A Systematic Study of Techniques to Directly Measure the Saturable Absorption of Graphene



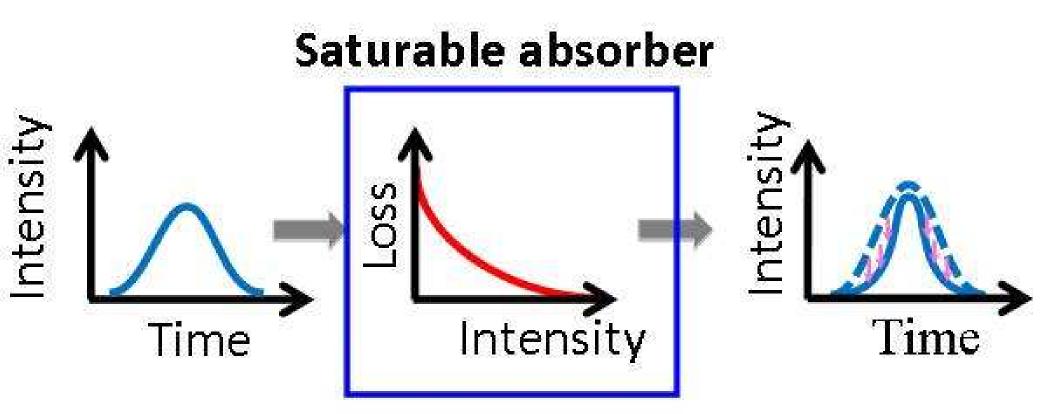
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Motivation

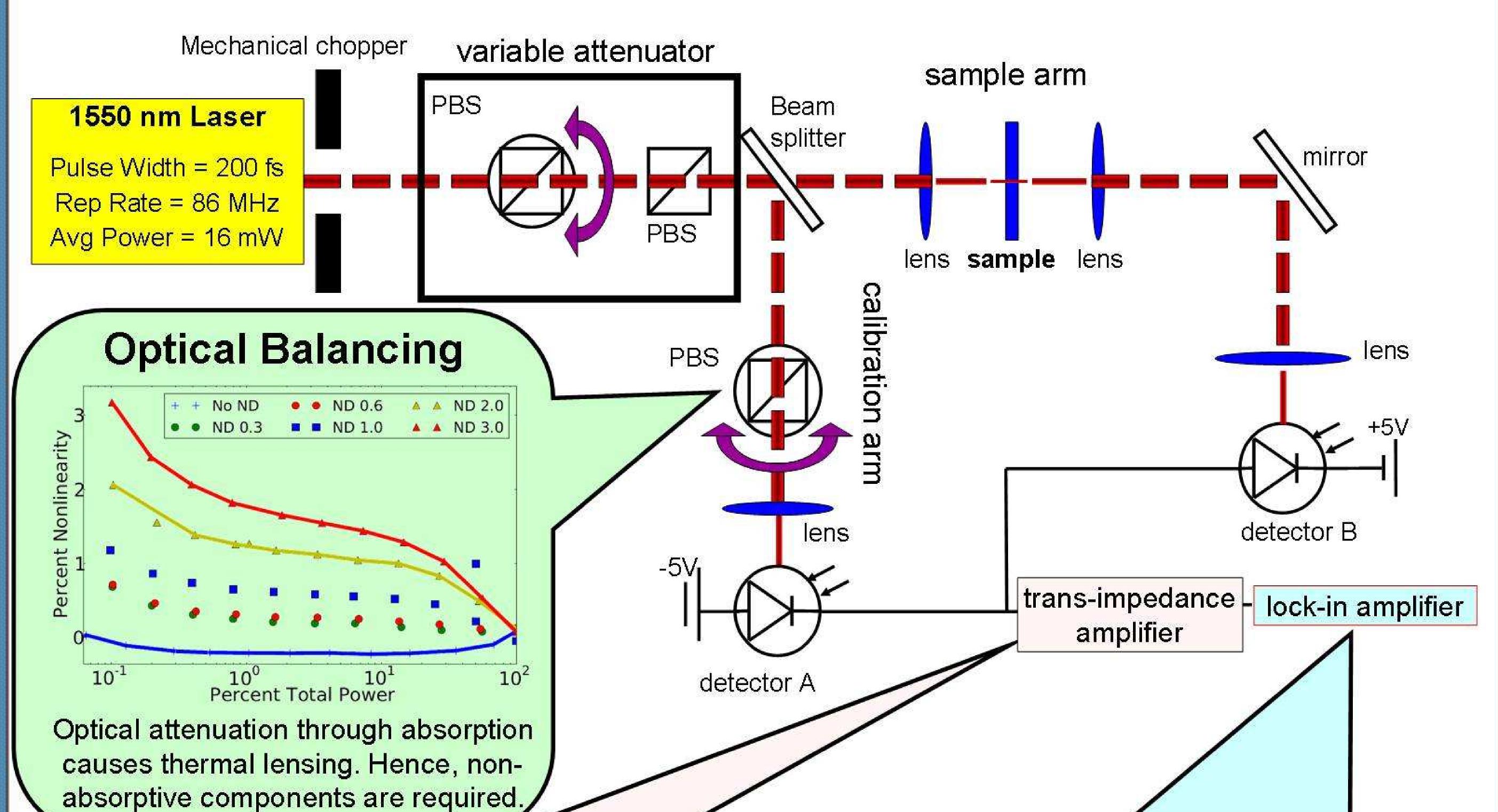
Graphene's electrical and mechanical properties have been well explored. However, there are many as of yet untapped applications for this novel material. For instance, to take advantage of graphene's potential as a saturable optical absorber, it is absolutely essential to characterize its optical properties precisely.



Saturable absorption of graphene a. Low energy spectrum of graphene. Blue: valence band; Red: conduction band.

- b. Absorption of a photon with $E_{photon} = \hbar \omega$. The vertical arrow indicates an inter-band transition.
- c. Thermalization of photogenerated carriers.
- d. At high optical intensities, the photogenerated carriers block further absorption.

Balanced Detection



Maintaining the Dynamic Range

A significant source of nonlinearity comes from the electronics themselves. The differences between two supposedly identical amplifiers can cause large variations over a dynamic range of three orders of magnitude. Instead one should electrically subtract the signals from the two photo detectors and amplify the subtracted signal with a single amplifier.

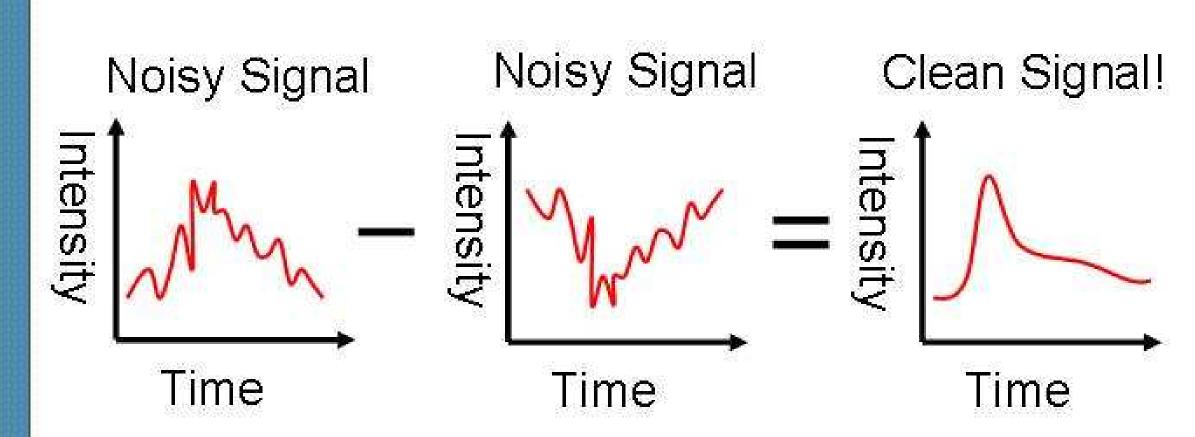
The Results Frat = $47.3\mu J/cm^2$ (208 MW/cm²) Saturable Loss = 1.69%Figure Graphene Monolayer Graphene Frat = $60.0\mu J/cm^2$ (264 MW/cm²) Saturable Loss = 0.83%Fluence on Graphene Sample ($\mu J/cm^2$)

With attention to all sources of systematic error, this technique can measure nonlinear absorption to an accuracy better than 0.1% after calibration over a dynamic range of over three orders of magnitude.

The Idea

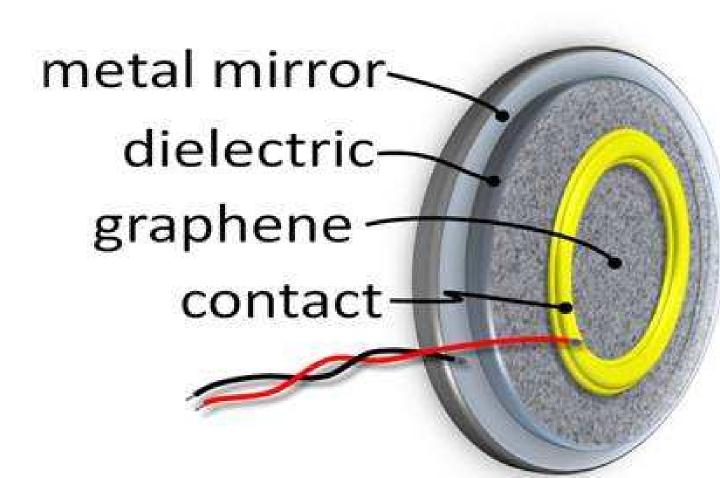
Nonlinear absorption can be small. To measure it over a large dynamic range can be very difficult.

Balanced Detection offers a solution while reducing the noise^{1,2}.



Balanced detection removes common-mode noise from the signal. In our specific case, one detector measures the optical absorption signal plus the laser-noise, the other one measures only the laser noise. The difference between the two is the actual signal without the noise.

The Future



Optical devices that utilize graphene's nonlinear absorption for passive mode-locking or active laser stabilization

References

- 1. Haiml, M et al. "Optical Characterization of Semiconductor Saturable Absorbers." <u>Applied Physics</u> B 79, 331-339 (2004).
- 2. Maas, D. J. H. C et al. "High Precision Optical Characterization of Semiconductor Saturable Absorber Mirrors." Optics Express 7571 (2008).

