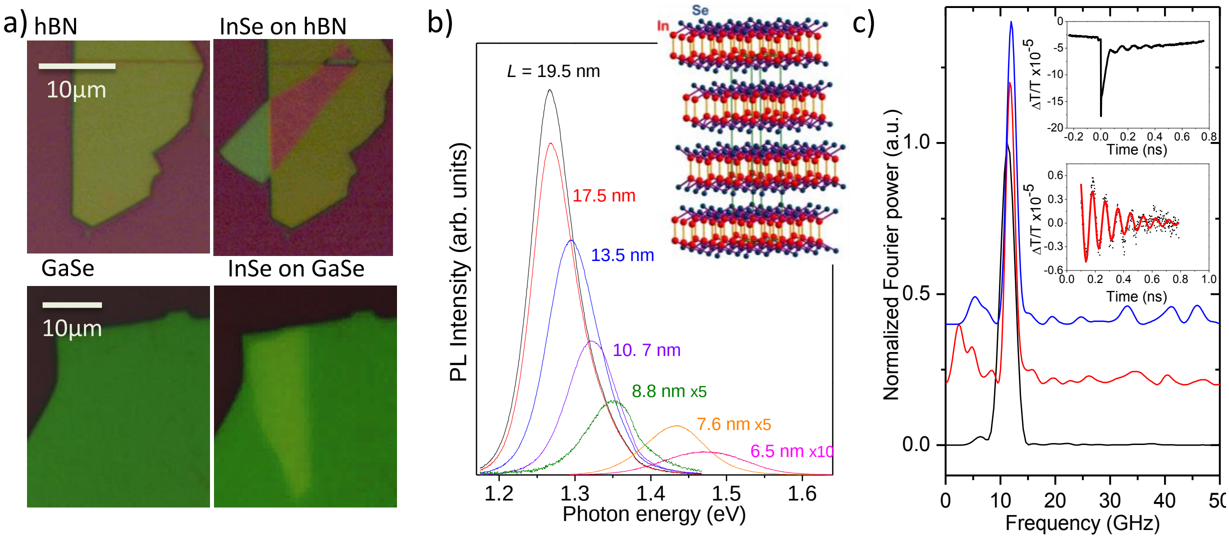
InSe hybrid heterostructures and nanomechanical probing of the heterostructure interface

J. D. G. Greener[1], R. Beardsley[1], G. W Mudd[1], N. Balakrishnan[1], S. Sandeep[1], Z.R. Kudrynskyi[1], A.V. Akimov[1], A. J. Kent[1], O. Makarovsky[1], Z.D. Kovalyuk[2], P.H. Beton[1], L. Eaves[1], A. Patanè[1]
[1]School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, UK
[2]Institute for Problems of Materials Science, The National Academy of Sciences of Ukraine, Ukraine
ppxjdg@nottingham.ac.uk

Among the large family of van der Waals (vdW) crystals, the metal monochalcogenide compounds (*e.g.* InSe, GaSe, etc.) have emerged as two-dimensional (2D) crystals with electronic properties of fundamental and technological interest. In their bulk form, these crystals have a direct band gap, which increases due to quantum confinement when the number of atomic layers, L, in the crystalline sheet is reduced. Correspondingly, a direct-to-indirect band gap transition occurs at small L and the energy-momentum relation of the valence band takes the form of a “Mexican hat”, referred to as a Lifshiftz transition. This property could lead to tunable magnetism, superconductivity, and enhanced thermoelectricity, thus expanding the applications of these 2D crystals ranging from bendable, high-gain photodetectors and field effect transistors with high electron mobility.[1]
Here we report on the fabrication by mechanical exfoliation and “stamping”, or by thermal annealing of new hybrid heterostructures that combine InSe with other crystals, including GaSe[2], graphene,[3] hBN, and In_2O_3 (Figure a). We examine the electronic transport through the vdW heterostructure and the charge transfer at the heterostructure interface, their dependence on the layer thickness (Figure b) and the mechanical adhesion of the InSe layer on the underlying substrate or layer. In particular, we use a picosecond acoustic technique to probe the high frequency (GHz) nanomechanical (i.e. phonon) vibrations of the InSe layer (Figure c). The frequency and the quality factor of the phonon resonances depend on the elastic properties of the nanolayer/nanolayer or nanolayer/substrate interface and enables a nanomechanical probing of the elastic bonds at the heterostructure interface. [4]



a) Optical images of hBN and GaSe before (left) and after (right) the stamping of a thin InSe nanosheet.
b) RT photoluminescence spectra and crystal structure of InSe nanosheets.
c) Power Fourier spectra of pump-probe transmission signals for an InSe nanosheet. The upper and lower insets are an example of the temporal evolution of the signal before and after subtracting the slow decaying background, respectively. The solid line in the lower inset is the fit to the experimental data by a simple model from which we extract the frequency and the quality factor of the oscillations.

References

[1] W. Huang et al., Cryst. Eng. Comm. DOI: 10.1039/C5CE01986A (2016).
[2] N. Balakrishnan et al., Advanced Optical Materials 2, 1064 (2014).
[3] G. W. Mudd et al., Advanced Materials 27, 3760 (2015).
[4] R. Beardsley et al., unpublished (2016).