Carrier distribution in mechanically exfoliated WSe_2/SiO_2 and suspended WSe_2 measured by scanning nonlinear dielectric microscopy

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Layered semiconductors have many potential applications because they can keep their semiconductor properties even when they are very thin. However, they also face challenges, such as the reduced performance of their transistor devices due to the influence from the interface with the substrates. One problem is hysteresis, which means transistor characteristics change depending on previous state. In this study, we used WSe_2, an ambipolar layered semiconductor without doping. We made a device structure that suspended WSe_2, avoiding any contact with substrates. We measured carrier distribution and polarity in WSe_2 with scanning nonlinear dielectric microscopy (SNDM). SNDM measures capacitance between tip and sample and image dominant carrier type and concentration. We found suspended WSe_2 had reversible carrier modulation with voltage, while WSe_2 on SiO_2 showed irreversible carrier modulation. This shows suspended device structures have better electrical characteristics than ones on substrates and SNDM is useful for characterizing layered semiconductors.

We compared two WSe_2 samples with different structures. Sample A had mechanically exfoliated 3-10 layers of WSe_2 on a Si substrate. Sample B had 3 layers of WSe_2 suspended on 40 nm-height Au wires on the same substrate. We measured the dominant carrier distribution and polarity by SNDM. Figure below show topography [(i)] and SNDM (dC/dV) images [(ii)-(v)] for sample A [(a)] and B [(b)]. (ii), (iii), (iv), and (v) show how dominant carrier concentration distributions changed with different DC bias voltages applied in decreasing and increasing order. Ideally, dominant carriers on WSe_2 are p-type at positive voltage, n-type at negative voltage, and non-polar at 0 V. However, the polarity in Figs. (a)-(ii) and -(iv) was, n-type and p-type, respectively, while DC bias voltage was 0 V. In addition, n-type contrast was partly found in Fig. (a)-(v) for +5 V. This indicates hysteresis phenomenon in sample A. In fact, contrast in Fig. (a)-(ii) at 0 V was different from that of (iv), though voltage was same. On the other hand, no hysteresis phenomenon was found for sample B. Contrasts in Figs. (b)-(ii) and -(iv) at 0 V were non-polar and almost the same. In addition, we confirmed n-and p-type contrast for -5 V and +5 V, respectively, as expected. These results show suspended structure reduces hysteresis phenomenon and exploits the ideal characteristics of WSe_2.

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