Modulation of Photoluminescence Properties of Monolayer Transition Metal Dichalcogenides via Chemical Doping

Shinichiro Mouri¹, Yuhei Miyauchi^{1,2,3} and Kazunari Matsuda¹

¹Institute of Advanced Energy, Kyoto University, Uji, Kyoto 611-0011, Japan

²Japan Science and Technology Agency, PRESTO, 4-1-8 Honcho Kawaguchi, Saitama 332-0012, Japan

³Graduate School of Science, Nagoya University, Chikusa, Nagoya 464-8601, Japan

E-mail: iguchan@iae.kyoto-u.ac.jp

1. Introduction

Monolayer transition metal dichalcogenides (1L-TMDs) have attracted much attention as a novel two-dimensional direct band gap semiconductor [1], and also are promising candidate to realize the future optoelectric devices including 'valleytronic' dvices [2]. However, the optical properties of 1L-TMDs is often limited due to the unintentional electron doping caused by atomic defects or impurities [3]. Therefore, establishing the convenient method to control the optical properties of 1L-TMDs is valuable for application and fundamental study. In this study, we demonstrate that the solution-based chemical doping is an effective method to modulate the photoluminescence (PL) properties of monolayer MoS_2 (1L- MoS_2) that is well known 1L-TMDs [4].

2. Results and Discussion

1L-MoS₂ was prepared by the mechanical exfoliation and deposited on SiO₂/Si substrate. Excitation light source for the PL experiments was the cw solid-state laser (2.33 eV) or monochromated light pulse (40MHz, 20 ps duration) from a super continuum broadband light source. We drop-casted a typical *p*-type dopant F₄TCNQ or *n*-type dopant NADH dissolved in solution (toluene or water, respectively) on the surface of the 1L-MoS₂.

Figure 1 shows the PL spectra of as-prepared and F_4TCNQ -doped 1L-MoS₂ at room temperature. The PL peak around 1.8–1.9 eV can be decomposed into two components corresponding to the exciton (Peak X) and trion (Peak X⁻) PL [3]. In the as-prepared 1L-MoS₂, the trion PL (X⁻, ~1.84 eV) is dominant, because excitons can be bound by unintentionally doped electrons. On the other hand, exciton PL (X, ~1.89 eV) becomes dominant in the F₄TCNQ-doped 1L-MoS₂ presumably because the doped-holes compensate the Fermi energy shift induced by doped electrons. Opposite direction control of PL can be possible by *n*-type dopant NADH. The electrons from NADH are additionally doped into 1L-MoS₂ and the trion PL weight is increased.

We also found that the nonlinear PL response of 1L-TMDs [5] is strongly depending on the carrier density. In as prepared 1L-MoS₂, the PL intensity is almost linearly increased with increasing excitation laser power. On the other hand, the PL intensity is saturated with increasing excitation power after F₄TCNQ doping. This result could be induced by the difference of many-body effects between ex-



Figure 1 PL spectra of as-prepared (above) and F_4TCNQ doped (below) monolayer MoS₂.

citons and trions.

3. Conclusions

Our findings suggest that both the extraction and the injection of carriers in 1L-MoS₂ can be realized by the solution-base chemical doping. It provides a strong advantage in tuning the optical and electrical properties of 1L-TMDs without using the device structures.

Acknowledgements

This study was supported by a Grant-in-Aid for Scientic Research from MEXT of Japan (Nos. 22740195, 25400324, 24681031, 23340085, and 25610074) and by PRESTO from JST.

References

[1] Q. H. Wang, K. Kalantar-Zadeh, A. Kis, J. N. Coleman, M. S. Strano, *Nat. Nanotechnol.* **7**, 699 (2012).

[2] K. F. Mak, K. L. He, J. Shan, T. F. Heinz, Nat. Nanotechnol. 7, 494 (2012).

[3] K. F. Mak, K. L. He, C. Lee, F. H. Lee, J. Hone, T. F. Heinz, J. Shan, *Nat. Mater.* **12**, 207 (2012).

[4] S. Mouri, Y. Miyauchi, K. Matsuda, *Nano Lett.* 14, 5944 (2013).

[5] S. Mouri, Y. Miyauchi, M. Toh, W. Zhao, G. Eda, K. Matsuda, ArXiv: cond-mat.mes-hall /1405.5781