On the Effect of 2-D Hexagonal Boron Nitride for Radio Frequency Circuits in Harsh Environments

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***Abstract*—Numerous applications now-a-days require radio frequency devices to be directly positioned in harsh environments, leading to corrosion and ultimately catastrophic failures. Electromagnetically transparent coating materials can be a very good candidate for addressing such an issue. 2-Dimensional hexagonal Boron Nitride is a newer material gaining a significant attention for its structural similarity with graphene and corrosion resistive functionality without being electrically conductive, unlike graphene. This paper investigates the behavior of electromagnetic wave propagation in 2-D hBN material on copper through comparative analysis based on microstrip transmission line design.**

***Index Terms*—hBN, corrosion, microwave, transmission line.**

I. INTRODUCTION

Recently, antennas and wireless communication systems are gaining popularity in diversified fields such as, precision agriculture, defense, marine, oil, and gas industries [1], [2]. The radio frequency (RF) circuits in such applications are required at times to be positioned directly in harsh environments such as underground or excessive exposure to sea atmosphere leading to undergo corrosion [3]. Lately, a study has demonstrated the effectiveness of 2-dimensional (2-D) based hexagonal boron nitride (hBN) layer(s) of nanometer thickness with microbial corrosion resistive properties on the surface of metals such as copper [4]. Based on literature surveys by the authors, it was found that such 2-D hBN layer(s) exhibits anisotropic property at the optical frequencies [5]. Although the electromagnetic properties of 2-D hBN were reported in KHz and THz frequency spectrums [6], nobody has yet analyzed the behavior of electromagnetic wave propagation in such a comparatively newer material of nanometer thickness at the microwave frequency spectrum.

For the first time, this paper presents a comparative study on the electromagnetic wave propagation through the interface of 2-D hBN layer(s) on copper for antimicrobial applications in microwave frequencies for RF applications.

II. METHODOLOGY

The cross section of a microstrip circuit with hBN coated copper is illustrated in Fig. 1. (a). In this study, the circuit was assumed to be surrounded by air. Due to the current manufacturing limitation of realizing the 2-D hBN layer(s) only on metallic surfaces, any possibility of applying such layers on the dielectric substrate were not considered in this study. Theoretically, integral form of Maxwell's equations can be used to relate normal and tangential field components along the interface of 2-D hBN and copper in such RF circuits. If **E** and **H** represent the electric and magnetic tangential fields, respectively, and **B** and **D** represent the electric and magnetic normal flux, respectively, then all field components become zero inside the copper surface assuming a perfect electric conductor. Hence, we can write,

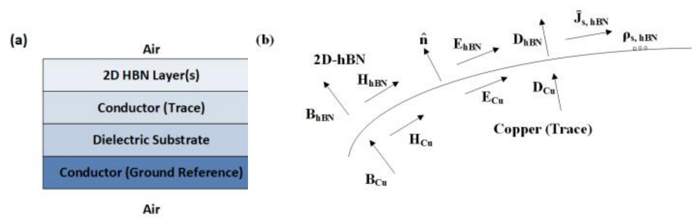

Fig. 1. (a) Cross section of a 2-D hBN coated microstrip RF circuit, (b) Fields at a general interface between 2-D hBN and Copper.

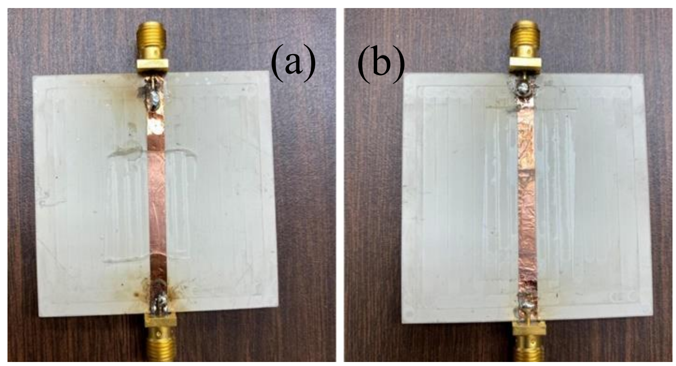

Fig. 2. 50 Ω Transmission Line with (a) 2-D hBN coated copper and (b) blank copper on the Rogers TMM4 substrate.

$$\hat{n}.\boldsymbol{D} = \rho_s \quad (1)$$

$$\hat{n} \times \boldsymbol{H} = \bar{J}_s \quad (2)$$

where, $\hat{n}$, ρ_s and $\bar{J}_s$ are the normal unit vector pointing out of the perfect conductor, electric surface charge density and current density on the interface, respectively. From (1) and (2), it can be observed that charges and surface currents are present at the interface and hence, the normal component **D** and the tangential component **H** are not continuous.

Next, two samples of 50 Ω transmission line of identical dimension were prototyped: one with the 2-D hBN coated copper (Fig. 2(a)) and another without any such coating, i.e. blank copper (Fig. 2(b)), as shown in Fig. 2. The substrate was chosen to be single side copper cladded Rogers TMM4 (ε_r = 4.5 and tanδ = 0.002) for both the cases with the cladded side as the reference ground. The dimensions of the substrates were 50.8×50.8×1.57 mm^3 and the 50 Ω transmission lines were 50×3×0.02 mm^3. The thickness of the reference planes for both samples were 0.017

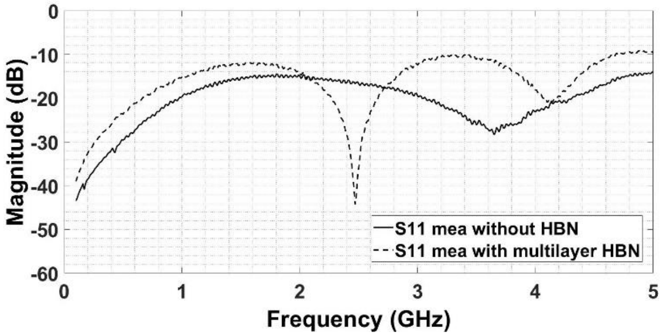

Fig. 3. Comparison of the magnitude of reflection coefficient in dB vs. frequency in GHz for prototyped transmission lines.

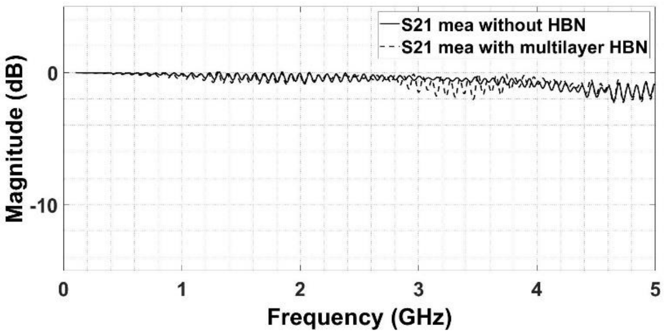

Fig. 4. Comparison of the magnitude of transmission coefficient in dB vs. frequency in GHz for prototyped transmission lines.

mm. The thickness of the 2-D hBN layer(s) on the first transmission line sample was 17 nm. The reflection and transmission coefficients (S_{11} and S_{21}, respectively) of both transmission lines were then measured using a Keysight PNA E831C network analyzer. Furthermore, the propagation constants for both the samples were extracted from measured S_{11} and S_{21} parameters and presented here as a comparative analysis.

III. RESULT and DISCUSSION

The measured reflection coefficient S_{11}, as shown in Fig. 3, although slightly degraded in presence of the 2-D hBN layer compared to the regular transmission line, the matching remained well above the 10 dB cutoff for the 2-D hBN coated prototype. However, more than 2 dB of transmission loss was observed in average for frequencies above 3 GHz, as shown in Fig. 4. A further comparative analysis on the attenuation constant of the two model clearly depicted an existence of certain frequency zones (1.5 GHz, 3 GHz) when the 2-D hBN coated sample exhibited very high attenuation, as shown in Fig. 5. A close observation on the comparative analysis of the phase constant plot in Fig. 6 also yielded nonlinear trends exactly at 1.5 GHz and 3 GHz. It is being envisioned that these observations will provide more insight on understanding and further analyzing the propagation of electromagnetic wave in 2-D hBN layer(s) at microwave spectrum, possibly by incorporating theories of boundary conditions and metasurfaces.

IV. CONCLUSION

A study on the propagation of electromagnetic wave in 2-D hBN coated copper were presented through an investigation of

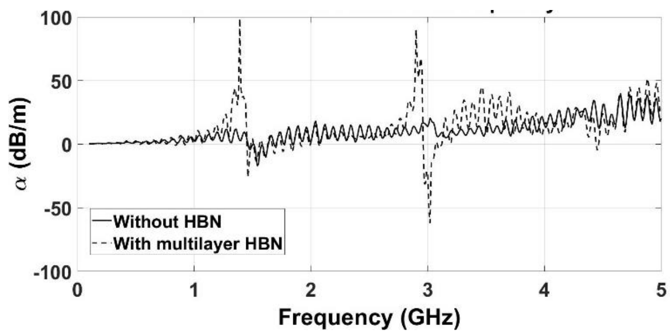

Fig. 5. Comparison of attenuation constant in dB/m vs. frequency in GHz for prototyped transmission lines.

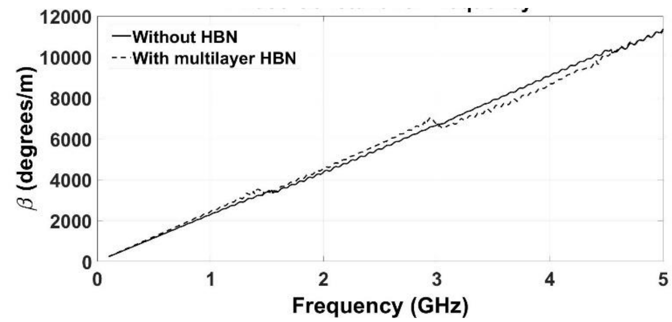

Fig. 6. Comparison of phase constant in degrees/m vs. frequency in GHz for prototyped transmission lines.

microwave signal propagation in microstrip circuit geometry. Certain frequency bands were identified to exhibit extreme attenuation for microwave propagation in 2-D hBN coated copper between 1 to 5 GHz. Further study using the results reported in this paper can be very beneficial for designing RF circuits exposed to harsh environments.

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