Raman scattering and photoluminescence studies of Bi$_2$Te$_3$/MoS$_2$ heterostructures

We report simultaneous study of optical phonons and excitons in Bi$_2$Te$_3$/MoS$_2$ heterostructures using Raman spectroscopy and photoluminescence (PL). Monolayer MoS$_2$ was grown on a SiO$_2$/Si substrate using chemical vapor deposition. Subsequently, topological insulator Bi$_2$Te$_3$ was directly fabricated on the monolayer MoS$_2$. Monolayer MoS$_2$ covered by the 40-nm-thick Bi$_2$Te$_3$ film was not seen under an optical microscope. In addition, Raman spectrum from the sample surface showed only the optical phonons of Bi$_2$Te$_3$ at 102 and 133 cm$^{-1}$, corresponding to the $E_{2g}^2$ and $A_{1g}^2$ phonon modes, respectively. Interestingly, however, when the as-grown sample surface was exposed at moderate laser power density, optical phonons of monolayer MoS$_2$ were observed at 384 and 405 cm$^{-1}$, corresponding to the $E_{2g}^1$ and $A_{1g}$ phonon modes, respectively. The observation of the optical phonons of MoS$_2$ was mainly due to a structural modification in Bi$_2$Te$_3$ under laser irradiation. With increasing the laser power density, a systematic change in the peak energy of the $A_{1g}$ phonon mode was observed. In contrast, the $E_{2g}^1$ phonon mode did not show any noticeable changes in its peak energy. It is noted that the in-plane $E_{2g}^1$ phonon mode is sensitive to strain, while the out-of-plane $A_{1g}$ phonon mode is affected by doping. Therefore, the optical phonon behaviors of MoS$_2$ indicate the variation in carrier density without structural deformation. To study the influence of the laser irradiation on the excitons in the Bi$_2$Te$_3$/MoS$_2$ heterostructures, laser-power dependent PL measurements were performed. The peak energies of the A and B excitons in MoS$_2$ varied systematically as a function of the laser power density, indicating that a band gap renormalization was occurred owing to the variation in carrier density. As a result, the correlated PL and Raman spectroscopy suggested that charge transfer might occur between Bi$_2$Te$_3$ and MoS$_2$. Our results demonstrated that laser irradiation could be utilized to modify structural and optical properties in Bi$_2$Te$_3$/MoS$_2$ heterostructures.

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