Tomoyuki Yamada
J. Pu, M.-Y. Li, J.-K. Huang, Y. Miyauchi, K. Matsuda, Y. Miyata, L.-J. Li, T. Takenobu
Dept. of Applied Physics, Nagoya Univ., Bldg.3 Room 262, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan

Contact : jiang.pu@nagoya-u.jp

Monolayer Transition Metal Dichalcogenide Lateral Heterojunction Light-Emitting Diodes

Recent advances of heterostructure fabrications based on transition metal dichalcogenides (TMDCs) yield atomically regulated interfaces due to their intrinsically passivated surfaces, allowing us to explore unusual electrical and optical phenomena and to make outstanding improvements to device performance [1-3]. Although, numerous experimental demonstrations of vertically stacked heterostructures have been realized using scotch-tape techniques, the investigation of physical properties of lateral heterojunctions, in which dissimilar TMDCs are artificially stitched together, has been still limited. In particular, lateral heterojunctions are easier to tune band offset for designing p-n junctions because of their spatial separation. Moreover, compared with manual transfer of vertical heterostructures, lateral heterojunctions are ideally adopted for the scalable approach of chemical vapor deposition (CVD) for creating atomically sharp heterojunction interfaces [4]. Here, we developed a scalable fabrication process for WSe_2-MoS_2 lateral heterojunction films and realized its light-emitting devices to evaluate electroluminescence (EL) properties at junction interfaces *via* electrolyte-based device structures [5].

The monolayer WSe_2–MoS_2 lateral heterojunction films were synthesized by two-step CVD process on the sapphire substrates [5]. As shown in Fig. 1, W electrodes were firstly patterned for the subsequent location-selective and slf-aligned growth of WSe_2 monolayers. And then, epitaxial growth of MoS_2 monolayers was performed to form the WSe_2-MoS_2 lateral heterojunctions. Finally, additional Mo pads were deposited, followed by spin-coating ion gel films, a mixture of an ionic liquid, [EMIM][TFSI], and a tri-block co-polymer, PS-PMMA-PS, for constructing W (electrode)-WSe_2-MoS_2-Mo (electrode) light-emitting structures, as shown in Fig. 2 [5-7]. As applying voltage between two electrodes, holes (electrons) are injected and accumulated in WSe_2 (MoS_2) mediated by electric double layers to form p-n junctions and generate light emission (Fig. 2a).

Figures 2b and 2c obviously indicate EL image generating along the junction interfaces. Interestingly, the comparison between photoluminescence (PL) and EL spectra shown in Fig. 3 revealed inconsistent behavior. Although both contributions of WSe_2 and MoS_2 were observed in the PL spectrum, EL only showed MoS_2 luminescence. This result suggests band structure evolution at the junction interfaces. Importantly, the lateral heterojunction interfaces are affetced by the straiin effects originating from the lattice constant mismatch; so that we will discuss the physical picture for the observed peculair EL properties based on the recent scanning tunneling spectroscopy study [8]. Moreover, we also realized lateral heterojunction light-emitting devices in WS_2-WSe_2 and WSe_2-$MoSe_2$ lateral heterojunction films, and achieved the improvements of their external quantum efficiency compared to reported homojunction light-emitting devices. These results provide a new direction to engineering optoelectronic device applications based on monolayer semiconductor heterostructures.

References

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Figures

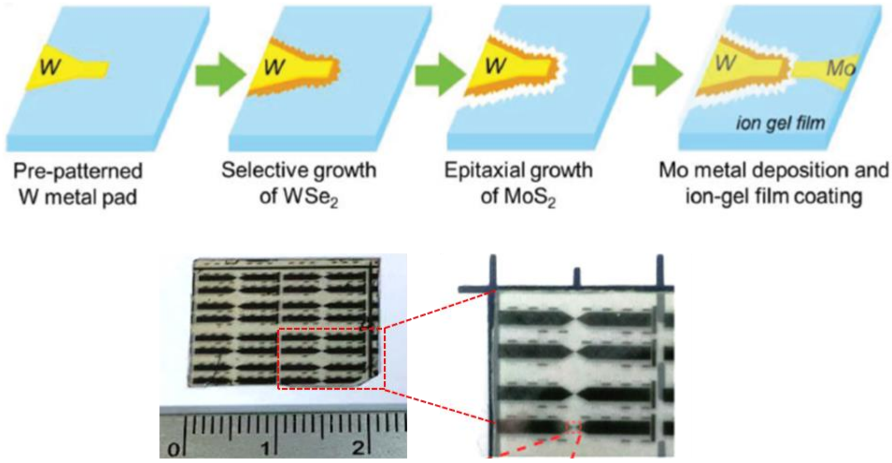

Figure 1: Schematic illustrations of the location-selective and self-aligned CVD process (top). The optical micrographs of the synthesized monolayer WSe_2-MoS_2 lateral heterojunction arrays on the sapphire substrates (bottom).

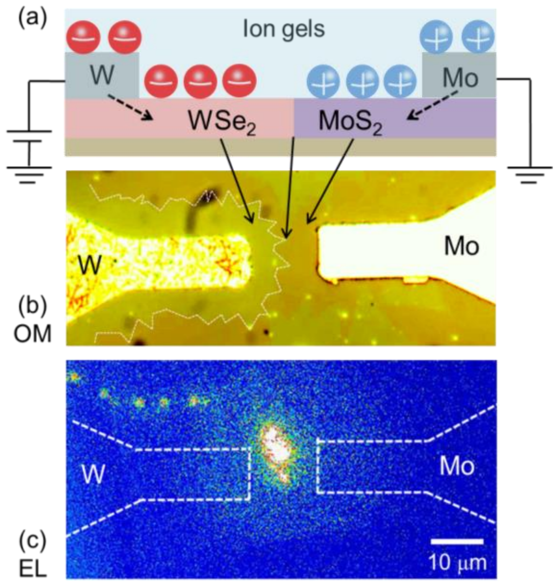

Figure 2:.(a) The schematic of electrolyte-based WSe_2-MoS_2 lateral heterojunction light-emitting diodes. (b) Optical image of lateral heterojunctions. (c) EL image from the heterojunction interfaces.

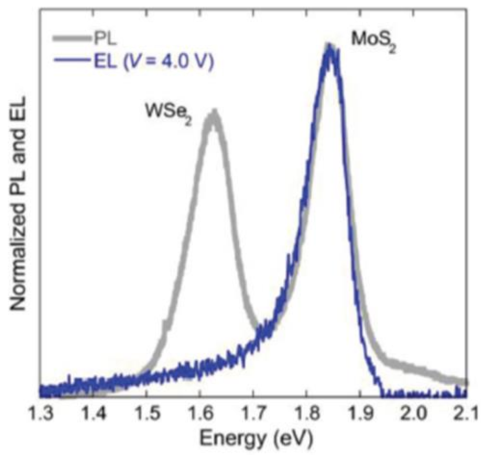

Figure 3: The comparison of PL (gray) and EL (blue) spectra at the lateral heterojunction interfaces.