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EMBG Resonators Based on Carbon Nanotubes for DNA Detection

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Abstract. The paper presents modeling, fabrication and measurements of microwave propagation in electromagnetic band gap (EMBG) CNTs based resonator for DNA detection. We report on sensing of DNA wrapped on multi walled carbon nanotubes (CNTs) deposited over a coupled lines area of two types of EMBG resonator structures. A new EMBG structure with coupled lines as a defect in the structure in order to obtain a EMBG resonator is proposed. Two types of EMBG resonator structures having the distance between the coupled lines 50 μm and 100 μm respectively have been used in order to find the best coupling with CNTs. The transmission magnitude and the phase for two types of EMBG resonators based on carbon nanotubes has been presented. Detection of DNA using EMBG resonators based on CNTs was demonstrated by a shift of the resonance frequency and an averaged phase shift of 20 degrees for a broadband frequency range of 6–20 GHz.

Keywords: electromagnetic bang gap, resonators, CNTs, DNA detection, high frequency.

1. Introduction

EMBG or PBG (photonic band gap) are artificial periodic structures that prohibit the propagation of electromagnetic waves in the microwave frequency band, which satisfy the Bragg reflection condition [1]. The microwave devices based on carbon nanotubes (CNTs) constitute a promising area of research and many microwave devices, such as filters, resonators, amplifiers, and oscillators, which have been already built and tested in the frequency range of 0.5–100 GHz, and even beyond, up to THz. Electromagnetic Band Gap structures (EMBG) have promising applications in microwave and millimeter wave domain. Carbon nanotube (CNTs) have many distinct properties that may be exploited to develop next generation of the sensors. CNTs based biosensors can be used to detect DNA. The detection of the deoxyribonucleic acid (DNA) represents a huge importance in molecular diagnosis of various diseases and early warning of serious illnesses. New DNA detection methods are required to be simple, fast and able to detect DNA with a reduced number of preliminary steps in the DNA sample processing. All these effective methods are termed free-label detection methods and carbon nanotubes (CNTs) play a leading role [2]. On the other hand, the dielectric properties of DNA are used to detect it at various electromagnetic frequencies [3]. In this paper is reported the fabrication of a new EMBG structure CNTs based resonators for DNA detection and also the experimental results at a high frequency.

2. Design and modeling

A schematic view of the design of the electrodes with different values of the impedance is presented in Fig. 1. The EMBG device is designed to have a number of resonant structures with different impedances [4]. The Bragg reflectors include eight periods in order to allow a good coupling of the input wave to the defect and to fabricate a compact device. For CPW transmission lines, the value of impedances have been calculated as $Z_1 = 40\ \Omega$ for the Bragg period having the dimension of the width W = 165 μm, $Z_2 = 116\ \Omega$ for the Bragg period having the gap width S = 165 μm and $Z_d = 46\ \Omega$ for the defect having the dimension of the width $W_d = 330$ μm. The defect in this case represents two coupled lines with 50 μm band gap between them. These differences of the impedance values are given by the wider gap between the signal and ground plane.

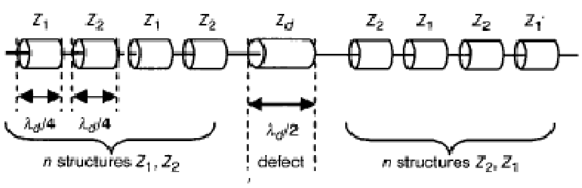
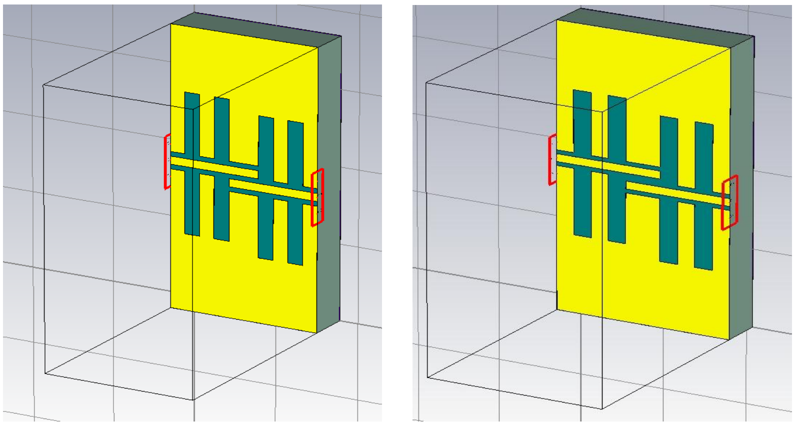


Fig. 1. EMBG resonator structure – schematic view.

The structures were modelled using frequency domain in CST Microwave Studio. The 3D electromagnetic solver (CST Studio Suite) uses time domain simulations and port definition option, S parameter extraction is optimized for electric field distribution (ideal for waveguide port and planar ports with multiple pin definition). The simulations have been performed for two types of EMBG resonators: (a) EMBG structure with 50 μm band gap between coupled lines and (b) EMBG structure with 100 μm band gap between coupled lines. The 3D view of the studied EMBG resonator structure with the distance of 50 μm between the coupled lines obtained by CST is presented in Fig. 2a. The 3D view of the studied EMBG resonator structure with the distance of 100 μm between the coupled lines obtained by CST is presented in Fig. 2b.



a) b)

Fig. 2. 3D view of EMBG resonator structure layout: a) with 50 μm between coupled-lines; b) with 100 μm between coupled-lines.

The simulated S parameters for both EMBG structures are presented in Fig. 3 and Fig. 4. The results of the simulation performed for the two EMBG structures demonstrate different values of the quality factor because of the different values of impedance in the defect region $Z_d = 46\ \Omega$ for 50 μm band gap between coupled lines and $Z_d = 51\ \Omega$ for 100 μm band gap between coupled lines. S_{21} parameter presents two resonant frequencies: 20.5 GHz for the structure with 50 μm between the coupled-lines, and 22.5 GHz, for the structure with 100 μm between the coupled-lines. The two EMBG resonant structures have been designed with the following layers: the substrate layer is 500 μm thick silicon, with a permittivity of 11.9, the second layer is silicon dioxide 0.5 μm thick SiO_2, with a permittivity of 3.9, the third layer is Ti for a good adhesion between SiO_2 and the conductor metal–gold having a thickness of 0.3 μm.

The frequency bandwidth for this structure is 1–30 GHz. The next step was to set boundaries for the structure, so the open boundary was chosen for all the sides of the structure, and with space for the top side. In the final stage of the preparations for the simulation, the waveguide ports were designed, the coordinates were defined, the type of the port was selected, meaning multipin port, with the layout Ground-Signal-Ground (GSG).

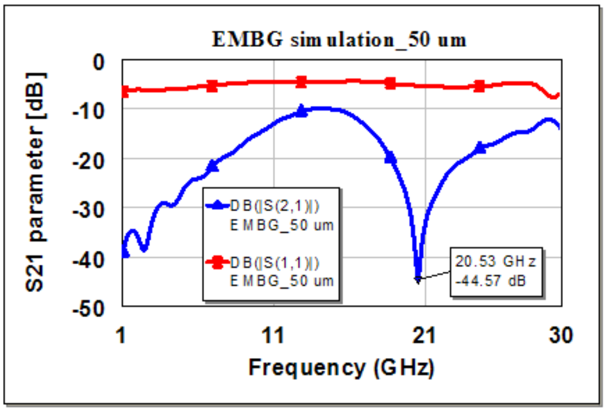


Fig. 3. S parameters of the EMBG resonant structure with 50 μm between coupled-lines.

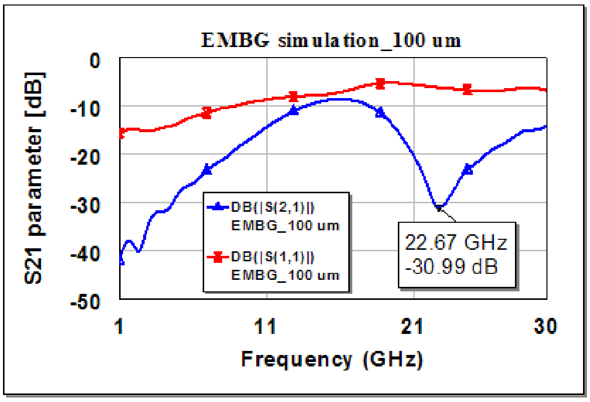
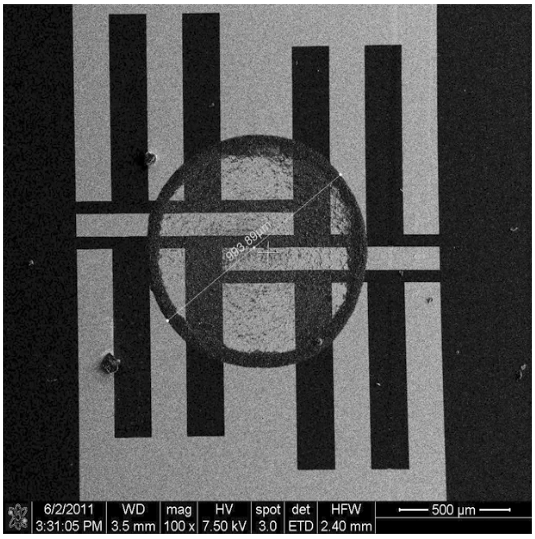


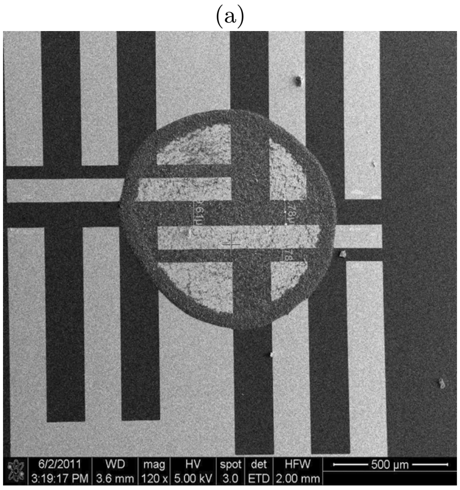
Fig. 4. S parameters of the EMBG resonant structure with 100 μm between coupled-lines.

3. Fabrication

The EMBG structures were manufactured on a SiO_2/high resistivity wafer. The fabrication has been done following the steps: (a) cleaning of the Si wafer (H_2SO_4 + H_2O_2, HF + DIH_2O), (b) thermal oxidation (t_{ox} = 0.5 μm), (c) sputtering Ti/Au deposition with layers of thicknesses 30 nm/300 nm (d) optical lithography consisting of treatment on hot plate at 110°C for 10 minutes, AZ5214 photoresist deposition by spinning with thickness of 1.5 μm, and UV exposure and developing), (e) Ti/Au etching through photoresist mask (f), cleaning in isopropyl alcohol and DI water in a ultrasonic bath for 1 minute. In the area of the coupled lines for the EMBG resonators, we have deposited a drop (0.2 µL) of the MWCNTs with the following concentrations: 10 g /l CNT and the SEM photos can be seen in Fig. 5 (a),(b) for EMBG–CNTs based resonator structures. Further, MWCNTs and DNA composite was prepared (10 g /l CNT with 0.5 g/l DNA) and the corresponding SEM photo in Fig. 6 (b). As can be seen in Fig. 6 (a) and Fig. 6 (b) texture differences are clearly visible i.e. before and after the DNA immobilization.

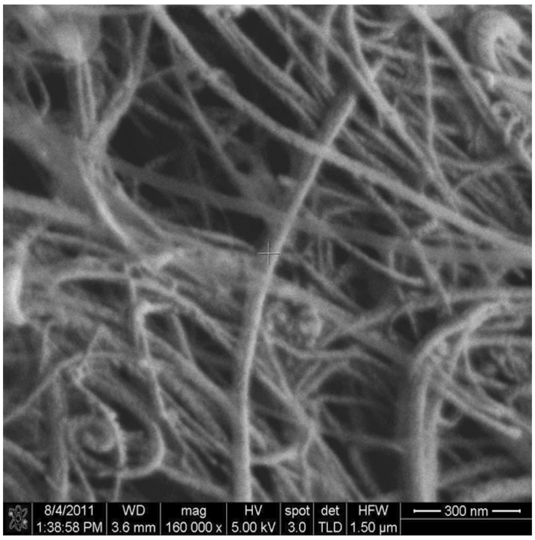


(a)

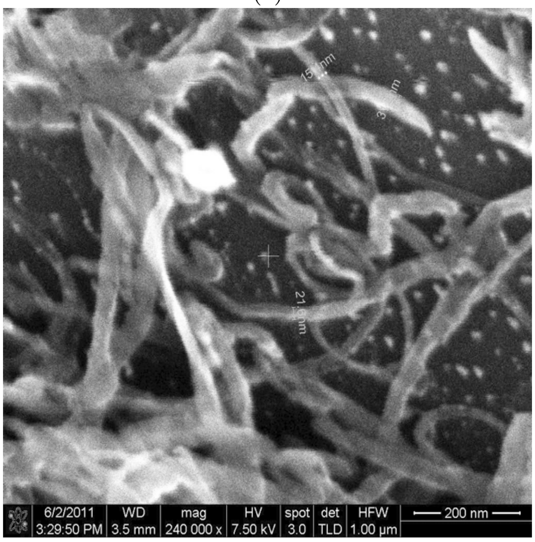


(b)

Fig. 5. The SEM photos showing the deposition of the MWCNTs in the area of the coupled lines: (a) EMBG-CNTs structure with 50 µm the distance between coupled lines (b) EMBG-CNTs structure with 100 µm the distance between coupled lines.



(a)



(b)

Fig. 6. The SEM photos showing the deposition of the MWCNTs and MWCNTs –DNA in the area of the coupled line: (a) detail of the CNTs, (b)detail of CNTs DNA composite after DNA immobilization.

3. Experimental results

Further, we have performed the microwave measurements and for this purpose we have used two types of depositions made on the coupled lines area for the EMBG resonators: coupled lines structure covered only with MWCNTs and coupled lines structure covered with the composite DNA-MWCNTs with the same concentrations as mention before. The coupled lines structures covered with MWCNT and with DNA-MWCNTs functionalized were measured directly on-wafer with a vector network analyzer (VNA) – Anritsu – 37397D connected to a Karl-Suss PM5 on-wafer probe station. The SOLT calibration standard was used to calibrate the system in the frequency range 1–25 GHz.

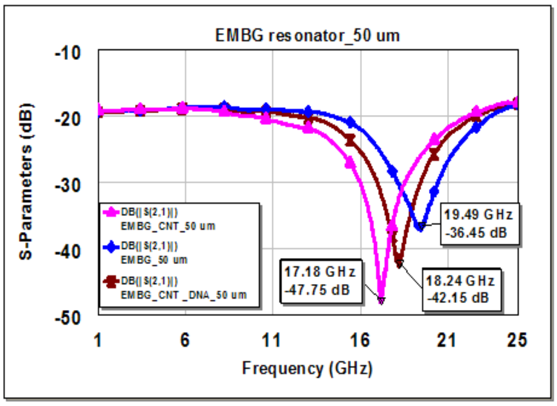


Fig. 7. S_{21} parameters for (1) EMBG resonator, (2) EMBG resonator structure covered with MWCNT and (3) EMBG resonator structure covered with DNA-MWCNT composite for 50 μm between coupled lines structure.

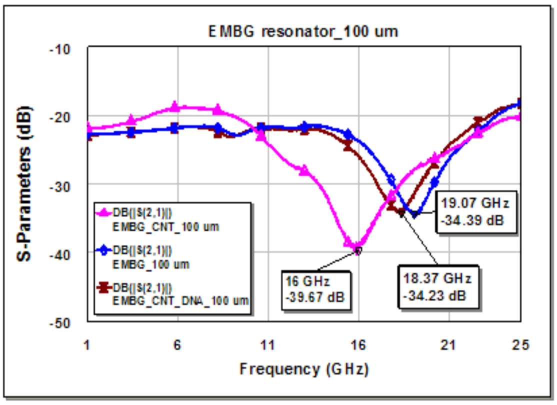


Fig. 8. S_{21} parameters for (1) EMBG resonator, (2) EMBG resonator structure covered with MWCNT and (3) EMBG resonator structure covered with DNA-MWCNT composite for 100 μm between coupled lines structure.

The transmission of the EMBG resonator structure with 50 μm between the coupled lines is presented in Fig. 7 and the results demonstrate a resonance of almost 20

GHz in a good agreement with the simulation results. The results of EMBG CNTs structure or EMBG CNTs DNA structure demonstrate a shift in frequency in comparison with the response of EMBG resonator structure respectively in the left side with 2.30 GHz for structure covered with MWCNTs and also in the left side with 1.3 GHz for the coupled lines covered with DNA-MWCNTs composite. We can see that the microwave signatures of the two compositions (CNTs and CNTs+DNA) are quite different. The DNA signature is expressed by a distinct increase of amplitude up to 6 dB and a frequency shift of the resonance frequency.

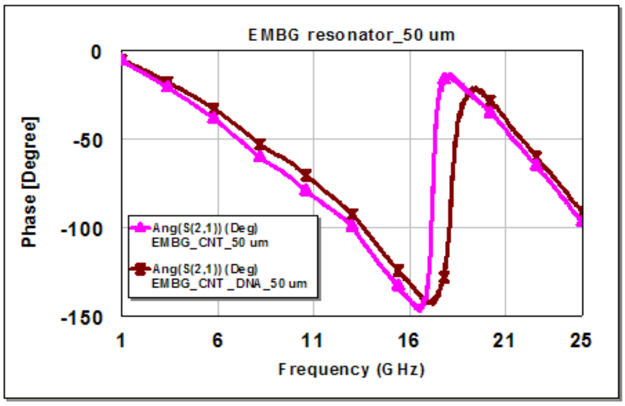


Fig. 9. The phase of the EMBG resonator structure with 50 μm between coupled lines covered by MWCNTs and by the DNA-MWCNT composite.

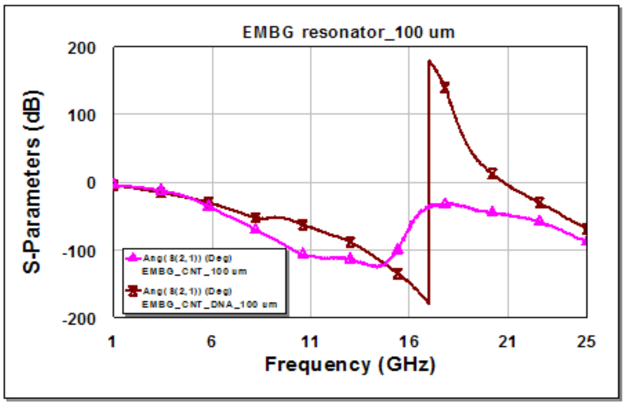


Fig. 10. The phase of the EMBG resonator structure with 100 μm between coupled lines covered by MWCNTs and by the DNA-MWCNT composite.

The transmission of EMBG resonator structure with 100 μm between the coupled lines covered with MWCNT and with DNA-MWCNTs composite are displayed in Fig. 8. The results of EMBG CNTs structure or EMBG CNTs DNA structure in this case demonstrate a shift in frequency in comparison with the response of EMBG resonator structure respectively in the left side 3 GHz for structure covered with MWCNTs and also in the left side with 0.6 GHz for the coupled lines covered with DNA-MWCNTs composite. The frequency shift between the two different resonators covered with MWCNTs+DNA are 1.06 GHz and 2.3 GHz due to different thickness of the MWCNTs+DNA depositions and thus different effective electric permittivity. The most interesting sensing parameter is the phase, which is shifted with an average of 20 degrees in the wide range 6–20 GHz (Figs. 9 and 10).

The distinct behavior in microwave range of MWCNTs and the DNA-MWCNTs composite EMBG resonator structures can be explained by the differences in the microwave effective permittivity which is calculated as around 2 for MWCNTs and 22 for DNA-MWCNTs composite. This is the reason why such a large phase shift occurs in Figs. 9 and 10 for the composite DNA-MWCNTs in contrast to the MWCNTs deposition. Repeated measurements over an interval of several days demonstrated that the electromagnetic responses of both the MWCNTs and the DNA-MWCNTs composite are stable in time. The next step is to use the ss DNA and ds DNA to sense the hybridization phenomena and thus to sense possible unhybridized situations for an early warning of various diseases This can be easily done since the difference in the permittivity between ss DNA and ds DNA is very big approximately 40 [5]. Biological and chemical sensors have been obtain using carbon nanotube. [6]. A DNA sensing using split-ring resonator in order to demonstrate the ss DNA and ds DNA hybridization phenomena using microwaves has been obtain for a resonance frequency of 12 GHz but the shift in frequency is only 20 MHz. [7]

EMBG resonators based on carbon nanotubes can be o solution in the future to revealed better the sensing ss DNA and ds DNA hybridization phenomena at higher frequencies.

4. Conclusions

In conclusion, we demonstrated using a new EMBG resonator structure based on CNTs a detection method of DNA at high frequencies. The CNTs plays a key role in this sensitive detection procedure due to its low effective permittivity in microwaves, which contrasts the high permittivity of the DNA in the same frequency region, and thus playing the role of a scaffold for DNA. The new EMBG structures using as a defect coupled lines with 50 μm the distance between them increase the quality factor of EMBG CNTs based resonator. The results are very important for developing DNA sensing devices in high frequencies domain and can be used to detect a very specific piece of DNA that may be related to a particular disease.

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References

[1] Huang S., Lee Y.H., *A novel approach for the control of wave propagation in electromagnetic band – gap structures*, 4^{th} *International Conference on Microwave and Milimeter Wave Technology Proceedings*, pp. 464–467, 2004.

[2] Gruner G., *Carbon nanotube transistors for biosensing applications*, Anal. Bioanal. Chem, **384**, pp. 322–325, 2006.

[3] Hölzel R., *Dielectric and dielectrophoretic properties of DNA*, IET Nanobiotechnol., **3**, pp. 28–45, 2009.

[4] Pistono E., Ferrari P., Duvillaret L., Coutaz J.L., Jrad A., *Tunable bandpass microwave filters based on defect commandable photonic bandgap waveguides*, Electronics Letters, **39**, 15, pp. 1131–1133, 2003.

[5] Wichaidit C., Peck J.R., Lin Z., Hamers R.J., Hagness S., van der Weide D.W., *Resonant slot antenna as transducers of DNA hybridization; a comutational feasibility study*, *International Microwave Symposium Digest*, pp. 163–166, May 20–25, Phoenix, USA, 2001.

[6] Hunt H.K., Armani A.M., *Label-free biological and chemical sensors*, Nanoscale, **2**, pp. 1544–1599, 2010.

[7] Lee H.-L., Lee H.-S., Yoo K.-H., Yook J.-G., *DNA sensing using split-ring resonator alone at microwave regime*, J. Appl. Phys., **108**, p. 014908, 2010.