Physics and Utilization of Terahertz Gas Photonics

by

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ABSTRACT

The generation and detection of terahertz waves in gases have the potential to revolutionize terahertz technology, but to date the underlying physical mechanisms have not been fully understood. This thesis aims to explain both phenomena non-perturbatively within a quantum mechanical framework. The resulting calculations lead to a more complete understanding of the science behind these effects and show the path forward to extending their capabilities. Experimental work is presented that both supports the theoretical modeling and represents new milestones in the useful spectral bandwidth of terahertz time-domain spectroscopy systems.

A two-step model is presented for the generation of terahertz waves in gases, where first the laser-atom interaction is treated quantum mechanically through numerical solution of the time-dependent Schrödinger equation, and then the subsequent dynamics (when there is no longer an applied field) are treated analytically. The second step of the process includes the interaction of the electron wave packets formed by the tunnel ionization process with their surroundings, resulting in a coherent "echo" in the terahertz waveform representing the decay of the coherent polarization caused by the asymmetric, beam-like propagation of the wave packets away from the atom. Experiments using a gas jet are shown that validate this physical model through the dependence of the process on optical phase and gas pressure. The experimental and theoretical results lead to a clearer understanding of the terahertz generation process, as well as a way to use the effect to better understand the dynamics of the formation of a laser-induced plasma in gases.

A non-perturbative, quantum mechanical treatment is also given to the detection of terahertz waves in gases, and a coherent heterodyne technique is introduced that allows for fully coherent measurement of terahertz waves. In this case, the results of solving the time-dependent Schrödinger equation and utilizing third-order perturbation theory converge under the conditions that are experimentally useful. This convergence allows for detailed calculations of the full, spatially-dependent process, including phase matching and focusing effects. These macroscopic effects allow for a proper understanding of which microscopic effects contribute to the observed phenomena, and allow a thorough investigation of the optimization of the process.

The understanding obtained via the modeling allows for the construction of terahertz time domain spectroscopy systems based on both terahertz generation and detection in gases, which exhibit unprecedented continuous bandwidths spanning the full terahertz range and beyond.