Harvesting energy from thermal noise through mechanical non-linearity of suspended graphene sheets

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It has been demonstrated that harvesting power from wide band noise energy sources can be more efficiently performed through non-linear bistable transducers [1]-[2], instead of using conventional linear micromechanical resonators. It is expected that the extrapolation of this concept to the energy extraction from thermomechanical noise [3]-[4] will need the small dimensions of a NEMS based transducer. In the present contribution a numerical model is proposed for the design of a bistable sheet of suspended graphene based on the analysis of its response to the thermomechanical noise driving force. As it is shown in Figure1, bistability behavior is obtained by the compression induced buckling of the suspended graphene layer. The mechanical characteristics of the grapheme sheet are defined by geometry, quality factor, Young modulus and density. The model allows solving numerically the motion equation of the bistable device when driven by the force associated to the thermomechanical noise (white and Gaussian).
A sweep of the compression parameter allows finding the maximum vibration amplitude (rms) of the grapheme sheet, which corresponds to the conditions of barrier height between potential wells that maximize the probability of the sheet to jump from one potential well to the other.

The shape of the potential energy, as a function of the out of plane displacement (z) of the sheet centre, is obtained from *ab initio* calculations. Figure 2 shows how this shape is modified depending on the intensity of the compression. With the appearance of the barrier, a bistable system is conformed, although the non compressed case is also nonlinear.

The motion equation to be solved numerically is the following:

$$m_{eff}\ddot{z} = -\frac{\partial V}{\partial z} - b\dot{z} + F_{noise}$$

Where $F_{noise} = \sqrt{\left(\frac{tw^2}{lQ}\right)\sqrt{16.7E\rho}(2k_BTB)}\xi(t)$ is the noise force where $\xi(t)$ represents a stochastic process, m_{eff} stands for the effective mass of the suspended sheet and b represents the mechanical damping of the system.

Figure 3 and 4 show the mechanical vibrational response to the noise force of such a system for different values of the compression. An evaluation of the vibration speed $\dot{z}_{rms}$ allows to determine the rms value of the mechanical power ($F_{rms} \cdot \dot{z}_{rms}$).
As it is shown in Figure 6, a local maximum of 6fW is harvested close to the optimal compression corresponding to the maximum vibration amplitud z_{rms}. However, an absolute maximum power around 7fW is obteined at 0% compression, which is consistent with the nonlinear shape of the potential energy in this conditions.

References

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Figures

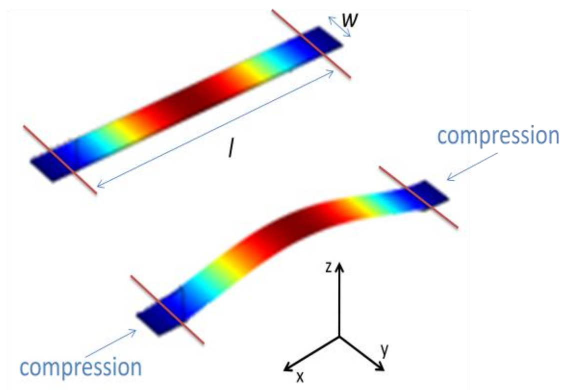

Figure 1: Non compressed and compressed suspended graphene sheet. Length l and width w.

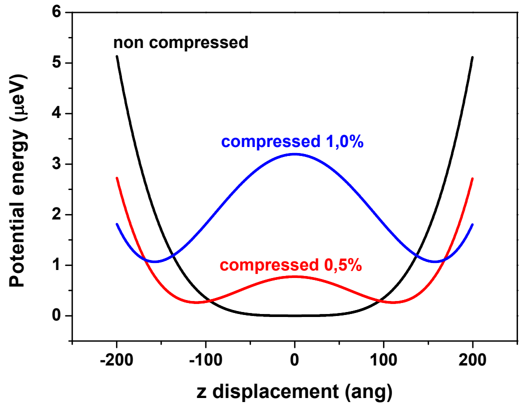

Figure 2: Potential energy vs. z displacement for different compression. l=300nm, w=0.25297nm

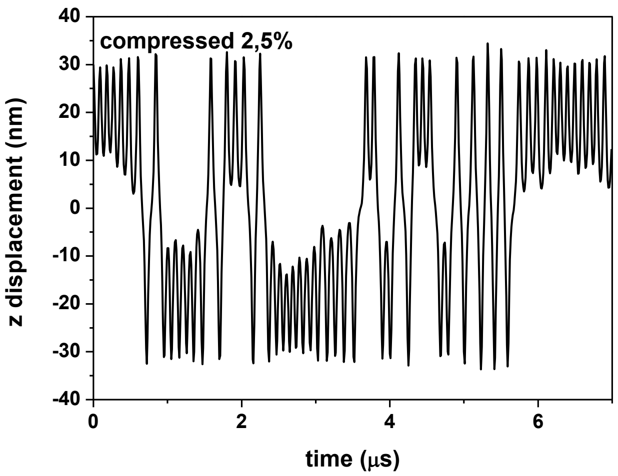

Figure 3: Time evolution of z displacement for a 2.5% compressed graphene. l=300nm, w=200nm

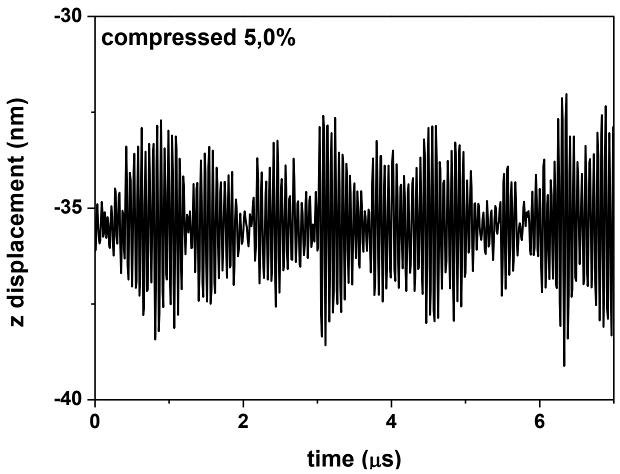

Figure 4: Time evolution of z displacement for a 5.0% compressed graphene. l=300nm, w=200nm

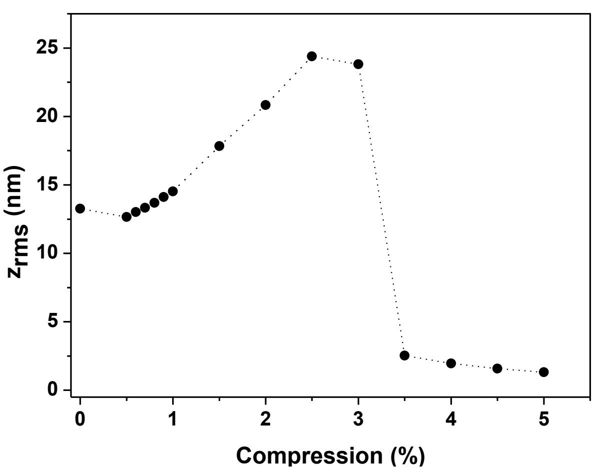

Figure 5: z displacement root mean square vs. compression. l=300nm, w=200nm

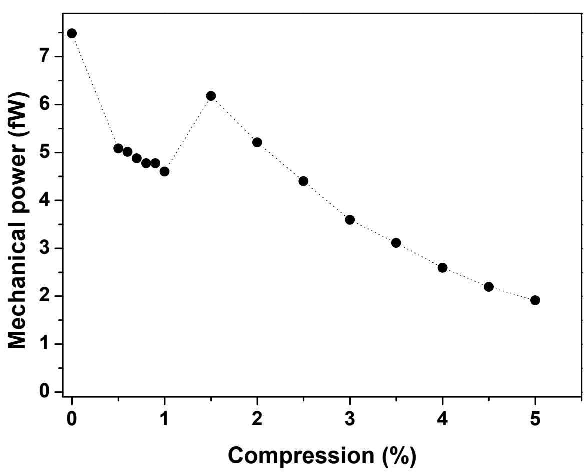

Figure 6: Mechanical power vs. compression. l=300nm, w=200nm