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Enhanced photovoltaic effect in intrinsic tungsten disulphide nanotube

Tungsten disulphide (WS_2) and other group-VI-B transition-metal dichalcogenides (TMDs) are exemplary low-dimensional semiconductors. The unit cell in their bulk form is composed of two layers. The inversion centre in the unit cell is located at the van der Waals gap. Hence, the inversion symmetry can be broken simply by for instance isolation of monolayers. Many peculiar phenomena and functionalities have been realized in such non-centrosymmetric TMDs [1-3], but the bulk photovoltaic effect (BPVE), which requires the inversion symmetry breaking as well, has not been studied up to now. This effect can be distinguished from the conventional photovoltaic effect that is observed at the interface of two different species, because the BPVE does not require any interface. We have studied BPVE in nano devices out of WS_2 in several different crystal symmetry, and discovered that a polar structure has a huge potential to enhance the BPVE [4]. My presentation will be based on this latest study.

We fabricated nano devices out of WS_2 in three different crystal symmetry: centrosymmetric bilayer, non-centrosymmetric monolayer, and non-centrosymmetric polar (multiwall) nanotube (Fig. 1). Monolayer WS_2 belongs to D_{3h} point group, which does not have the inversion symmetry yet not classified as polar. The polar nature of the nanotube was confirmed based on the chirality of the each wall composing a multiwall nanotube, which can be determined from the transmission electron microscope and electron diffraction measurement [5]. Each device has two electrodes composed of Cr (5 nm) and Au (200 nm). WS_2 materials are kept intrinsic, that is, no carrier doping method was adopted in this study.

The electrical current between two electrodes were monitored in each device upon laser irradiation under high vacuum at room temperature. The incident laser was focused onto the sample through objective. We found that only in nano devices with WS_2 nanotube, a sizable short-circuit current was observed, which indicates that WS_2 nanotube shows BPVE. This is, to the best of our knowledge, the first observation of BPVE within devices made of nano material.

A unique feature was also observed in the laser power dependence of the short-circuit current: the current depends on the power linearly at low power region, while at high power region the dependency is square-root. This crossover is consistent with the theoretical prediction of the shift current based on the quantum mechanics [6]. The shift current originates from the difference in the Berry connection between initial and final Bloch states of the optical excitation process [6]. As monolayer WS_2 does has finite Berry connection, it is in principle possible to observe the BPVE. The group theory also allows the BPVE to appear in D_{3h} point group [7]. However, our nano devices out of monolayer WS_2 do not exhibit recognizable short-circuit current, even though the amount of the light absorption in the monolayer WS_2 is similar to that in WS_2 nanotube. Such a large suppression of BPVE in monolayer implies that the polar structure plays a crucial rule in the enhancement of the BPVE.

Finally, we found the light-to-current conversion efficiency in WS_2 nanotube is much larger than that in conventional bulk materials that show BPVE. This fact indicates the great potential of WS_2 and other TMDs for harvesting solar energy.

References

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Figures

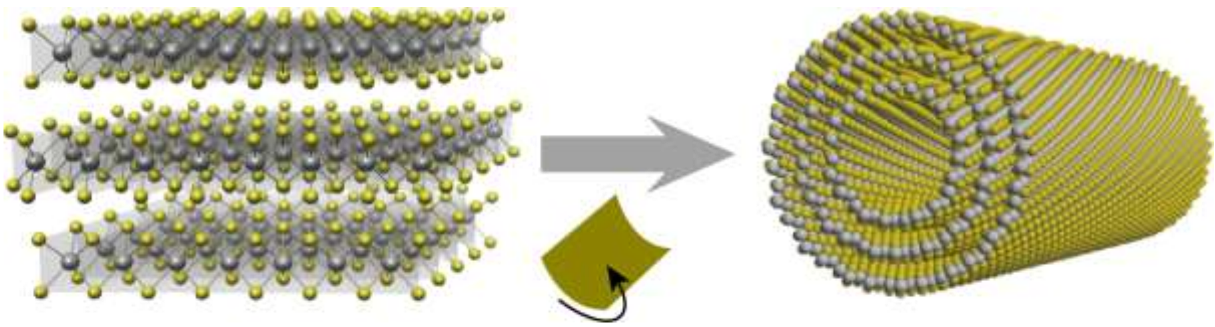

Figure 1: Schematics of two-dimensional TMD (left) and nanotube (right). Grey and yellow spheres represent transition-metal and chalcogen atoms, respectively.