Nanomechanical probing of the interface of InSe-hBN heterostructures

J.D. Greener[1], A.V. Akimov[1], R. Beardsley[1], Z.R. Kudrynskyi[1], A.J. Kent[1], Z.D. Kovalyuk[2], A. Patanè[1]
[1]*School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, UK*
[2]*Institute for Problems of Materials Science, NAS of Ukraine, Chernivtsi 58001, Ukraine*
ppxjdg@nottingham.ac.uk

Indium Selenide (InSe), a metal monochalcogenide compound from the large family of readily exfoliated van der Waals (vdW) materials is established as a two-dimensional (2D) crystal of both fundamental and technological interest due to its electronic properties. The direct band gap (E_g =1.26 eV at 300K) of bulk InSe is increased due to quantum confinement effects when the number of atomic layers in the crystalline sheet is reduced [1]. On the other hand, hexagonal Boron Nitride (hBN) is a wide bandgap ($E_g \approx$ 6 eV at 300K) insulator [2] and has been successfully used in conjunction with InSe and graphene to create high-mobility 2D graphene-InSe field effect transistors [3].

Here we report on the nanomechanical properties of InSe and InSe/hBN heterostructures (Fig. 1a) fabricated by mechanical exfoliation and stamping techniques of atomically thin flakes on sapphire and Si substrates. We use a picosecond acoustic technique to probe the high frequency (GHz) nanomechanical vibrations of the flakes under optical pumping of the InSe layer (Fig. 1b). A 120 fs pulsed laser is split into pump (400 nm) and probe (800 nm) beams. The pump beam creates hot electron-hole pairs in the InSe flake. The carriers generated are coupled to the lattice by electron-phonon interactions and the thermoelastic effect, resulting in local stress and resonant vibrations of the layers, which are monitored by the probe beam with 1 ps temporal resolution. The spectrum and the quality factor of the phonon resonances depend on the elastic properties of both the nanolayer/nanolayer and nanolayer/substrate interface. Single InSe flakes on sapphire tend to behave as free standing membranes with resonant frequencies in the GHz range that increase linearly with decreasing thickness of the flake [4]. In contrast, our data and analysis of the InSe/hBN heterostructure indicate a perfect elastic coupling (i.e. acoustic mismatch) between InSe and hBN (Fig. 2). Our technique demonstrates a non-invasive method of studying interface properties on the atomic level. Studies of nano-mechanical properties of vdW heterostructures may open up opportunities for novel heterostructure designs and applications in thermoelectric devices.

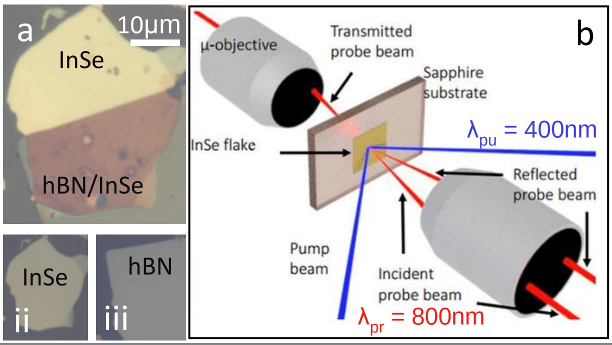

Figure 1: a) hBN/InSe heterostructures with InSe (i) and hBN (ii) flakes.
b) Sketch of the pump-probe experiment.

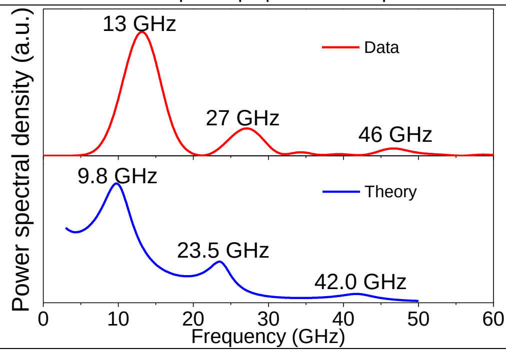

Figure 2: Measured (red) and calculated (blue) Fourier spectra of the pump-probe transmission signal for a hBN/InSe heterostructure, assuming acoustic mismatch between flakes and strong coupling to the substrate.

References

[1] G. W. Mudd *et al*, Sci. Rep. 6 (2016) 39619
[2] K. Watanabe *et al*, Nature Mat. 3.6 (2004) 404
[3] D. Bandurin *et al*, Nature Nano. (2016)
[4] R. Beardsley *et al*, Sci. Rep. 6, (2016) 26970