Revealing Local Exciton Dynamics on a Monolayer WS_2 probed by Time-resolved Multiprobe STM

Hiroyuki Mogi[1*], Ryosuke Mizuno[1], Naoki Wada[2], Yasumitsu Miyata[2], Yusuke Arashida[1], Atsushi Taninaka[1], Shoji Yoshida[1], Osamu Takeuchi[1] and Hidemi Shigekawa[1]

[1]University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8537, Japan
[2]Tokyo Metropolitan University, 1-1, Minamiosawa, Hachioji, Tokyo 192-0397, Japan
[*]e-mail: mogi.hiroyuki.fp@u.tsukuba.ac.jp, https://dora.bk.tsukuba.ac.jp

Transition metal dichalcogenides (TMDCs) atomic layer semiconductors has attracted much attention for the application of high-performance, ultra-thin electronic/ optoelectronic devices due to its strong light-matter coupling. One of the features is the presence of stable excitons in room temperature (binding energy is order of ~100 meV). The optical characteristics are strongly influenced by the exciton structure, and large exciton resonance peaks came out in the optical spectrum. In addition, exciton flow control has reported by applying stress, gate voltage[1], and as exciton Hall effect[2], etc which is expected to be novel information transfer devices. To study detailed spatiotemporal exciton dynamics in nm-scale is absolute necessary for further applications.

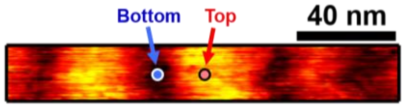

Fig. 1 STM topographic image of WS_2 ripple structure.

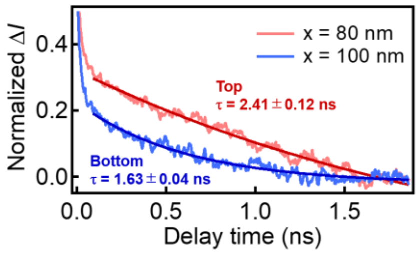

Fig. 2 Time resolved signal measured on the top/ bottom of the WS_2 ripple.

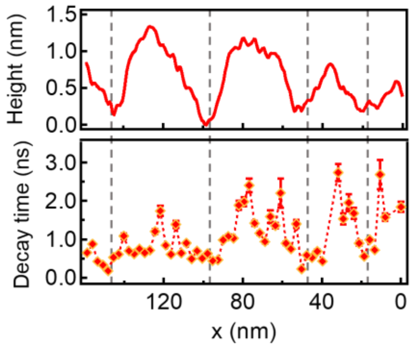

Fig. 3 Line profile of topographic image (up) and extracted decay times (down).

So far, exciton dynamics have been investigated by the time-resolved photoluminescence method and pump-probe measurement. However, in general, the spatial resolution is limited to sub-µm. In this study, aiming to evaluate exciton dynamics on a nm-scale, we conducted experiments using a time-resolved MP-STM that was originally developed by combining a femtosecond laser system and a photoexcited multi-probe STM (MP-STM). The sample is WS_2/WSe_2 lateral heterostructure grown on SiO_2/Si substrate by chemical vaper deposition method.

In this optically excited STM setup, tunneling current was dominated by exciton separation by the tip-induced electric field of several nm-scale revealed by I-V characteristics and a current mapping. As a result of pump-probe measurement, we found that the transient exciton density dynamics can be detected via tunneling current signal resulting from the exciton density depending separation rate change by exciton-exciton screening effect. As shown in Fig.1, we focused on the ripple structure near the grain boundary in WS_2 region and evaluated the probe position dependence of the time-resolved signal. As a result, different decay time constant components were obtained at the top and bottom of the ripple structure as shown in Fig.2. From the probe position dependence of decay time shown in Fig.3, it was clarified that exciton lifetime is longer at the top of the ripple and short at the bottom. This technique is expected to play an important role in the progress of exciton research on nanostructures of atomically thin semiconductors.

[1] T. Mueller, E. Malic, *NPJ 2D Mater. Appl.* 2, 29 (2018)
[2] M. Onga, Y. Iwasa et al, *Nature Materials* **16**, 1193–1197 (2017)