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Electrochemically Doped Light-Emitting Devices of Transition Metal Dichalcogenide Monolayers

Recently, 2D layered materials have attracted much attention for exploring new electronic, optoelectronic, and photonic applications. Particularly, direct bandgap and unique electronic structure in monolayer transition metal dichalcogenides (TMDCs) provides a platform for exploring novel optoelectronic functionalities and devices [1,2]. One of the most interesting properties of TMDCs is topological features, such as a non-centrosymmetric two-dimensional crystal, strong spin-orbit interaction, non-zero Berry curvature and resulting spin-valley coupling [3]. Actually, circularly polarized light emission has been demonstrated [4,5].

Although the optical properties of TMDCs are very promising, light-emitting devices require intentional doping techniques to form p-n junction. However, reliable doping methods for TMDCs have not yet been fully established. Therefore, the fabrication of TMDC light-emitting devices are still limited, and this fundamental barrier has made investigating electroluminescence (EL) properties of TMDCs inevitably difficult [2]. To overcome this issue, we recently developed the electrochemical method to dope both holes and electrons [6-10], and proposed a simple approach to form p-n junction universally in TMDCs [11-13].

Firstly, as shown in Fig. 1, we fabricated ion-gel (a mixture of ionic liquid and triblock co-polymer) gated EDLTs (Electric Double Layer Transistors) using large-area TMDC monolayers, such as MoS_2 and WSe_2, grown by chemical vapor deposition [6-10]. The Fermi level of TMDCs can be continuously shifted by applying gate voltage, and we can induce both hole and electron transport in these devices. The hole mobility of WSe_2 can be enhanced up to 90 cm^2/Vs at high carrier density of 10^{14} cm^{-2}, whereas the MoS_2 showed electron mobility of 60 cm^2/Vs. By the combination of p-type WSe_2 and n-type MoS_2, we fabricated CMOS inverters [10].

Here, we use this technique to form p-n junction (Fig. 2) and apply this method into various forms of TMDCs, such as monolayer polycrystalline films (Fig. 3(a)), single crystalline flakes (Fig. 3(b)), and lateral heterojunctions (Fig. 3(c)), to achieve photo-detection [11] and EL emission [12,13]. Particularly, using single crystal samples, we have performed temperature and position dependent measurements of EL and investigated their optical properties. Very interestingly, we observed robust circularly polarized EL emission, arising from spin-valley coupling in TMDCs. Our approach paves a versatile way for using TMDCs in discovering new functional optoelectronic devices.

References

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Figures

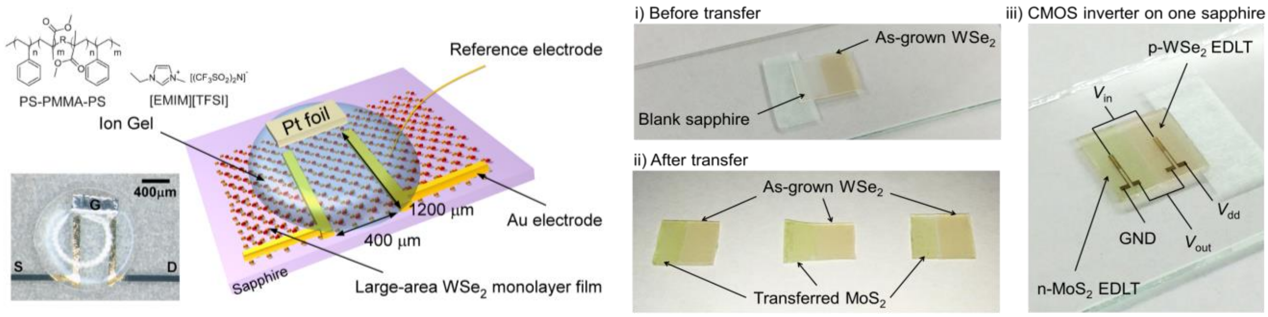

Figure 1: Schematic illustrations of ion-gel gated EDLT (left) and p-type WSe_2/n-type MoS_2 CMOS inverters (right).

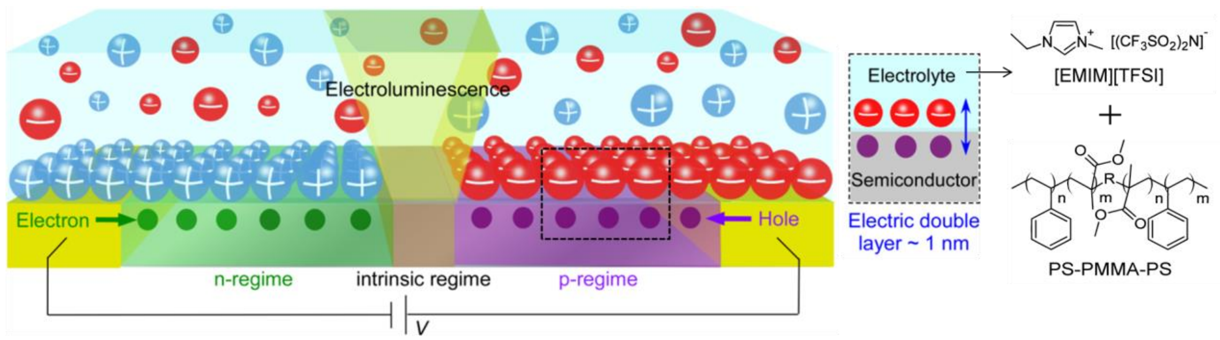

Figure 2: Schematic illustrations of a proposed light-emitting device.

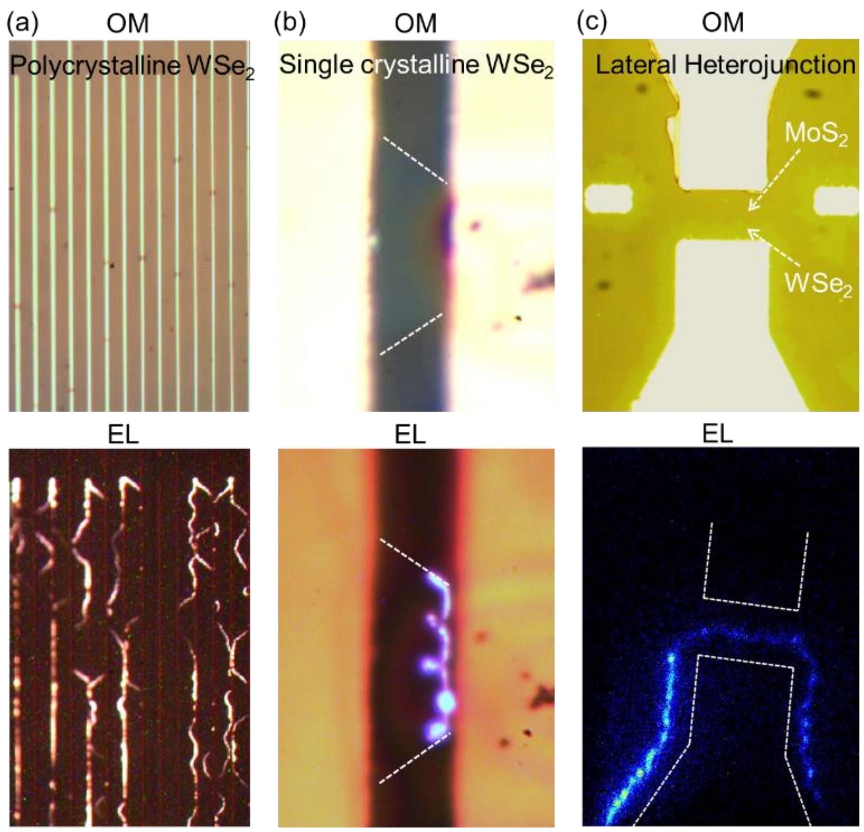

Figure 3: Optical microscope (OM) and electroluminescence (EL) images of various form TMDCs.