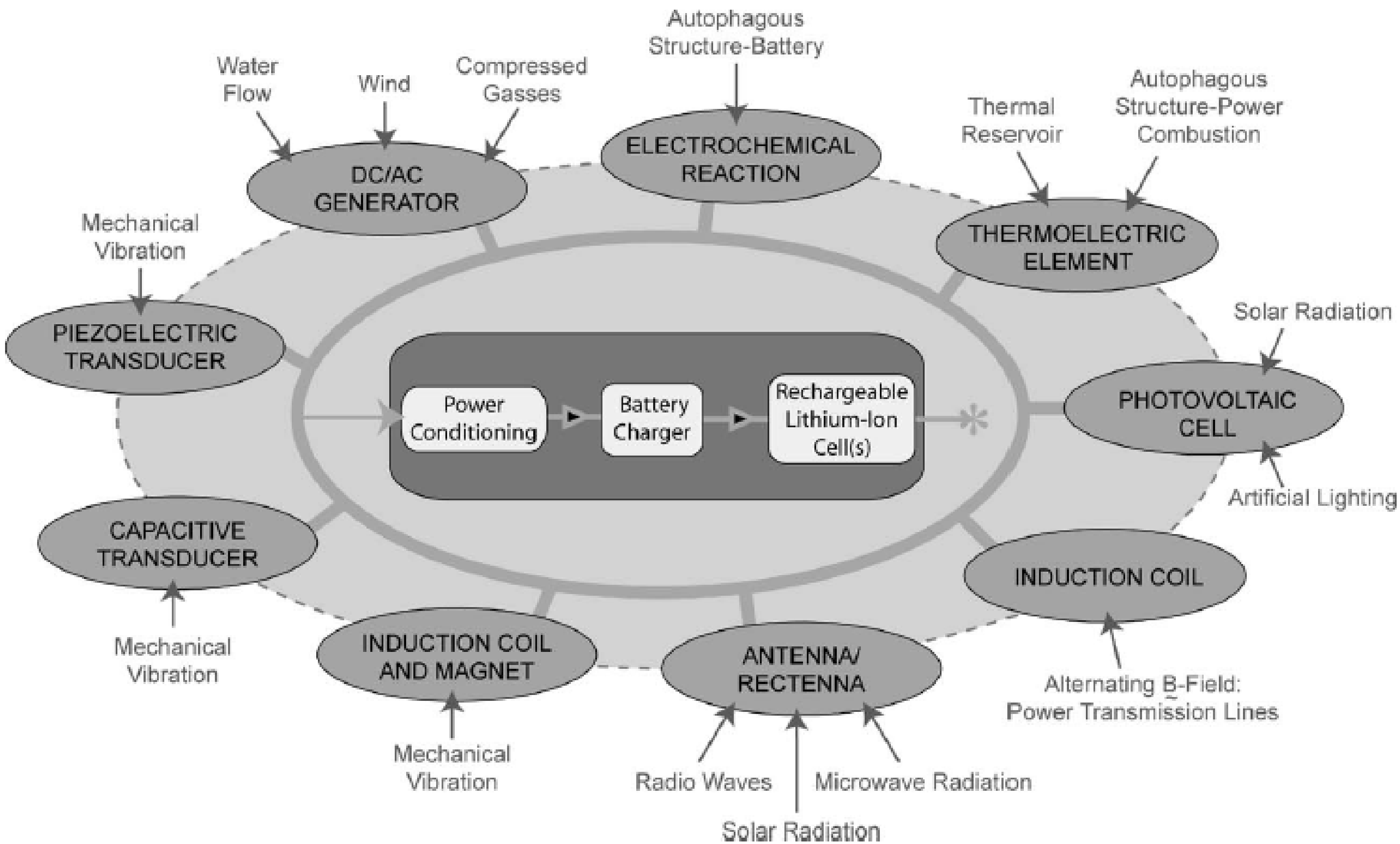
Conversion of mechanical noise into useful electrical energy using piezoelectric 2D materials

G. Abadal and F. Torres
NOEMS for ENERGY LABORATORY (NANERG LAB)
Departament d'Enginyeria Electrònica, Escola d'Enginyeria, Universitat Autònoma de Barcelona, Bellaterra (Barcelona), SPAIN
M. López-Suárez and L. Gammaitoni
NiPS Laboratory, Dipartimento di Fisica - Università di Perugia, I-06123 Perugia, ITALY
W.J. Venstra
Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628CJ, THE NETHERLANDS
R. Rurali
Institut de Ciència de Materials de Barcelona (ICMAB-CSIC) Campus de Bellaterra, 08193 Bellaterra, Barcelona, Spain

7th International Conference on Unsolved Problems on Noise
Barcelona, Casa Convalescència, Spain, July 13-17 2015

Energy Harvesting (EH)



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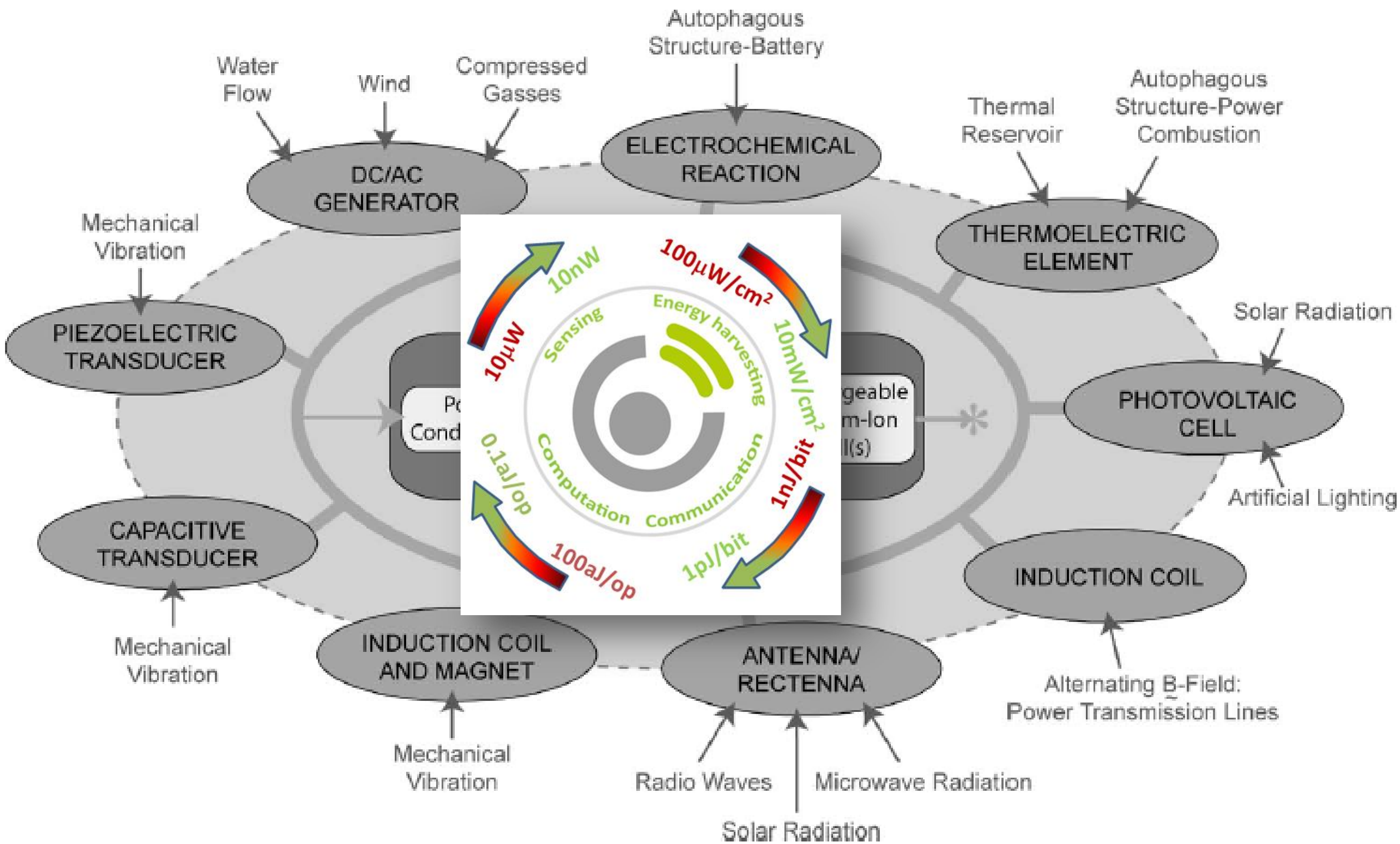

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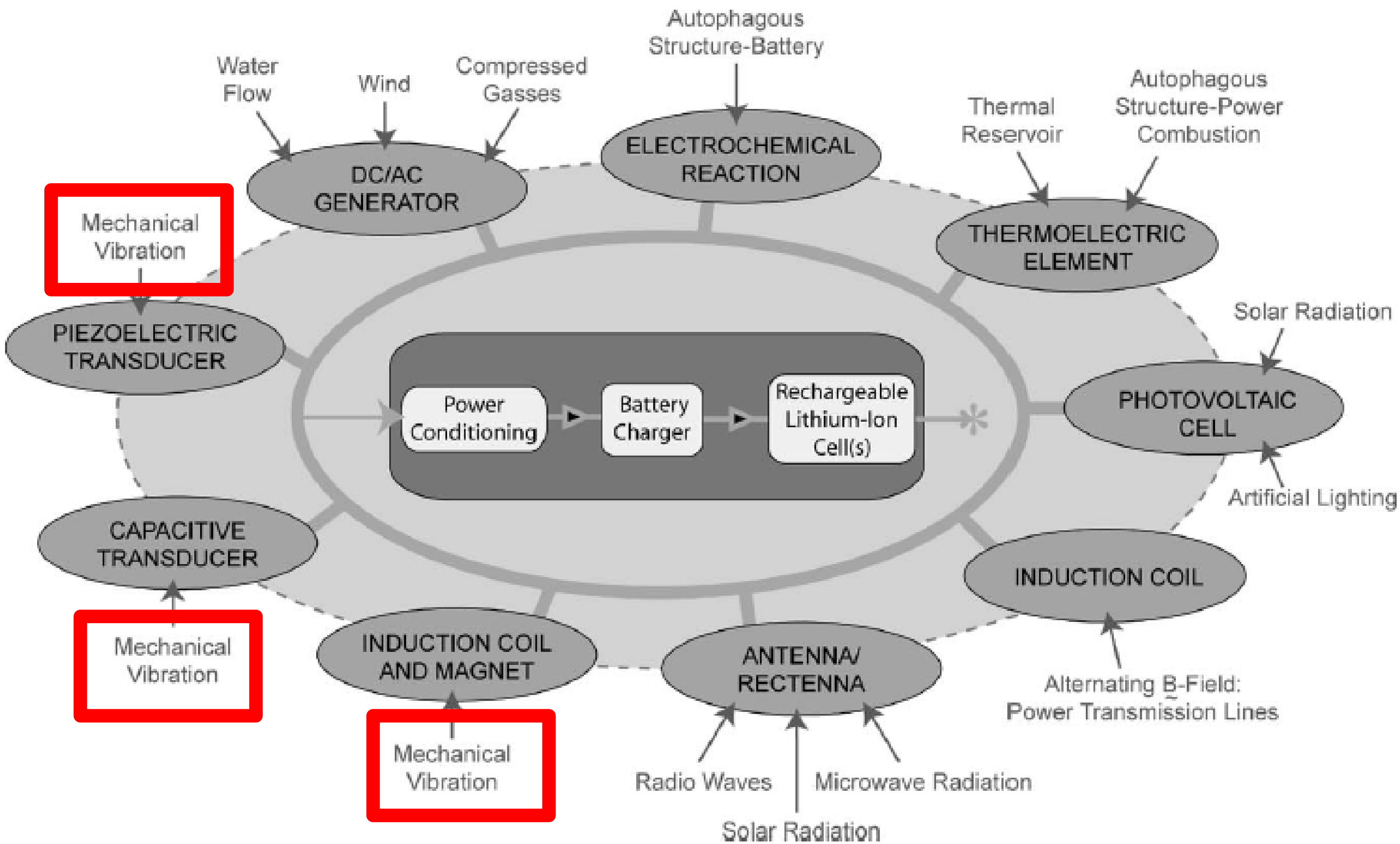
Vibration Energy Harvesting (VEH)



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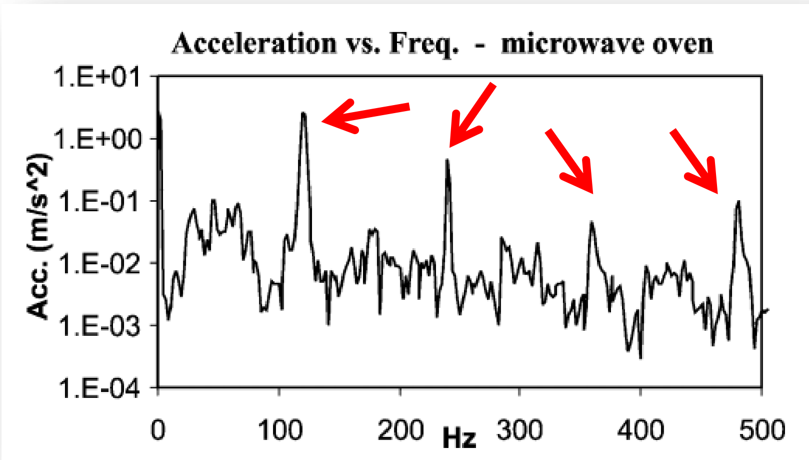
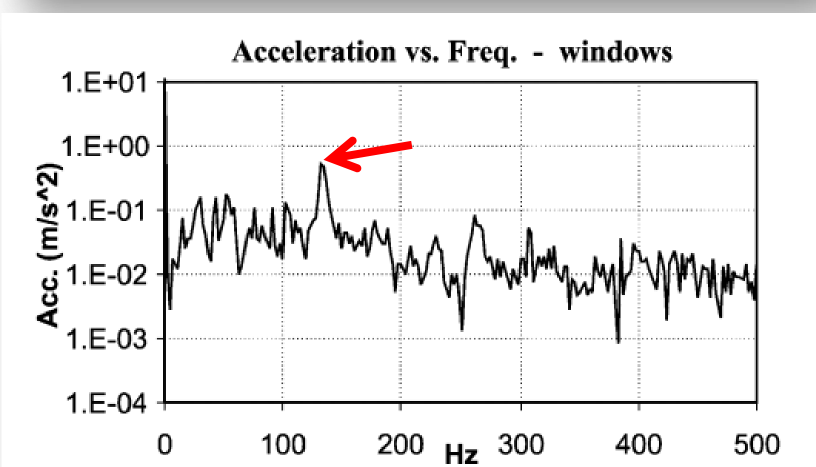
Vibration Energy Harvesting (VEH)

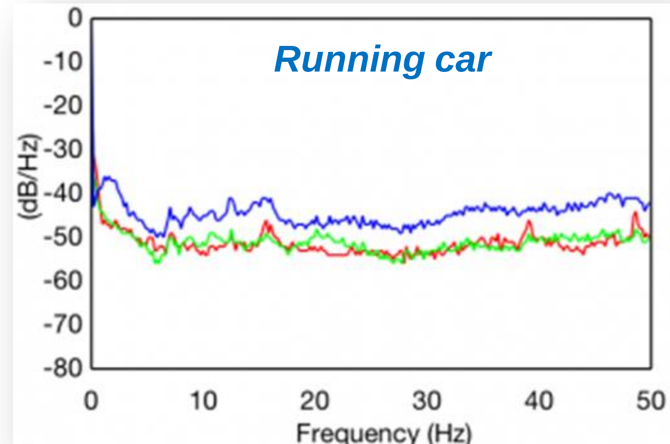
Characteristic frequencies
Narrow band sources

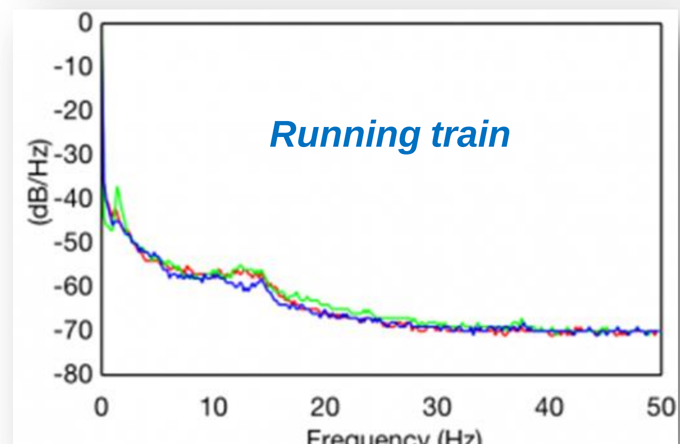




From S. Roundy et al., Computer Communications, 26, 1131–1144, 2003

NO Characteristic frequencies
Wide band sources



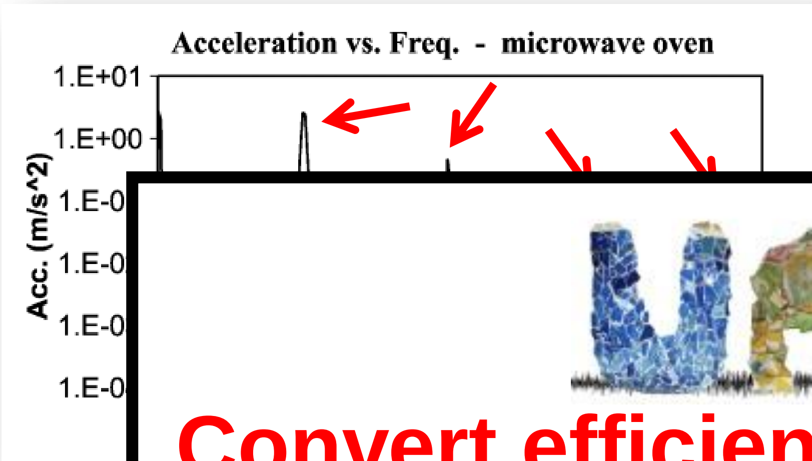


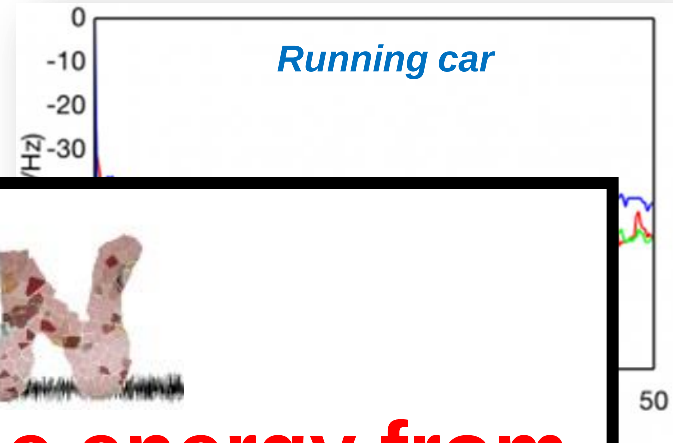
From: Neri, I., Travasso, F., Mincigrucci, R., Vocca, H., Orfei, F., & Gammaitoni, L.; Journal of Intelligent Material Systems and Structures, 2012

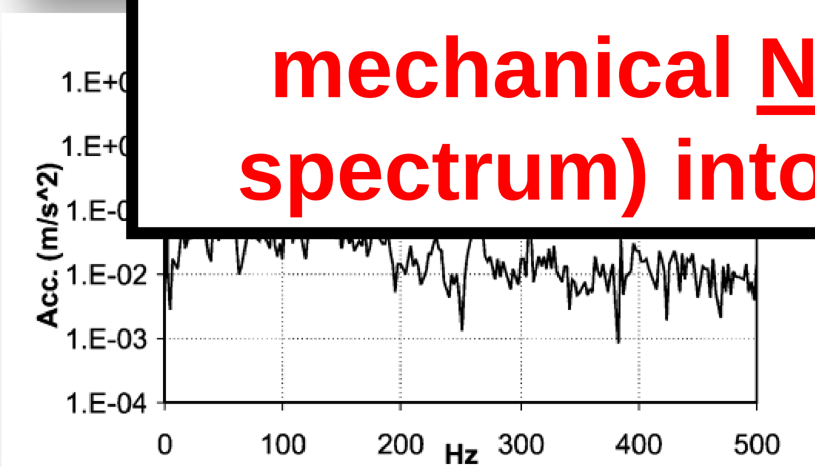
Vibration Energy Harvesting (VEH)

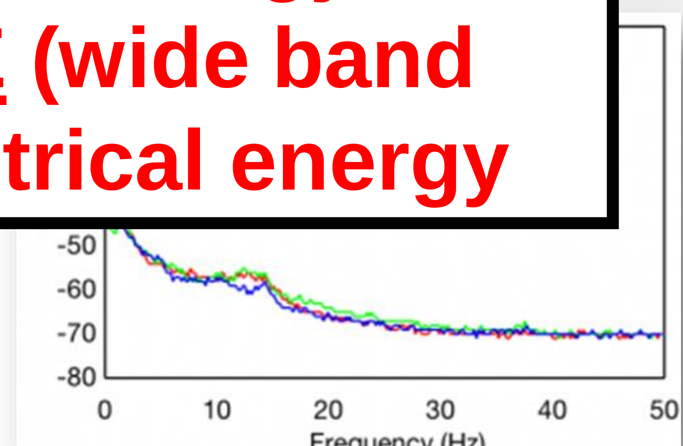
Characteristic frequencies
Narrow band sources

NO Characteristic frequencies
Wide band sources









Convert efficiently the energy from mechanical NOISE (wide band spectrum) into electrical energy

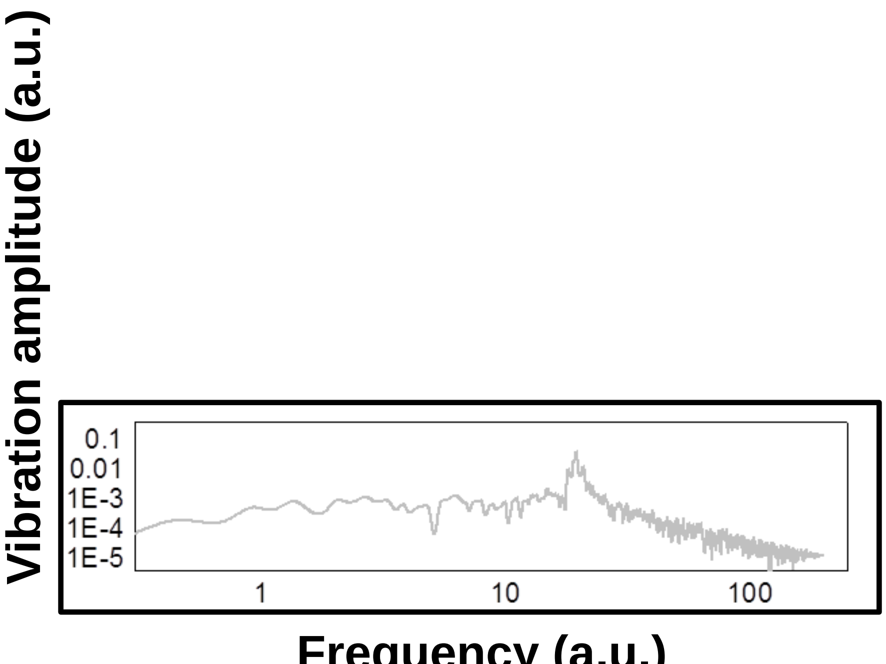
From S. Roundy et al., Computer Communications, 26, 1131–1144, 2003

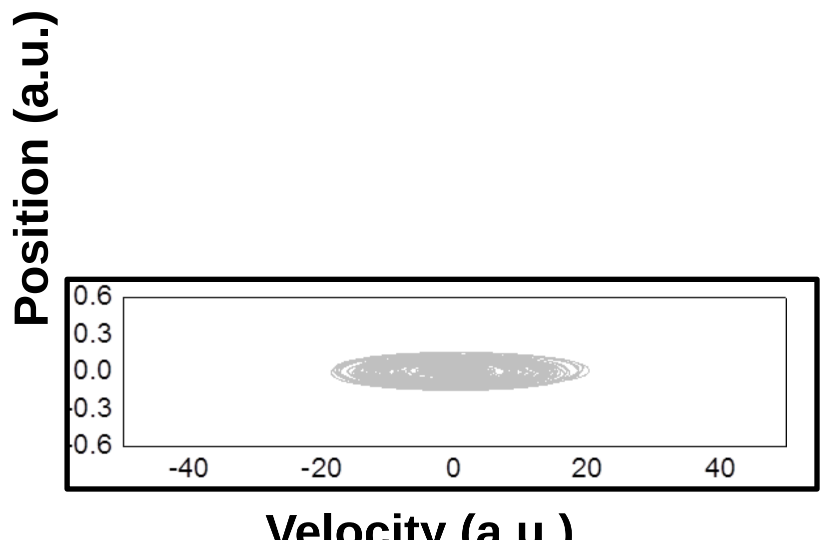
From: Neri, I., Travasso, F., Mincigrucci, R., Vocca, H., Orfei, F., & Gammaitoni, L.; Journal of Intelligent Material Systems and Structures, 2012

Outline

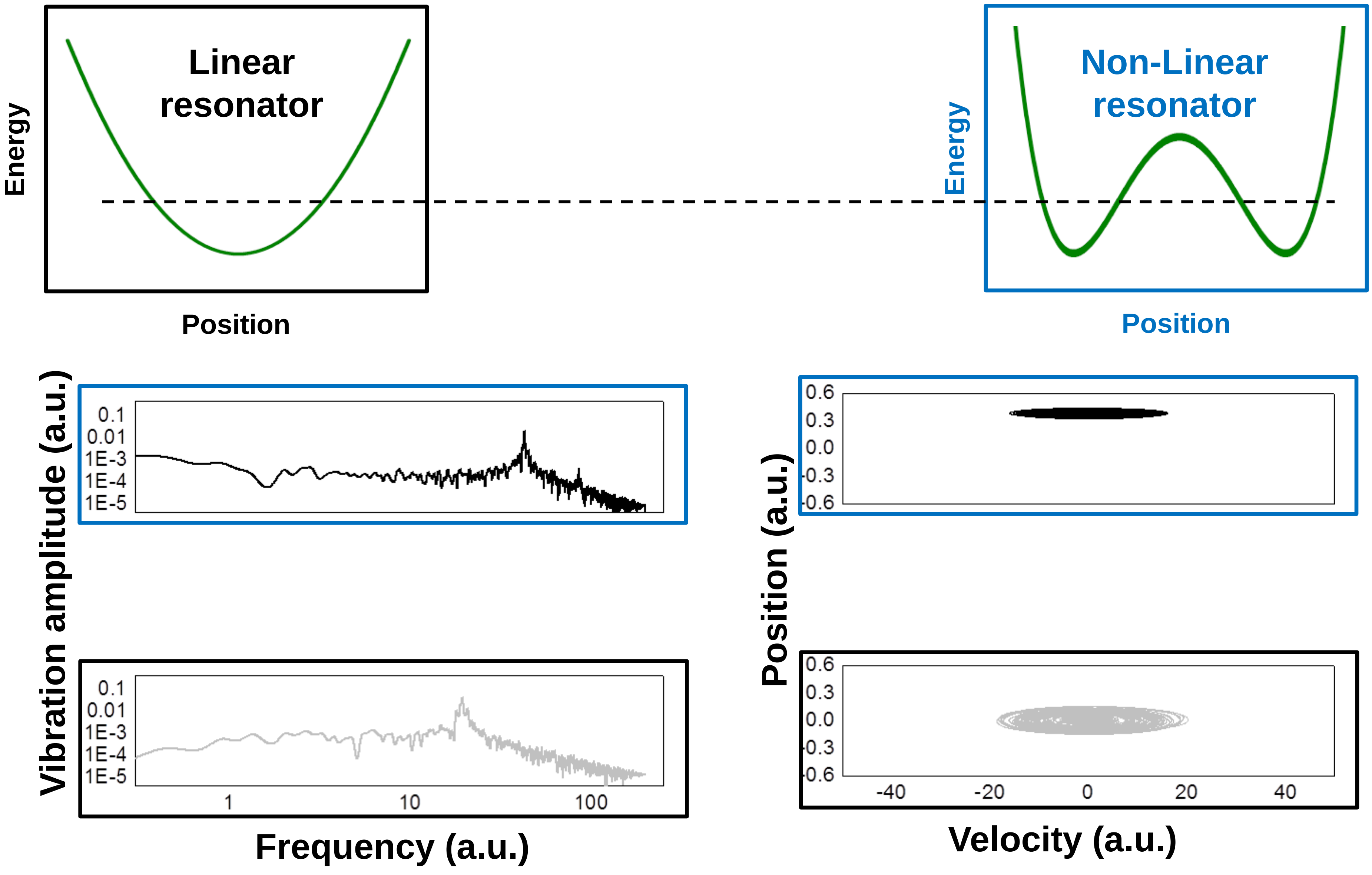
- Introduction. Wideband Vibration Energy Harvesting (WBVEH)
- From mm-scale to μm-scale bistable WBVEH
- nm-scale bistable WBVEH:
  NEMS based on piezoelectric 2D materials
- Conclusions

Wideband Vibration Energy Harvesting. Bistable approach





Wideband Vibration Energy Harvesting. Bistable approach



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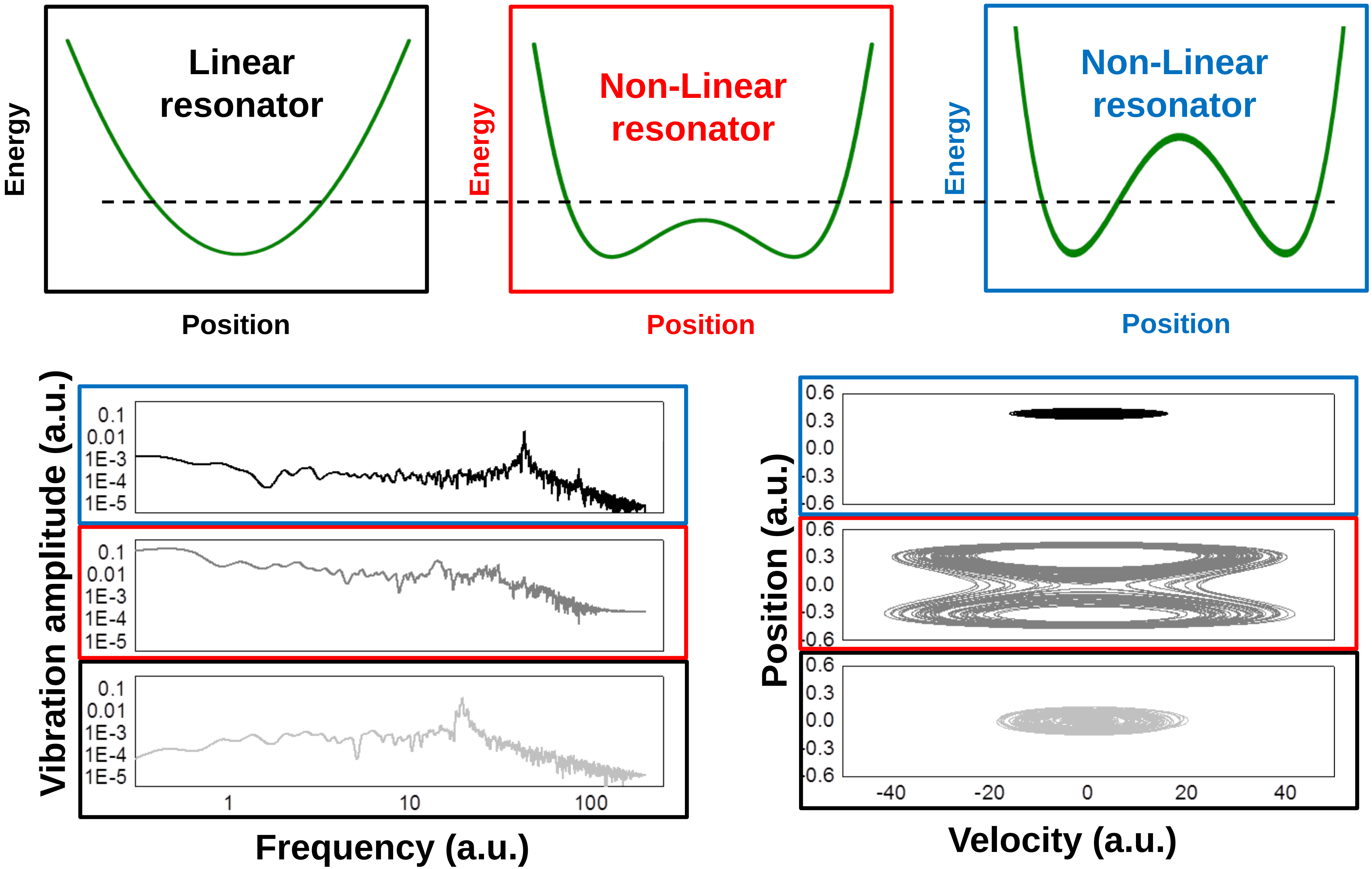

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Wideband Vibration Energy Harvesting. Bistable approach

PRL 102, 080601 (2009) PHYSICAL REVIEW LETTERS week ending 27 FEBRUARY 2009

Nonlinear Energy Harvesting

F. Cottone,* H. Vocca, and L. Gammaitoni†

NiPS Laboratory, Dipartimento di Fisica, Universitá di Perugia, and Instituto Nazionale di Fisica Nucleare, Sezione di Perugia, I-06100 Perugia, Italy

(Received 18 September 2008; published 23 February 2009)

Ambient energy harvesting has been in recent years the recurring object of a number of research efforts aimed at providing an autonomous solution to the powering of small-scale electronic mobile devices. Among the different solutions, vibration energy harvesting has played a major role due to the almost universal presence of mechanical vibrations. Here we propose a new method based on the exploitation of the dynamical features of stochastic nonlinear oscillators. Such a method is shown to outperform standard linear oscillators and to overcome some of the most severe limitations of present approaches. We demonstrate the superior performances of this method by applying it to piezoelectric energy harvesting from ambient vibration.

DOI: 10.1103/PhysRevLett.102.080601 PACS numbers: 05.40.Ca, 05.10.Ln, 05.45.−a, 84.60.−h

APPLIED PHYSICS LETTERS 102, 153901 (2013)

Inducing bistability with local electret technology in a microcantilever based non-linear vibration energy harvester

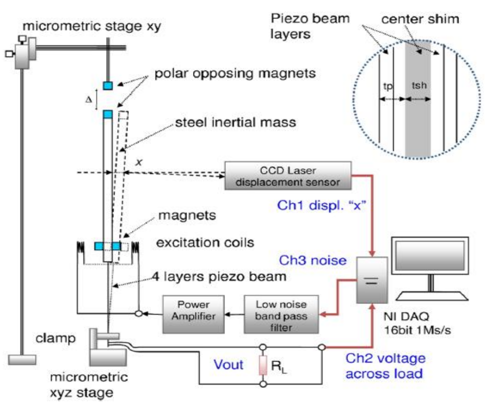
M. López-Suárez,[1,a)] J. Agustí,[1] F. Torres,[1] R. Rurali,[2] and G. Abadal[1]

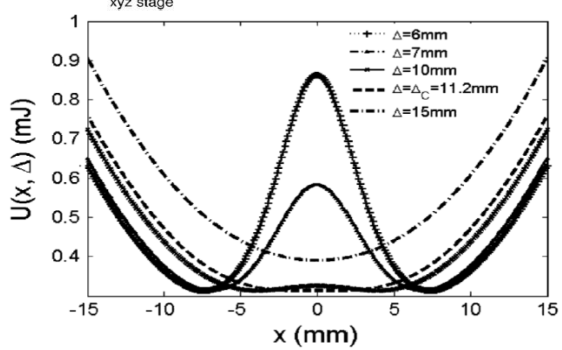
[1]*Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain*

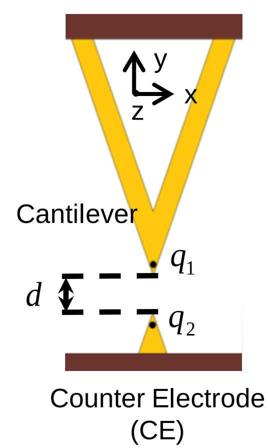
[2]*Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de Bellaterra, Bellaterra 08193, Spain*

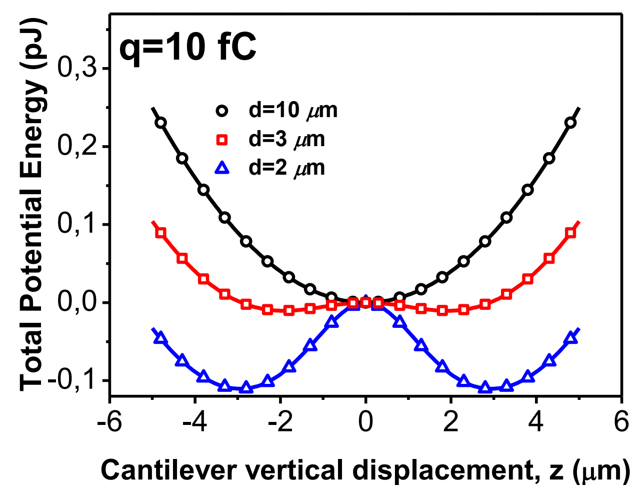
(Received 22 January 2013; accepted 21 March 2013; published online 16 April 2013)

A micro-electro-mechanical system based vibration energy harvester is studied exploring the benefits of bistable non linear dynamics in terms of energy conversion. An electrostatic based approach to achieve bistability, which consists in the repulsive interaction between two electrets locally charged in both tip free ends of an atomic force microscope cantilever and a counter electrode, is experimentally demonstrated. A simple model allows the prediction of the measured dynamics of the system, which shows an optimal distance between the cantilever and the counter electrode in terms of the root mean square vibration response to a colored Gaussian excitation noise. © 2013 American Institute of Physics. [http://dx.doi.org/10.1063/1.4800926]

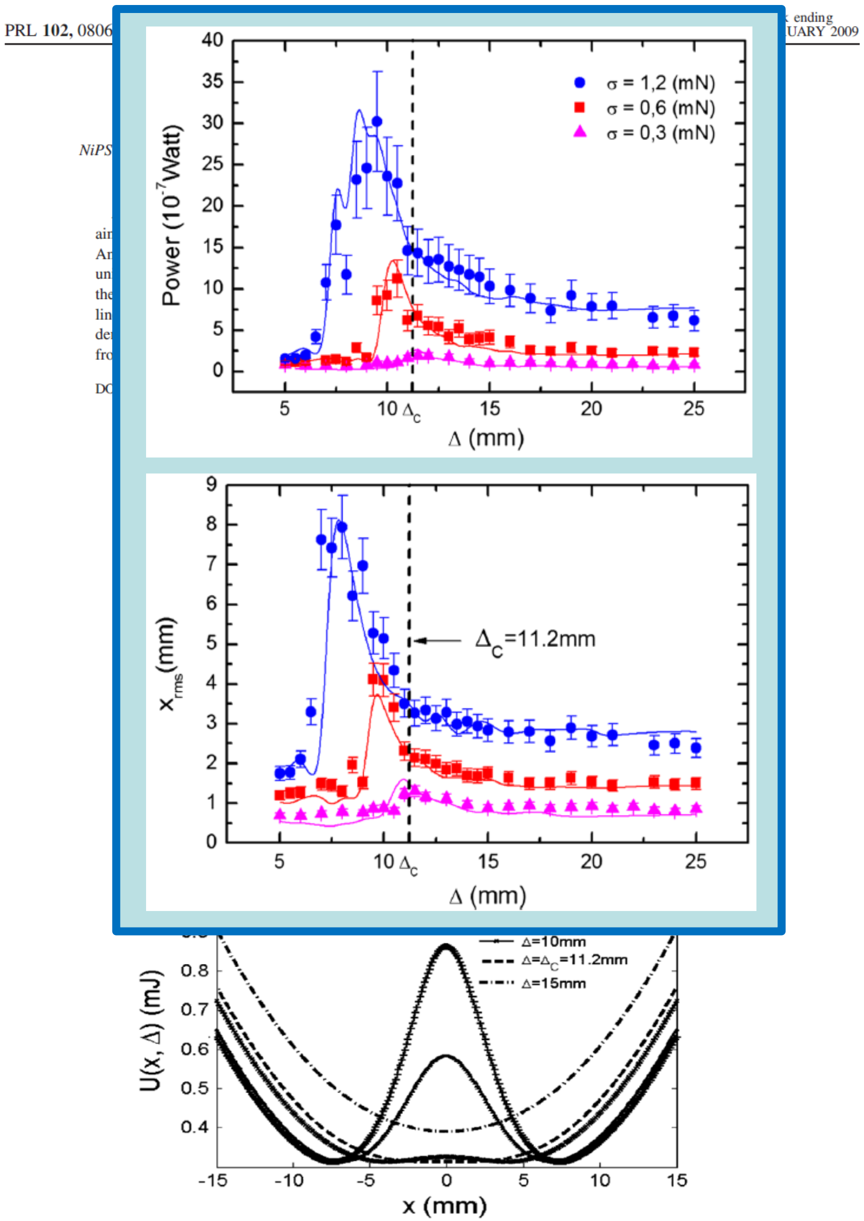


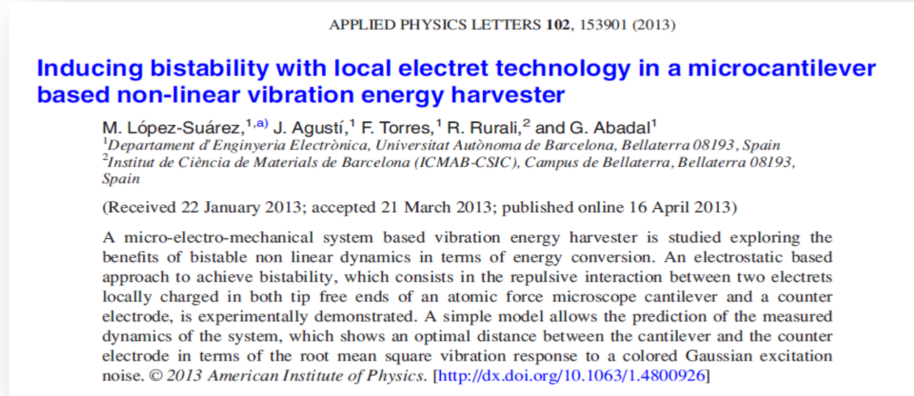






Wideband Vibration Energy Harvesting. Bistable approach





APPLIED PHYSICS LETTERS **102**, 153901 (2013)

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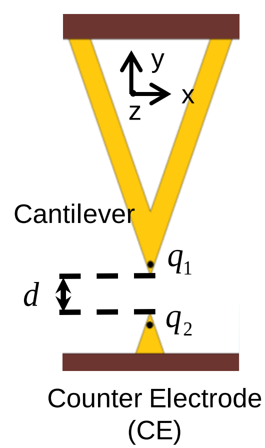
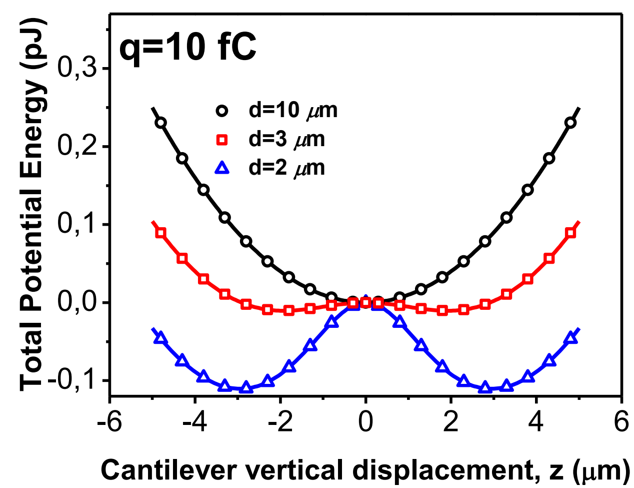
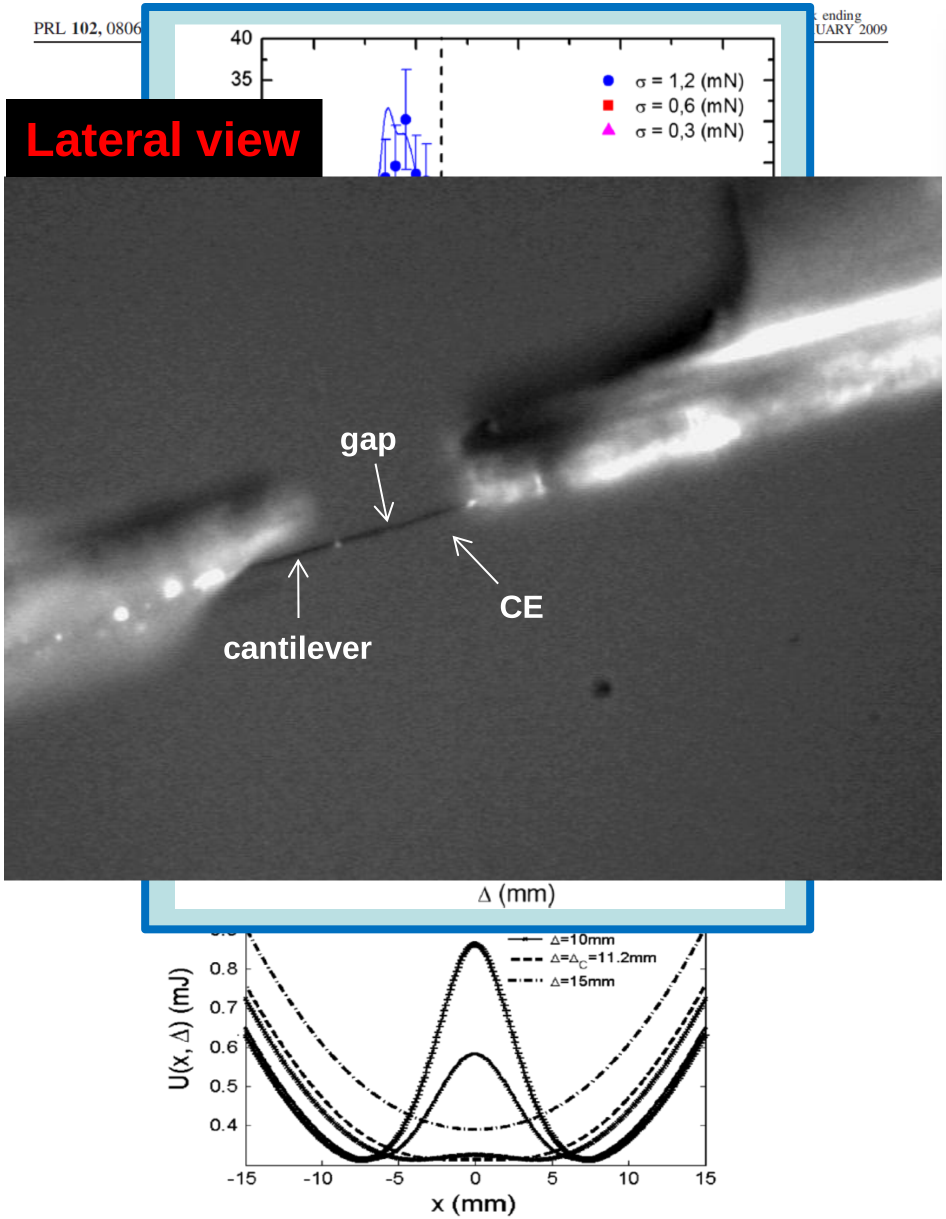




Wideband Vibration Energy Harvesting. Bistable approach

PRL 102, 0806 ... ending ... UARY 2009

Lateral view



APPLIED PHYSICS LETTERS 102, 153901 (2013)

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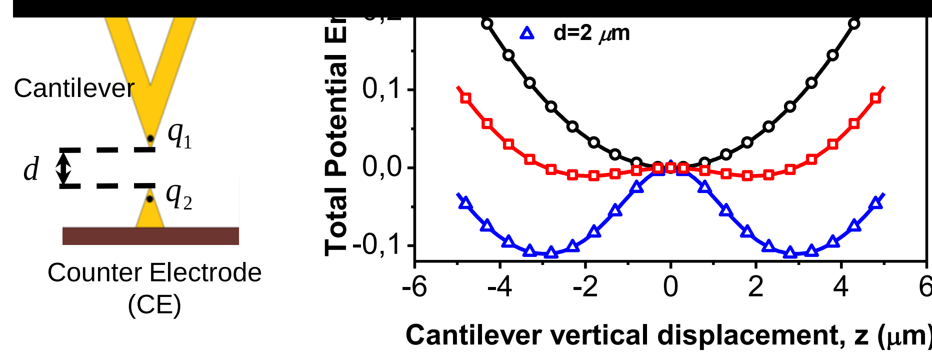
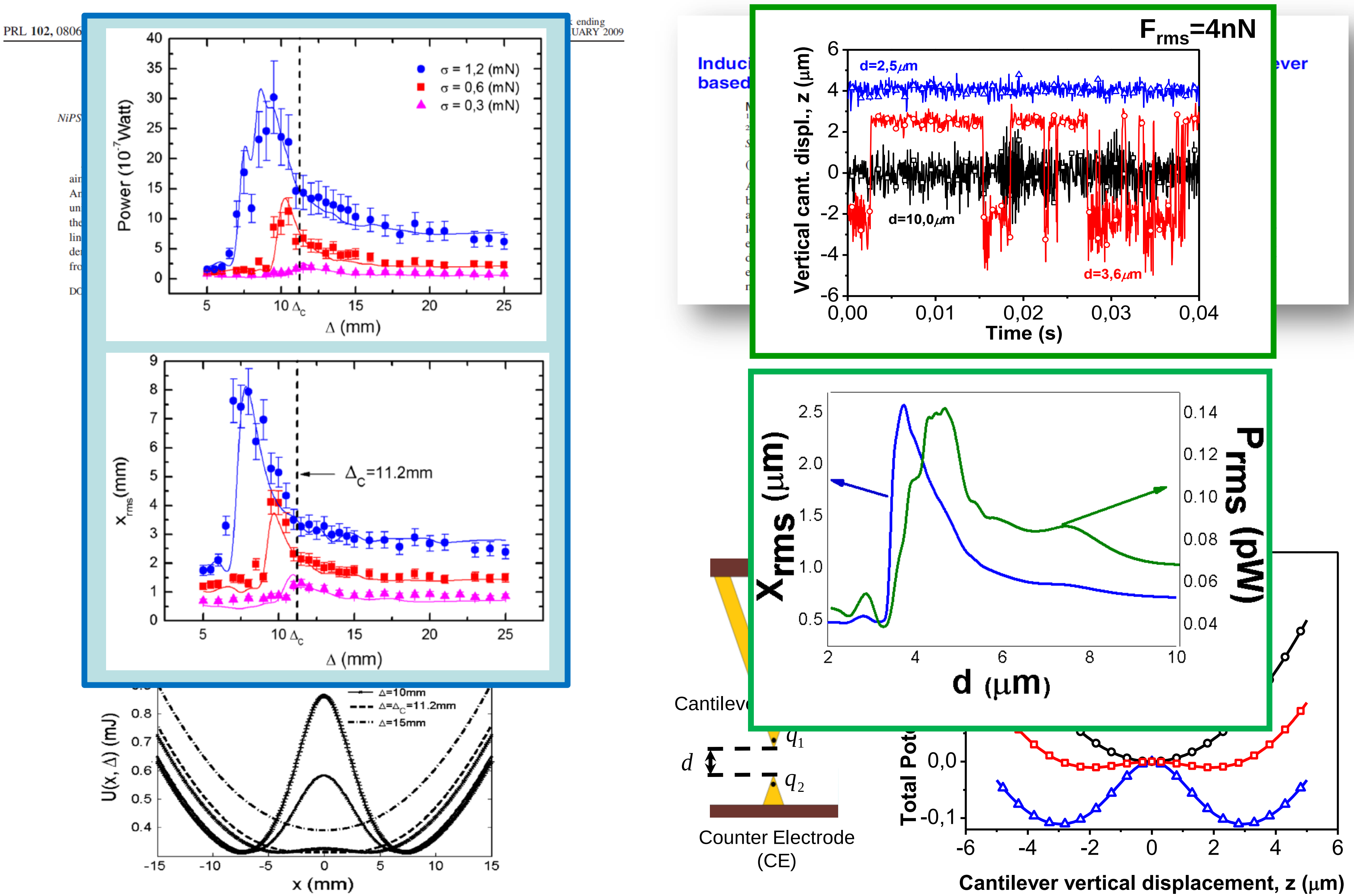
[2]Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de Bellaterra, Be

Top view

[redacted]



Wideband Vibration Energy Harvesting. Bistable approach



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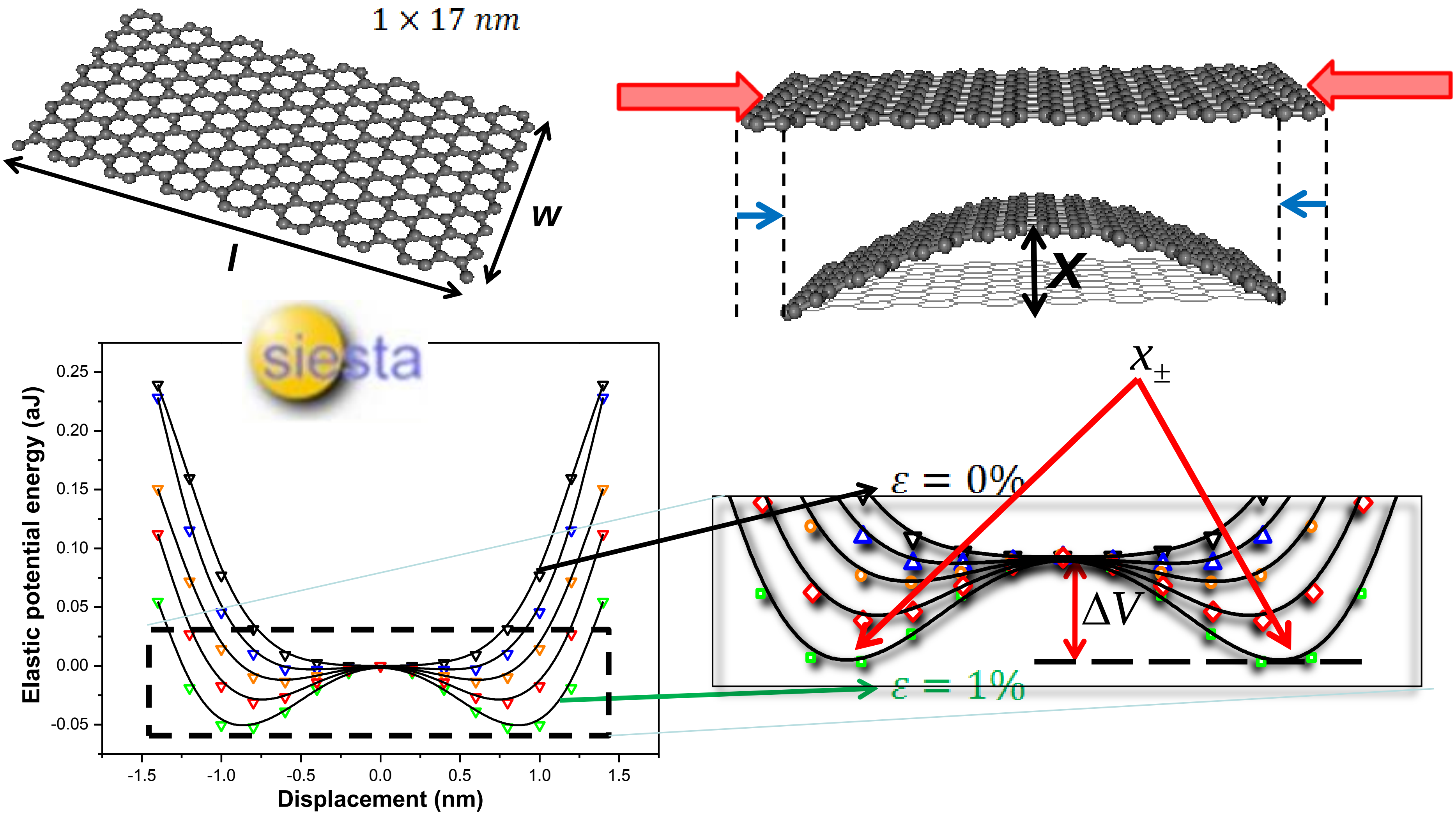
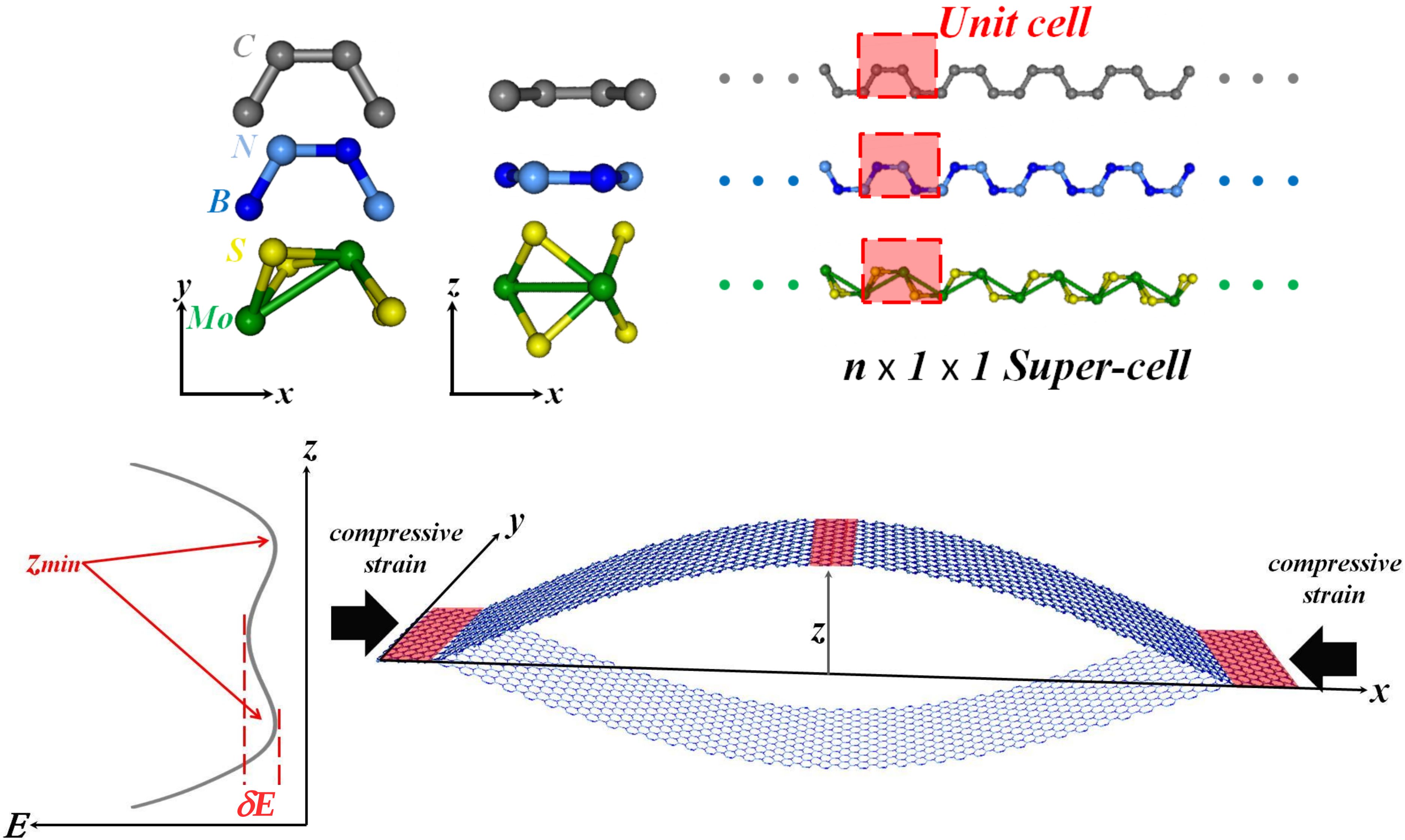
nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials



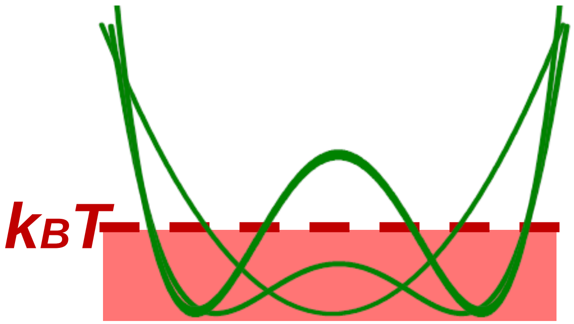
nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials



nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials.
GRAPHENE

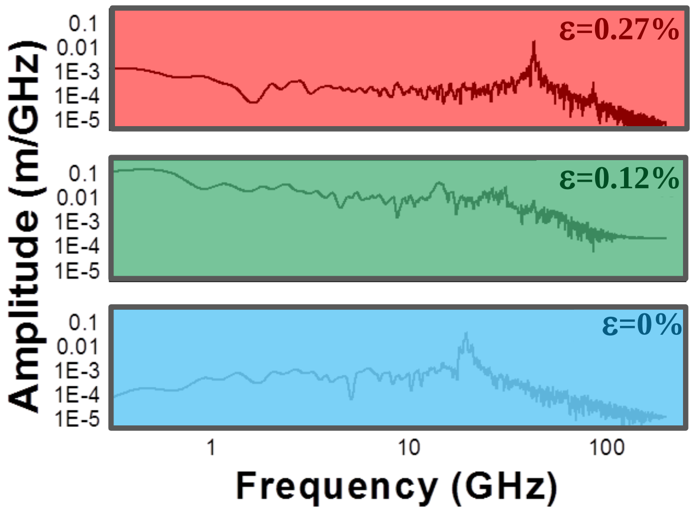
Langevin equation
Spring-mass model

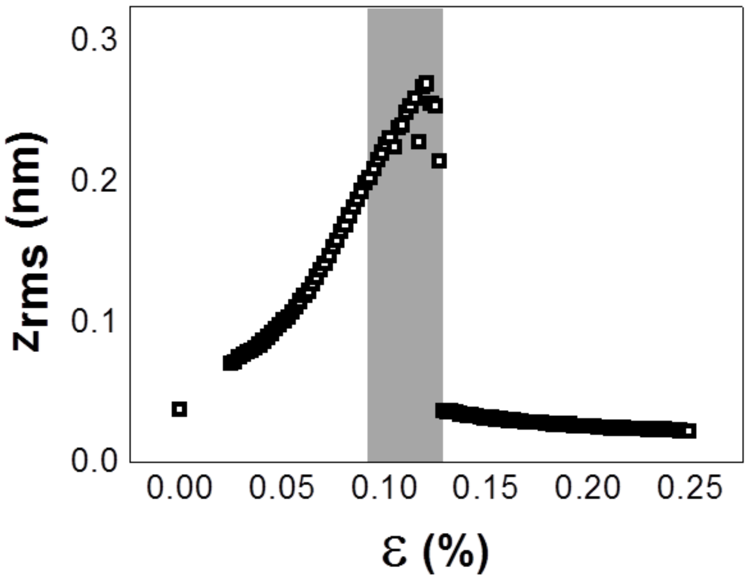
$$m_{eff}\ddot{z} = -\frac{\partial E(z)}{\partial z} - b\dot{z} + F_{rms}\xi(t)$$

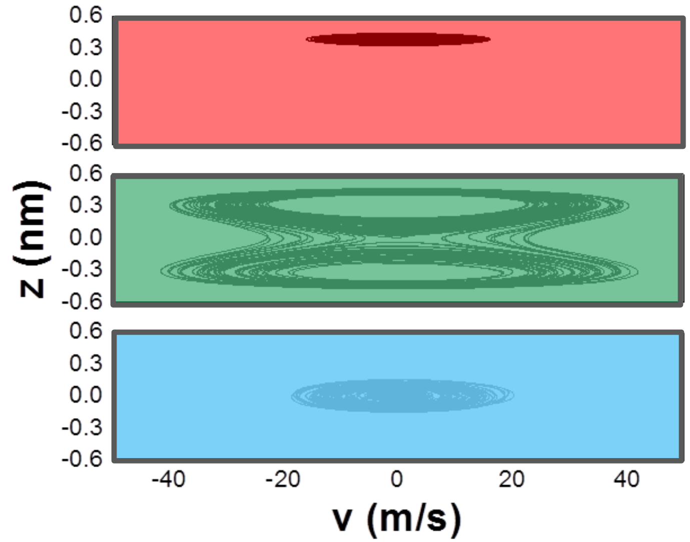


$$F_{rms}^{th} = \sqrt{4k_B TbB}$$

$$@T = 300K$$







nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials.

GRAPHENE

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **84**, 161401(R) (2011)

Nanostructured graphene for energy harvesting

Miquel López-Suárez,[1] Riccardo Rurali,[2,*] Luca Gammaitoni,[3] and Gabriel Abadal[1]

[1]*Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*

[2]*Institut de Ciència de Materials de Barcelona (ICMAB–CSIC), Campus de Bellterra, E-08193 Bellaterra, Barcelona, Spain*

[3]*NiPS Laboratory, Dipartimento di Fisica, Universitá di Perugia, and Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, I-06100 Perugia, Italy*

(Received 1 August

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harvesting devices. Mac
H. Vocca, and L. Gamma
at the nanoscale, we pro
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Microelectronic Engineering 111 (2013) 122–125

Contents lists available at SciVerse ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

ELSEVIER

Buckling suspended graphene nanoribbons to harvest energy from noisy vibrations

M. López-Suárez [a,*], R. Rurali [b], G. Abadal [a]

[a] *Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain*

[b] *Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de Bellterra, E-08193 Bellaterra, Barcelona, Spain*

A R T I C L E I N F O

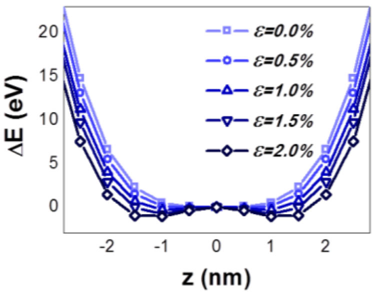
Article history:
Available online 26 February 2013

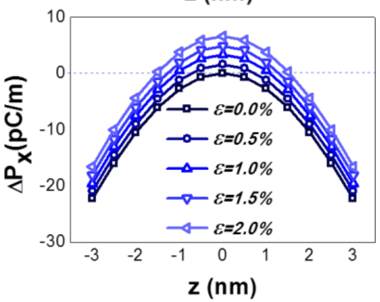
Keywords:
Energy harvesting
Energy scavenging
Bistable systems
Non-linear systems
Graphene

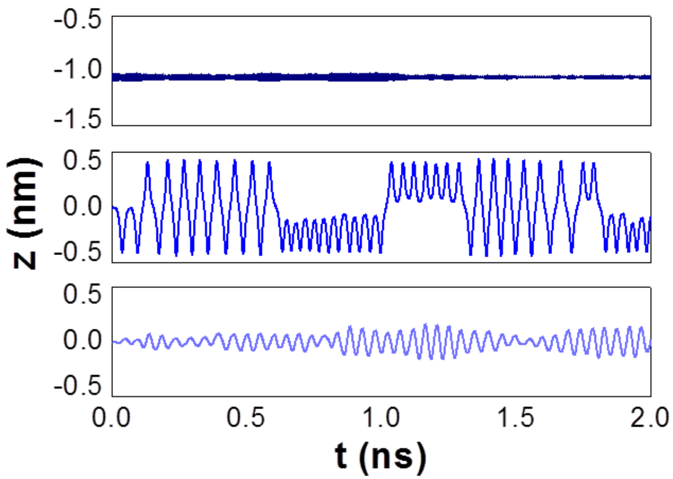
A B S T R A C T

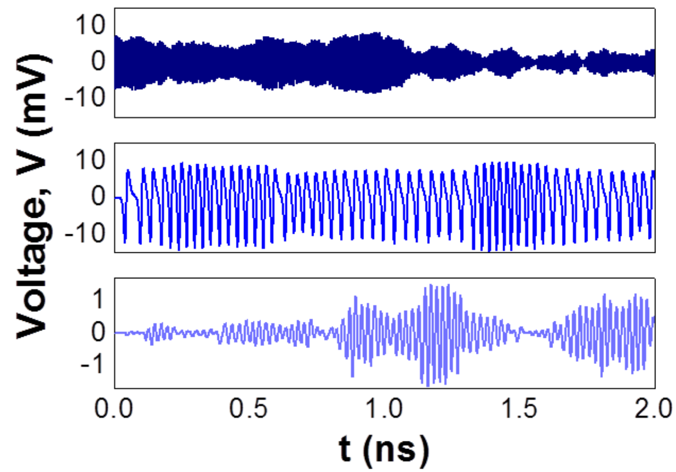
Most mechanical vibrations in our environment can be classified as noisy vibrations, since they have no preferred frequency and a spectrum that spreads to the low frequency range. Bistable systems have shown to be a solution to the existing frequency mismatch between the energy source and the harvester device. In this work a parametric study is carried out in order to show the dependence of these improvements with the quality factor Q of a vibrating beam and the different responses when driven by different types of model noise. Specifically, we studied Colored Gaussian Noise instead of the much more common White Gaussian Noise, considered as a reference in most studies.

nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials. h-BN

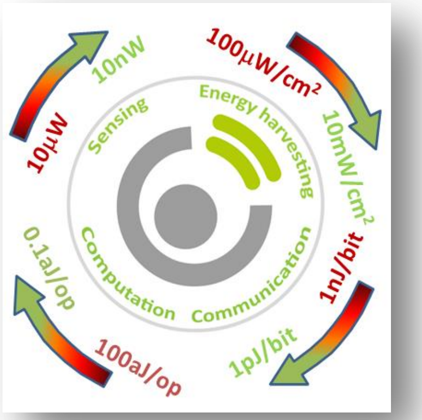


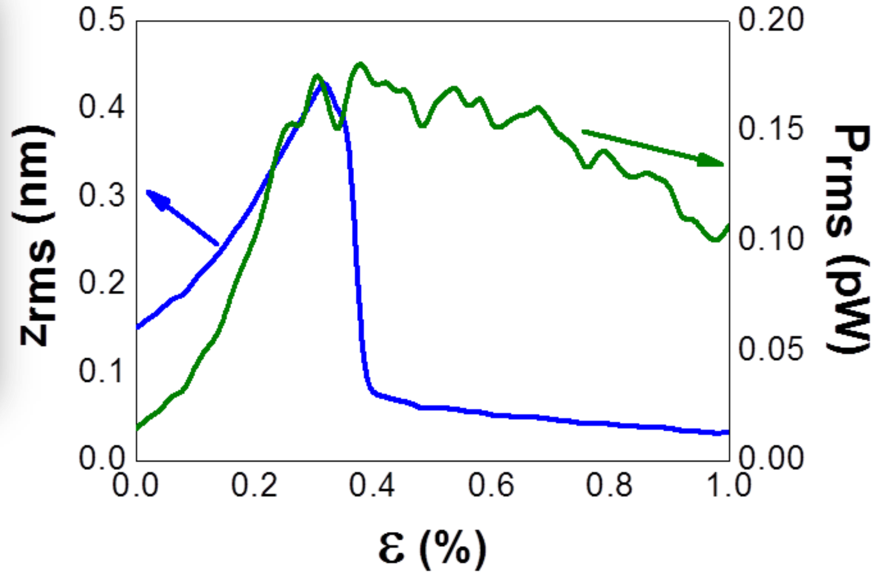






F_{rms}=5 pN





P=0.15 pW
PD*=15 mW/cm^3

***A realistic V=10µm^3 is considered to include mechanical anchors**

nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials. h-BN

Nanotechnology > Volume 25 > Number 17

Piezoelectric monolayers as nonlinear energy harvesters

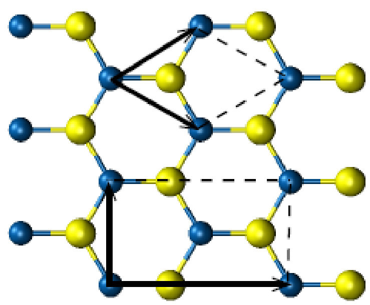
Miquel López-Suárez[1], Miguel Pruneda[2,3], Gabriel Abadal[1] and Riccardo Rurali[4]
Show affiliations

Miquel López-Suárez *et al* 2014 *Nanotechnology* **25** 175401. doi:10.1088/0957-4484/25/17/175401
Received 3 dicembre 2013, accepted for publication 3 marzo 2014. Published 10 aprile 2014.

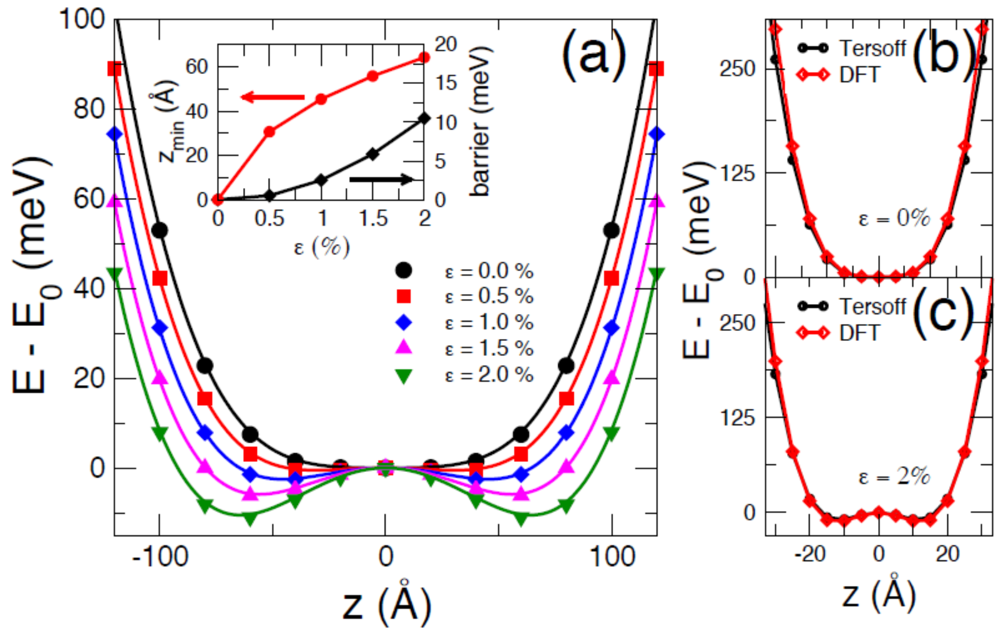
Abstract

We study the dynamics of h-BN monolayers by first performing *ab-initio* calculations of the deformation potential energy and then solving numerically a Langevine-type equation to explore their use in nonlinear vibration energy harvesting devices. An applied compressive strain is used to drive the system into a nonlinear bistable regime, where quasi-harmonic vibrations are combined with low-frequency swings between the minima of a double-well potential. Due to its intrinsic piezoelectric response, the nonlinear mechanical harvester naturally provides an electrical power that is readily available or can be stored by simply contacting the monolayer at its ends. Engineering the induced nonlinearity, a 20 nm^2 device is predicted to harvest an electrical power of up to 0.18 pW for a noisy vibration of 5 pN.

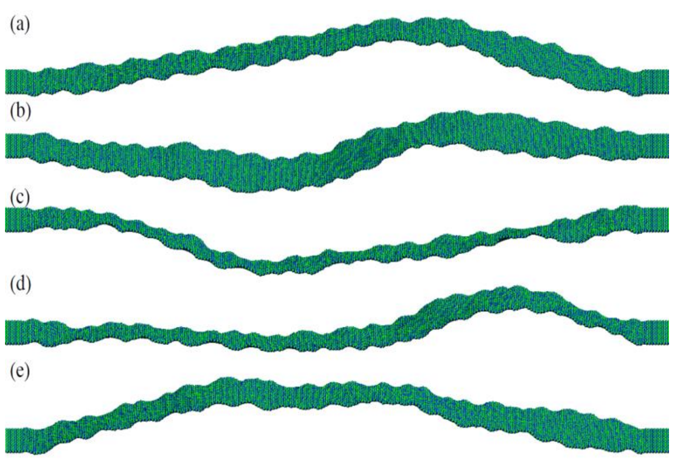
nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials. h-BN



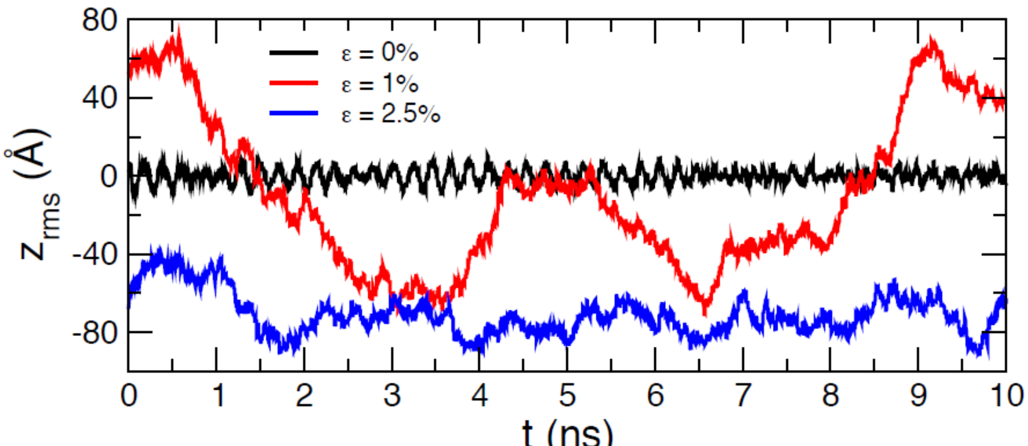
233x30 supercell of the rectangular 4-atom unit:
100.8nm x 7.5nm armchair nanoribbon
27,960 atoms.



Molecular dynamics: NVT ensemble using LAMMPS code and Langevin thermostat.



Snapshot of the dynamics of a BN nanoribbon subjected to a compression of 1.5%.



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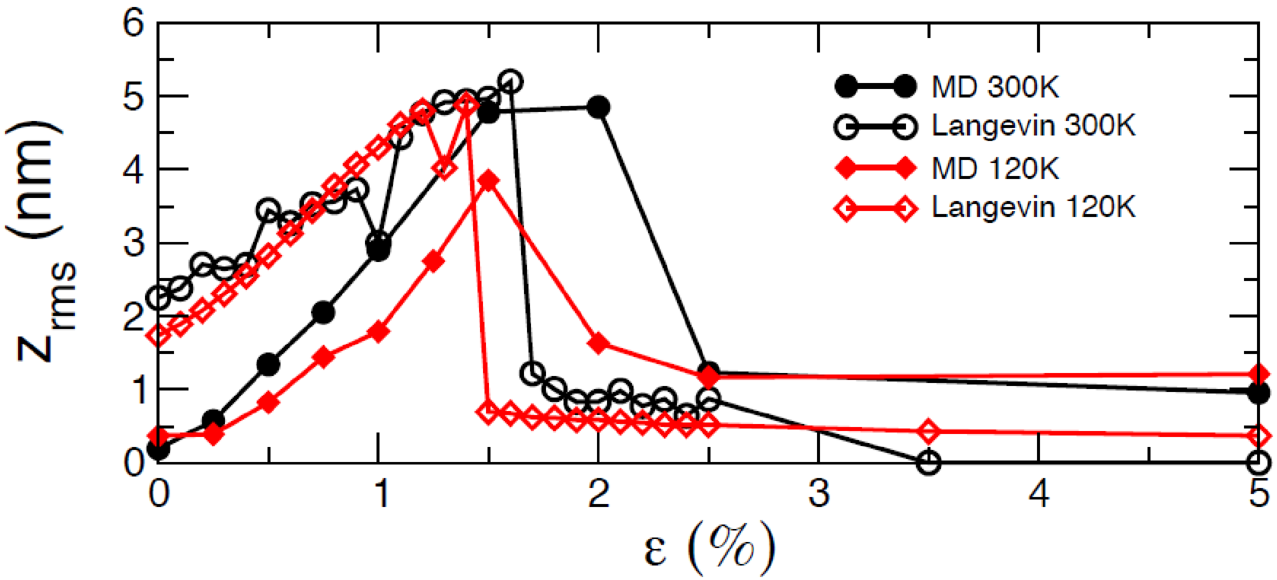
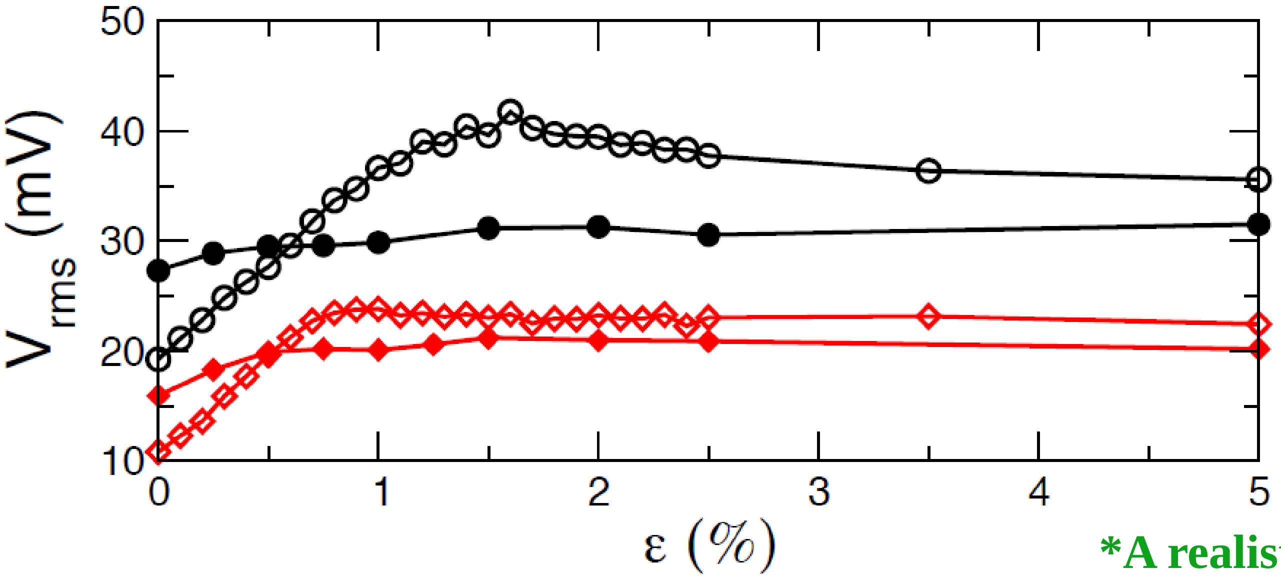


F_{rms}=1.3 nN



P=8 pW

PD*=80 mW/cm^3

***A realistic V=100μm^3 is considered to include mechanical anchors**

nm-scale bistable WBVEH: NEMS based on piezoelectric 2D materials. h-BN

Nano Energy (2015) **15**, 329–334

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COMMUNICATION

Noise energy harvesting in buckled BN nanoribbons from molecular dynamics

Miquel López-Suárez[a,*], Gabriel Abadal[b], Luca Gammaitoni[a], Riccardo Rurali[c]

[a]*Department of Physics, University of Perugia, via A. Pascoli, 1, 06100 Perugia, Italy*
[b]*Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Spain*
[c]*Institut de Ciència de Materiales de Barcelona (ICMAB-CSIC), Campus de Bellaterra, 08193 Bellaterra, Barcelona, Spain*

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Abstract

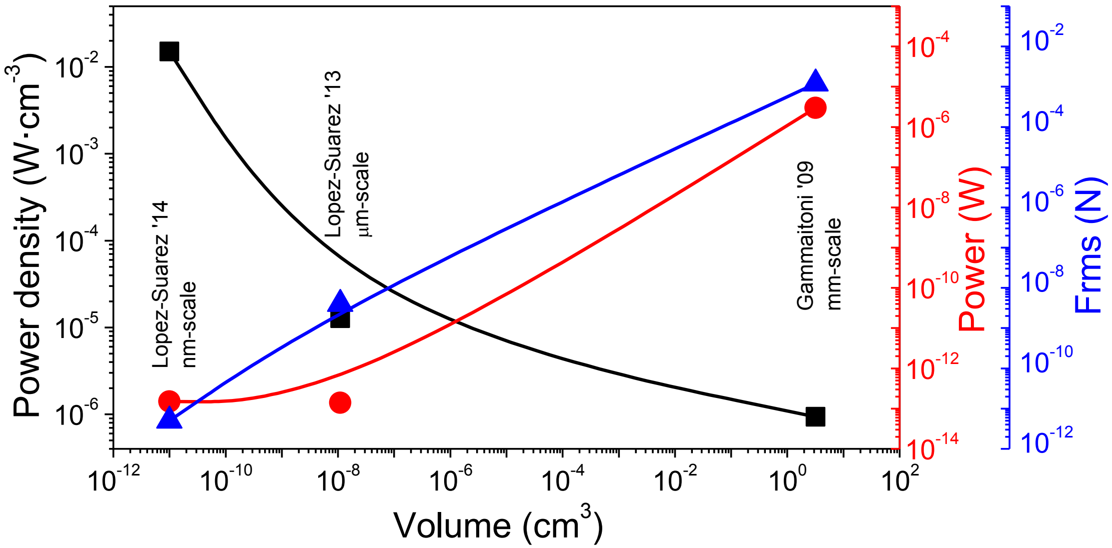
We present molecular dynamics calculations of a *h*-BN nanoribbon designed for vibrational energy harvesting. We calculate the piezoelectric voltage generated at the ends of the device as a function of time and for different levels of an external compressive strain. Through the full atomistic description of the nanoribbon dynamics we demonstrate that driving the system into a non-linear dynamical regime greatly increases its harvesting efficiency. A comparative analysis of the piezo-voltage dependence on the compressive strain, obtained from a previously reported description of the nanoribbon dynamics and from the more accurate molecular dynamics, reveals that the method here presented gives a more precise description of the effect of in-plane vibration of the atoms on the harvesting performance of the device.

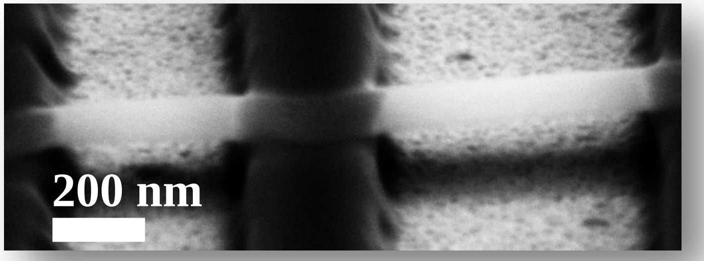
Conclusions

- Non-linear based strategies for the implementation of WBVEH can be downscaled to the **μm-scale** using **MEMS** and to the **nm-scale** using **NEMS**.

- The advantages of downscaling are:
  - The adaption to **low intensity** mechanical noise sources.
  - The **enhancement** of the harvested **power density**.

- However, there is a lack of **experimental results** to validate the predicted performance of the studied nanoelectromechanical converters based on **piezoelectric 2D materials**.





Gabriel Abadal

Francesc Torres

NANERG LAB

NOEMS for ENERGY LABORATORY

NANO-OPTOELECTROMECHANICAL SYSTEMS FOR ENERGY LABORATORY

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Warner Venstra
TU-Delft
The Netherlands

Miquel López-Suárez
NiPS Lab, U.Perugia
Italy

Riccardo Rurali
ICMAB
Spain

Luca Gammaitoni
NiPS Lab, U.Perugia
Italy