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A Flexible PVA/$CaCO_3$ Dielectric Film for Microwave Antenna Applications

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Abstract

This work presents the fabrication of a biodegradable dielectric substrate material for microwave applications. Water soluble Poly(Vinyl Alcohol) (PVA) with naturally available calcium carbonate based dielectric films were synthesized using solution casting method. The physical properties of PVA based composite film can be tuned by adding $CaCO_3$ particles. The PVA substrate with degradable composition has a thickness of 1.3 mm with dielectric properties ($\varepsilon_r = 1.64$, tan $\delta = 0.039$) measured at S-band frequency using cavity perturbation method. As a proof of concept, on the synthesized PVA/$CaCO_3$ composite film, a printed dipole antenna is fabricated and designed to operating at 2.45 GHz. This PVA composite film is robust, flexible and has the potential to replace non-biodegradable materials with good promising material properties.

1 Introduction

Modern microwave devices have great fascination for advanced materials because of their impact on overall system efficiency and concern for e-waste pollution. The significance of microwave materials and to explore their diverse applications at microwave frequencies is presented in [1]. Nowadays, physically degradable materials that can disappear at controlled traits in various environments have huge demand in microwave electronics [2]. Recently, the bio-based materials such as poly(lactic-co-glycolic acid) [3], poly(butylene succinate) [4], etc., have been developed as supporting materials for transient microwave technology. Among them, poly(vinyl alcohol) (PVA) is a hydrophilic synthetic polymer. It is bestowed with advantages such as bio-compatibility, biodegradability, non-toxicity, high chemical stability etc., due to their large amounts of hydroxyl groups [5]. Advanced researches have utilized PVA polymer for antimicrobial application [6], food packaging [7], EM shielding material [8] etc., with composition of silk sericin, chitosan and cobalt-ferrite nanocomposites material respectively. Emran et al have demonstrated RF humidity sensor using water soluble PVA polymer for wide moisture conditions [9]. PVA is an adhesive materials commonly used for microwave phantom application that exhibits complex dielectric characteristics similar to biological tissues [10]. It has enhanced surface properties of microwave absorbers due to their long pair of atoms that act as modifiers [11]. Fang Xu et al have reported PVA with TiO_2 metal oxide films for transient electronics application with controlled degradable rate. It has been reported that the life time and characteristics of pure PVA films can be tuned by metal oxide additives [12]. PVA/$CaCO_3$ is one of the most versatile bio-mineral with anhydrous crystal nature of polymorphs such as calcite, aragonite and vaterite. It is widely used as reinforcement filler material in polymer industry for enhancing stiffness, hardness and heat resistance [13]. PVA with modified $CaCO_3$ have been used for the adsorption of heavy metals [14]. In this work, we have prepared a PVA/$CaCO_3$ based dielectric film using solution casting technique. The dielectric properties of PVA films are modified with $CaCO_3$ particles. In this paper, we also have demonstrated the use of PVA/$CaCO_3$ dielectric film as a substrate material for microwave antenna fabrication.

2 Degradable film fabrication

The procedure for synthesizing degradable dielectric substrate is schematically shown in the Figure 1. Firstly, 4.3 g of PVA (98 % degree hydrolysis and viscosity of aqueous solution = 25-32 cPs, Sigma Aldrich) was added into 100 mL Double Distilled (DD) water and heated for 2 h

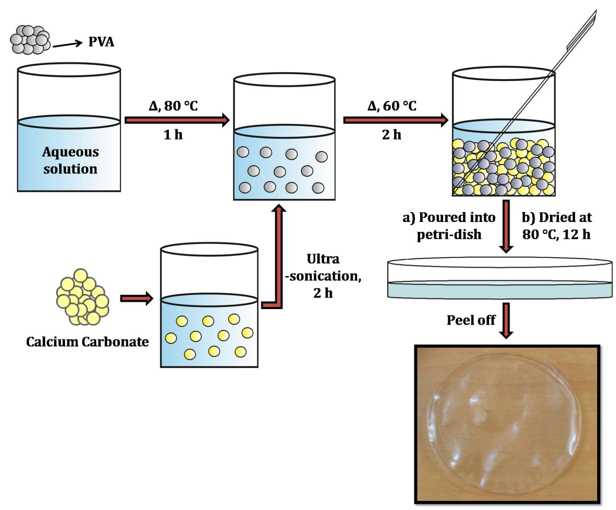

Figure 1. Schematic representation of fabrication process of PVA/$CaCO_3$ film using solution casting method.

at 40 °C until a homogeneous solution is obtained (solution A). Secondly, $CaCO_3$ (5 *wt%*) was dissolved in 60 mL of DD water followed by sonication for 2 h (solution B). PVA/$CaCO_3$ solid gel solution was prepared by adding the solution B drop-wise into solution A. Then, the as prepared homogeneous solution is poured into transparent petridish and dried in hot air oven for 2 h at 80 °C . Finally, PVA/$CaCO_3$ transparent dielectric film is peeled off smoothly. The flexible PVA/$CaCO_3$ film increases the mechanical strength and thermal stability of the PVA film. The dielectric properties of fabricated thin film ($\varepsilon_r = 1.64$, tan $\delta = 0.039$) is measured at S-band using cavity perturbation method.

3 Antenna design and Fabrication

Figure 2 depicts the geometry of printed dipole antenna. A dipole antenna having arm length L1 and width W1 is printed on both sides of the PVA/$CaCO_3$ substrate with the thickness 1.3 mm, $\varepsilon_r = 1.64$ and tan $\delta = 0.039$ to operating at 2.45 GHz. The dotted lines (black) indicate the bottom layer of metallization on the substrate. Impedance matching of the antenna is improved by the slot between strip lines. The discontinuity at the right angle bend of the microstrip feed and dipole arm can affect the performance of the antenna. The excess capacitance at the bend is reduced by optimizing a miter at the microstrip line and dipole strip joint [15]. An adhesive copper tape is used to realize the conductive parts. Simulation of the antenna was done using Ansoft HFSS and the reflection co-efficients of the prototype was measured using Anritsu MS2038C vector network analyzer.

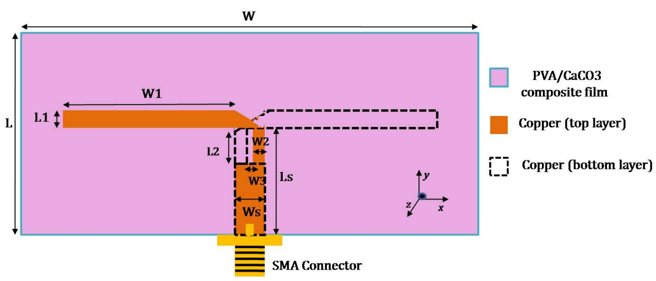

Figure 2. Geometry of microstrip fed printed dipole antenna on PVA/$CaCO_3$ dielectric film *(W = 60, L = 20, W1 = 22.5, L1 = 4, W2 = 22.5, L2 = 2, W2 = 1.8, W3 = 0.4, Ws = 4, Ls = 10)* (All units are in mm).

4 Results and Discussion

Figure 3 shows the reflection co-efficient of printed dipole antenna. This prototype resonates at 2.45 GHz with 2:1 VSWR impedance bandwidth ranging from 2.27 GHz to 2.69 GHz. The inset figure shows the corresponding current distribution of printed dipole antenna. It is observed that the printed dipole strips are resonating at quarter wavelength. Figure 4 shows the measured reflection co-efficient of printed dipole antenna corresponding current

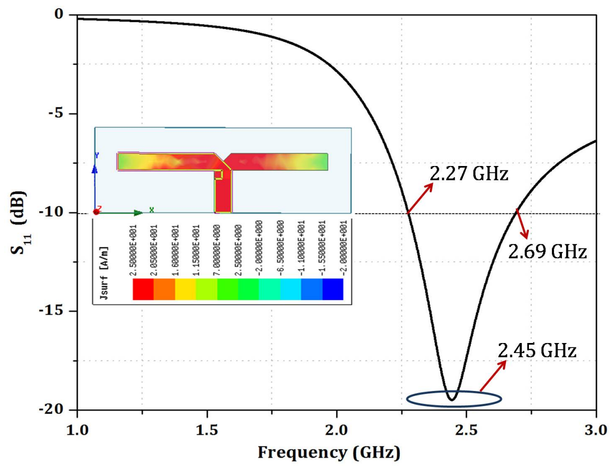

Figure 3. Reflection characteristics of printed dipole antenna and corresponding surface current distribution.

distribution of printed dipole antenna. It is observed that the printed dipole strips are resonating at quarter wavelength. Figure 4 shows the measured reflection co-efficient of printed dipole antenna. The photographs of flat and bend conditions of the fabricated biodegradable substrate film is shown as inset Figure 4. In both condition. In both conditions, fabricated antenna is resonating at 2.45 GHz and exhibits good impedance matching. The radiation pattern of PVA/$CaCO_3$ dielectric film based dipole antenna is presented in Figure 5 and the peak gain of 2.2 dBi. The printed dipole antenna on PVA/$CaCO_3$ substrate exhibits an omnidirectional radiation pattern at 2.45 GHz.

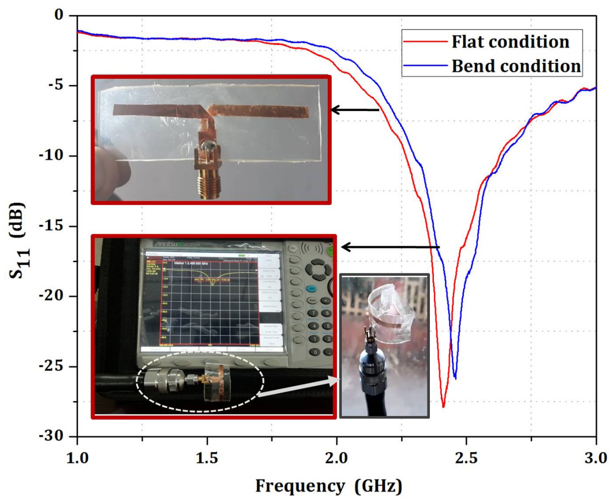

Figure 4. Measured reflection characteristics of fabricated printed dipole antenna on flat and bend condition.

5 Conclusion

A novel PVA/$CaCO_3$ dielectric film is synthesized by solution casting method. The dielectric properties of PVA film is increased upon adding $CaCO_3$ additives. The composite substrate materials has improved the mechanical and the physical properties of the degradable film. A printed

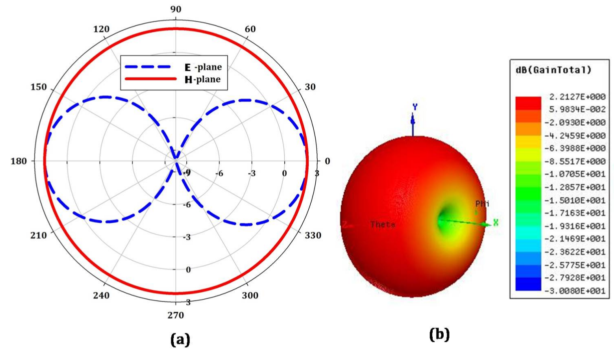

Figure 5. (a) Two dimensional radiation pattern (b) Three dimensional radiation pattern of printed dipole antenna on PVA composite film.

dipole antenna is fabricated on PVA/$CaCO_3$ to operate at 2.45 GHz. The dipole antenna exhibits a peak gain of 2.2 dBi with omni-directional radiation pattern. The fabricated film is robust, flexible and is eco-friendly. The proposed biodegradable substrate film is an excellent candidate to replace petroleum based materials used for in microwave applications.

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