Upconversion of Interlayer Excitons in Electroluminescent WSe_2/MoS_2 based Heterostructures

James A. Howarth[1]
J. Binder[2,3], F. Withers[4], M. R. Molas[2,3], T. Taniguchi[5], K. Watanabe[5], A. Wysmolek[3], M. Danovich[1], V. Fal'ko[1], A. K. Geim[1], K. S. Novoselov[1], M. Potemski[2,3], A. Kozikov[1]

[1]*School of Physics and Astronomy, The University of Manchester, Manchester, UK* [2]*Laboratoire National des Champs Magnetiques Intenses, Grenoble, France* [3]*Faculty of Physics, University of Warsaw, Warsaw, Poland* [4]*Centre for Graphene Science, University of Exeter, Exeter, UK* [5]*National Institute for Materials Science, Tsukuba, Japan*

james.howarth@manchester.ac.uk

The development of complex two-dimensional (2D) van der Waals heterostructures has allowed for many exciting developments within the field of optoelectronics. One area of recent interest has been the study of spatially indirect, interlayer excitons [1]. A device may be fabricated to incorporate a type-II band alignment heterojunction, such as that shown in Figure 1a, for which it is energetically favourable for electrons and holes to each accumulate in two different materials. Here, we fabricate vertical heterostructure LEDs, with an architecture depicted in Figure 1b, following [2]. The devices include a type-II heterojunction, formed between two transition metal dichalcogenide (TMD) monolayers: WSe_2 and MoS_2. The active heterojunction is encapsulated between few-layer hexagonal boron nitride (BN), acting as tunnelling barriers, and graphene electrodes to bias across the device. The electrical operation of the device allows for the tunnelling of electrons and holes each into only one layer of the device, providing a unique regime for studying interlayer excitons that is not available in pure photoluminescence studies. Specifically, we are able to study regimes with large carrier concentrations, in which Auger-like processes become significant. In Figure 2, we observe an upconversion process from Auger-like recombination of the interlayer exciton, demonstrated by the emission of intralayer excitons at biases where direct pumping of TMD intralayer excitons is not possible.

References

[1] Rivera, P., et al., Nature Communications, 6 (2015) 6242
[2] Withers, F., et al., Nature Materials, 14 (2015) 301-306

Figures

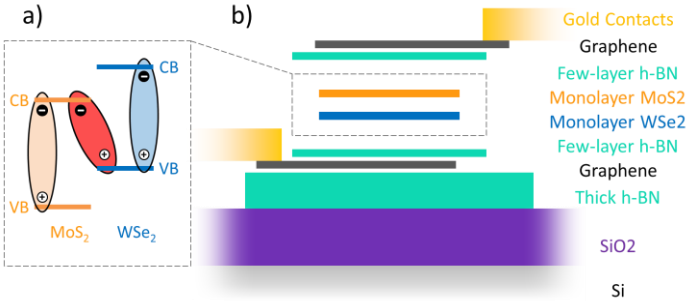

Figure 1: a) Band alignment of a heterojunction with a type-II band alignment. b) The device architecture of a light-emitting diode incorporating a type-II heterojunction.

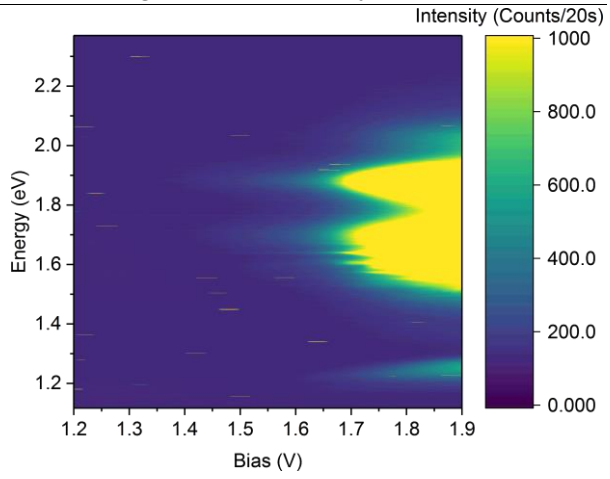

Figure 2: Electroluminescence bias dependence from a device in which upconversion is observed. The onset of emissions around 1.65eV and 1.90eV, corresponding to WSe_2 and MoS_2 monolayer excitons respectively, occurs for biases below 1.50V