LED based on van der Waals heterostructures

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Outline

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- History of LED
- Band structure engineering
- Optoelectronic properties of heterostructures
- Transition metal dichalcogenide (TMD) based devices
- Conclusion

History of LED

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- 1907 – British experimentist H. J. Round
- 1924 – 1930 – Russian engineer O. V. Losov
- Second World War – K. Lehovec
- 1962 – Nick Holonyack
- Mid 1960s - Commercial LED
- 1987 – AlGaAs diodes
- 1993 – GaP diodes
- 2014 – the blue LED

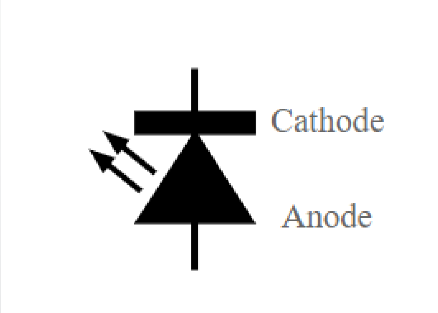

Figure 1.: LED circuit symbol

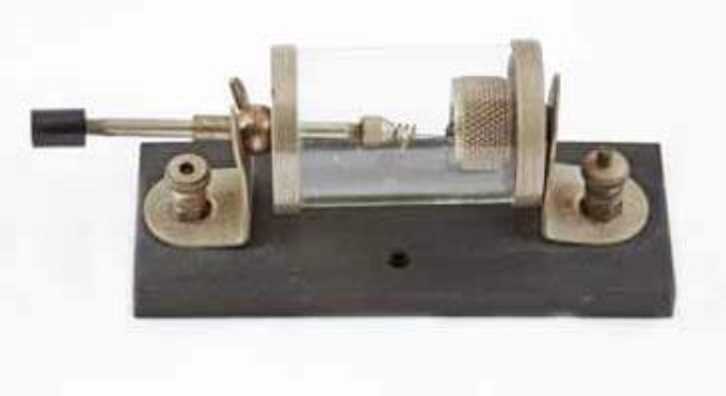

Figure 2.: Cat's whisker detector

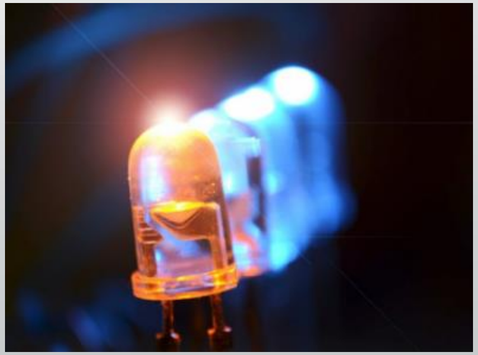

Figure 3.: Commercial LEDs

Band structure engineering

- Low-dimensional nanomaterials
  - heterostructures based on atomically thin crystals
- Tunnelling diodes and transistors, photovoltaic devices
- Transition metal dichalcogenides
  - Direct band gap semiconductors
- Light emitting vdW heterostructures
  - Alignment of electronic band and Coulomb interaction effects

Band structure engineering

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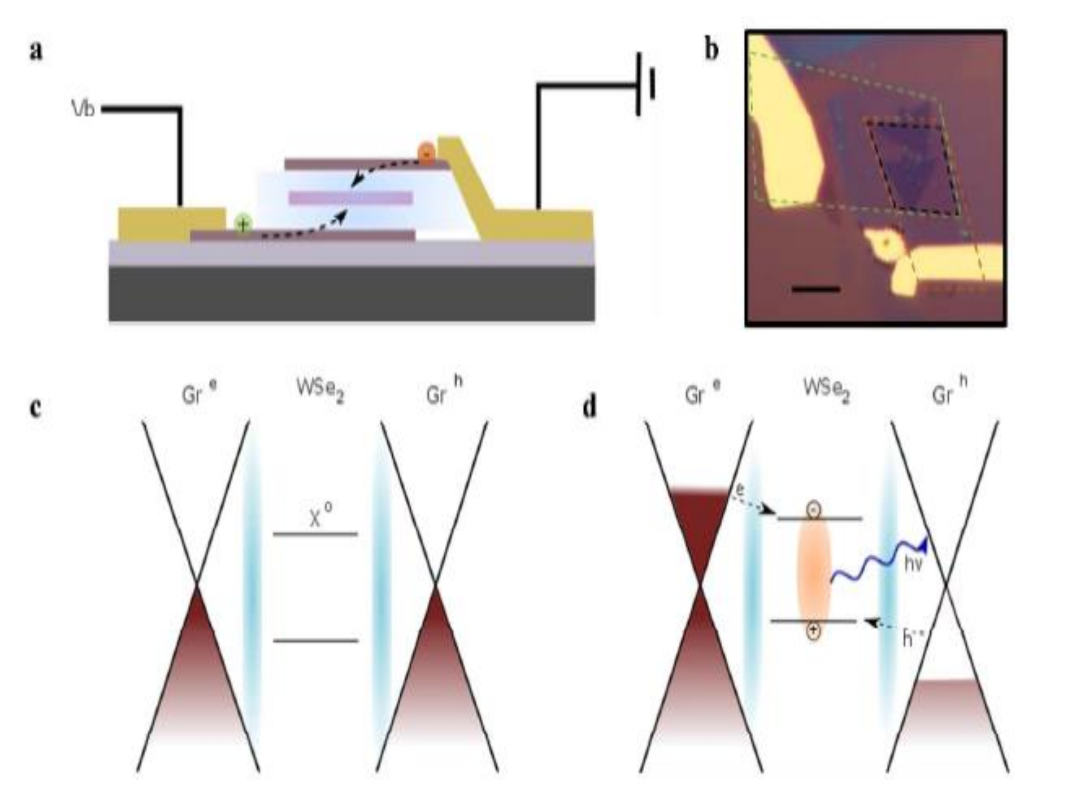

Figure 4. : a) Schema of vertical heterostructure. b) Optical image of LED. c) Schematic of device's electronic structure in unbiased state and under external bias d). Taken from (3).

- Vertical heterostructures
  - reduce contact resistance, higher current densities, luminescence from the whole device area
- Si/Sio2 substrate
- Stacked graphene layers – conductive layer
- Central layer of TMDs – quantum wells
- Thin layer of hexagonal boron nitride – tunnel barrier
- No external bias – the Fermi level of graphene lies within the band gap of WSe2
- Biased device – the Fermi level rises

Optoelectronic properties

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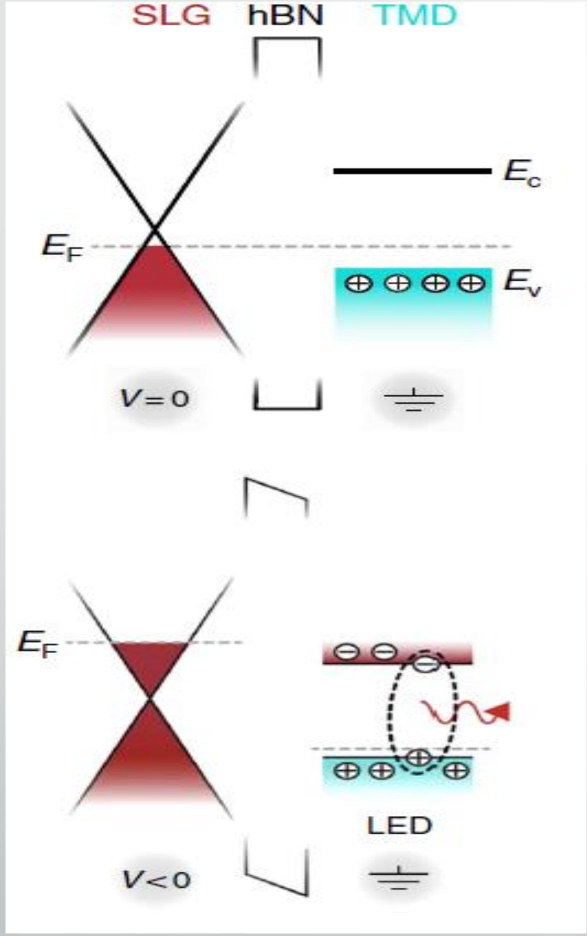

Figure 5.: Heterostructure band diagram.
Taken from (4).

- Injecting carriers electrically into the material
- Carriers remain in the TMDs layer
- Electron and hole form exciton and recombine
- hBN causes carries stay in the TMDs

Optoelectronic properties

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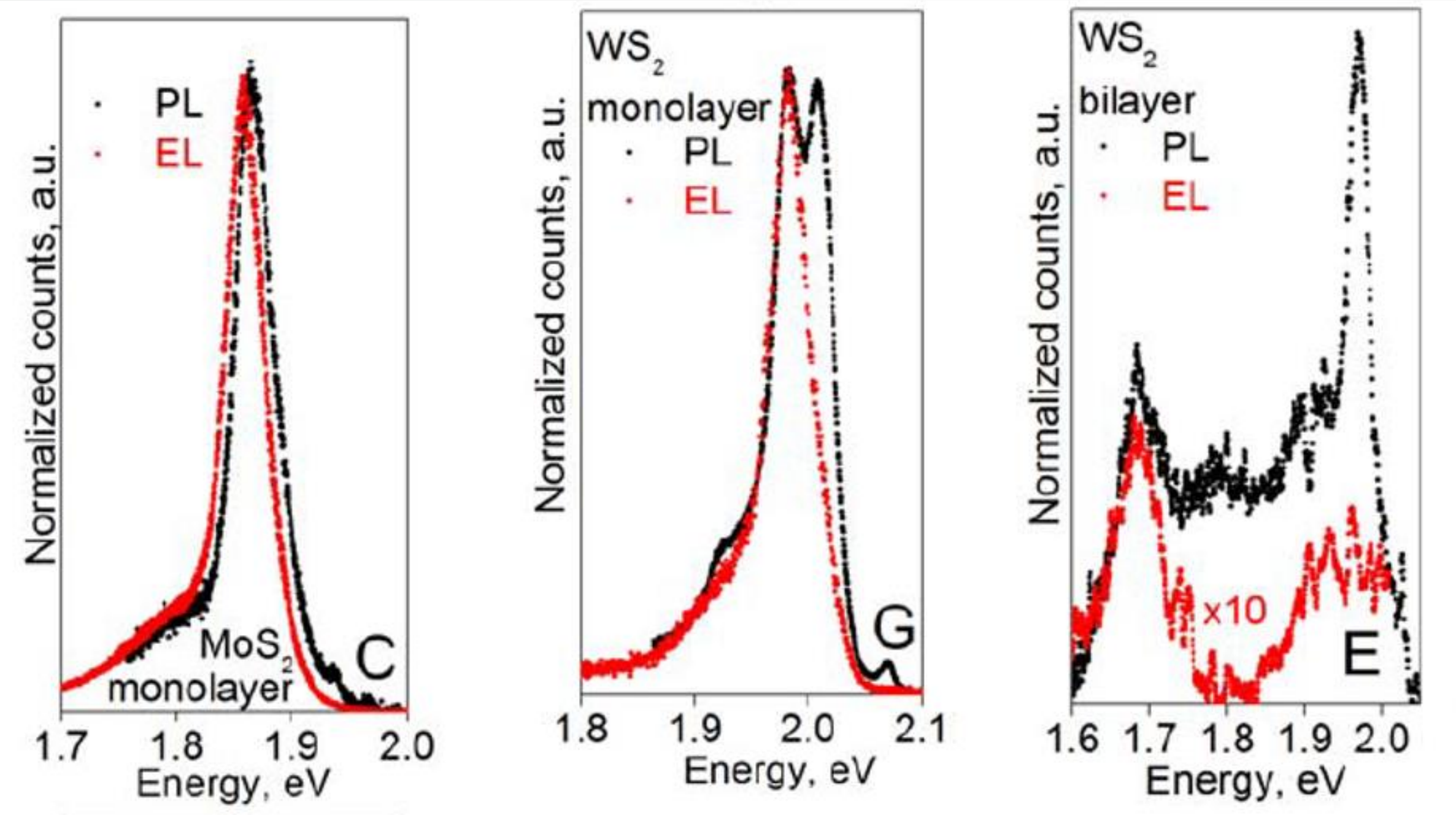

Figure 6.: Photoluminescence and electroluminescence comparison. Taken from (1).

Conclusion

- Fine control over the tunnelling barriers
- Quantum efficiency above 1%
- Flexible and bendable stacks
- Semi-transparent devices

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Thank you for your attention

Resources

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3. Clark, G.; Schaibley, J. R.; Ross, J.; Taniguchi, T.; Watanabe, K.; Hendrickson, J. R.; Mou, S.; Yao, W.; Xu, X. Nano Lett. 2016, 16, 3944–3948.
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