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SIMULATION AND MEASUREMENT OF INSET-FED MICROSTRIP PATCH ANTENNAS ON BiNbO4 SUBSTRATES

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ABSTRACT: This work presents an experimental investigation of the properties of microstrip patch antennas on bismuth niobate ceramic substrates. The substrate fabrication process and characterization are described. Several prototypes were built and measured for wireless communication systems. A good agreement was observed between measured and simulated results. The very high electrical permittivity of the ceramic substrate provided a reduction of the antenna dimensions. © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1034–1036, 2010. Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25098

Key words: microstrip patch antenna; high permittivity; ceramic substrate; antenna optimization; wireless systems

1. INTRODUCTION

With many applications on modern communication systems, wireless equipments are almost indispensable. Because of that, one of the most important technological challenges is the development of faster, smaller, and multifunctional terminal equipments. Because of the mobility of the wireless communication users, the bottom of line is the development of small-size antennas and devices that are able to handle the defined system requirements. The miniaturization of electronics systems requires smaller antennas. Nevertheless, a very good characterization of the antennas is needed. One of the available techniques to minimize the antenna size is the use of ceramic materials with very high permittivity. One of the advantages of ceramic materials over other dielectric materials is the possibility of fabricating compact and easy to build several microwave integrated circuits, such as microstrip patch antennas [1, 2].

Recently, ceramic dielectric substrates based on bismuth and niobium mixed oxides were proposed as candidates for micro-wave applications, because they can be sintered at low temperatures and exhibit very good dielectric properties [3]. Most of the known commercial microwave dielectrics such as SnO2, TiO2, and Ba(Mg, Ta)O3 can be sintered only at very high temperatures (T > 1400°C), higher than the melting point of internal metal conductor such as copper and silver [2]. Therefore, it is necessary to develop microwave dielectric materials that can be sintered at lower temperature.

The purpose of this work is to prepare ultrafine vanadium-doped antiferroelectric bismuth niobate (BiNbO4) powders using coprecipitation technique, from water-soluble salts, and sintering ceramic rods to application as substrate on development of wireless communication devices and circuits. This work describes an experimental investigation of microstrip antennas on BiNbO4 substrates that exhibit very high electrical permittivity (εr > 20), high quality factor (Q > 1000), and a very small temperature coefficient at the resonant frequency (τF ≈ 50 ppm°C) [4–10]. The numerical and measured results obtained in this work for the proposed antennas on BiNbO4 substrates are in good agreement. These antennas are excellent candidates for wireless system applications.

2. EXPERIMENTAL TECHNIQUES

Generally, the traditional solid-state method is used for the preparation of ceramic dielectric oxides. Wet chemical techniques, such as combustion and sol–gel, were found to produce these oxides with several advantages, namely, nanosized particles, high reactivity, and very good homogeneity in composition. Sometimes metastable phases are also formed by these methods. Coprecipitation is one of the most successful techniques for synthesizing ultrafine ceramic powders having narrow particle size distribution [3]. Bismuth-based dielectric ceramics have been proposed as new candidate for low-temperature-cofired ceramics dielectrics because of their low sintering temperature and excellent dielectric properties [4–10].

2.1. BiNbO4 Substrate Fabrication

For preparing BiNbO4 doped with vanadium compound, niobium oxide, bismuth nitrate, vanadium oxide, and ammonium hydroxide were used as starting materials. For the preparation of BiNbO4 by coprecipitation, stoichiometric amount of Bi(NO3)3·5H2O was dissolved in dilute HNO3. A required quantity of Nb2O5 and V2O5 (sinter aids) was dissolved in HF (hydrofluoric acid) after heating at hot water bath for 2 h and both were mixed together. Addition of vanadium lowered the phase transition temperature and decreased the sintering temperature of BiNbO4 ceramic. An excess of ammonium hydroxide was added, by dropwise with constant stirring, to the above solution mixture to precipitate both bismuth and niobium as hydroxides, and addition of ammonium hydroxide was continued to ensure complete precipitation. After precipitation, it was filtered and washed several times with distilled water and dried. The precursor was calcined at T = 750°C for 4 h to get pure phase samples. After calcination, the powder was macerated in a mortar for about 12 h. The required mass of resultant powder was compacted in a matrix designed and built in tool steel with diameter, D = 30.0 mm, resulting in a disc-shaped substrate. Finally, the substrate was sintered at T = 890°C for 2 h. After returning to room temperature, the substrate was ready for plating.

2.2. BiNbO4 Substrate Characterization

The X-ray diffraction (XRD) was used to characterize these powders. Figure 1 shows the XRD measurement results for the BiNbO4 sample. These powders are highly crystalline. The
crystal structure is orthorhombic and the X-ray pattern matches with the reported values for α-BiNbO₄ (ICSD-074338) and β-BiNbO₄ (ICSD-010247). The adjustment was performed using the Rietveld Method, by Maud software version 2.064. The calculated lattice parameters are as follows: \(a = 5.618 \text{ Å}, \ b = 11.713 \text{ Å}, \ c = 4.984 \text{ Å}\). The average particle size for the powders calculated from Debye-Scherer’s formula is about 660 nm. In this work, a brand Shimadzu XRD 6000 was used for the XRD analysis, using a CuK\(_\alpha\) radiation source of 1.5418 Å with a voltage of 30 kV and current of 20 mA in powdered samples.

3. ANTENNA GEOMETRY

For the antenna prototype, a dielectric disc-shaped substrate on BiNbO₄ was built with a relative electrical permittivity, \(\varepsilon_r\), equal to 47.8, at the resonant frequency. Figure 2(a) shows the dimensions of the substrate: diameter \(D = 26.0 \text{ mm}\) and thickness \(h = 2.5 \text{ mm}\). A rectangular microstrip patch with a conducting inset fed, for impedance matching purpose, was printed on the top of the substrate that was grounded, as shown in Figure 2(b). The other dimensions of the antenna are as follows: \(L_0 = 7.3 \text{ mm}, W_0 = 1.0 \text{ mm}, x_0 = 1.0 \text{ mm}, L = 18.0 \text{ mm}, W = 16.0 \text{ mm}, \) and \(0.0 \text{ mm} \leq y_0 \leq 5.0 \text{ mm}\). A photo of the antenna is presented in Figure 3.

4. NUMERICAL RESULTS

The behavior of the return loss versus frequency as well Smith Chart impedances for the rectangular patch inset fed microstrip antenna were obtained using a HP 8714C network analyzer. The software Ansoft HFSS [11] was used for the simulation and optimization process of the same antenna. The best input impedance result was obtained in the HP 8714C for \(y_0 = 4.0 \text{ mm}\), as shown in Figure 4. The values for the input impedance are 51.15 \(\Omega\) for the real part, and -2.20 \(\Omega\) for the imaginary part, that obtained for \(y_0 = 4.0 \text{ mm}\). The real value of \(Z_{\text{in}}\) is in good agreement with the impedance matching, 50 \(\Omega\), with a relative percentage error, Error (%) = 2.3.

The proposed antenna return loss versus frequency behavior, considering \(0.0 \text{ mm} \leq y_0 \leq 5.0 \text{ mm}\), for 1.0 mm steps, measured in the HP 8714C network analyzer and simulated in Ansoft HFSS, is shown in Figure 5.

The results for return loss versus frequency \(S_{11}(\text{dB}) \times \text{Freq(GHz)}, \) measured in HP 8714C network analyzer and simulated in the Ansoft HFSS [9], for the best obtained result, corresponding to \(y_0 = 4.0 \text{ mm}\) are shown in Figure 6.

Table 1 shows the proposed antenna resonant frequency parameters: resonant frequency, \(F_R\), return loss, \(S_{11}\) (dB), and bandwidth, \(B_W\) (\(S_{11} < -10 \text{ dB}\)), measured in the HP 8714C network analyzer and simulated in the Ansoft HFSS software for \(y_0 = 4.0 \text{ mm}\). Based on these results, the fractional
The bandwidth expressed by BW (%) = (BW/FR) was calculated and is shown in the Table 1. The measured and simulated results for the return loss versus frequency are in good agreement. The relative percentage error at the central frequency is equal to 1.3.

5. CONCLUSIONS

An experimental investigation of the resonant properties of rectangular patch inset fed microstrip antennas on ceramics BiNbO4 doped with vanadium oxide (V2O5) substrates was performed. The resonant frequency parameters for this antenna were optimized using the Ansoft HFSS software. A HP 8714C network analyzer was used in the measurement setup.

The input impedance matching is obtained with optimization of the inset fed transmission line microstrip. Measured and simulated results for the return loss versus frequency are in good agreement. The analysis of microwave circuits like other antennas, filters, ring resonators, and antennas arrays using BiNbO4 ceramics substrates will be considered in future works.

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### Table 1

| Parameters | Measured (HP 8714C) | Simulated (Ansoft HFSS) |
|------------|----------------------|-------------------------|
| Freq (GHz) | 2.903                | 2.865                   |
| S11 (dB)   | −32.03               | −19.05                  |
| BW (MHz)   | 80.0                 | 30.0                    |
| BW (%)     | 2.76                 | 1.05                    |

AN INCOMPLETE FACTORIZATION PRECONDITIONER BASED ON SHIFTED LAPLACE OPERATORS FOR FEM ANALYSIS OF MICROWAVE STRUCTURES

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ABSTRACT: In this article, the tangential vector finite element method combined with the high-order basis functions is applied for the analysis of electromagnetic problems based on Helmholtz equations. Different from conventional preconditioners, the preconditioner presented in this article is derived based on the shifted Laplace operator, and the