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Terahertz Pulse Excitation Spectroscopy of Thin Bismuth Layers and Their Heterostructures

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Ultra-short electric pulses generated by femtosecond laser beams are widely used to investigate the physical properties of various materials, including semiconductors. Terahertz excitation spectroscopy (TES) is a powerful non-contact characterization technique that enables the investigation of electronic properties and heterojunction band structure in semiconductors. TES provides fundamental insight into a material's internal electric field, carrier dynamics, and electronic structure. It has been shown that, by examining the dependence of THz emission on the excitation wavelength, important band-structure parameters can be determined, including the direct bandgap, subsidiary valley position, and heterostructure offset value [1]. Recently, this technique has been applied to determine the electronic parameters of thin layers such as bismuth [2]. While investigation of GaSb azimuthal angle dependencies revealed novel way to characterize conduction band valley positions [3].

Bismuth undergoes a semimetal-to-semiconductor transition when confined to nanometer-scale thicknesses (~30 nm), with quantum size effects inducing bandgap opening and tunable optical properties. Ultrathin 9 nm Bi films were grown on (100)-oriented GaAs and GaSb substrates. The Bi/semi-insulating GaAs heterostructure exhibited a unique spectral response, characterized by an onset at 1.41 eV, a peak at 1.5 eV, and a pronounced polarity reversal of the emitted terahertz pulses at 1.67 eV. Band-structure modeling has attributed this reversal to two competing photocurrent-generation mechanisms. At lower energies, intrinsic heterojunction electric fields dominate, whereas at higher energies the photo-Dember effect, arising from ballistically propagating carriers, becomes dominant [3]. A significant enhancement of the THz pulse amplitude was observed for Bi layers on p-GaAs and p-GaSb samples compared with the bare substrates. This phenomenon can be attributed to the stronger electric field at the Bi/GaAs interface, thereby demonstrating the overshoot effect of photoexcited holes. This enhancement mechanism appears to be universally applicable to Bi thin films on p-type semiconductors and is considered a promising candidate for efficient surface THz pulse emission.

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