Manipulation of pseudo-spins in semiconducting nanomaterials

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In the technology of spin-based quantum information, freely controlling a single spin in a solid to any of its coherent superposition states is a key functionality. A nature way to control a carrier spin is by means of magnetic field. Nevertheless, for scalable quantum systems, it is required to *locally* control each devices and the use of external uniform magnetic fields is not a practically good way. To solve the problem, one might seek for alternative quantum states acting as pseudo-spins that do not need real magnetic fields but receive other locally tunable fields, like electrical bias or mechanical stresses, for the coherent control. In this work, we shall present our recent theoretical investigations of single valence hole in semiconducting quantum dots (QDs) using the multi-band *k.p* theory and valley excitons in two-dimensional (2D) transition-metal dichalcogenide (TMD) monolayers in layer-stacking structures by using the Bethe-Salpeter equation approach. In the former, due to quantum confinement of QD, the heavy- and light-levels are well separate and the lowest states of a valence hole are the heavy-hole-like doublet that behave as a pseudo-spinor. In the latter, the valley of an exciton can be regarded as pseudo-spin that are advantageous in the optical manipulation.

Unlike the real spin of conduction electron, the heavy hole pseudo-spin possesses the pronounced anisotropy of g-factor,[1] and suited for the application of electrical g-tensor modulation (g-TM),[2,3] where local electrical bias can be used for the pseudo-spin control. A success of g-TM technology essentially requires that one of the g-tensor components of a hole spin carrier is sign-reversible by electrical gating. As a main result of our theoretical studies, we show that, by slightly stressing a un-strained GaAs/AlGaAs QD, the required electrical bias to achieve such a sign-reversal of hole g-factor is dramatically dropped by 1-2 orders of magnitude to the experimentally accessible scale. [4]

From the studies of TMDs, one realizes that the valley excitons therein are intrinsically subjected to the electron-hole exchange interaction that acts as an in-plane pseudo-magnetic field and makes the fast depolarization of valley.[5,6] The fast depolarization of excitonic valley is one of remaining concerns in the emergent valleytronic applications. As a main result, we show that the poor screening in TMD monolayers leads to strong inter-layer excitonic couplings in layer-stacking devices. The inevitable strong inter-layer couplings in stacking-structured devices leads to significant energy transfers and substantially affect the valley depolarization rates.

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References

[1] R. Kaji, T. Tominaga, Y.-N. Wu, M.-F. Wu, S.-J. Cheng, and S. Adachi, Phys. Status Solidi B **254**, 1600486 (2017)
[2] Y. Kato, R. C. Myers, D. C. Driscoll, A. C. Gossard, J. Levy, and D. D. Awschalom, Science **299**, 1201 (2003).
[3] J. Pingenot, C. E. Pryor, and M. E. Flatté, Appl. Phys. Lett. **92**, 222502 (2008).
[4] Y. N. Wu, M. F. Wu, Y. W. Ou, Y. L. Chou, and S. J. Cheng, Phys. Rev. B **96**, 085309 (2017)
[5]K. F. Mak, *et al.* Phys. Rev. Lett. **105**, 136805 (2010)
[6] H. Yu, *et al.* Nature Commun. **5,** 3876 (2014).