringe field is small to the total capacitive energy, but for small devices the fringe field energy comes to dominate [15]. The intensity of the fringe fields at the edge is higher than that of the E-fields between electrodes. Therefore, the purpose of this work is to improve the tunability and DC bias characteristics utilizing fringe fields. The novel tunable MIM capacitor with the meshed electrode is proposed. It turns its fringe fields to good account and improves its tunability and applied bias characteristics.



(a) Rectangular-type electrode



(b) Mesh-type electrode

Fig. 1 Fabricated MIM tunable capacitors with different top electrode types.

The tunable MIM (metal-insulator-metal) capacitors were fabricated on the silicon substrate in coplanar waveguide (CPW) configuration. The substrate resistivity was 1~30 Ω cm. The bottom electrode layer (Pt) of 2300 Å was deposited and patterned using the sputtering and dry etching process, respectively. The PZN thin film of 2000 Å was deposited on a Pt layer by RF-magnetron sputtering. The deposition was carried out from $Pb_6ZnNb_6O_{22}$ target material in an O_2/Ar atmosphere. During reactive RF magnetron sputtering, off-axis type system geometry was used. The base pressure in the process chamber was 3.0×10^{-6}Torr, while the working pressure was maintained at 10 mTorr using a throttle valve. High purity Ar and O_2 (>99.99 %) were used as base and reactive gases, respectively. The plasma discharge was generated at a constant RF power of 150 W and the O_2/Ar flow rate ratio was held at 10 % (2/20 SCCM). Using the Inductive Coupled Plasma (ICP) dry etcher the PZN film was patterned to cover the bottom electrodes. After patterning, post-annealing processes were carried out at 600 ℃ for 3 hours in air to crystallize the film. Finally, the Pt layers of 2300 Å for the top electrodes and coplanar-waveguide (CPW)-probe pads were deposited by the sputtering process and patterned by the dry etching process for the conventional top electrode and meshedone. The both line width and spacing of the mesh pattern were the same as 2.5㎛. The capacitor areas for the rectangular and meshed electrode were 1,200 $㎛^2$ and 1,137$㎛^2$, respectively. Relative dielectric constant of the PZN thin film was 240 at 10 MHz. Fig. 1 shows the photography of the fabricated tunable MIM capacitors in CPW configuration.

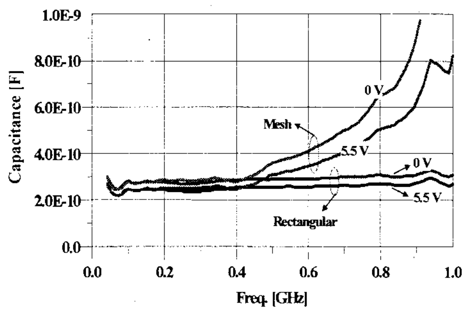


Fig. 2 Frequency dependence of the effective capacitance for the fabricated capacitor with meshed electrodes with different bias voltages, compared to the conventional capacitor.

III. Measurements

The effective capacitance (Ceff) and percentage tenability (T) of the fabricated capacitors were analyzed by measuring complex reflection coefficients (S11) with a vector network analyzer (HP 8510C) and a probe station. A thru-reflect line (TRL) calibration was performed with a standard calibration kit. Using the measured S11 data, the effective capacitance (Ceff) and tunability (T) are analyzed, as following equations,

$$C_{eff} = -\frac{1}{2\pi \cdot freq. \cdot \text{Im}(Z_{11})} \ [F]$$

$$T = \frac{C_{max} - C_{min}}{C_{max}} \ [\%]$$

where Z11is the total impedance of the device under test calculated from the measured S11. Cmin and Cmaxare the measured minimum and maximum capacitance, respectively, within the applied bias voltage range.

Fig. 2 shows frequency dependence of the effective capacitance ofthe fabricated capacitor with meshed electrodes with different bias voltages, compared to the conventional one with the rectangular electrode. Due to nearly similar area, the effective capacitances for two capacitors are about the same below 450 MHz. However, as frequency increases, the effective capacitance of the capacitor with the meshed electrode much more increases than the rectangular-type electrode due to fringe fields. Moreover, its change to the applied bias voltage is also greater than the conventional one. These results demonstrate that the meshed electrode makes more fringe fields than the conventional one and its capacitance increases athigh frequencies. In addition, it can easily change its permittivity due to high fringe fields.

Fig. 3 presents effective capacitance-tunability characteristics of the two tunable capacitors as function of frequency. The tunability of the rectangular-type capacitor is nearly constant as the frequency increases. However, the tunability of the mesh-type capacitor increase as the frequency increases over 450 MHz. Particularly, at 900 MHz, the mesh-type capacitor achieves the tunability of 31 % that is 18.5 % higher value than that of the rectangular-type one.

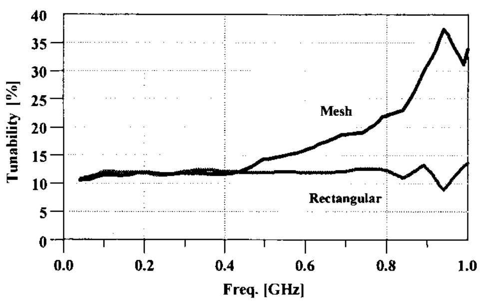


Fig. 3 Tunability comparison between the mesh-type capacitor and the rectangular-type one.

IV. Conclusion

A novel tunable MIM capacitor with the meshed electrode is presented in order to improve the tunability characteristics utilizing fringe fields. The capacitors were fabricated on the Si substrate using lead zinc niobate (PZN) thin film dielectric. The fabricated capacitor with the meshed electrode achieved the effective capacitance tunability of 31 % that is 18.5 % higher value than that of the conventional capacitor with the rectangular-type electrode.

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