Nano-Antenna for NMR Spectroscopy

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Abstract—**This paper presents a potential new way to detect radio-frequency signals originating from nuclear magnetic resonance in the presence of a high static magnetic field. Our work concerns the design and the characterization of a nano-antenna based on nanoelectromechanical systems. For this purpose, single carbon nanotube devices have been selected for their unique interplay between electrical and mechanical characteristics. Following, the careful determinations of the field emission properties and the resonance frequencies of the device, the detection of a radio-frequency signal from an external radio-frequency source is shown to be realistic. Work is in progress in order to validate the use of this type of nano-probe for the NMR investigations of reference and real samples.**

***Keywords**- NEMS; Nano-antenna; NMR; Field-emission*.

I. INTRODUCTION

Nuclear Magnetic Resonance spectroscopy is a powerful technique to determine structures, molecular conformations, electronic and dynamical properties of liquids and solids samples. Recently, NMR has received considerable interest to perform experiments at the nanoscale on micrometer sized samples in order to determine the local properties of matter [1]. Our aim is to use NanoElectroMechanical Systems (NEMS) based on carbon nanotube (CNT) known to present electro-mechanical resonances in the MHz range [2]. This new type of device may substitute standard NMR probe and improve sensitivity and resolution.

II. MATERIALS & METHODS

A. *Carbon Nanotube*

Figure 1. shows a CNT built from one graphene rolled sheet. The symmetry and the structure of CNT control their electronic properties. They can be either metallic or semiconductor.

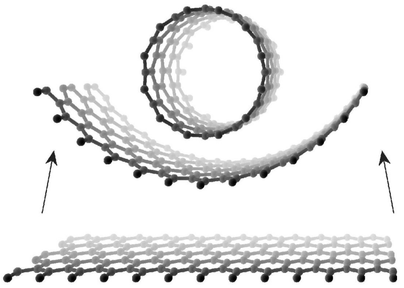

Figure 1. A graphene sheet rolled up to form a carbon nanotube.

In our case, metallic multiwall CNT have been selected. The interplay between the electrical and mechanical characteristics (stiffness and resonance) of the CNT constitute a promising NanoElectroMechanical Systems. This coupling between electrical and mechanical characteristics turns this system to be a hypersensitive detector of radio-frequency signals [3].

Figure 2 presents the dependance of the resonance frequency of the CNT with radius and length [2].

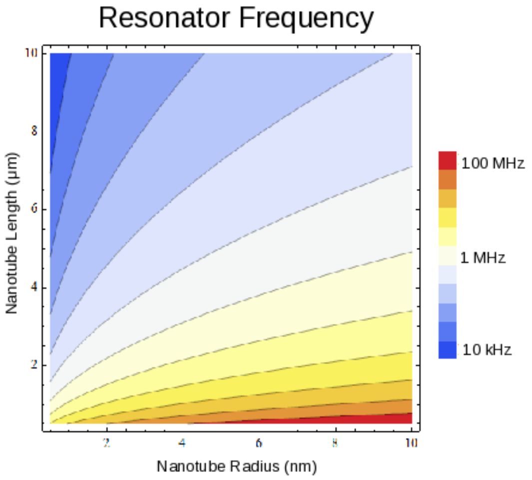

Figure 2. Resonance frequency as a function of carbon nanotube length and radius [From Ref.(2)].

From Scanning Electron Microscopy images (not shown here), the CNT characteristics (radius about 8 nm and length 500 nm) have been determined for our sensors, giving a resonance frequency of about 10 MHz.

This value is compatible with frequencies generally encountered in conventional NMR.

B. NMR spectroscopy

A NMR experiment consists to detect radio frequency signals originating from an ensemble of spins from nuclei like ^{13}C, ^{1}H, ^{31}P polarized by a strong static field (4.7 Tesla in our case). The magnetization of the sample is tilted by RF pulses emitted from a macroscopic antenna (1cm sized coil). The relaxation behavior to equilibrium generates an electromagnetic field at the Larmor frequency, proportional to the applied magnetic field and characteristic of the observed nucleus. In principle, this recovery signal is detected by a macroscopic or microscopic receiving antenna placed in the vicinity of the sample. The Fourier transform of the recorded signal provides a spectrum containing spectroscopic information of the sample under investigation. In this report, we downsized the receiver to the nanoscale with the use of CNT-NEMS.

III. EXPERIMENTS

A. CNT-NEMS characterization

Figure 3 shows the schematic setup used to polarize the CNT in vacuum with a V_{DC} bias voltage.

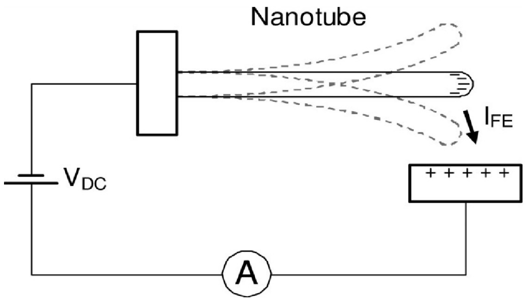

Figure 3. Field-emission effect on CNT [2].

V_{DC} is applied between the nanotube and the counter electrode, causing field emission from the nanotube to the counter electrode. A pico-amperemeter is used to measure the direct field-emission current, as presented in figure 5.

B. Detection of RF signal

Figure 4 shows the experimental setup made of an external source of RF signal which can be a standard antenna or in the future our NMR sample, the CNT receiver and the detection/digitization implemented within the NMR console.

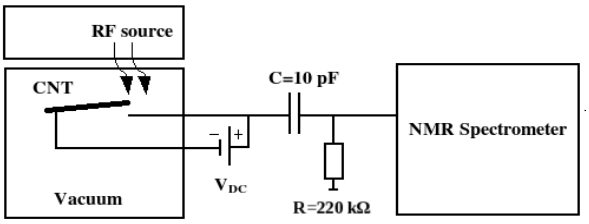

Figure 4. Schematic view of the setup used to detect a RF signal from an external source with a CNT-NEMS.

If the nanotube is biased sufficiently high by V_{DC}, one observes an electronic field-emission current (see figure 5). In this case, the RF signal can be detected via mechanical vibrations of the charged CNT and an alternative current is transmitted. The signal is filtered by a high pass filter in order to prevent the DC current component to damage the acquisition board of the NMR spectrometer. The AC signal is digitized and analyzed on the NMR console (see figure 6).

IV. RESULTS

Figure 5 presents the direct field-emission current from the charged CNT as a function of the bias voltage. From this measurement , it can be seen that a V_{DC} between 60 and 90 Volts gives a direct current between 40 and 100 µA. A good compromise is to measure, in this range, the alternative current component injected by the RF signal.

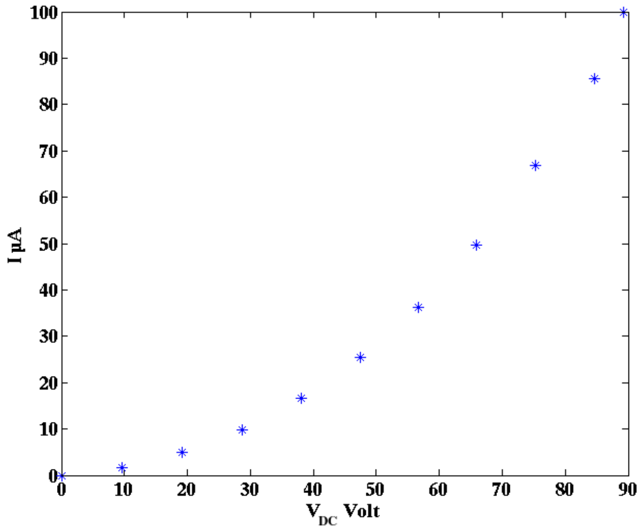

Figure 5. Direct field-emission current characteristics.

Figure 6 shows the intensity of the detected RF signal versus the frequency from 2 to 13 MHz . The intensity of the signal reaches a maximum at a resonance frequency experimentally found at 12.5 Mhz. This value is in very good agreement with the calculated frequency expected from CNT characteristics. Increasing V_{DC} from 60 Volts to 89 Volts at this frequency, enhances by a factor 2 the detected alternative current.

As soon as the CNT-NEMS device is capable to carry high direct current, higher polarization voltage seems to provide better sensitivity to detect RF signal.

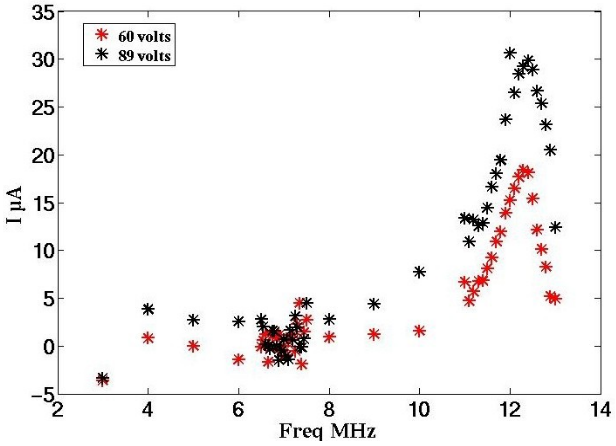

Figure 6. Detected alternative current component emitted from an external source of RF signals as a function of frequency.

V. CONCLUSION

In this report, we demonstrate the possibility to use NEMS based on CNT to detect RF signals in the conventional range of frequencies used in NMR experiments. The characterization of the device allows to determine its resonance frequency and an optimal bias voltage to gain higher sensitivity at an ultimate nanometer size.

Work is under progress to validate this approach for the detection of NMR signals.

REFERENCES

[1] C. L. Degena, M. Poggioa,b, H. J. Mamina, C. T. Rettnera, and D. Rugara, “Nanoscale magnetic resonance imaging ”, in PNAS, vol. 106, no. 5, pp. 1313-1317, February 3, 2009.

[2] Jeffery A. Weldon, B. Aleman, A. Sussman, W. Gannet, and A. Zettl, "Sustained Mechanical Self-Oscillations in Carbon Nanotube", in Nano Letters, Vol. 10, pp. 1728-1733, April 2010.

[3] K. Jensen, J. Weldon, H. Garcia, and A. Zettl, "Nanotube Radio", in Nano Letters, Vol. 7, No. 11, pp. 3508-3511, october 2007.