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Non - Destructive Method for Thickness Measurement of Dielectric Films using Metamaterial Resonator

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Abstract. This paper describes an efficient method for the precise measurement of thickness of dielectric films using metamaterial Broadside Coupled Split Ring Resonator (BCSRR). The experimental arrangement is based on the frequency shift occurring in the metamaterial resonating structure due to the changes in effective capacitance between the rings of BCSRR due to the field perturbation effect occurring in its neighborhood. The measurement setup includes a BCSRR structure fabricated using two separate dielectric substrates, kept in between the transmitting and receiving probes of a Vector Network Analyzer (VNA). Dielectric samples of different thicknesses are introduced between the BCSRR rings, which in turn produces a shift in the resonant frequency of the sensing probe. Thin samples made of FR4 epoxy board, polyamide and polyethylene sheets are used for the study. The resonant frequency shifts are noted for sheets of known thicknesses and a calibration graph between the frequency shift and thickness is plotted. This graph is used for obtaining the unknown thickness of any sample of the same material by observing its corresponding resonant frequency. This method may be extended to the thickness measurement of thin films of low loss dielectric materials.

INTRODUCTION

Split Ring Resonator (SRR) based metamaterial structures play vital role in the field of industrial research due to its wide variety of evolving applications. Different SRR based metamaterial structures are engineered with the growing interest for various applications. Amongst the SRR structures, Broadside Coupled Split Ring Resonators (BCSRR) have grabbed special attention in the past few decades due to its resonant properties that are enhanced by various near field perturbations[1- 4]. In this paper we make use of these resonant frequency dependent properties of BCSRR to employ it as a dielectric thickness sensor. The narrow resonant curve of BCSRR which can be tuned by varying the dielectric environment makes it a perfect choice for various applications like sensing of dielectric properties [5-7].

TABLE 1. Structural Parameters and resonant frequencies of BCSRR probes used for thickness measurement.

BCSRR	Inner Radius r (mm)	Slit Width s (cm)	Width of the ring w (cm)	Resonant Frequency f_0(GHZ)
I	0.33	0.022	0.05	3.8836
II	0.3	0.05	0.06	4.210
III	0.2	0.04	0.10	5.010

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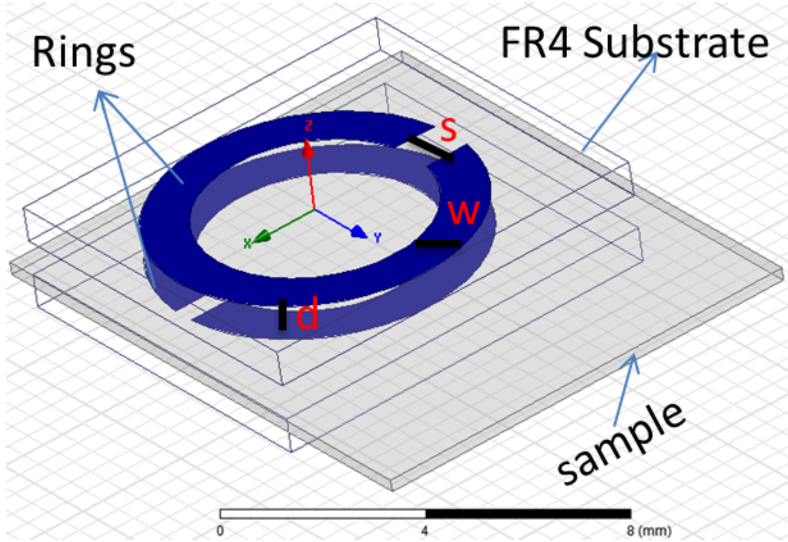

FIGURE 1. Structural representation of BCSRR with sample inserted between the rings

DESIGN AND EXPERIMENTAL SETUP

BCSRR structure used as a test probe for the thickness measurement consists of two copper rings of inner radius *r*, slit width *s* and width *w* which is fabricated on FR (Flame Retardant) epoxy boards of thickness 0.78 mm and dielectric permittivity 4.4[8]. Figure 1 shows the schematic diagram of BCSRR metamaterial structure. Table 1 gives the structural parameters and resonant frequencies of three different BCSRR test probes used for the work. The resonant frequency of the BCSRR is given by the equation,

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

where *L* and *C* are the effective equivalent inductance and capacitance of the BCSRR unit. The resonant frequency of the BCSRR depends on *L* and *C,* which in turn depends on the dielectric properties of the material.

Vector Network Analyzer (VNA) operated in 3-6 GHz frequency range is used to measure the resonant frequency shifts. The experimental set up for the precise introduction of the test sample into the space between the BCSRR rings is achieved using a micrometer set up having *X* and *Y* movement. The BCSRR test probe is set between the transmitting and receiving monopoles which are connected to the VNA [8]. The spacing between the rings is kept at 1 mm. The samples include FR4 boards with thicknesses varying from 0.15 mm to 0.75 mm and adhesive taps of poly ethylene and polyamide having thicknesses varying from 0.1 mm to 0.4 mm. A schematic representation of the test probe with the sample placed in between the rings is shown in Fig. 1.

RESULTS AND EXPERIMENTAL VERIFICATION

In order to analyse the resonant behavior of BCSRR with samples of varying thickness, we performed the experimental study using standard samples of FR4, polyamide and polyethylene sheets. Figure 2 depicts the resonant graphs obtained for the FR4 standard sample using BCSRR test probe III. It is clear from the above figure that as the thickness of the sample increases from 0.15 mm to 0.75 mm, the resonant frequency shows a corresponding decrease. The thickness of standard samples along with its resonant frequencies observed is used to draw a calibration graph. The calibration graph obtained for the three test probes for FR4 sample is shown in Fig.2a and the thickness of unknown sample is extracted in terms of its resonant frequency. It is found that the resonance frequency shifts towards the lower frequency side as the dielectric thickness increases.

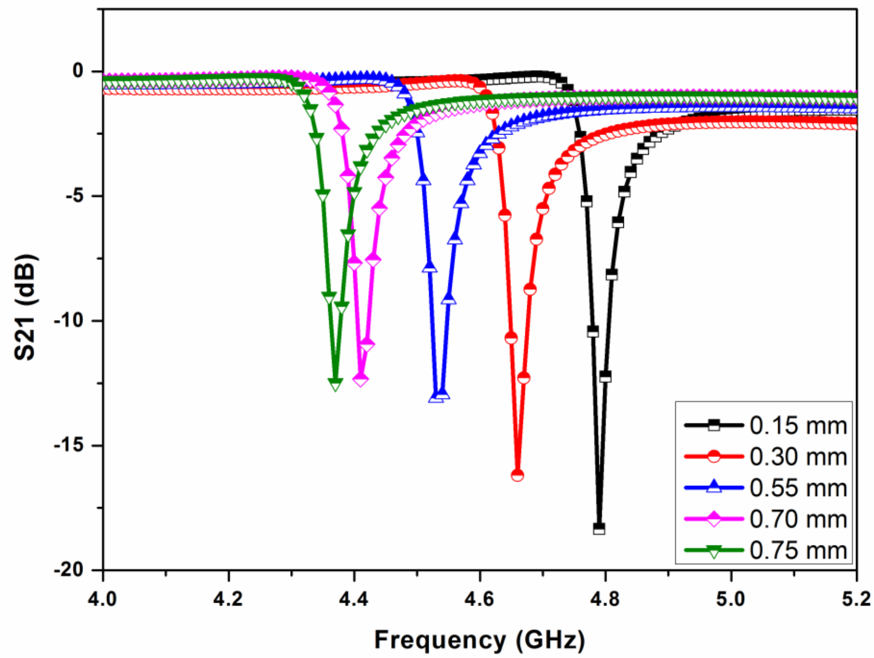

FIGURE 2. Transmission spectra of BCSRR with FR4 epoxy sheets of the different thickness introduced between the rings

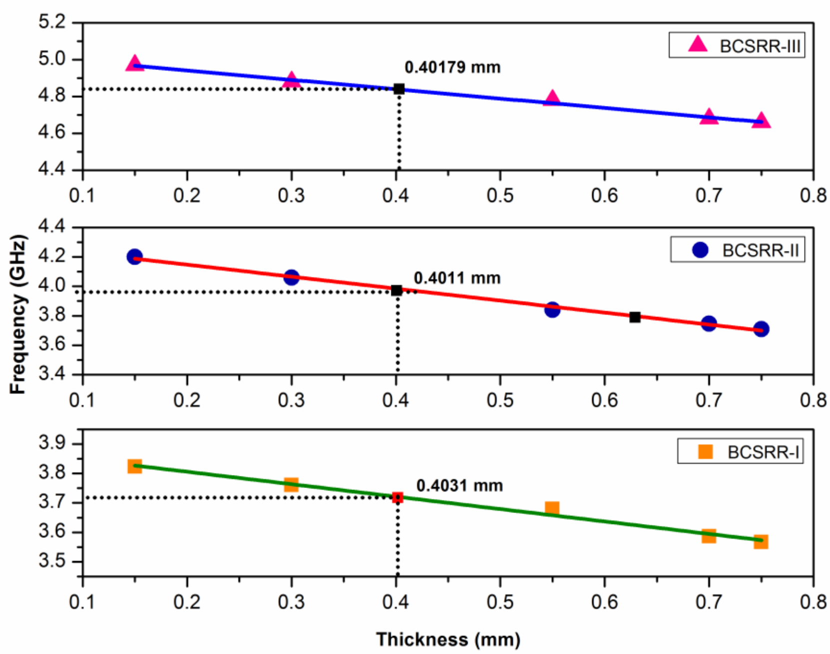

FIGURE 3. Calibration graphs plotted using FR4 epoxy standard samples of different thickness using 3 BCSRR test probes. The interpolated unknown thickness with its measured resonant frequency is also known.

Even the minute change in sample thickness causes a frequency shift in the MHz range suggesting the effective use of BCSRR as a thickness sensor. The frequencies obtained when the FR4 sheets of unknown thicknesses inserted between the space between BCSRR rings are noted and the corresponding thickness are measured using interpolation techniques from the calibration graph drawn. The obtained frequencies are marked on the calibration graph and thus the unknown thicknesses can be obtained graphically. These thicknesses are further confirmed using a traveling microscope. Table 2 gives the values obtained from calibration method and direct measurement.

TABLE 2. Thickness obtain by calibration graph and optical microscope for FR4 sample

Sample with unknown thickness	Measured resonant frequency(GHZ)	Thickness from the calibration graph (mm)	Thickness using optical microscope (mm)
I	4.6239	0.4033	0.402
II	4.48062	0.6001	0.595

The study is further extended to measure much smaller thicknesses by measuring the frequency shifts corresponding to the polyamide sheets and poly ethylene sheets of thicknesses up to 0.4 mm. Figure 4 gives the calibration graph drawn from the results obtained when the polyethylene sheets and polyamide sheets of thicknesses 0.1 mm - 0.4 mm are used as samples. The depicted graph can be used for finding unknown thicknesses as demonstrated above. If we have a calibration graph drawn between standard samples, it can be employed as an effective way of determining the thin film thicknesses, which in turn have potential applications in chemical and biological aspects.

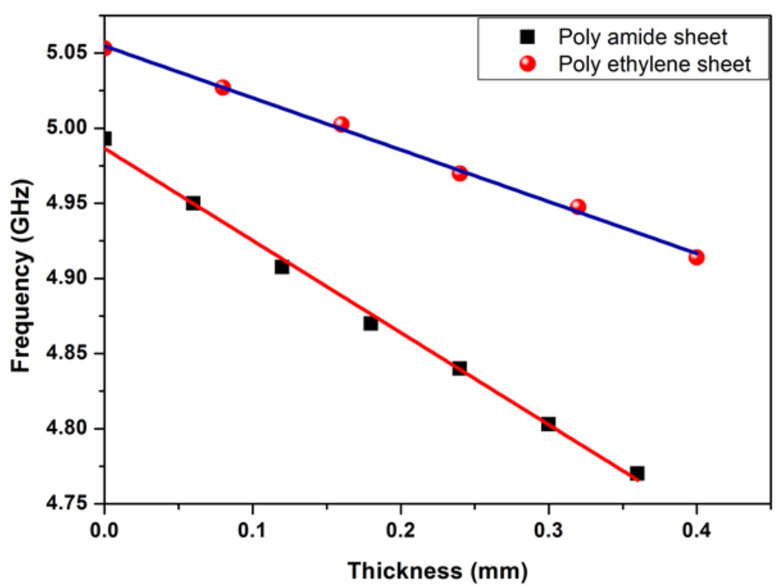

FIGURE 4. Frequency shifts corresponding to polyamide and polyethylene samples of different thickness

CONCLUSION

In this paper BCSRR is introduced as an effective thickness measurement sensor for measuring very small thicknesses. The resonant frequency shift properties of BCSRR in the presence of a dielectric sheet introduced between the rings of the BCSRR is employed for this study. The study can be extended for the measurement of thin film thickness measurements.

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