Citation for the 2021 (the 9th) Nishina Asia Award

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For his pioneering contributions to valleytronics in two-dimensional semiconductors and van der Waals heterostructures

Realization of relativistic "Dirac fermions" in two-dimensional materials such as graphene is not only interesting from cross-disciplinary interest between condensed matter and high-energy physics, but also as a platform to exhibit various exotic phenomena, and eventually to realize useful functionalities. In condensed matter realization, multiple copies of Dirac fermions are often realized as required by the symmetry and topology of the system. They usually occur at different points of the momentum space. This provides an extra degree of freedom called "valley", in addition to the spin degree of freedom.

As one of his pioneering contributions concerning the valley degree of freedom, Dr. Wang Yao discovered theoretically the "valley Hall effect", in which currents associated to two valleys flow to opposite directions orthogonal to the applied electric field [1]. This effect arises when the inversion symmetry is broken in graphene, for example, by the substrates. The Dirac fermions then acquire masses (namely the excitation gap opens) so that the Dirac masses for the two valleys have opposite signs. The resulting Berry curvature naturally induces the valley Hall effect. This discovery has generated a significant interest in the field, and become one of the fundamentals of *valleytronics*: exploitation of the valley degree of freedom to realize devices with useful functionalities. It was still difficult to probe and control the valley degree of freedom with certainty in experiments. Dr. Yao made another groundbreaking contribution with the prediction of the valley-selective optical transitions by circularly polarized light [2]. This enabled versatile controls and precise measurements of the valley degree of freedom. Valleytronics has become an experimentally demonstrated reality, largely thanks to these pioneering contributions by Dr. Yao.

Dr. Yao's works have also vitalized the study of new group of materials, especially transition metal dichalcogenides, such as monolayer MoS_2. They have a structure similar to graphene, but with the inversion symmetry broken. Thus they turned out to be an ideal playground for valleytronics, naturally realizing the valley Hall effect and the valley-selective optical transitions as it had been predicted by Dr. Yao. In fact, significant spin-orbit couplings exist in this class of materials, leading to new physics. Dr. Yao also elucidated the interplay between the spin and valley degrees of freedom in these materials [3]. In particular, spin-polarized excitations can be created by choosing the frequency properly for the circularly polarized light, thanks to the valley-selective optical transition and the spin-orbit coupling. This further enriched the emerging field of valleytronics.

Dr. Yao has also provided numerous other interesting ideas, such as long-lived interlayer excitons in moiré materials [4], stimulating theoretical and experimental studies in the field. In addition to his theory papers which have been influential for experimental studies, he also often helps experimental study directly through collaborations with experimentalists.

Valleytronics has evolved into an important field in physics and for future engineering, with the new class of two-dimensional semiconducting materials as an ideal platform. There is no doubt that Dr. Yao's contributions have been essential for this evolution, and that he continues to be a widely recognized leader in the field. Based on these achievements, Dr. Yao deserves the Nishina Asia Award.

References

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