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Synchronization of nanowire self-oscillators

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Abstract

We performed field emission measurements with SiC nanowires self-oscillators. Applying an additional AC excitation locks 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 %. An unusual behavior of the phase of the locked self-oscillator is observed showing for instance spontaneous phase modulated signal generation at the nanoscale.

1. Introduction

A Nanoelectromechanical system (NEMS) is an electrical device capable of spatial motion at the nanoscale. This type of device is promising for ultrasensitive force and mass detection, in biological applications, and it has potential for miniaturized, very low-power consumption RF switches and time bases, for wireless applications. 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]. However, after a decade of development, the frequency stability is still the main obstacle for applications that aim to replace the quartz technology. Recently, the NEMS community started to explore 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.

2. Experimental system

We studied SiC semiconductor nanowires with lengths of several tenths of microns and diameters around 100 nm attached to tungsten tips. 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. A negative DC voltage of about 100 V is necessary to be in the field emission regime, where electrons tunnel out of the nanowire toward the counter electrode. Above a field emission current of several hundreds of pA the nanowire apex and the field emission 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.

3. Results

We have applied an additional electrostatic AC force with a counter electrode placed at a few microns of the sample. This force 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 %. The difference between both frequencies is called the detuning frequency

3.1 Arnold tongue

Synchronization depends on the detuning frequency and on the amplitude of the external force. If the detuning is too important the self-oscillator unlocks or desynchronizes. Generally, increasing the amplitude increases as well the detuning value for unlocking. The region where a self-oscillator can be synchronized is called an Arnold tongue and is shown in figure 1.

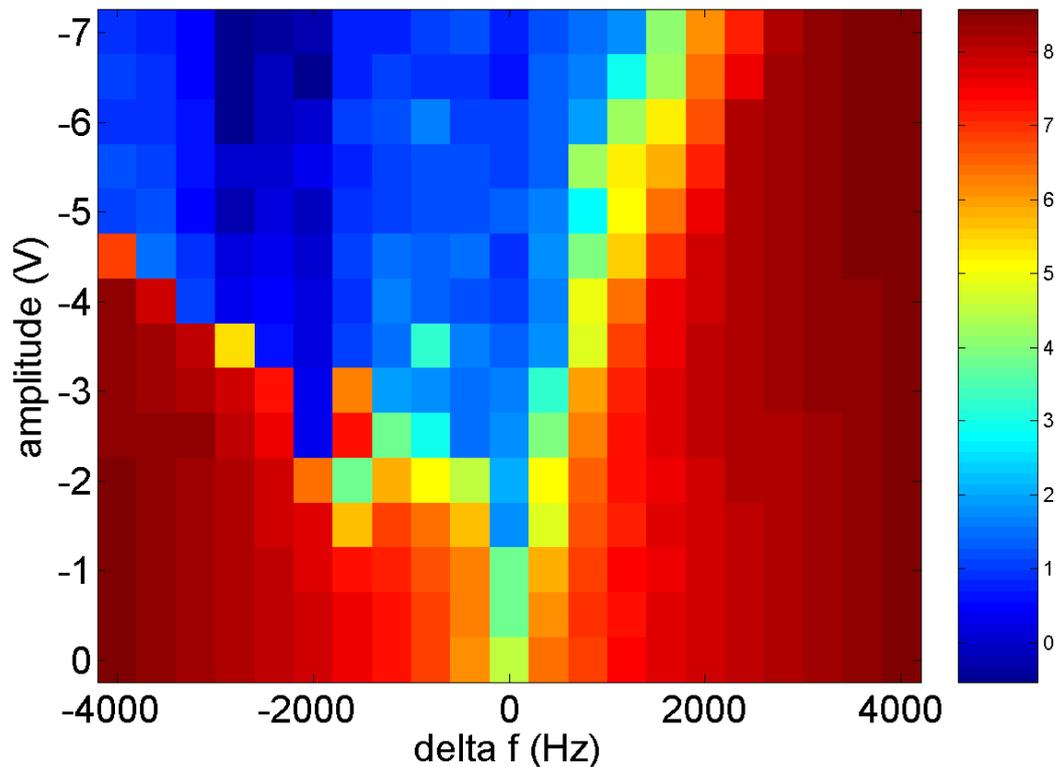


Figure 1: Dephasing diagram for various frequency mismatches (Δf) between self-oscillator frequency and external excitation and various excitation amplitudes in volt. The blue region is the Arnold tongue and corresponds to the locked or synchronized state and the red region to the unlocked state.

3.2 Phase dynamics

For strong forcing the self-oscillator can not be described by a single overdamped degree of freedom like the phase. Amplitude of oscillations and phase are coupled which leads to a transition from overdamped to damped and then to phase and amplitude self-oscillations in the rotating frame. The phase dynamics was obtained by Hilbert transform of the field emission current and substraction of phase drift due to the external drive in order to be in the rotating frame.

4. Conclusion

This paper presented 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 for the generation of frequency modulated signals at the nanoscale.

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7. References

1. A. Ayari, P. Vincent, S. Perisanu, et al., "Self-Oscillations in Field Emission Nanowire Mechanical Resonators: A Nanometric dc-ac Conversion," *Nano Letters*, **7**, July 2007, pp. 2252-2257.
2. A. Lazarus, T. Barois, S. Perisanu, et al., "Simple modeling of self-oscillations in nanoelectromechanical systems," *Applied physics Letters*, **96**, May 2010, pp. 193114-193116.
3. A. Lazarus, E. de Langre, P. Manneville, et al., "Statics and dynamics of a nanowire in field emission," *International Journal of Mechanical Sciences*, **52**, Nov 2010, pp. 1396-1406.
4. P. G. Steeneken, K. Le Phan, M. J. Goossens, et al., "Piezoresistive heat engine and refrigerator," *Nature Physics*, **7**, Apr 2011, pp. 354-359.

5. T. Barois, et al., "Role of fluctuations and nonlinearities on field emission nanomechanical self-oscillators," *Physical Review B*, **88**, Nov 2013, pp. 195428.
6. A. Smith and C. Jones, "A Compact, Broadband Antenna," International Symposium on Antennas and Propagation Digest, Atlanta, GA, 2004, pp. 1036-1039.
7. A. Smith and C. Jones, "An Improved Compact, Broadband Antenna," International Symposium on Antennas and Propagation, London, UK, 2005.