Abstract

Semiconducting materials and structures are building blocks of many modern electronic devices. Optical spectroscopy techniques are exceptionally useful for investigating semiconductors, as spectral dependence of optical parameters contains information about important aspects of solid state physics, including the band structure. Nonetheless, they can exhibit certain limitations in the case of opaque or highly scattering structures, typical for some novel, low-dimensional systems. An alternative approach of using photoacoustic spectroscopy is proposed to resolve such issues. A dedicated experimental setup has been designed and built for such purpose, including custom measurement cells for detecting photoacoustic signal.

Photoacoustic spectra of InGaO and GaAs/GaAsBi core-shell nanowires revealed that the proposed sensing method is insensitive to light scattering, allowing for probing optical absorption of porous nanostructures. Nanowires' orientation affects the background signal contribution originating from the opaque silicon substrate having the band gap lower than the top material. For GaAs/GaAsBi the substrate absorption contribution can be controlled by tuning the modulation frequency of the exciting light beam, affecting the thermal diffusion length which is the effective signal generation depth. Experimental confirmation of this effect allows for depth profiling of multilayer systems deposited on opaque substrate.

Exclusive sensitivity of photoacoustic and photothermal measurements to nonradiative deexcitation processes allows for probing the band gap energy in confined nanostructures with high quantum yield, giving complementary data useful for determining the exciton binding energy. Quasi-two-dimensional CdSe nanoplatelets with different thickness have been used to demonstrate such effect, with the results showing increased exciton binding energy in thinner nanoplatelets, in all cases higher than the room-temperature thermal energy.

Photoacoustic spectra of bulk van der Waals crystals reveal the absorption edge in the vicinity of fundamental indirect band gap, expected in the chosen transition metal mono- and dichalcogenides. Along with modulation spectroscopy results, a complete information about optical transitions is obtained. Additionally, the spectra of single layer MoS_2 are blue-shifted with respect to the ones on bulk material, indicating the band gap character transition upon reduced system dimensionality.

The conducted research confirms that photoacoustic spectroscopy is a powerful experimental technique for investigating emerging semiconducting materials and structures, giving complementary data on effects corresponding to nonradiative recombination. The development of new measurement configurations and sensing techniques extend the experimental abilities to studies of thermal transport in semiconductors.