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Miniaturized notch antenna based on lanthanum titanium perovskite oxide thin films

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ABSTRACT

This paper presents the integration of a dielectric lanthanum titanium oxide compound as thin film in a discrete capacitive component operating at microwaves. The integration in a notch antenna of a MIM (Metal/Insulator/Metal) structure based on this oxide material is numerically and experimentally studied. Oxide films are deposited by reactive magnetron RF sputtering of an $La_2Ti_2O_7$ target. The films are composed of an unusual phase: the orthorhombic $La_2Ti_2O_7$ compound, with a textured growth on Pt/Si and Pt/$SrTiO_3$ substrates. Moderate dielectric constant values (Epsilon around 60) and low loss (Tan Delta lower than 0.005) are obtained at 1 GHz. Inserting this original MIM capacitor in the antenna structure results in a shift to a lower value of its operating frequency. This shift, from 885 MHz to 317 MHz, corresponds to a significant size reduction of 64.2%. The measured values are confronted with simulation obtained by numerical software.

1. Introduction

The generalization of wireless communicating objects has intensified the need for miniaturization of integrated devices, in particular antennas. Many techniques have been developed [1], including the use of localized capacitive loading based on a dielectric thin film [2,3] that can be used in different antenna topologies. Z. Ma et al. [4] reported on a capacitor composed of two concentric electrodes deposited on $Ba_{1-x}Sr_xTiO_3$ (BST)/Pt substrate, the perovskite BST compound being the dielectric material. However, this configuration suffered from very high capacitance and dielectric loss values [5], not consistent with those required for antenna miniaturization.

In the present paper, we introduce a capacitor based on perovskite-type oxide $La_2Ti_2O_7$ (LTO) dielectric thin films and detail their integration in a slot antenna. Our previous studies on thin film deposition [6,7] and dielectric characterization [8] of $La_2Ti_2O_7$ oxide and $LaTiO_2N$ oxynitride compounds have shown that the oxide films present loss less than 0.02 at 10 GHz. In the present work, particular design is carried out to integrate the LTO based MIM (Metal/Insulator/Metal) components in a slot antenna structure. Special attention is given to the miniaturization ratio and to the loss introduced by the LTO based-component.

2. Calculation

The MIM structure is made of two concentric metallic disks (radii R and r) deposited on the dielectric LTO layer (Fig. 1), that is itself deposited on conductive substrates, such as platinized substrates (silicon or $SrTiO_3$). The value of the total capacitance corresponds to the capacitance formed by the central disk [4], and is controlled by the film thickness and dielectric constant, and the central disk diameter.

The antenna structure consists of a notch cut from the edge of the ground plane. It is the complementary structure of a conventional quarter wavelength monopole antenna. This structure shows easy integration in printed circuit and significant miniaturization ratio when loaded with a correctly positioned capacitor [9]. The antenna is loaded with the MIM structure at the open end of the slot (Fig. 2). The slot length is L = 44.6 mm (~λ_0/47; F_0 = 900 MHz, without capacity) and its width is W = 2 mm The antenna is fed by coupling with a microstrip line and the impedance matching is achieved by varying the position of the supply line (a) and the stub length (L_f). The substrate used here is FR4 polymer, with a thickness of 0.8 mm, a dielectric constant ε_r ~ 4.4 and a loss tangent of 0.02 at 1 GHz. The microstrip line has a width of 1.51 mm to obtain a 50 Ω characteristic impedance.

The simulation of this configuration was performed with Ansoft HFSS v13 [10], using R = 80 μm. Fig. 3a presents the evolution in function of the frequency of the reflection coefficient S_{11}, for various central disk radius r values, that is different capacitance values. For these simulations, a dielectric constant of 60 [8] and a thickness of 500 nm were used for the dielectric LTO thin film; different r radius values from 20

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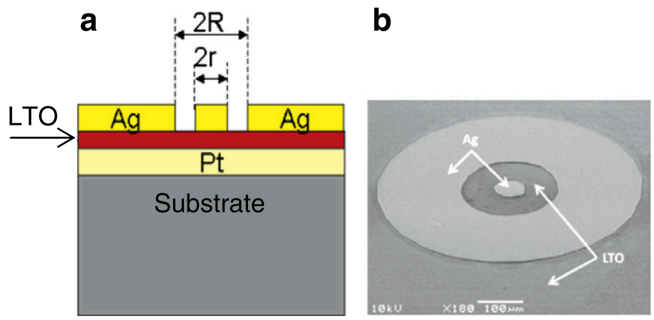

Fig. 1. MIM capacitor structure based on $La_2Ti_2O_7$ (LTO) dielectric oxide films. (a) Schematic cross-section view and (b) scanning electron microscopy image.

to 40 μm were used. We observe a shift of the antenna reflection coefficient towards low frequencies as the disk radius increases. As a result, the loaded antenna can work at a lower frequency than that imposed by its dimension, which corresponds to a miniaturization of the antenna. Simultaneously, as expected [9] and as shown in Fig. 3b, the antenna radiating efficiency drops rapidly from 62% to 12%. Consequently, a trade-off between miniaturization ratio and antenna efficiency should be considered.

3. Experimental details

3.1. Dielectric LTO thin film deposition

The LTO thin films are deposited by RF magnetron sputtering (Plassys MP4505S) on conducting substrates (Pt/Si and Pt/$SrTiO_3$ substrates) from a homemade $La_2Ti_2O_7$ oxide target. For these depositions, the RF power (P_{RF}) is fixed at 1.8 W·cm^{-2}, the substrate temperature (T_S) is 800 °C and a total pressure (P_T) of 3.6 Pa is used. The oxygen concentration in the process gas mixture, defined as [O_2/(Ar + O_2)], is 25 vol.%. For this study, two different thicknesses of films (470 nm for LTO-1/Pt/Ti/SiO_2/Si sample and 1200 nm for LTO-2/Pt/$SrTiO_3$ sample) are tested. The LTO films are identified by X-ray diffraction as the $La_2Ti_2O_7$ compound with an orthorhombic crystalline cell [11]; they are (011) textured on platinized substrates.

3.2. MIM capacitor design and implementation

Concentric metallic disks constituting the upper electrodes of the MIM structure are made by standard photolithography and wet-etching of a metallic bilayer. This metallization is realized by magnetron sputtering deposition; the used parameters are: P_{RF} = 150 W, T_S = T_{Amb} (~20 °C) and P_T = 1 Pa. The bilayer is formed of a 2 μm-thick silver film and a 5 nm-thick titanium film, the latter being used to ensure the adherence between the metallic layer and the LTO oxide film. Silver is chosen because of its high electric conductivity (σ ~ 6.1.10^7 S/m). The platinum layer of the substrate serves as the lower floating electrode of the MIM structure.

The notch antenna is printed on a standard FR4 substrate chosen for its low cost. The MIM capacitor is placed at the open end of the notch. The connections between concentric electrodes and the ground plane are made by a 25 micron diameter of gold bonding-wires (Fig. 4a).

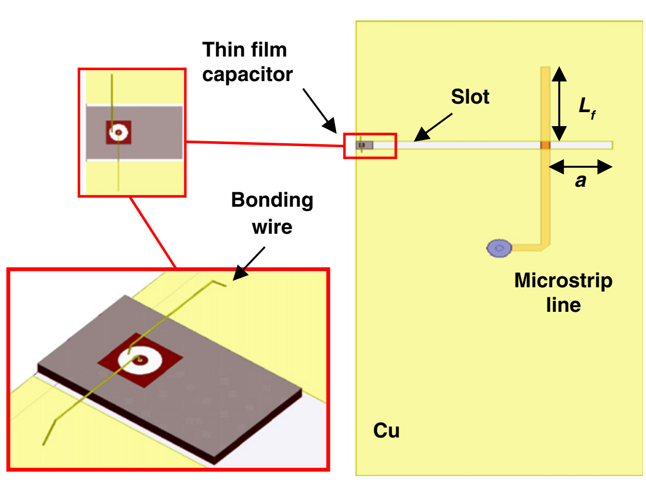

Fig. 2. Loaded antenna design based on localized MIM capacitor.

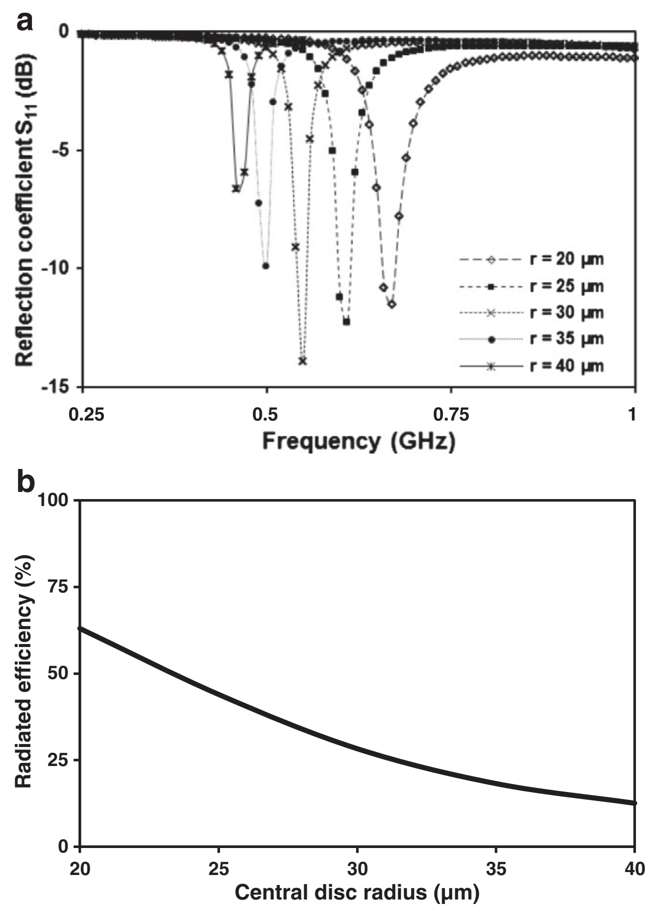

Fig. 3. (a) Simulated reflection coefficient as a function of frequency for different central disk radius r values and (b) simulated radiated efficiency as a function of central disk radius, of antennas based on $La_2Ti_2O_7$ dielectric oxide films.

3.4. RF characterization

The characterization of the MIM capacitor is achieved by using a network analyzer (Agilent 8510C) associated with a microprobe station (Signatone H100). The Ground–Signal–Ground probes, which have a pitch of 150 μm, are provided by Picoprobe. The intrinsic parameters (dielectric constant ε′ and loss tanδ) of $La_2Ti_2O_7$ thin films are obtained from the measurement of the S_{11} reflection coefficient of the MIM capacitor and from a RF differential extraction method developed in [4]. The radiation measurement of antenna prototypes is carried out in a large anechoic chamber.

4. Results and discussion

Concerning the intrinsic properties of $La_2Ti_2O_7$ films, measurements of MIM structures (Fig. 4b) give capacitance values of 1.5 and 3.8 pF