Atomically thin electicaly tunable light-emitting diodes

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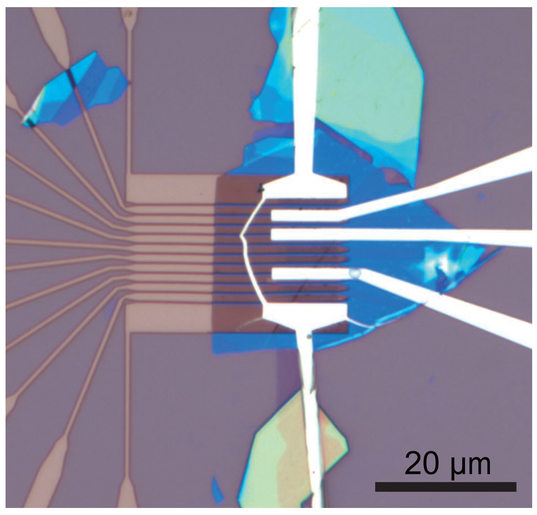
1. Introduction

In contrast to a bulk crystal, single layer WSe_2 is a direct band-gap semiconductor that appeared to be an interesting candidate for optoelectronic application such as light-emitting diode (LED) due to its unique optical and electrical properties.

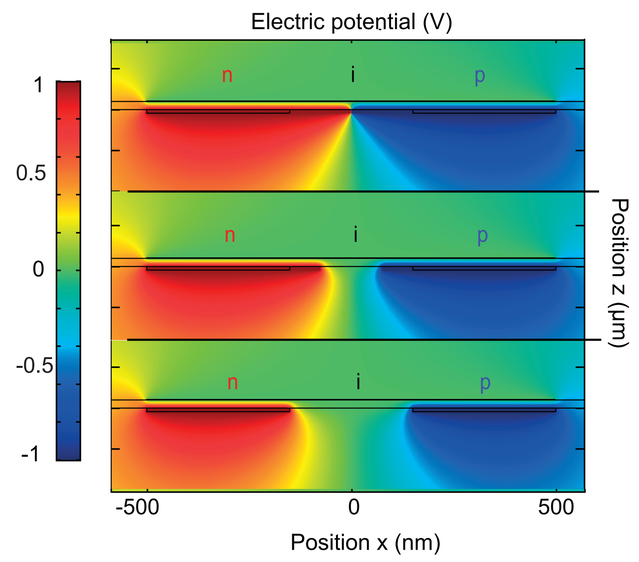
We present here a device based on atomically thin ambipolar semiconductor that exhibit different functionalities including transistor and p-n/n-p diodes. We also demonstrate and further characterise light emission from the electrostatically established lateral p-n junction. As a light-emitting diode, this device provides a basic element for new generation transparent and flexible optoelectronics.

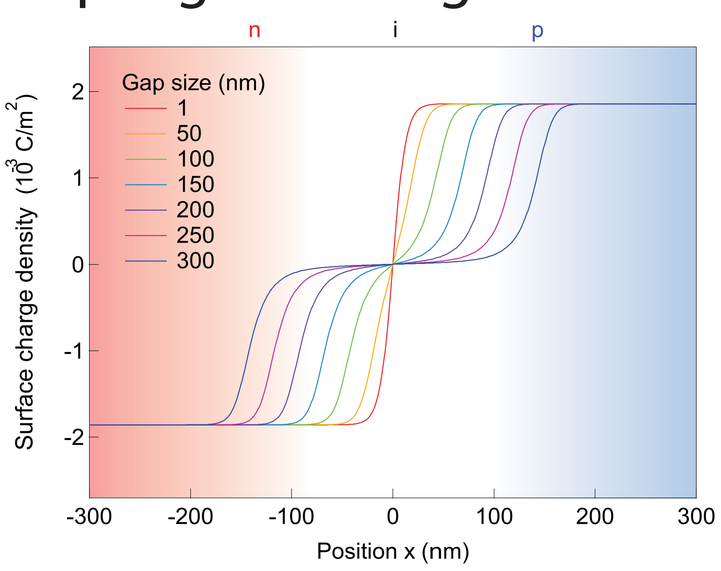
2. Device based on monolayer WSe_2 crystal



Optical image and a schematic profile of a fabricated device on a single layer WSe_2. The flake was assembled in a van der Waals heterostructure with hBN and then transferred onto prefabricated array of metallic gates with following contact definition by EBL.

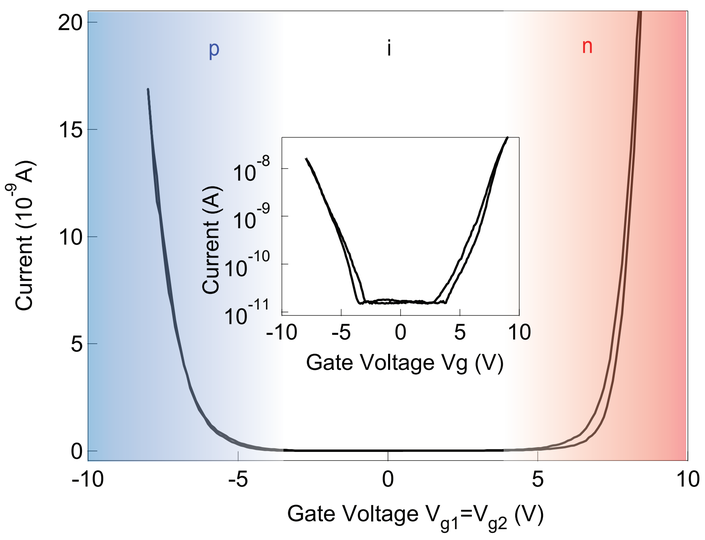
3. Numerical simulations of a split gate configuration





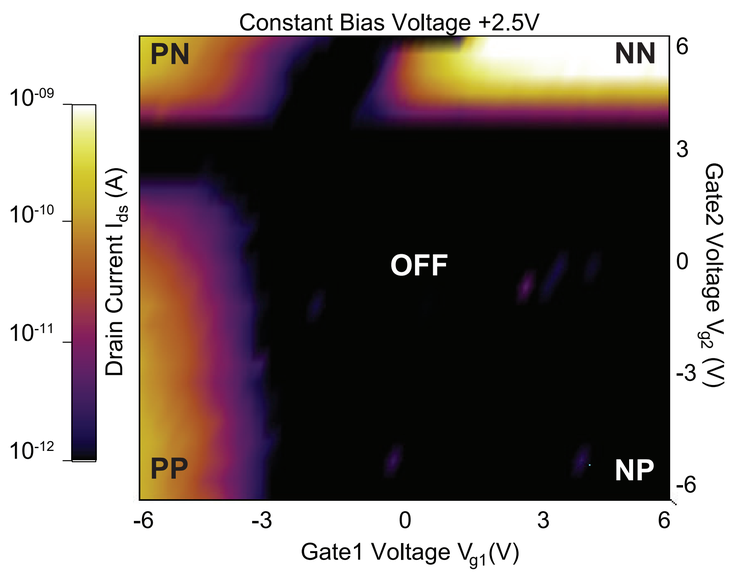
Theoreticallycalculated electrical potential distribution for the device in a split gate configuration for 1nm, 150nm and 300nm gate gap size. Corresponding surface charge density distribution in a direction along the device channel shows formation of two separated n-doped and p-doped regions of the semiconductor as well as not doped intrinsic area above the gate gap.

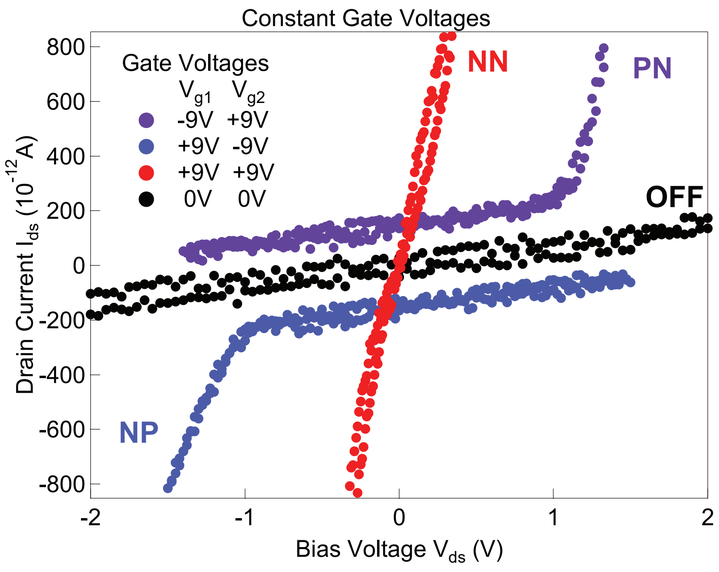
4. Ambipolar 1L WSe_2



I_s-V_g characteristic of the monolayer of WSe_2 on the local back gates reveals ambipolar behavior of the flake. Subnanometer chanel thickness enables efficient electrostatic gating over the vertical direction.

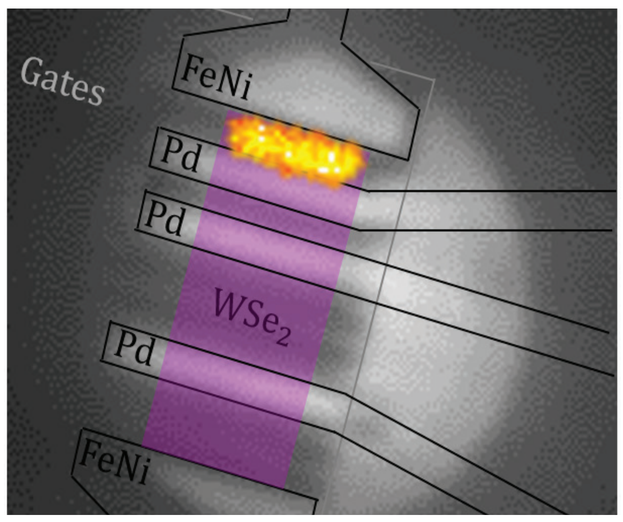
5. Electrical characterisation of the device





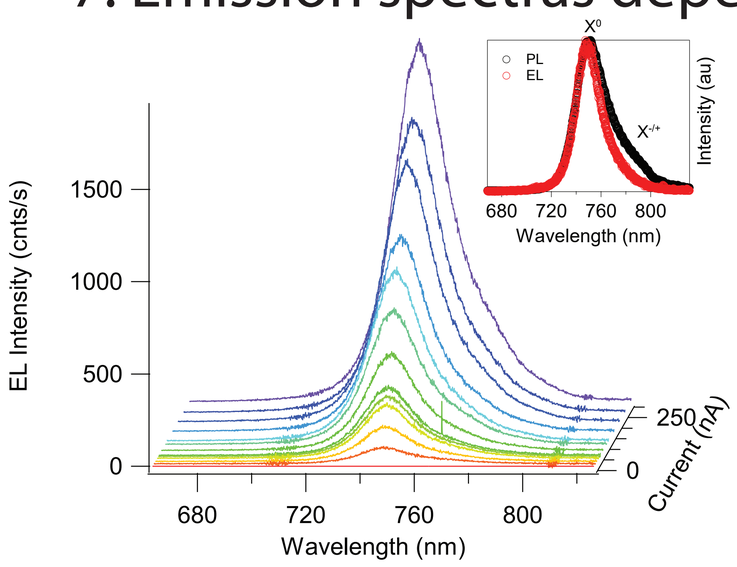
Single device has mutiple electrically tunable functionalities. Four corners of map of the current though the device at a constant bias and independent sweeping of the gate voltages represents four possible device regimes. Homogeneous gating of the chanel makes it n- or p-type resistor with linear I-V characteristic, while opposite biasing of split gates (PN or NP regimes) rectifies bias current.

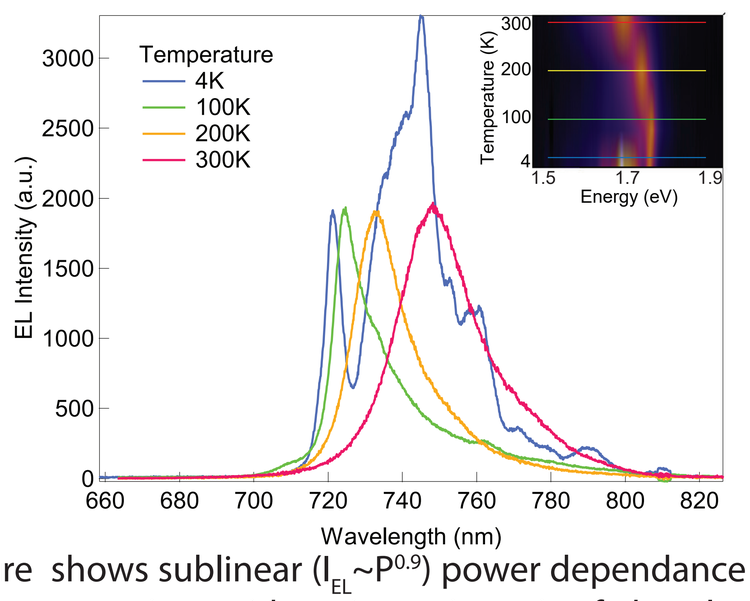
6. Light emission



In the PN regime electrons originated from n-doped region recombines with holes from p-side with light emission in the junction area. EL map is superimposed on the reflection image of the LED device.

7. Emission spectras dependencies





Electroluminescence (EL) spectra at room temperature shows sublinear (I_{EL}~$P^{0.9}$) power dependance and domination of excitonic origin of light emission in comparison with exciton-trion mix of photoluminescence (PL). Temperature decrease (inset map) leads to linewidth narrowing and blueshift of the main emission peak due to WSe_2 bandgap opening. Moreover at 4K other emission features becomes pronounced (blue spectra) like biexciton and impurities and defect bounded excitonic states.

8. Conclusion

- Atomically thin WSe_2 shows ambipolar behaviour with possible p- and n-type conductivity of the channel
- Single layer WSe_2 on a split gates shows multiple functionalities as a function of electrostatic doping
- Device in the PN configuration represent basic optoelctronics building block (p-n LED). Under the forward bias it emits light in the junction region
- Room temperature EL is dominated by neutral exciton recombination and affected by impurities and defects at lower temperatures

Acknowledgement

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