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Signal amplification in a synchronized field emission NEMS

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Abstract – We present in this paper a study on highly resistive SiC nanowires in a singly clamped geometry. We demonstrate that these field emission nanoelectromechanical systems (NEMS) can be synchronized to an external AC signal and act as an amplifier.

1 INTRODUCTION

A Nanoelectromechanical system (NEMS) is an electrical device capable of spatial motion at the nanoscale. Devices based on this principle are expected to perform ultrasensitive mass or force detection, for instance in biological applications, as well as to have potential for miniaturized, very low-power consumption RF switches and time bases, for wireless applications. However, after more than ten years of development, their frequency stability is still the main obstacle for applications that aim to replace the quartz technology. Recently, it has been shown that several categories of NEMS can self-oscillate either by extrinsic feedback in a phase locked loop type configuration or with an intrinsic nanoscale active mechanism [1-4]. This opens the path for exploiting the ubiquitous cooperative phenomenon of self-oscillators: synchronization as observed in neurons, heart/breathing systems, population of flashing fireflies, lasers, charge density waves or Josephson junctions. Synchronization can be used for example for signal processing, filters, amplifiers, more sensitive sensors or clinical treatment of Parkinson disease. A major interest of synchronization for RF-NEMS applications is the possibility to stabilize their resonant frequency.

In the next paragraph we will present our experimental results on highly resistive self-

oscillating nanowires in a singly-clamped geometry. We will show that these devices show synchronization behavior under specific conditions; the third paragraph is dedicated to a basic analysis of the various mechanism involved in this phenomenon.

2 RESULTS

The samples studied in this experiment are SiC nanowires (see figure 1) with lengths of several tenth of microns and diameters around 100 nm attached to sharp tungsten tips (see table 1). The experimental set up consists of a UHV chamber with a scanning electron microscope column. The sample is placed on a XYZ piezoelectric nanomanipulator in front of a counter electrode.

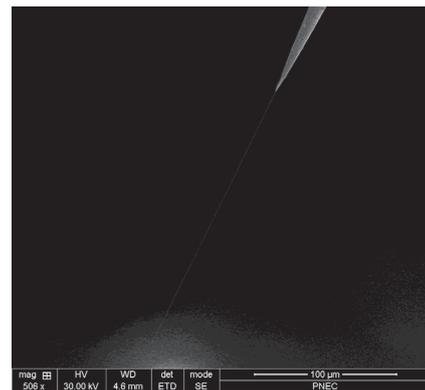


Figure 1: Scanning electron microscope image of sample 2.

2.1 Self-oscillation in field emission

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A negative DC voltage of about 100 V is applied to the sample in order to be in the field emission regime, i.e. in the regime where electrons tunnel out of the nanowire toward the counter electrode. Above a field emission current of several hundreds of pA the nanowire position as well as its emitted current start to self-oscillate. The frequency of oscillation corresponds to the mechanical resonant frequency of the nanowire. This self-oscillation is due to an electromechanical instability of the system as described in details in [2-3]. It can be seen as a positive feedback loop between the position of the wire apex and its voltage and is similar to a vacuum tube oscillator where the role of the grid is played by the position.

Parameter	Sample 1	Sample 2
<i>Length</i>	200 μm	200 μm
<i>Radius</i>	110 nm	160 nm
<i>Frequency</i>	45 kHz	32 kHz
<i>Current</i>	3 nA	150 pA

Table 1: Experimental parameters of the samples.

2.2 Synchronization

We have applied an additional moderate AC excitation (either by electrostatic or piezoelectric actuation) that locked the self-oscillation natural frequency of the nanowire to the external frequency as long as both frequencies do not deviate from each other by more than 10 %. Here we will concentrate on the electrostatic actuation.

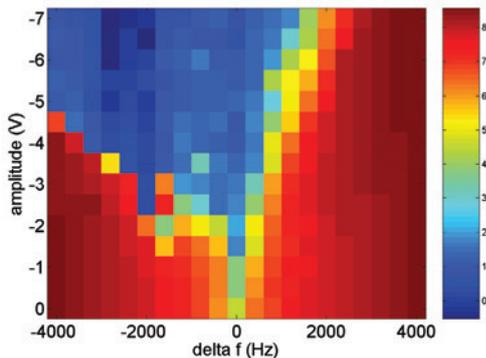


Figure 2: Dephasing diagram for various frequency mismatches (Δf) between self-oscillator frequency and external excitation and various excitation amplitudes in volt. The blue region corresponds to the locked or synchronized state and the red region to the unlocked state.

Figure 2 presents a typical synchronization diagram of a SiC sample showing the usual Arnold tongue shape. Such a diagram is obtained by recording the

instantaneous field emission current with a secondary electron detector for various AC amplitudes and frequencies. Then, the phase of the self-oscillating signal is extracted by numerical analysis and compared to the external AC signal. As the system is rather noisy synchronization takes place only for an AC voltage above a threshold of the order of 1 Volt. Then, the higher the voltage, the higher the detuning range for synchronization. The amplitude of the synchronized AC signal is of the same order of magnitude as the DC current.

3 ANALYSIS

In a field emission NEMS, the current flowing through a nanowire splits into 4 different currents : a capacitive current, a motional current, a voltage modulated field emission current and a spatially modulated field emission current. This last current is often the dominant one and is at the origin of the electromechanical instability. Now, if an additional AC signal is applied, the capacitive current is a parasitic signal that can be reduced by carefully designing the capacitive environment and is not dominant in our case. The second current is a transduction current typical in NEMS actuated capacitively but is efficient only in the close vicinity of the resonant frequency (the frequency range is directly related to the quality factor of this forced oscillator). The third current, i.e. the voltage modulated current, is the one used in the old vacuum tube amplifier and is amplified by the synchronization phenomena that coupled it non-linearly with the fourth current improving both amplification and bandwidth.

4 CONCLUSION

We presented in this paper the electromechanical behavior of SiC nanowires in a field emission configuration. We showed that in the self-oscillation regime, these devices can be synchronized to an external AC signal in a wider range than a simple resonant circuit. This non-linear regime can be used as an electrical and force amplifier with potential application for ultrasound detection.

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