First Generation of Ultrathin Polarized NanoMaterials for Millimeter-wave (26-40 GHz) Textile Antenna Applications

Trang Thai*(1), Justin Ratner (1), Wenhua Chen(2), Tushar Thrivikraman(1), Gerald DeJean(3), and Manos Tentzeris(1)
(1) School of ECE, Georgia Institute of Technology, Atlanta, GA 30332, USA
(2) State Key Lab on Microwave & Digital Communication, Tsinghua Univ., Beijing, 100084, P.R.China
(3) Microsoft Research, One Microsoft Way, Redmond, WA 98052, USA
E-mail: trang.thai@gatech.edu

Introduction

Since their discovery seventeen years ago, carbon nanotubes (CNTs) have been a subject of intense investigation and have proven useful in a broad range of applications. The prospect of utilizing CNTs covers many interests from gas sensing and shielding to nanotube antennas and other important microwave applications. Different CNT based materials and designs have been investigated at microwave range for gas sensing applications [1][2]. Although there are many measurements that have been performed on CNT materials, much care takes place at low frequencies or in the optical frequency range. In [3], the effective parameters, permittivity and permeability, of a randomly aligned multiwalled carbon nanotube (MWCNT) sample embedded in waveguide are calculated from S-parameters utilizing effective medium theory. Measuring the reflection and transmission is advantageous over methods that require a current through the nanotubes because CNTs have high impedance (~10k Ω) that is difficult to match with standard laboratory equipment. In this paper, impedance study is performed with a new experiment set up on a novel CNT material, the Polarized Nano-Material (PNM) textile, with three different polarization schemes in Ka band (26.5 – 40 GHz) to serve various microwave applications and effective material engineering concepts.

Novel Polarized Nano-Material (PNM) textile is formed by the use of many paralleled nanotubes that are highly polarized and have an excellent shielding effect. Its electric field absorbing properties at 3 – 7 GHz were presented in [4]. Here, the electrical properties of this novel PNM textile are pursued at millimeter wave frequencies to establish a foundation for microwave material engineering and PNM-based microwave designs. While many theoretical studies have predicted carbon nanotubes as resonators, their behaviors have not been experimentally observed at microwave frequency range. The impedance analysis of the PNM material in this paper directly shows for the first time the radiation effect of CNTs functioning as radiators.

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Material Fabrication and Measurements Set up

The CNTs are grown on a silicon substrate into superaligned nanotube arrays. They are self-assembled into yarns of up to 30 cm in length. As bundles of CNTs are pulled out from the super aligned CNT arrays, continuous yarns of pure CNTs can be obtained and easily aligned parallel to one another due to van der Waals interactions. The yarns are composed of parallel threads that have diameters in the range of several hundreds of nanometers (Fig. 1a) [4]. The width of the yarn approximately depends on the number of threads in the yarn. The CNT yarns were constructed into three schemes of alignment that form three types of polarizations as shown in Fig. 1b. There are 20 layers of the PNM textile weaved one by one onto a waveguide aperture and joined by another identical waveguide section. Thus although it is difficult to estimate accurately, the thickness of the PNM sample is roughly on the scale of a few micron. The class of both waveguides is WR-28 that operates in the *Ka*-band (26.5-40 GHz). The waveguides joined together form a waveguide-type transmission line as shown in Fig. 2. Scattering parameters of 3 different polarizations of PNM embedded in the two waveguide sections were measured with the Agilent E8363B vector network analyzer.

Scattering Parameter Results and Impedance Analysis

The return loss (S11) and insertion loss (S21) results are shown in Figs. 3 and 4. These results show similar characteristics with respect to those presented previously in [4] on the same PNM textile. It is observed in Fig. 3 that polarization 2 has its return loss close to -20 dB indicating that only a small amount of the signal is reflected; while the return loss of polarizations 1 and 3 is above -3 dB showing great reflection. The insertion loss in Fig. 4 show the same consistent results, e.g., while most electric field is blocked by polarizations 1 and 3, polarization 2 behaves more like an open waveguide with its insertion loss close to 0 dB. The shielding effect of polarizations 1 and 3 are due to the alignment of CNTs along the electric field polarization; thus, the conductivity along the nanotube principle axis cancels out most of the field. Values for S-parameters obtained here in 26.5 – 40 GHz are little different from those presented in [4] at the range of 3 – 7 GHz. This indicates that the PNM materials are highly suitable for wideband applications.

The impedance of the PNM material can be computed based on the S-parameters [3][5]. The real and imaginary parts of the impedance of the PNM layers are shown in Fig. 5. The impedance profiles of polarizations 1 and 3 show the distinct resonance characteristics of radiators. They both resonate at around 31 and 38 GHz. These behaviors were predicted in [6] and other studies, and although similar behavior was observed in the optical range, this is the first time the collectively resonance behavior of the carbon nanotubes is shown in the microwave range due to highly aligned CNTs in the PNM layers. This will pave the way for further research on the radiation of CNTs in relation to their resonator-like behavior. The impedance profile of polarization 2 shows no resonance. This, again, confirms the prediction that most currents are induced along the nanotube main axis instead of the axial axis.

Conclusions

A novel PNM textile with extremely small thickness on the order of a few micron was characterized at millimeter wave frequencies (26.5 – 40 GHz), and the impedance analysis of the material was presented. The results show that the PNM is an excellent absorber for wideband applications; the highly polarized materials can be utilized for polarization detection and sensing applications. The impedance results of the PNM textile show that CNTs can function as resonators at microwave frequencies due to the long nanotubes, hence, paving ways for further theoretical and experimental studies on these behaviors. In future research efforts, the PNM will be characterized in gas to establish a foundation for wireless gas sensor designs in the microwave frequency range.

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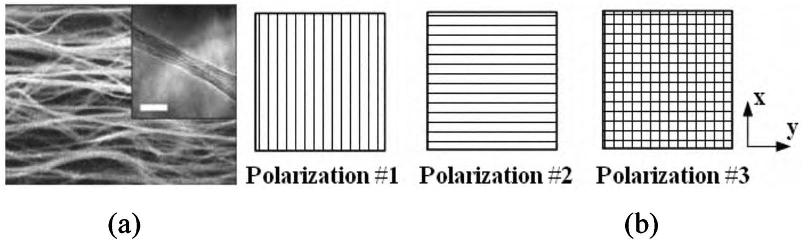

Fig. 1. (a) Capture of PNM textile, and (b) Different polarization schemes. [4]

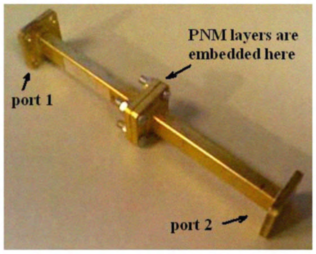

Fig. 2. PNM embedded in waveguide sections for measurements of S-parameters.

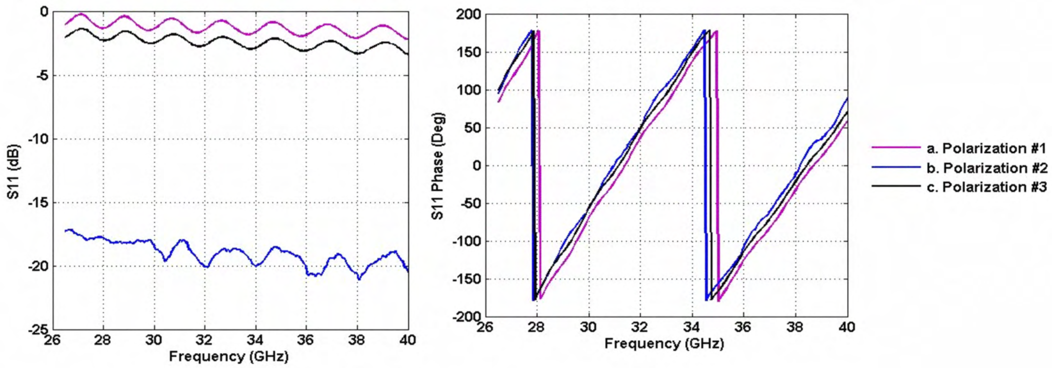

Fig. 3. S11 magnitude and phase of the embedded PNM layers.

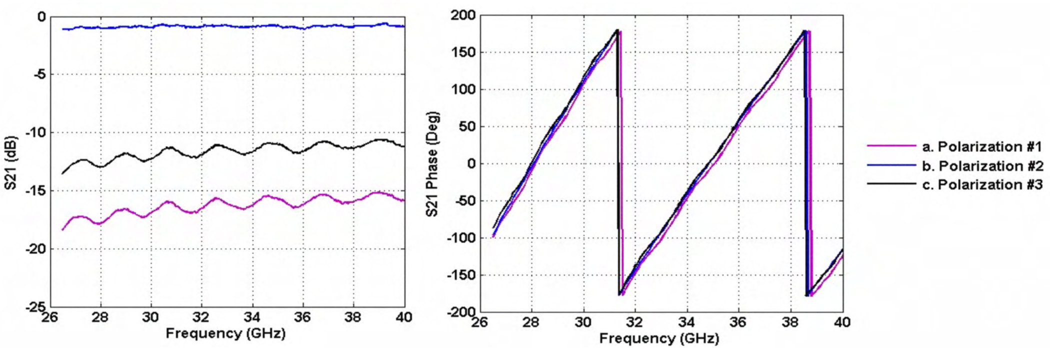

Fig. 4. S21 magnitude and phase of the embedded PNM layers.

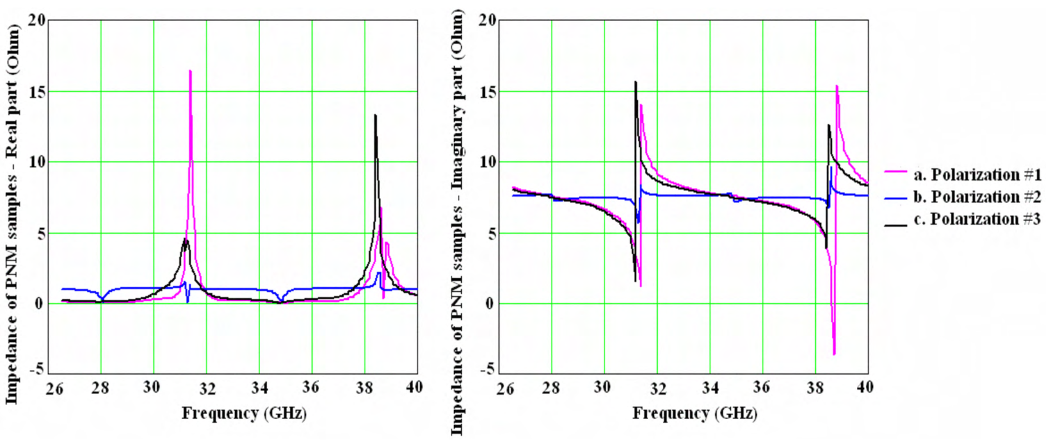

Fig. 5. Real and Imaginary part of the impedance of the PNM material.