Growth and Optical Properties of High-Quality Monolayer WS_2 on Graphite

Yu Kobayashi[1], Shogo Sasaki[1], Shohei Mori[1], Hiroki Hibino[2], Zheng Liu[3], Kenji Watanabe[4], Takashi Taniguchi[4], Kazu Suenaga[3], Yutaka Maniwa[1], and Yasumitsu Miyata[1,5]*

[1] Department of Physics, Tokyo Metropolitan University, Japan, [2] NTT basic research laboratories, NTT Corporation, Japan
[3] Nanotube Research Center, AIST, Japan, [4] National Institute for Materials Science, Japan, [5]JST, PRESTO, Japan
E-mail: ymiyata@tmu.ac.jp

1. Introduction

Atomic-layer transition metal dichalcogenides (TMDCs) have attracted appreciable interest due to their tunable bandgap, spin-valley physics, and potential device applications. However, the quality of TMDC samples available still poses serious problems, such as inhomogeneous lattice strain, charge doping, and structural defects. In this presentation, we report on the growth of high-quality, monolayer WS_2 onto exfoliated graphite by high-temperature chemical vapor deposition (CVD).[1]

2. Results & Discussion

Figure 1a presents an optical image of triangular-shaped WS_2 grains which have relatively dark contrast on graphite. Atomic force microscope (AFM) observation reveals that a similar WS_2 grain has uniform height of around 0.7 nm, which indicates these grains correspond to monolayer WS_2. The low-energy electron diffraction (LEED) pattern of this area shows two hexagonal patterns which derived from graphite for the outer spots and from the monolayer WS_2 for the inner spots. This hexagonal pattern of the WS_2 means that such triangular-shape grains are single crystals, which is also confirmed from dark-field LEEM image.

Figure 1b shows representative low-temperature photoluminescence (PL) spectra for monolayer WS_2 grown on graphite and SiO_2/Si substrates. The PL peak for WS_2 on graphite has a symmetric profile and small FWHMs, whereas for WS_2 on and SiO_2/Si, an asymmetric and broad peak was observed. It should be noted that for the graphite sample, the linewidth becomes sharper from 21 meV at room temperature to 8 meV at 79 K. This value (8 meV at 79 K) is comparable to that of high quality, exfoliated $MoSe_2$ monolayers reported previously (5 meV at 15K).[2] Furthermore, in the present samples, no additional peaks are observed for charged and/or bound excitons, even at low temperature. These optical responses are completely different from the results of previously reported TMDCs obtained by mechanical exfoliation and CVD. In the case of the SiO_2/Si substrate, the linewidth at 79 K is still large (around 40–50 meV), which is close to that at room temperature (45–60 meV). This weak temperature dependence of the linewidth and inhomogeneous broadening of the PL peak is evidence for the microscopic distribution of lattice strain and charged impurities. In contrast, the graphite substrate provides an ideal condition for WS_2 without such inhomogeneous factors due to its atomically-flat and impurity-free surface.

3. Conclusions

It is concluded that the combination of high-temperature CVD with cleaved graphite surface is an ideal condition for TMDC growth with a large grain size and uniform optical properties. In particular, CVD-grown monolayer WS_2 on graphite gives rise to a single PL peak with a symmetric Lorentzian profile and very small FWHM values of 8 meV at 79 K. Compared with WS_2 on SiO_2/Si substrates, the WS_2 grown on graphite is less affected by charged impurities and structural defects. The present findings should pave the way for the preparation of high-quality and non-doped TMDCs, and such samples will enable further investigation into the intrinsic properties of TMDC atomic layers.

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References

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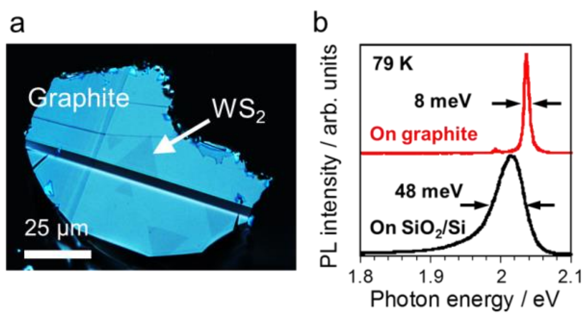

Figure 1. (a) Optical image of WS_2 crystals on graphite. (b) Photoluminescence spectra of WS_2 grown on graphite (red) and SiO_2/Si (black) substrate at 79 K.