Nonlinear absorption characteristics of Monolayer and Bilayer/Multilayer of TMDC.

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The nonlinear absorption properties of TMDC depends on the changes of band gap where monolayer of TMDC has a direct bandgap and the bilayer and multilayer have an indirect band gap. The bandgap of the monolayer is wider than that of bilayer and multilayer. This absorption process is described by Jablonski diagrams which may include two-step absorption with one-photon for each step, two-photon absorption to the real final state through a virtual intermediate state. In the one-photon excitation, the electric dipole transition $|i\rangle \rightarrow |f\rangle$ is allowed due to other parities between two states. Hence the saturable (negative) absorption (SA) is observed due to the higher ground-state absorption cross-section than the excited-state absorption cross-section, $\sigma_{GSA} > \sigma_{ESA}$. But in the two-photon excitation, the electric dipole transitions $|i\rangle \rightarrow |n\rangle$ and $|n\rangle \rightarrow |f\rangle$ are allowed due to same parities between the initial and final states. Therefore, the reverse saturable (positive) absorption (RSA) is dominant due to the higher value of the excited-state absorption cross-section than the ground-state absorption cross-section. The band gap changes due to the number of layers and temperature switches RSA to SA or vice versa. The atomic layers with SA are utilized for laser Q-switch and mode-locker, while the atomic layers with RSA are utilized for optical power limiter. Acknowledgement: This work at HU is supported by ARO W911NF-15-1-0535, NSF HRD-1137747, and NASA NNX15AQ03A.

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