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Valleytronic Properties of 2D Materials

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1. Introduction

Layered Transition metal dichalcogenides (TMDs) are fruitful platform for electronics, spintronics, and opto-valleytronics. The monolayer TMDs have a similar crystal structure as staggered graphene and thus various physics predicted for inversion asymmetric graphene also inheres in monolayer TMDs. Especially, valley related physics are of particular importance. The broken inversion symmetry splits six Fermi pockets, locating at the first Brillouin zone edges, into two inequivalent groups (±K). The existence of valley degree of freedom is the base requirement for valleytronics. The broken inversion symmetry also lead to finite and valley-depended Berry curvature, which leads to valley-depended optical selection rule (valley circular dichroism), Zeeman-type spin splitting, and valley Hall effect [1]. After the fundamental investigation of valley circular dichroism in TMDs by polarization-resolved photoluminescence, valley-dependent spin splitting [2] and light-induced valley Hall effect [3] were experimentally observed.

2. Experimental results

Here we first report the stacking dependent circular dichroic photoluminescence in mono- and multi-layered MoS_2. It is well known that the all unique properties of monolayer MoS_2 emerge from the broken inversion symmetry of the monolayer structure. In the commonly used 2H MoS_2, the monolayers with different directions are alternately stacked so as to make the whole crystal symmetric. On the other hand, in the 3R structure, the monolayers with the same orientations are stacked so that the broken inversion symmetry of monolayer is maintained. We fabricated multilayered flakes by exfoliation of 2H and 3R crystals of MoS_2 single crystals. The circular dichroic coefficient in the photoluminescence (PL) was found to be independent of the layer numbers in the 3R structure. In sharp contrast, the 2H based few layered flakes showed a dramatic reduction of the circular polarization of PL with increase of layer numbers [2]. This marked difference implies that the interlayer interaction takes an essential role in the PL properties in multilayer MoS_2.

We then investigated *p-n* junctions embedded in TMDs, in terms of opto-electronic applications. Taking advantage of the ambipolar transport characteristics, *p-n* junctions can be electrostatically formed in channel TMD materials using field effect transistor (FET) geometry [4]. Among various FETs, electric double layer transistor (EDLT), a FET using liquid dielectrics, have been manifested their potentials upon TMDs by field-induced superconductivity [5] or control of spin relaxation [6]. For opto-electronic devices, we observed electrically controllable helical electroluminescence from TMD *p-n* junction formed by EDLTs [7]. In a stark contrast, such a functionality is absent in junctions formed by conventional FETs [8]. The origin of this phenomenon lies in the anisotropic band dispersion (trigonal warping) that, under in-plane electric field, leads to valley-depending carrier transport and electron-hole recombination. Within the conventional FETs, the in-plane electric field is expected to be too small to induce these effects, implying the potential of EDLTs.

3. Conclusions

We have demonstrated unique optical properties of TMD mono- and a few-layered TMDs which originates from the valley degree of freedom. Development of manipulation and detection techniques of valley degree of freedom could be a promising route toward dissipation minimum electronics based on noncharge information carriers.

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