Tuning nonlinear damping of atomically thin membranes

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Abstract. In the last decade, nonlinear damping has attracted much attention in the study of nanomechanical resonators. Amongst the different mechanisms that affect nonlinear damping, intermodal coupling is particularly interesting as it can be enhanced near internal resonance conditions. In this talk, we present theory and experiments to investigate the influence of this mechanism on the nonlinear damping of opto-thermally driven graphene membranes.

Introduction

Nanomechanical systems are ubiquitous in a variety of applications in modern technology. The advent of graphene, and the ability to fabricate single-atom thick membranes, have made it possible to reach the ultimate sensing capabilities that not so long ago were dreamed of. But this revolutionary downscaling has been associated with severe constraints on the linear operation of these membranes since signatures of nonlinear dynamics already emerge at excitation amplitudes of only a few pN [1].
Although the field of nonlinear dynamics dates back several centuries, studies into the nonlinear damping of atomically thin membranes are only recently started. Here, we present theory and experiments to study nonlinear damping of graphene nanomechanical systems. We show the presence of successive internal resonance conditions in nanomembranes that amplify intermodal coupling. We fit our experimental data with a model that incorporates van der Pol and Duffing nonlinearities, and show that mode coupling can be held responsible for the variations observed in the nonlinear damping coefficient of the resonator.

Results and discussion

Our experiments are performed on graphene nanodrums that are opto-thermally driven into resonance. An interferometric setup is used to detect the mechanical motion of the nanodrums at MHz frequencies. The setup consists of a blue and a red laser focussed at a Fabry-Perot cavity formed by a bottom silicon layer and a suspended graphene layer. By modulating the intensity of the blue laser, we obtain both parametrically and directly driven resonance modes. Fig 1(a) shows a typical measurement result obtained for a 10 nm thick graphene nanodrum with a diameter of 5μm. When increasing the blue laser driving power an interesting phenomenon is observed: the parametrically resonant mode ($f_{0,1}$) successively interacts with driven modes ($f_{2,1}$ and $f_{0,2}$). We develop a reduced order model to fit the parametric resonance curves in the presence of internal resonance and observe that the nonlinear damping coefficient of the parametric mode increases up to nearly 80% when the frequency shift of the parametric resonance brings it into a two-to-one internal resonance with a higher mode (See Fig 1(b)). This mechanism can isolate mode coupling induced nonlinear damping from other nonlinear dissipation sources. It also provides a way to controllably engineer nonlinear damping of nanomechanical resonators, complementing existing toolsets for tuning linear damping [3], linear stiffness [4] and nonlinear stiffness[5].

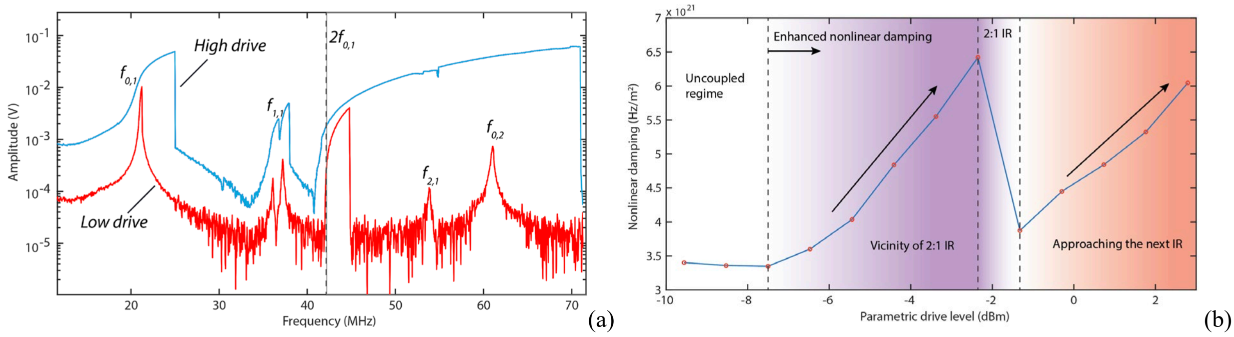

Figure 1: (a)Nonlinear dynamic response of the nanodrum; (b) variation of nonlinear damping as a function of drive amplitude.

References

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