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Heavy Doping Effect in $MoTe_2$ Crystal by High Density Laser Irradiation and TFET Device Application

Transition metal dichalcogenides (TMDCs) have been attracted a lot of interest due to their interesting electrical and optical properties [1]. $MoTe_2$, one of TMDC materials, has a relatively small band gap (0.9 eV) compared to MoS_2 hence it is easy to show ambipolar gate action. In $MoTe_2$ crystal, Te atoms can easily be knocked off from the crystal by laser irradiation, and then the vacancies can act as impurity sites [2]. In our recent study, we have succeeded control the carrier density control even including the n/p inversion by laser irradiation. Also, $MoTe_2$ has low potential barrier to change the crystalline structure from 2H to 1T' even by stretching the crystal accordingly the electrical property changes from semiconducting to metallic. Laser irradiation is one of the promising key tools to control the polymorphism. Since Te atoms can be easily bounced off from the crystal [3] and then high density of Te vacancies may introduce the phase transition [4]. However, our recent study suggests that the matter provided by focused-laser irradiation is not such a structural phase transition from 2H to 1T' but a decomposition of a $MoTe_2$ crystal. Nevertheless, we have succeeded to realize a very good ohmic contact by semi-metallic Te atoms for both n- and p-type $MoTe_2$. According to our component analysis using EDX, the ratio of Mo and Te was reduced to be 1 to 1 in the residue at the irradiated region. And then, a heavily doped region was formed surrounding the decomposed region. Furthermore, we found that the carrier polarity can be controlled by selecting the environment during the irradiation. Using such techniques, we have demonstrated to realize a CMOS inverter and a tunneling field effect transistor (TFET).

Multilayer $MoTe_2$ crystals were exfoliated onto Si/SiO_2 substrates. Continuous-wave-green laser beam (λ = 532 nm) was focused and irradiated onto the $MoTe_2$ crystal under ambient or vacuum condition at a power density more than 10^5 W/cm^2 using an objective lens. A crater was created after the focused laser for less than 1 sec as shown in Fig. 2. The thickness was reduced from 100 nm to 10 nm after the irradiation. The area surrounding the decomposed region is heavily doped as schematically shown in Fig. 2c. Such heavily doped p- and n-type region can be used for a realization of a TFET device. The other demonstration of a TFET device composed of laser-controlled p- and n-type $MoTe_2$ crystals in Fig. 3. Clear band-to-band tunneling (BTBT) was observed in the reverse-bias condition.

References

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[4] Z. Wang, et al., ACS Appl. Mater. Interfaces **9**, 23309 (2017).

Figures

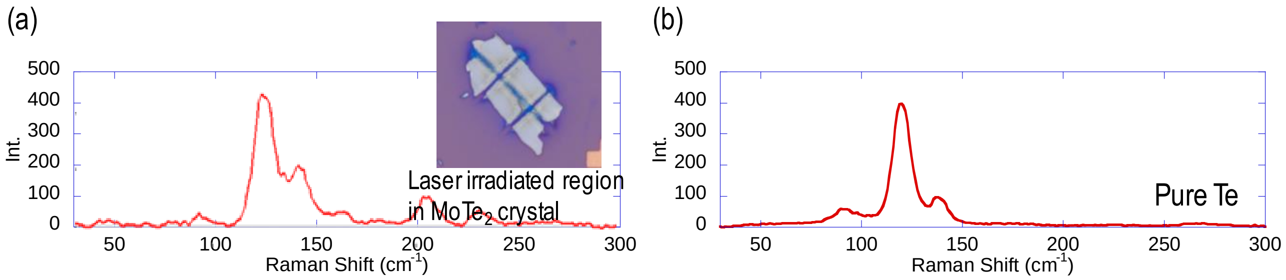

Figure 1: Raman scattering spectrums of (a) high density laser irradiated region and (b) pure Te.

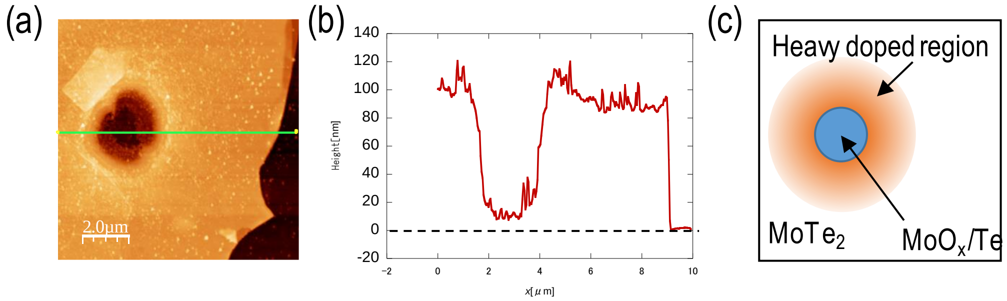

Figure 2: (a) AFM image around a high density laser irradiated region, (b) the line profile and (c) schematic drawing the spatial composition.

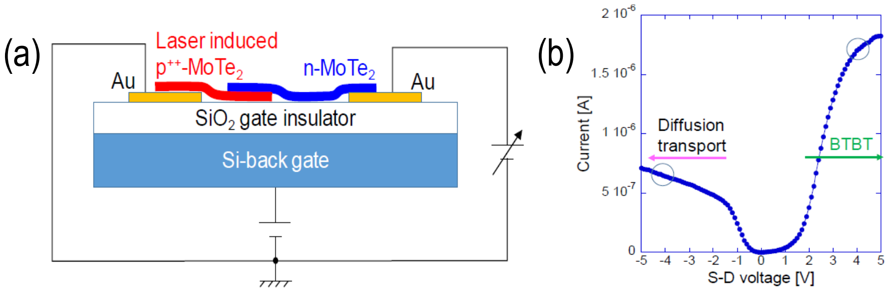

Figure 3: (a) Demonstration of TFET device prepared by stacking of laser irradiated $MoTe_2$ crystals and (b) device operation.