Excitation Dependent Energy Transfer in 2D Heterostructure

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Monolayer (1L) thick two-dimensional (2D) transition metal dichalcogenides (TMDs) exhibit strong light-matter interaction [1]. Vertical heterostructures (HSs) made by the stacking of different TMDs have already shown promises for future optoelectronic device applications [2]. Interlayer charge (CT) and energy transfer (ET) are the two main photocarrier relaxation pathways in the TMD HSs. The interlayer CT process mainly occurs due to the energy level offset between the two materials, which survives only up to few nm distance [3]. Whereas, the long-distance interlayer ET process can survive up to several tens of nm [4]. Our previous work [5] has shown that due to the strong *overlap* between the *optical bandgaps* of the two TMDs, interlayer ET process dominates over the traditional CT process. In the present work [6], we explore the effect of resonant *overlap* between the *high-lying* excitonic resonances in the long-distance ET process in HS made by the 1Ls of molybdenum disulfide (MoS_2) and tungsten diselenide (WSe_2). At, low temperature (8 K) resonant excitations from the lower bandgap WSe_2 B and D excitonic levels create more photocarriers at the higher bandgap MoS_2 layer, resulting an enhanced (~2×) MoS_2 PL emission from the HS area. With the increasing temperature the enhanced PL emission starts to destroy due to the increased electron-phonon scattering. Our work provides a new insight into the long-distance interlayer ET process from the *lower-to-higher* bandgap TMD material, which will be beneficial in developing TMD-based future optoelectronic device applications.

References:

[1] U. Wurstbauer, B. Miller, E. Parzinger, and A. W. Holleitner, *J. Phys. D: Appl. Phys.* 50 (2017) 173001.
[2] N. Huo, Y. Yang, and J. Li, *J. Semicond.* 2017, 38 031002.
[3] L. Britnell, R. V. Gorbachev, R. Jalil, B. D. Belle, F. Schedin, M. I. Katsnelson, L. Eaves, S. V. Morozov, A. S. Mayorov, N. M. R. Peres, A. H. C. Neto, J. Leist, A. K. Geim, L. A. Ponomarenko, and K. S. Novoselov, *Nano Lett.* 2012, 12, 3, 1707–1710.
[4] F. Federspiel, G. Froehlicher, M. Nasilowski, S. Pedetti, A. Mahmood, B. Doudin, S. Park, J-O Lee, D. Halley, B. Dubertret, P. Gilliot, and S. Berciaud, *Nano Lett.* 2015, 15, 2, 1252–1258.
[5] A. Karmakar, A. Al-Mahboob, C. E. Petoukhoff, O. Kravchyna, N. S. Chan, T. Taniguchi, K. Watanabe, and K. M. Dani, *ACS Nano* 2022, 16, 3, 3861–3869.
[6] A. Karmakar, T. Kazimierczuk, I. Antoniazzi, M. Raczyński, T. Taniguchi, K. Watanabe, A. Babiński, A. Al-Mahboob, and M. R Molas, *arXiv*:2301.05644.