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MECHANICAL AND PHYSICAL BEHAVIOUR OF DIELECTRIC MATERIALS FOR AN ANTENNA APPLICATION

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Abstract—The analysis of dielectric material integrated on antenna by realizing on DR properties especially on dielectric constant to achieve smaller antenna size enabling it to be used in cellular communication at Wireless Local Area Network (WLAN). In many electromagnetic applications, there are several problems of the miniaturized antenna in any communication system where miniaturization of an antenna conventionally will affect its radiation characteristics such as antenna efficiency, radiation patterns, and bandwidth. A large number of parameters need to be suitably tuned to achieve the desired functionality of a device, hence the development strategy of antenna has to be very effective and flexible. The idea of miniaturize antenna can be improved by the utilization of high dielectric constant as antenna material. The motivation for this work has been inspired by the need for small size, compact, structure simplicity, high efficient, and low cost antenna suitable for the range of 2.3 GHz to 2.5 GHz. The research would be taken in four phases: In Phase I, characterization dielectric material of bismuth titanate. In Phase II, the output of Phase I will be used for numerical investigation of antenna using Computer Simulation Technology (CST) software. Then, the output from phase II will be validated in phase III where the comparison of results with existing model will be done to ensure the result output can be used for miniaturize size antenna.Through this research, the proposed antenna with high dielectric constant material will demonstrate an improvement of automated technologies composed of novel dielectric resonator antenna, DRA with wide-bandwidth, high power gain and low loss characteristics.

Index Terms—Dielectric Material, Antenna, Bismuth Titanate, WLAN

I. Introduction

The idea of using dielectric resonators as antennas first came from Long [1] as a way of creating a microstrip antenna by replacing the leaky conducting patch and substrate by a dielectric resonator in order to take advantage of the leakage from the resonator. This investigation took place at the US Army Harry Diamond Laboratories during the summer of 1981. The theory was based on perfectly conducting magnetic wall boundary approximations. The investigated shape was a cylinder. The first results showed that it was possible to achieve a radiation pattern similar to that of an electric dipole parallel to the ground plane, originating from the HE_{11} mode. Also, the impedance bandwidth was better compared to the microstrip antenna. The following autumn Long, together with McAllister and Shen systematically investigated different shapes and sizes, as well as materials, at the University of Houston, which is resulted in the first publications starting from 1983 and the term dielectric resonator antenna was used for the first time. In these papers the feeding was made by coaxial lines with probes extending in to the resonators through drilled holes.

A DRA is a high radiation efficiency radiator. As its name implies, a dielectric resonator is used to be operated as the radiating part. Some people may think that the dielectric resonators are only used with filters. This is because of the high Q-factor which the DRs have possess higher order modes [2- 3]. If a dielectric resonator is excited for the lower modes, it will have a low Q-factor and can operate as an antenna with good characteristics. The DRs can be formed in different shapes offering more design flexibility, it can be rectangular, cylindrical, hemispherical, or their deformations. These different DRAs can be fed by various coupling mechanisms exciting many radiating modes with different radiation characteristics. In general, DRAs can be designed to be placed on ground plane or on a lower permittivity substrate [4].

Conventional antenna had make issues where the antenna size is relatively large to achieve higher sensitivity for the purpose of huge coverage signal. The large size of antenna will lead to larger devices which is opposing the high demanding in wireless celullar communication industry. Shrinking the size, simplifying the interface and retaining the antenna capability to fulfill the ever shrinking system requirements are very challenging for antenna designers. In fact, increasing the effective dielectric material parameters results in the antenna size reduction with the promising of the high efficiency. In this research, the properties of the dielectric materials will be characterized to be applied on the antenna which to create miniaturization of antenna size.

Preparation of Bulk Material

The family of Bismuth Titanate, ($Bi_4Ti_3O_{12}$) layered-structured ferroelectrics materials are attractive from the viewpoint of their application as electronic materials such as dielectrics, piezoelectrics and pyroelectrics, because they are characterized by good stability of piezoelectric properties, a high Curie temperature and a good

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resistance versus temperature. Bismuth titanate (BiT) powders can be prepared using different methods, depending if the creation will be filmed coating or ceramics. The structures and properties of bismuth titanate materials show a significant dependence on the applied synthesis method. In this study, an attempt had been made to give an approach to analyzing the structure, synthesis methods and properties of bismuth titanate ferroelectrics materials. In the formation of BiT of molar formula $Bi_4Ti_3O_{12}$, the starting materials consist of bismuth nitrate pentahydrate and titanium (IV) isopropoxide. A flow chart is illustrated in Figure 1.

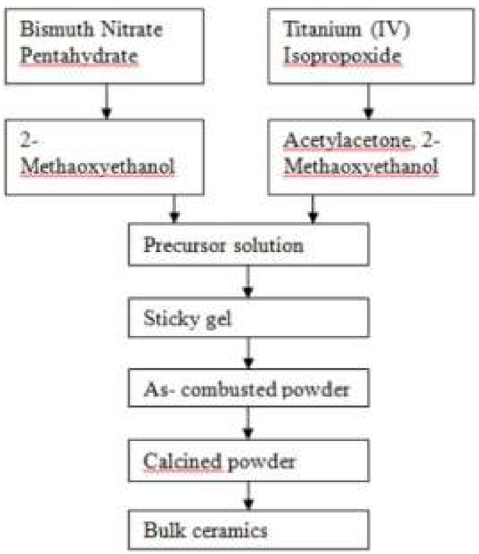

Fig 1. Flow process of the preparation $Bi_4Ti_3O_{12}$ powders and bulk ceramics using soft combustion technique.

Bulk BiT analysis

A. Inspection of paddy residue/sand pellet

Microstructure using Scanning electron Microscope (SEM)

The morphologies of the Bismuth Titanate particles are obtained using scanning electron microscope (SEM). Figure 2 presents SEM facility at Universiti Malaysia Perlis (UniMAP). SEM is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties. Magnification in a SEM can be controlled over a range of up to 6 orders of magnitude from about 19X to 300,000X. These morphologies will provides the SEM image of BiT for the analyzation of particles surface area.

Fig. 2. Scanning electron microscope

Measurement of dielectric properties of Dielectric resonator component over the frequency range of 100 MHz - 20 GHz

To measure intrinsic electrical properties of BiT, the measurement system included an Agilent 85070 B High Temperature Dielectric Probe, an Agilent Microwave Network Analyzer, and Agilent 85070 software. Figure 3 shows the High Temperature Probe measurement procedure, which is done by contacting the probe to a flat surface of a solid, or immersing it into a liquid or semisolid. The fields at the probe end "fringe" into the material and change as they come into contact with the MUT. This probe propagates signal into the MUT, and the resulting measured reflections are then converted into dielectric properties values via Agilent 85070B software. This measurement system made dielectric measurements quickly and easily with no special fixtures or containers required.

Fig. 3. Dielectric Properties measurement with Agilent 85070B High Temperature Dielectric Probe Kit measurement system setup

Results and Discussion

Mechanical Characterization of Dielectric Materials

Field Emission Scanning Electron Microscopy (FESEM) micrographs of the BiT powder and the sintered pellet are shown in Fig. 3. It can be seen from the figure that extensive grain growth occurred, which led to platelet formation on the order of 200 nm to 10. The platelets of BiT form a brick wall like structure by aligning on top of each other, as expected with less platelets damaged during sample preparation.

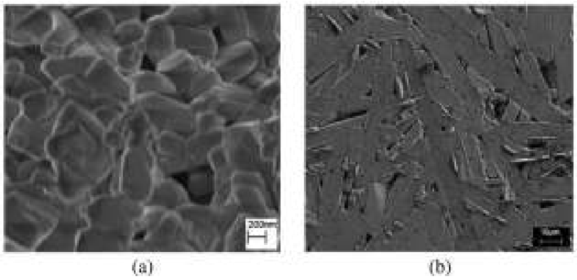

Fig. 3. FESEM image of BiT: (a) calcined powder at 750°C for 3 h and (b) sintered bulk ceramic at 1100°C

Dielectric Properties of Dielectric Materials

By observing Fig. 4, the dielectric constant and dielectric loss of the bulk BiT ceramic material was determined to be about 21 and 1.4 respectively, at 2.3 – 2.5 GHz. The compilation of the results obtained for the values of the dielectric properties also can be seen in Table 1. In the frequency studies,the dielectric loss of the BiT ceramic material was found to be constant over the frequency range of 1 to 10 GHz. This shows that high densification and less porosity is available in the BiT ceramic material which make it a tough and resistance to high temperature.

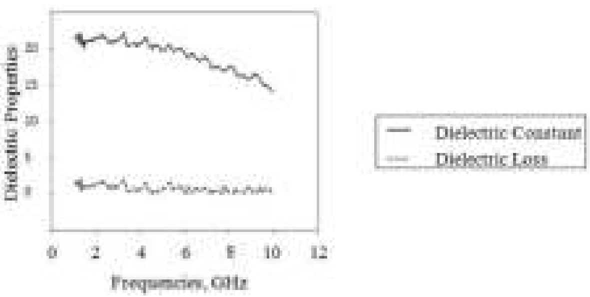

Fig. 4. Dielectric properties of BiT ceramic material Table 1 shows that, for the frequency range of 2.3 to 2.5

GHz, the dielectric constant was in the range of 21.550 to 21.1562. The values obtained were high, especially at higher frequencies, and they are necessary values for this BiT ceramic material which microstructures that have uniform grain size and good relative density are essential for a DR that is to be applied in microwave antennas.

Table 1. Dielectric properties of BiT at selected frequencies in the range of 2.3 to 2.5 GHz

Frequency, GHz	Dielectric Properties of BiT	
	Average Dielectric Constant, ε'	Average Dielectric Loss, ε''
2.3050	21.5500	1.6087
2.3500	21.4747	1.5500
2.3950	21.4920	1.4747
2.4400	21.6087	1.4920
2.4850	21.2278	1.2278
2.5300	21.1562	1.1562

Antenna Design Results

Simulation of design with the simulated return loss, gain, diretivity and radiation efficiency were made using Computer Simulation Technology software (CST). Return loss curve which indicate with S11 is shown in Fig. 5. The resonance frequency, 10 dB width is 2.4 GHz for both conventional microstrip patch antenna and bismuth titanate array antenna. The benefit of the BiT array antenna is that it is miniaturized and exhibited the lowest return loss with a good impedance matching while the conventional microstrip antenna was high in return loss.

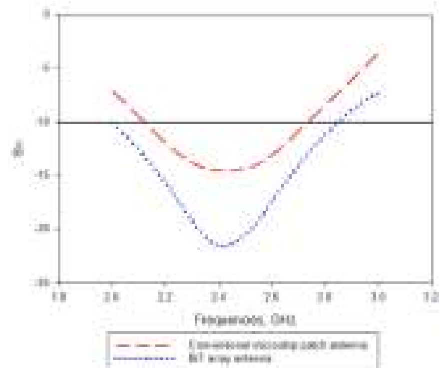

Fig. 5. S_{11} of conventional microstrip antenna and BiT array antenna

The results are summarized in Table 2. In Table 2, the size of the antennas is described by the width, height and thickenss of whole antenna. The bandwidth of miniature BiT array antenna is 35.4% which is larger as compared to conventional microstrip antenna with only 24.2 % at 2.4 GHz resonance frequency. The radiation efficiency obtained for the BiT array antenna and conventional microstrip antenna were 94.7 % and 72.1 % respectively. This high radiation efficiency for BiT array antenna is due to it exhibited less conduction loss as compared to conventional microstrip antenna with more than 90% metal based.

Table 2. The achieved performance and physical size of two antennas

parameters	Conventional microstrip antenna	BiT array antenna
Dimensions (mm)	40 x 40 x 1.6	25 x 20 x 1.6
Gain (dBi)	3.1	7.1
Directivity (dBi)	4.3	7.5
Radiation efficiency (%)	72.1	94.7
Bandwidth (%)	24.2	35.4

Conclusion

Microwave dielectric properties measurement at range of 2.3 – 2.5 GHz on ceramic material made of Bismuth Titanate revealed high dielectric constant and low loss factor, offer an attractive solution for applications such as microwave devices. At the present time, antenna miniaturization is of great concern due to the physical benefits and the bismuth titanate (BiT) ceramic material attached on the antenna design satisfies this need. A miniature antenna structure having attractive return loss and radiation characteristics has been proposed. The miniaturization on microstrip patch antenna by loaded with very high permittivity ceramic material ($\varepsilon'= 15$) has been experimentally demonstrated. The return loss result indicates resonance approximately 2.4 GHz and an antenna miniaturization are obtained using high permittivity ceramic material is proven. The miniaturized antenna can be then integrated with wireless router and wireless modem.

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