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Room-Temperature Valley-Polarized Light-Emitting Devices *via* Strained Monolayer Semiconductors

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Abstract

We establish a unique method to create the room-temperature chiral light-emitting devices. We fabricate the electrolyte-based light-emitting devices with strained transition metal dichalcogenide (TMDC) monolayers on the plastic substrates. This approach enables the electrical generation and control of circularly polarized electroluminescence at room temperature, arising from valley degree of freedom of TMDCs. Our results will pave a new way to realize practical chiral light sources based on monolayer semiconductors.

1. Introduction

The valley contrasted electronic structure in monolayer transition metal dichalcogenides (TMDCs) provides unique optical functionalities, such us anomalous Hall effects and circularly polarized light emission [1-3]. In particular, the electrical control of circularly polarized light emission is one of the most desired device applications toward opto-valleytronics. Although several experimental demonstrations of chiral light-emitting devices have been reported, such as the electrolyte-gated transistors and the spin injections to the heterostructures, they have mostly realized at low temperatures and/or required high magnetic fields [4-6]. Therefore, these techniques have been lack of practical utilities, and thus, the light-emitting devices that can control valley-polarized electroluminescence (EL) at room temperature are significant challenge. Interestingly, we recently found out that the local strains implanted inside CVD-grown TMDC monolayers might serve as a key role to generate circular polarized EL nearly room temperature [7]. Moreover, the recent paper revealed the strain-induced valley magnetizations in MoS_2, and that magnetization effects also obtained at room temperature [8]. On the basis of these observations, here, we try to realize the room-temperature valley-polarized light-emitting devices by combining electrolyte-based structures with strained TMDC monolayers.

2. Experimental

Device fabrications and measurements

The single-crystalline monolayer WS_2 flakes were grown on sapphire substrates by CVD method, followed by transferring them onto PEN substrates using solution-based transfer process, as shown in Fig. 1a [9,10]. After that, two Au electrodes were deposited on monolayer flakes. Finally, the thin ion-gel films, a mixture of ionic liquid, [EMIM][TFSI] (Fig. 1b, Top), and tri-block co-polymer, PS-PMMA-PS (Fig. 1b, Bottom), were spin-coated on the surfaces of the substrates and monolayers to construct two-terminal light-emitting structures [10-13].

The devices were set on the home-built bending stage with the polarization-resolved optical set-up, where is combined a 1/4 wave plate with a linear polarizer [14]. Just by applying voltage to the devices, the EL is generated from electrolyte-induced p-i-n junctions, as shown in Fig. 1c [12,13]. The helicity of emitted lights from the devices were selectively detected by the angle of 1/4 wave plate to identify right- (σ^+) and left- (σ^-) handed circularly polarized light, respectively. The polarization-resolved EL measurements were done for the device with flat and strained conditions.

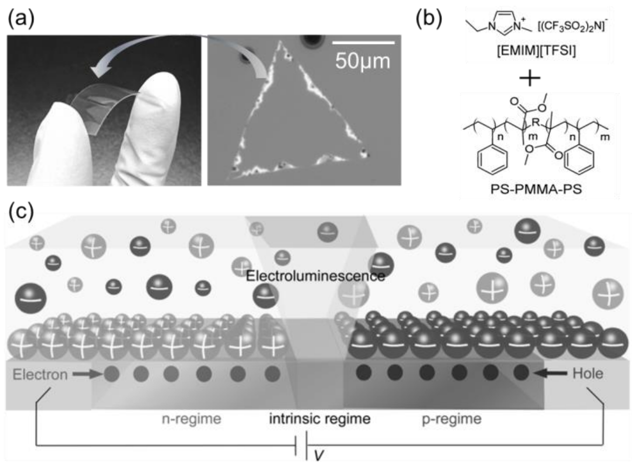

Fig. 1 (a) The transferred WS_2 monolayer flakes onto PEN substrate. (b) The chemical structures of an ionic liquid and a tri-block co-polymer. (c) The schematic of the electrolyte-based light-emitting structures.

Results and Discussion

We firstly performed the PL mapping for channel regions of the devices with both flat and strained conditions on the transferred WS_2 monolayers. We obviously found that uniform red-shifts of PL peak energy were occurred, which directly indicates the strain-induced band shrinkage and corresponds to 1 % uniaxial strain induced in monolayer flake [15]. In the flat and strained condition, next, we applied AC voltage to the devices to integrate EL intensity, and the chirality of EL was selectively detected by controlling the quarter-wave plate (Fig. 2, bottom). The AC measurements were introduced to avoid time-dependent device degradations. Finally, we placed a Si photodiode on the top of the devices to collect each helicity of EL as the photocurrents. It is noted that, the measured photocurrents were integrated by all pulsed voltages to evaluate EL polarizations.

As shown in the left panels of Fig. 2, we observed EL polarizations (P = [σ^+ - σ^-]/[σ^+ + σ^-]) up to +20 % at room temperature, in which the photocurrents of the σ^+ component were greater than those of the σ^- (the shaded area in Fig. 2), with the presence of the strain effects and the electrical currents. On the other hand, there were no EL polarizations in the flat condition. In addition, we also confirmed similar robust EL polarizations in another device, meaning the reproducible performances of strain-induced chiral EL. Interestingly, we can also switch EL polarizations (P ~ -6 %) through by inversing the current directions, shown in the right panel of Fig. 2. These results provide the electrical generation and control of valley-polarized EL at room temperature *via* strained monolayer TMDCs.

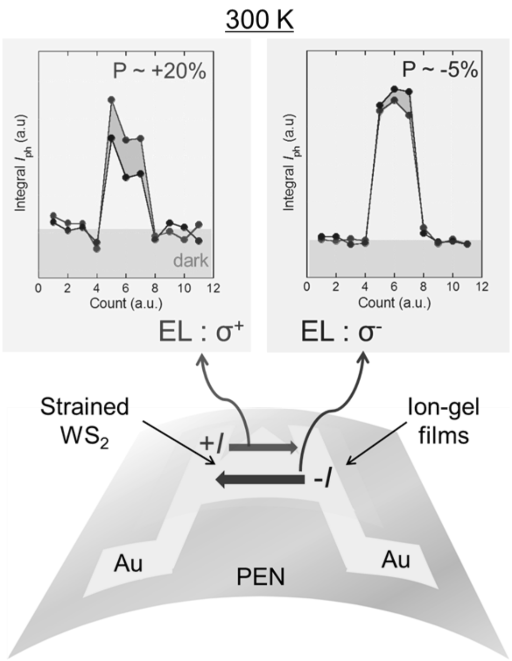

Fig. 2 Room-temperature valley-polarized light-emitting devices *via* strained monolayer WS_2. The top panels show the electrical switchable EL polarizations.

3. Conclusions

We firstly realized room-temperature valley-polarized light-emitting devices by using strained monolayer WS_2. The combination of transferrable CVD-grown monolayers and electrolyte-based structures enables the light-emitting device fabrications on PEN substrates. In the strained devices, the obtained EL shows EL polarizations at room temperature, and importantly, their EL helicity can be electrically controlled by the current directions. These demonstrations possibly offer a new way for achieving practical chiral light sources based on monolayer semiconductors.

Acknowledgements

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Appendix

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