Terahertz-Radiation-Induced Nonlinear Effects in Biomolecules

by

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ABSTRACT

Terahertz (THz) electromagnetic waves covering the spectral range from 0.1 THz to 10 THz have demonstrated several applications in the field of ultrafast spectroscopy, chemical sensing, and material characterization. With the advancement in THz sources and detectors, the list of applications of terahertz technology is growing, but the studies devoted to understanding the interaction of this radiation with biological systems are limited.

Biomolecules exhibit collective vibrations with frequencies lying in the terahertz region. THz spectroscopy thereby provides a unique method to probe the collective motions of proteins and their hydration dynamics. THz radiation is generally considered to be safe and noninvasive for biomedical applications due to its low photon energy as compared to gamma- and X- rays. But with the development of high-power THz sources, it is imperative to understand the resonant effects of THz radiation with molecules and to investigate whether any molecular structural changes can be induced by terahertz radiation. The understanding of nonlinear effects of THz radiation is also crucial to address health/radiation concerns regarding impact of intense THz radiation on cells and tissues.

Recent development of high-power THz sources has led to a surge in studies investigating the nonlinear dynamics of semiconductors induced by THz radiation. However, there are only a handful of studies offering the detailed or in-depth investigations of the dynamics of biomolecules under intense THz radiation. This dissertation focuses on the interaction of high-power terahertz (THz) radiation with amino acids and proteins. The technique developed in this dissertation to investigate the nonlinear effects is THz-radiation-induced fluorescence modulation in proteins and amino acids. Fluorescence is one of the well-established and widely used techniques in the field of biological sciences. Thereby, fluorescence from the molecules acts as excellent probes for investigating the structural/molecular changes induced by intense THz radiation. By monitoring the THz radiation induced fluorescence modulation, the short- and long- term dynamical changes leading to structural modifications of biomolecules are investigated.

The depletion of fluorescence in tryptophan molecules induced by continuous-wave THz radiation depends on the frequency of the THz source and correlates with the changes in the THz absorption coefficient of tryptophan. The nonuniform quenching over the emitted spectral range and the temperature-dependent response of fluorescence modulation is attributed to changes in the vibrational population density induced by THz radiation.

Green fluorescent protein (GFP) exhibits fluorescence depletion for low THz frequencies (0.2 THz, 1.08 THz and 1.2 THz), and fluorescence enhancement for high THz frequencies (1.4 THz, 1.63 THz, 1.89 THz and 2.55 THz). Irreversible and reversible depletion of fluorescence is observed in whey protein for different optical excitation intensities but same THz intensity. Under a fixed intensity of THz radiation, the magnitude of fluorescence depletion decreases with increasing THz frequency. Such fluorescence modulations are attributed to potential conformational changes in protein structures arising from resonant couplings with THz radiation.

This technique has the feasibility to extend to other biomolecules and may have potential applications in the fields of THz biosensors and THz imaging. The studies performed in this dissertation further our understanding of the interaction of high-power THz radiation with biomolecules and may also address concerns regarding impact of intense THz radiation on cells and tissue or biomolecules.