Applications of Molecular Coherence: from Ultrafast Waveform Synthesis to Detecting Coronavirus

A V Sokolov[1]

[1]*Institute for Quantum Science and Engineering, Texas A&M University, and Dept. of Physics&Astronomy, 4242 TAMU, College Station, TX, USA. Contact Phone: +9793306338*
Contact Email: sokol@tamu.edu

Molecular coherence is the central feature of multiple techniques and corresponds to a situation where molecules of a sample are prepared in a coherent superposition state. The high degree of quantum coherence can lead to remarkable results. One example is a technique termed molecular modulation, which allows ultrafast laser pulse shaping and non-sinusoidal field synthesis via coherent Raman generation [1]. We report progress toward the development and application of a novel Raman light source that allows simultaneous pulse shaping and beam shaping [2]. Additionally, recent work has shown that an increased and cleverly manipulated molecular coherence enables improvements in optical detection and sensing [3]. Raman-driven coherence is complementary to infrared-excited coherence in a molecular ensemble [4]. Spontaneous Raman micro-spectroscopy is an excellent tool, but it suffers from two problems: low scattering efficiency (requiring long acquisition times) and optical diffraction (preventing studies of nanoscale structures). In our work, these limitations are mitigated by using coherence-enhanced and plasmonic tip-enhanced Raman techniques [5]. First, when additional laser pulses are used to excite molecules of a sample into a coherent state (making a large number of molecules vibrate in unison), Raman signal generation is enhanced multi-fold [6]. Second, we circumvent the diffraction limit (which sets the resolution of ordinary microscopy) by using a near-field technique where a metalized scanning tip acts like a plasmonic nano-antenna and allows efficient collection of spectroscopic signal from a nanometer-scale hot spot (such tip-enhanced technique was recently used, for example, for direct readout of nucleic acid sequences [7]). These two approaches – the coherent laser signal generation and tip-enhanced detection – when combined, will lead to rapid chemical mapping of bio-agents and pathogens, aiding in rapid and sensitive detection, diagnostics, treatment, monitoring treatment outcomes and drug development. This adds a new strategy to the currently used genotypic analysis (e.g. by polymerase chain reaction, PCR) or detection by specific antibody-based methods [8].

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