Atomically thin semiconductors for nanophotonics

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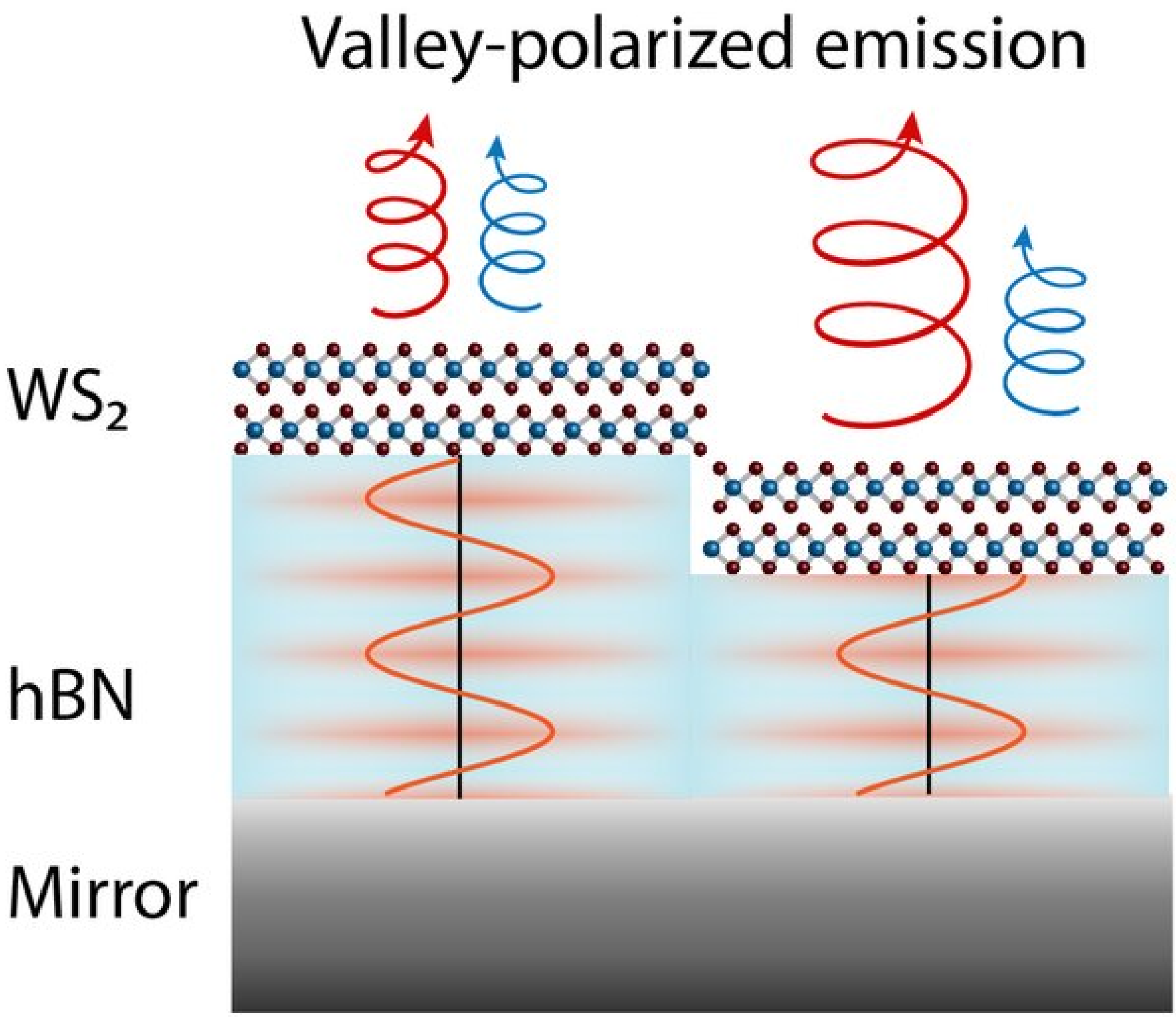

Credit: Rasmus Godriksen

Atomically thin semiconductors such as molybdenum disulfide and tungsten disulfide are promising materials for nanoscale photonic devices. These approximately 2D semiconductors support so-called excitons, which are bound electron-hole pairs, that can align vertically along the thin plane of the materials.

Excitons are bound electron-hole pairs that can interact with electrical charges, spins, and phonons. This range of interactions indicates that excitons could herald a new wave of devices based on nanoscale photonics and optoelectronics.

For his Ph.D. thesis, Rasmus Godiksen investigated the exciton behavior in atomically thin semiconductors, focusing on emitted light, by exploring the potential of excitons in ultra-thin semiconductors such as molybdenum disulfide (MoS_2) and tungsten disulfide (WS_2). The semiconductors are so thin that can be approximated as 2D materials. So, in effect, Godiksen studied excitons in 2D materials.

Sensitivity

First, Godiksen and his collaborators showed that the 2D excitons are very sensitive to their nanoscopic environment. Using photoluminescence (PL) imaging techniques, they measured fluorescence fluctuations due to charge transfer to the semiconductor. Such fluctuations are spatially correlated over tens of micrometers in WS_2 monolayers on metal films.

Due to charge fluctuations from trap states (which are states that trap excited carriers such as electrons, holes, and excitons), they follow power-law statistics with simultaneous changes in emission intensity, lifetime, and exciton-trion ratios. Power-law statistics is an indicator of trapping and de-trapping of excitons, so this provides evidence of trapped states.

Valley degree of freedom

Excitons in WS_2 also have a degree of freedom with regard to valleys, which couples spin polarization to momentum direction. Valleys in the band structure can be explored using circularly polarized light. Exciting or detecting an exciton in one valley can be used in information technologies, for example.

To explain the contrast in spin-valley polarization in a few layers of WS_2 and tungsten diselenide (WSe_2), Godiksen used layer- and temperature-dependent circularly polarized PL measurements. This related their contrasting polarizations to a different momentum of their conduction band minima.

The overall spin-valley dynamics are governed by the exciton and valley lifetimes. Valley polarized emission is determined by competing lifetimes—the exciton lifetime and the valley lifetime. By decreasing the exciton lifetime, it's possible to increase valley polarized emission. This is because excitons recombine and emit light faster than they scatter to the other available valleys.

By changing the distance of a WS_2 bilayer to a mirror, the excitation enhancement increases exciton-exciton annihilation resulting in higher polarization.

Silicon nanoresonators

Finally, Godiksen studied the use of silicon nanoantenna to further enhance the interaction of circularly polarized light with valley-polarized excitons. He showed that crystalline silicon nanodisks preserve the circular polarization of light in the near field as required for additional enhancement of valley-polarized emission.

Godiksen's results advance the understanding of the interactions of excitons with charges, spins, and photons with implications for a range of nanophotonic devices using atomically thin semiconductors.

Single-photon sources are interesting for quantum computing, molecular sensors could increase sensitivity down to the single molecule level, and valleytronic devices could pave the way for a new generation of electronic devices based on valley polarization.

More information: Atomically Thin Semiconductors For Nanophotonics. research.tue.nl/en/publication … rs-for-nanophotonics

Provided by Eindhoven University of Technology

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