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Microwave and electrical properties of $SrTiO_3$ for DRA Application

Norhizatol Fashren Muhamad[1,2,a)], Rozana Aina Maulat Osman[1,2,b)], Mohd Sobri Idris[2,3,c)], Mohd Najib Mohd Yasin[1,d)], Mohd Faizal Jamlos[4,e)], Nor Azura Malini Ahmad Hambali[1,f)]; Mohd Nazree Derman[2,g)]

[1]*School of Microelectronic Engineering, Universiti Malaysia Perlis, KampusTetapPauh Putra, 02600 Arau, Perlis, Malaysia.*
[2] *CoE Frontier Material Research, School of Material Engineering, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia.*
[3] *School of Materials Engineering, Universiti Malaysia Perlis, jejawi, 02600 Arau, Perlis,Malaysia.*
[4] *Advanced Communication Engineering Centre (ACE), School of Computer & Communication Engineering, Universiti Malaysia Perlis, 01000 Kangar, Perlis.*

[a)] Corresponding author: norhizatolfashren@gmail.com
[b)]rozana@unimap.edu.my
[c)]sobri@unimap.edu.my
[d)]faizaljamlos@unimap.edu.my
[e)]azuramalini@unimap.edu.my
[f)]najibyasin@unimap.edu.my
[g)]nazree@unimap.edu.my

Abstract. Appropriate level of dielectric constant and low dielectric loss are basic requirements for microwave device, especially in dielectric resonator antenna (DRA). In this paper, investigation with experimental studies of $SrTiO_3$ ceramic fabricated as cylindrical dielectric resonator antennas (CDRAs) was conducted. Ceramic powder was prepared using conventional solid state reaction method. X-ray Diffraction exposes physical properties $SrTiO_3$ which exhibit cubic structure. The electrical properties such as dielectric constant (ε_r) and dielectric loss (tan δ) were studied in variation of temperatures and frequencies. At room temperature the dielectric constant $SrTiO_3$ is about 240. The dielectric loss obtain shows very low loss value roughly below 0.07. The return loss and bandwidth of CDRAs at their respective resonant frequencies are shown in this paper.

INTRODUCTION

Dielectric Resonator Antenna (DRA) has more advantages and better prospects such as small size, low profile, high radiation efficiency, large bandwidth, flexible feed arrangement, wide range of material dielectric constants, ease of excitation, easily controlled characteristics and ease of integration with other microwave integrated circuit (MIC) components [1]. DRA can be designed with different shapes to fulfill various design requirements. Among the different DRA shapes, cylindrical DRA offers greater design flexibility where the ratio between the radius to height (a/h) controls the resonance frequency, the quality factor (Q_f) and bandwidth of antennas [2]. Furthermore, DRA can also be excited with different feeding methods such as coaxial probes, microstrip lines, slots and co-planar lines [3]. The increasing demands in mobile communication systems required materials applicable in most microwave applications and manufactured inexpensively using the least amount of space possible.

Microwave dielectric material with high dielectric constant for volume efficiency is a major requirement in modern wireless communication technology. Furthermore, a low dielectric loss for better selectivity and a near-zero temperature coefficient of resonant frequency (τ_f) for stable frequency stability is also critical requirements for practical applications [2]. $SrTiO_3$ is such material that has been of recent interest of study. It has diverse technological application, whether from integrated microelectronics or in electronic ceramic industry and microwave devices. These features are attributed by their high dielectric permittivity, tunability and low microwave loss, high breakdown strength and low leakage current density [4].

EXPERIMENTAL PROCEDURE

$SrTiO_3$ was synthesized using solid-state synthesis route at high temperature by mixing ceramic powder (Aldrich) as the starting materials. Stoichiometries amount of strontium carbonate and titanium oxide were mixed and ground by using a pestle and mortar. After that, the powders were pressed to mould the round shape pellet and heated at 1400°C for 12 h with a heating rate of 5 °C /min. Then, the sample was further heated at temperature 1550°C for 5 h in air. The sample was tested by making use of a Bruker D2 Phaser benchtop X-ray diffractometer equipped with LYNXEYE 1D detector with Cu–Kα radiation at room temperature. The sample was analysed using a step size of 0.02° and dwell time of 0.2s per step. The electrical properties of ceramic such as permittivity (ε_r) and dielectric loss (tan δ), were studied by using HIOKI 3522-50 LCR HiTESTER. For this purpose, sintered pallet was coated with silver paste as an electrode. The sample was measured over the frequency range of 10 Hz – 100 kHz with different temperatures between 30°C and 600°C. The permittivity was calculated from the capacitance using the following equation:

$$\varepsilon r = \frac{C\ d}{\varepsilon_0\ A} \quad (1)$$

Where C is the capacitance (F), ε_0 the free space dielectric constant value (8.85×10^{-14} Fcm^{-1}), A the capacitor area (cm^2) and d the thickness (cm) of the ceramics.

Microwave dielectric properties of $SrTiO_3$ ceramic materials at the microwave frequency were measured using an Agilent ENA series Network Analyzer (Model No.: E5017C). According to Long et al., the resonant frequency of Cylindrical DRA excited in HEM_{11} mode can be written as:

$$f_r = \frac{3 \times 10^8}{2\pi\sqrt{\varepsilon r}}\sqrt{\left(\frac{1.841}{a}\right)^2 + \left(\frac{\pi}{2h}\right)^2} \quad (2)$$

Where ε_r is the permittivity, a is the radius of the sample and h is the height of the DR antenna. The parameters of ε_r, a and h can control the resonance frequency of DRA.

The proposed geometry and configuration Cylindrical DRA structure via aperture couple feeding method is shown in Fig. 1 [5]. Aperture coupling feeding method was used to avoid the unwanted radiation from the microstrip line since the feed network were isolated from the radiating element [6]. This antenna consists of a cylindrical DR on the top of Plexiglas substrate, a slot cut in a ground plane and microstrip line at the bottom. The dimension of proposed antenna shows in table 1. The return loss (S_{11}) of sample was measured and the bandwidth as well as working resonant frequency were determined.

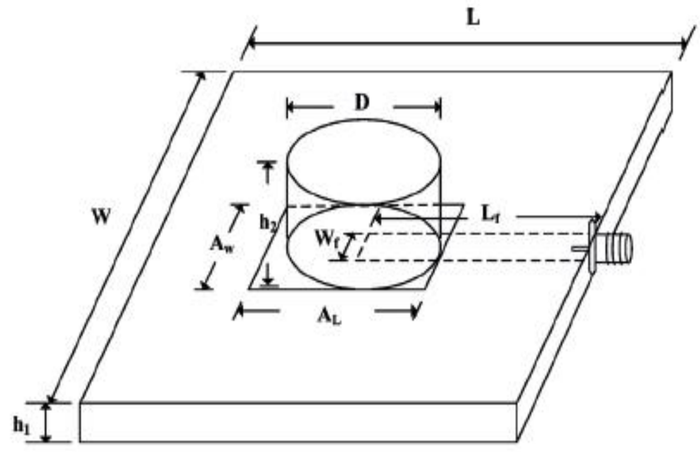

FIGURE 1 Antenna geometry and configuration.

TABLE 1 Dimension of proposed antenna.

Parameter	Dimension (mm)
W	30
L	29
$\mathbf{H_1}$	1.5
$\mathbf{A_L}$	12
$\mathbf{A_W}$	12
$\mathbf{L_F}$	15
$\mathbf{W_F}$	3
D	11.08
$\mathbf{h_2}$	1.33

RESULT AND DISCUSSION

The structure of the oxide $SrTiO_3$ was first studied using powder X-ray diffraction data within 10° to 80° value of 2θ in range as shown in Fig. 2. All the peaks are sharp and there is no unwanted peak is found in XRD pattern, representing the crystal is single phase without any impurities and identical to the reported PDF card no: 00-035-0734 [7]. From the diffraction pattern, the lattice parameter along with the average crystallite size for the sample has been calculated as shown in Table 2. $SrTiO_3$ was indexed Cubic phase (space group: *Pm-3m*) with unit cell with lattice constant formulated by a = 3.9000Å.

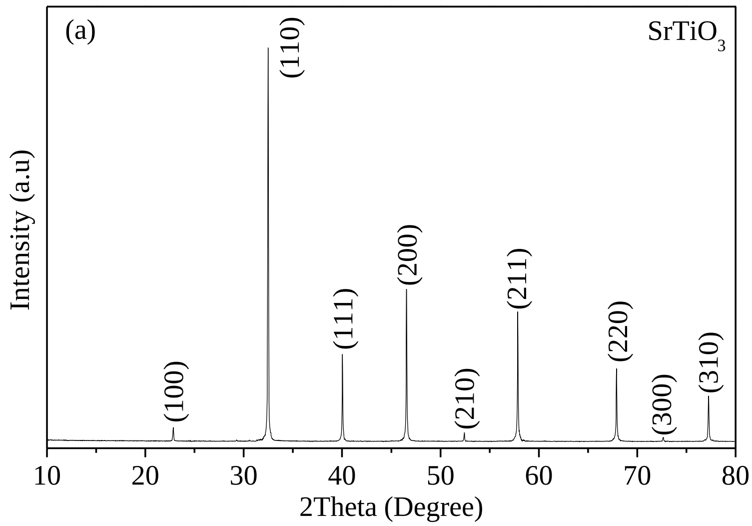

Figure 2 Index XRD pattern of $SrTiO_3$.

Table 2 Latice parameter,crystallite size and space group of $SrTiO_3$.

	$SrTiO_3$
a (Å)	3.9000 (1)
b (Å)	3.9000 (1)
c (Å)	3.9000 (1)
v ($Å^3$)	59.5 (1)
Crystallite Size (Å)	973.14

The Dielectric Constant (ε_r) was calculated from the measured capacitance (Cp) obtain by LCR meter between 30°C - 600°C temperatures. The variations of dielectric constant with temperature at some selected frequencies for $SrTiO_3$ ceramic are shown in Fig. 3. The dielectric constant decreases gradually up to a certain temperature and increases rapidly with increasing temperature. This due to the typical ceramics behaviour where exhibit high permittivity at the higher temperature. At room temperature, the dielectric constant of $SrTiO_3$ is around ε_r = 240 at frequencies 1 KHz to 100 KHz.

Figure 4 shows the dielectric loss (tan δ) of $SrTiO_3$. The dielectric loss for the $SrTiO_3$ measured at below 200°C temperature shows very small loss which about 0.00191 but by increasing the temperature from 200°C to 600°C, the dielectric loss value fluctuate and increased at about 1. From 450°C upward the value of dielectric loss is rapidly increased up to a maximum value about 3 was observed at temperature 600°C. The peak appeared at temperature 300°C or 1 KHz indicating presents of relaxation process of $SrTiO_3$ ceramic[8], [9].

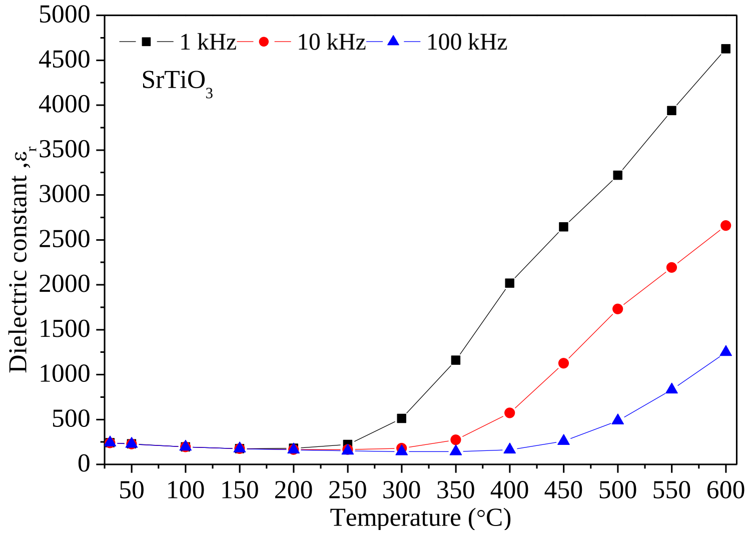

Figure 3 Temperature dependence of dielectric constant (ε_r) for $SrTiO_3$.

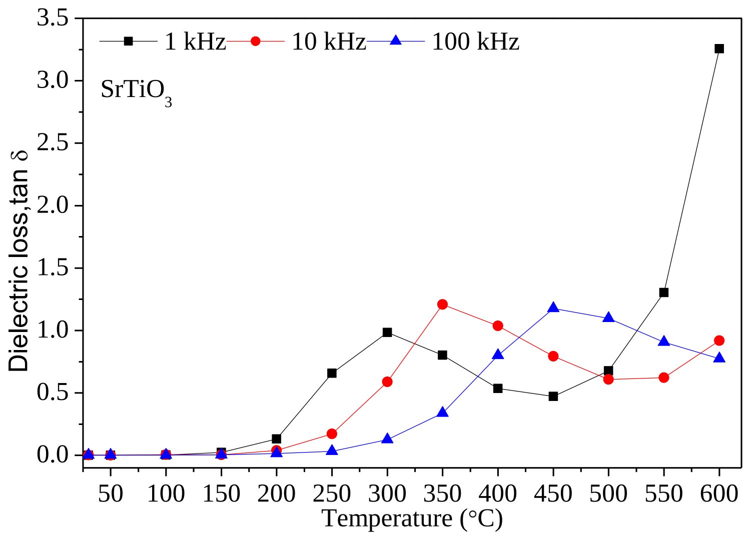

FIGURE 4 Dielectric loss (tan δ) of $SrTiO_3$.

In order to study the antenna efficiency the proposed DR antenna was fabricated and its main characteristic was measured. The effective return loss (S_{11}) of antenna to deliver power from source to the antenna is at below -10db. Indicating 90 percent of power effectively transferred to the antenna and only 10 percent is reflected back. If S_{11}=0 dB, then all the power is reflected from the antenna and nothing is radiated. Figure 5 shows the return loss of $SrTiO_3$ at different frequencies. The reflection coefficient of the sample shows the multi-resonance peak (multiband). The highest return loss is recorded at resonance frequency of 6.1 GHz, which give about -34dB. Moreover, the percentage bandwidth of measurement antenna is around 13.1%.

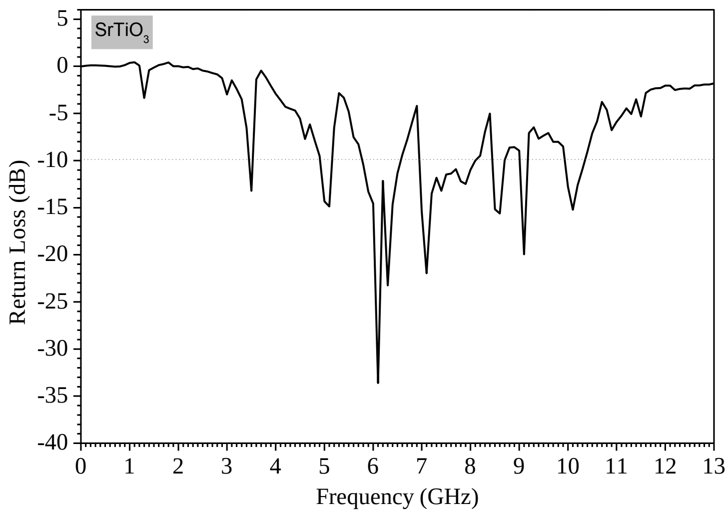

Figure 5 Return loss (S_{11}) of the Cylindrical DRA versus Frequency for $SrTiO_3$.

CONCLUSION

In this paper, design, fabrication and testing of $SrTiO_3$ ceramic material for CDRAs are presented. $SrTiO_3$ ceramic were prepared using the solid state reaction method. X-ray diffraction exposed physical properties $SrTiO_3$ which exhibit cubic phase. This is proven by the lattice parameter and unit cell volume of the samples. In terms of the dielectric properties, at room temperature the dielectric constant decreased from 240. Meanwhile, The dielectric loss obtain shows very minimum loss value roughly below 0.00191 at room temperature. This very useful for antenna efficiency. The working frequency of DRA is at 6.1 GHz. The measurements of DRAs confirm that $SrTiO_3$ can be used as such materials for DRAs.

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