European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

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Year 3: 1 July 2014 - 30 June 2015 (*Ongoing Action*)

NEW PRINCIPLE OF GAS MOLECULE DETECTION BASED ON NONLINEAR ELECTROMAGNETIC RESPONSE OF GRAPHENE NANORIBBONS

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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European Network on New Sensing Technologies
for Air-Pollution Control and Environmental Sustainability

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by the EU Framework Programme

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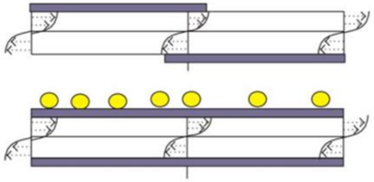
Scientific context and objectives in the Action

Background / Problem statement: Basic research in the Action: theoretical modeling and simulation of the response of acoustic piezoelectric resonators in AQC (specifically, a theory of QCM and SAW sensors).

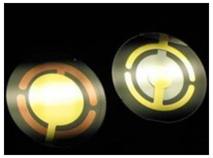
New project: theory of graphene-based nanosystems for sensing

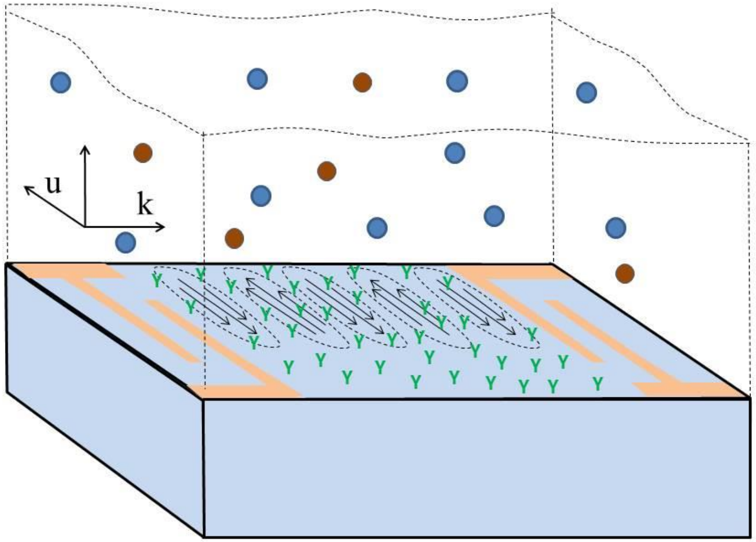
- **WG2 projects**.**Our main objective** is to develop basic theoretical description and modeling of the acoustical sensors for AQC and biomedical applications, in particular, for health care applications with a final goal of software product for the experimental data analysis.
- Another goal is to **develop a new theoretical approach to NEMS graphene nanoribbon for sensing in AQC and NP** monitoring applications



Research activities:

1. Modelling of the response of acoustic SAW-based and QCM sensors in AQC





Research goals and objectives: acoustic sensors are standard high resolution analytical tools for gravimetrical measurements.

The new challenge is the analysis of soft and biological materials where the viscous losses of energy can essentially Influence measured acoustic sensors characteristics :

Examples : aerosols, bacterial toxins, proteins, polymer /organic coatings

$$\frac{\Delta V}{V}(m,\mathrm{G}^*), \frac{\Delta f}{f}(m,G^*), \gamma(m,G)$$

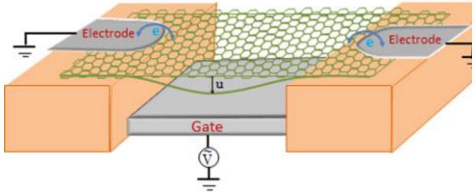
Current research activities (a new project):

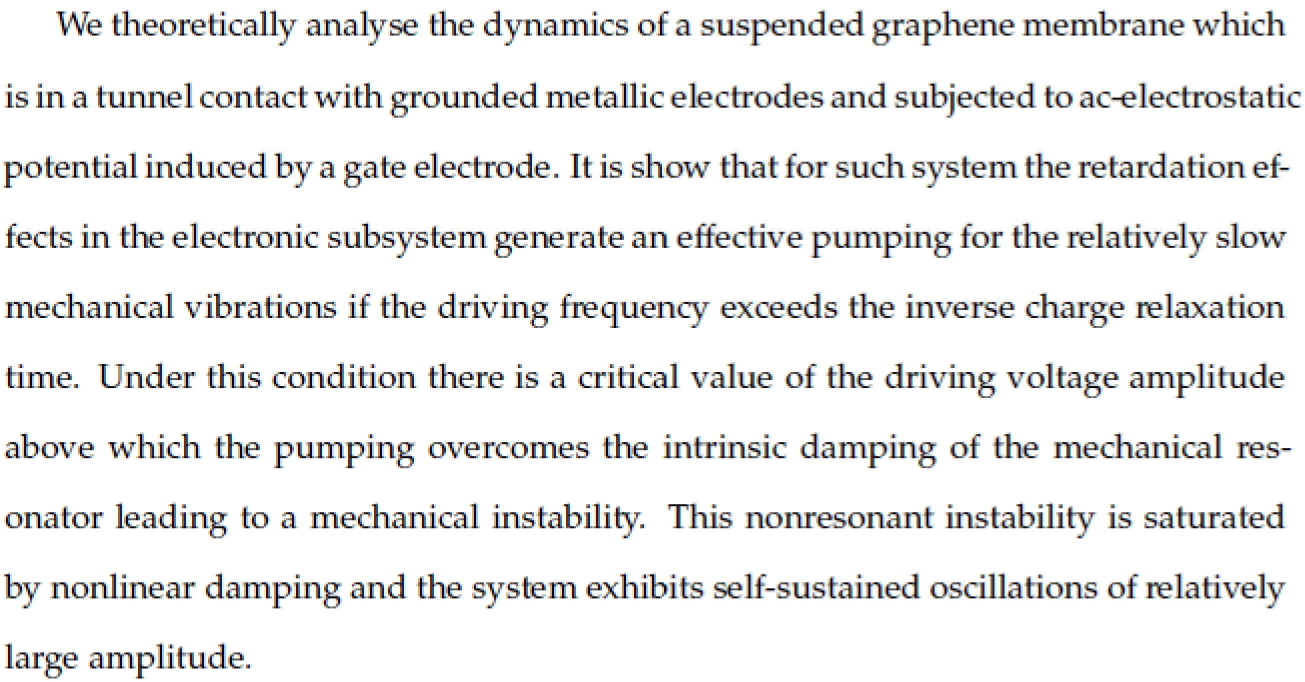
2. NONLINEAR ELECTROMAGNETIC RESPONSE OF GRAPHENE NANORIBBONS

- **Problem statement: Nonresonant high frequency excitation of mechanical vibrations in graphene-based nanoresonator and potential applications in sensors**
- **Co-workers: M. Eriksson, L.Gorelik, M.Voinova (Chalmers University of Technology, Goteborg, Sweden)**

Current research activities (a new project):

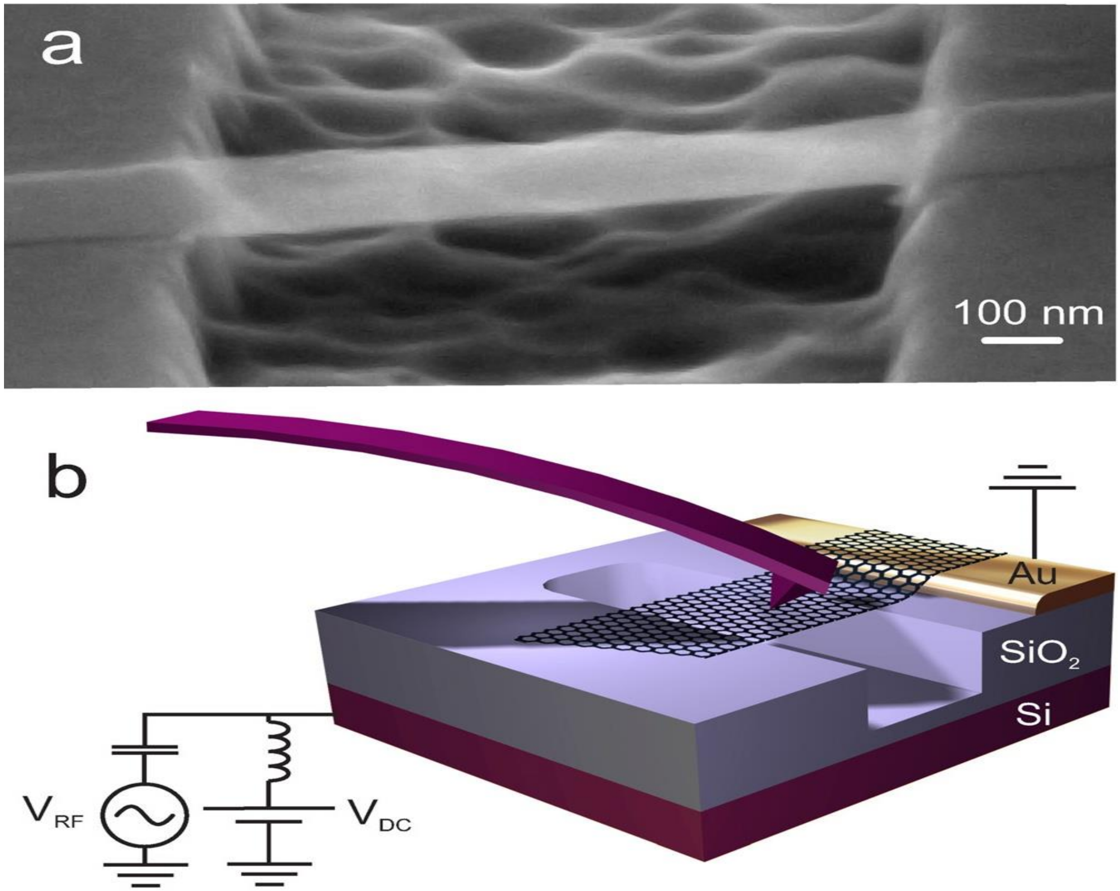
2. NONLINEAR ELECTROMAGNETIC RESPONSE OF GRAPHENE NANORIBBONS





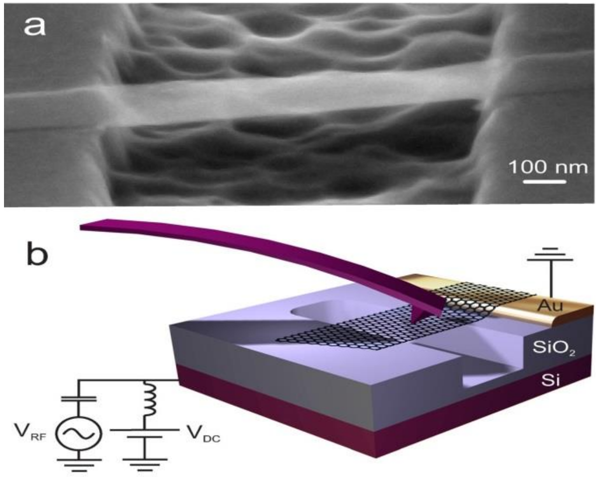
We theoretically analyse the dynamics of a suspended graphene membrane which is in a tunnel contact with grounded metallic electrodes and subjected to ac-electrostatic potential induced by a gate electrode. It is show that for such system the retardation effects in the electronic subsystem generate an effective pumping for the relatively slow mechanical vibrations if the driving frequency exceeds the inverse charge relaxation time. Under this condition there is a critical value of the driving voltage amplitude above which the pumping overcomes the intrinsic damping of the mechanical resonator leading to a mechanical instability. This nonresonant instability is saturated by nonlinear damping and the system exhibits self-sustained oscillations of relatively large amplitude.

The system under consideration



Experiments (picture):
D.Garcia-Sanchez, A.M. ven der Zande, A.San Paulo, B.Lassagne, P.L.McEuen, and A.Bachtold. Imaging mechanical vibrations in suspended graphene sheets. Nano Letters 8 (2008)

Resonance excitation of graphene nano-ribbon*

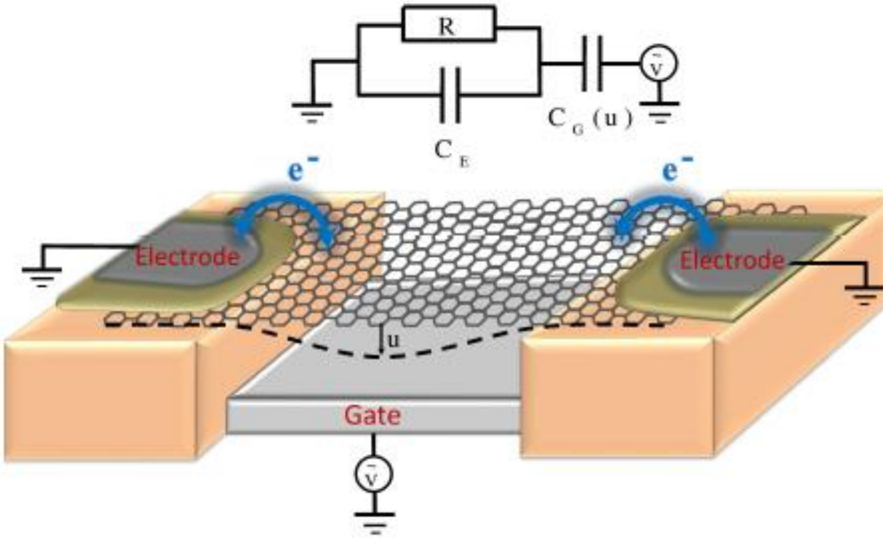


- The graphene system was excited at resonance conditions (the application of oscillating RF voltage to graphene resulting in electrostatic force oscillations at resonance frequency)

Experiments :

***) D.Garcia-Sanchez, A.M. ven der Zande, A.San Paulo, B.Lassagne, P.L.McEuen, and A.Bachtold. Imaging mechanical vibrations in suspended graphene sheets. Nano Letters 8 (2008)**

- **Fig.1: the system: suspended graphene nanoribbon**



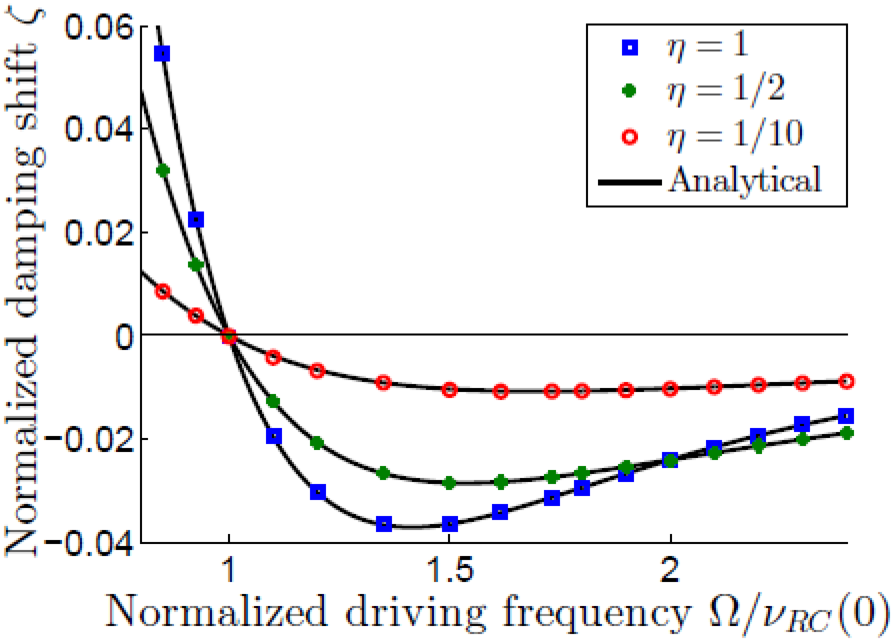


Figure 2: Markers indicate numerical simulations of the normalized damping shift of (Eq. 1) and (Eq. 2) for different values of η and parameter values $\omega_m/\nu_{RC}(0) = 10^{-2}$ and $u/d \sim 10^{-2}$. The solid black lines are the corresponding analytical solutions ζ from (Eq. 7). When the driving frequency exceeds the inverse retardation time $\nu_{RC}(0)$ the damping shifts becomes negative.

NONLINEAR ELECTROMAGNETIC RESPONSE OF GRAPHENE NANORIBBONS

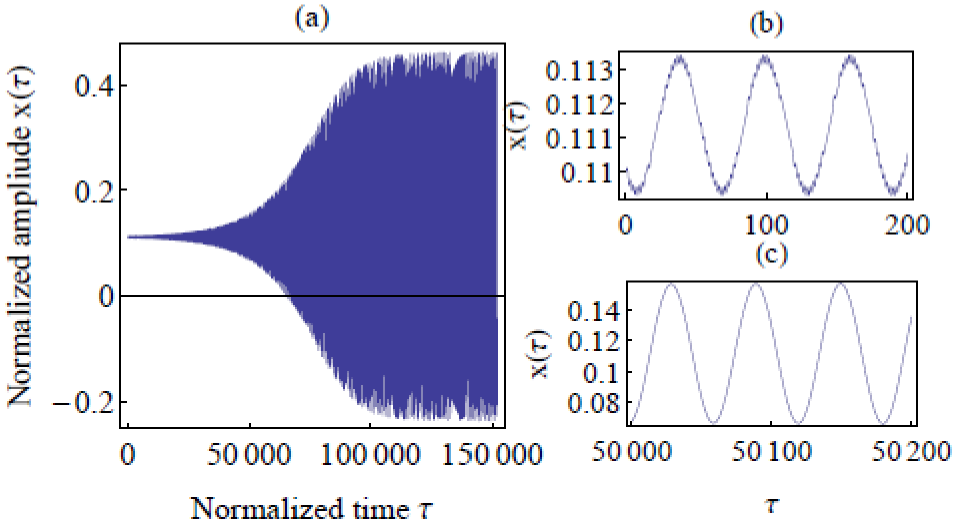


Figure 3: Time evolution of the membrane deflection obtained by direct numerical simulations of (Eq. 1) and (Eq. 2) including the nonlinear damping in the form discussed in the text. The parameters $\epsilon = 10^{-2}/2$, $\Omega/\nu_{RC}(0) = 3/2$, $\omega_m/\nu_{RC}(0) = 10^{-1}$, $Q = 10^4$ and $a = d/20$ were chosen in order to clearly demonstrate (a) the exponential amplitude growth and saturation due to the nonlinear damping and (b) small amplitude modulation of fast oscillations with frequency 2Ω. This modulation is not visible in (c) since the ω_m component has been pumped to a relatively large amplitude.

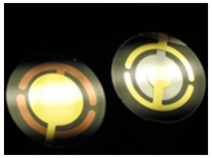
CONCLUSIONS

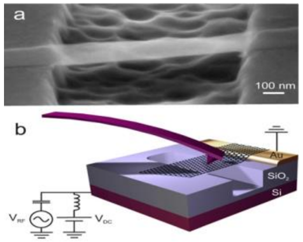
We present:

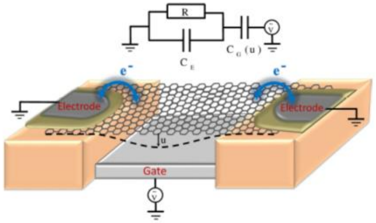
*** Theoretical analyse of the predicted phenomenon of self-sustained mechanical vibrations in the system of the suspended graphene nanoribbon subjected to the high frequency electro-magnetic field.**

*** Theory shows the principal way of applications of electromechanical effects in graphene nano-ribbons for optomechanical transduction.**

Suggested **R&I Needs** for future research







- Experimental verification of the theoretically predicted phenomenon of **nonresonant mechanism of high frequency excitation** of mechanical oscillations of graphene-based NEMS
- ***Innovative:*** we show the possibility to control the Q-factor of the graphene-based nanoresonator by the amplitude, frequency or amplitude and frequency of the external electromagnetic field

Suggested **R&I Needs** for future research to Action WGs/SIGs General Assembly

Experimental realization of the system of graphene-based electromechanical system suspended over the trench

Future theoretical development and modelling:

The analysis of charge sensitivity of the suggested graphene-based nanoelectromechanical sensor

Theoretical modelling and experimental verification of the gas sensing options (specifically, for the ammonia gas)