Front. Phys. Vol. 14, No. 5 (2019)
http://journal.hep.com.cn/fop

Institute of Laser Spectroscopy, Shanxi University

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Overview
Established in 2010, the Institute of Laser Spectroscopy dedicates its work to research in ultracold atoms and molecules, single-molecule quantum optics, spectroscopic techniques & applications, and optoelectronics energy materials & devices. Located at Wucheng Campus of Shanxi University, the institute comprises an important part of the State Key Laboratory of Quantum Optics and Quantum Optics Devices.

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Research Foci

Ultracold molecules: Developing diverse optical, magnetic and microwave control techniques to realize atomic or molecular quantum degenerate gas and to explore quantum many-body physics therein. Utilizing various transition schemes to produce ultracold heteronuclear polar NaCs and RbCs molecules. The group also carries out quantum precision measurements harnessing the unprecedented precision of atomic and molecular transition frequencies.

Rydberg atoms and molecules: Utilizing magneto–optical trap (MOT) and dipole trap, atoms are cooled to temperatures of micro Kelvin. Through two-photon excitation, Rydberg states of Cesium atoms are achieved and can be further controlled with external electrical or magnetic fields. Formation of large Rydberg molecules in the configuration of Rydberg–Rydberg atoms is investigated. Based on the quantum effects of Rydberg atoms, novel methods are developed for microwave sensing with ultrahigh sensitivity, offering new benchmarks for experiments and industrial applications.

Single-molecule Quantum Optics and Nanophotonics: Effective measurement and control of a single molecule is an important ingredient in the study of molecule–photon interaction, and is key to realize quantum control. The goal of this research field is to study the photophysical and coherent properties of single molecules, to manipulate their optical and electrical properties, to prepare single photon quantum states based on single molecules, and to apply these properties and techniques to quantum information processing. We also focus on the fundamental optical properties and dynamics of other single emitters, such as single quantum dots, single metal nanoparticles, individual perovskite nanocrystals as well as functional 2D materials.

Applied Optics: Laser spectroscopy (LS) is a powerful technique for trace gas detection with high sensitivity and selectivity, and has found successful applications to diverse fields, such as environmental monitoring, industrial process control, defense and homeland security, and medical diagnostics. Among LS techniques, laser absorption spectroscopy (LAS) and photo acoustic spectroscopy (PAS) are especially important for developing laser–based trace gas analyzer in the application fields. The research platforms of cavity enhanced absorption spectroscopies, such as cavity ringdown spectroscopy (CRDS) and noise immune cavity enhanced optical heterodyne molecular spectroscopy (NICE-OHMS), and quartz enhanced photo–acoustic spectroscopy (QEPAS), have been built in the lab.

Materials and Devices for Optoelectronic Application: RGB lasers are perfect illumination light sources in projection displays. The existence of speckle degrades the image quality. By studying the coherence properties of lasers, and designing and fabricating speckle-suppressed devices, laser projectors with high image quality is developed. We also develop and utilize new functional materials for optical related applications, including high-efficient light absorption, electro–magnetic interference shielding, and optoelectronic catalyst for environment-friendly energy conversion system.

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Recent Projects

Quantum Simulation Based on Ultracold Quantum Gases: Ultracold polar molecules provide promising candidates for quantum simulation. Based on this unique system, we will develop state-of-the-art quantum control and measurement techniques such as Feshbach resonance, Stimulated Raman Adiabatic Passage (STIRAP), optical lattices, ultrasensitive and ultraresolution probe. This will pave the way for quantum simulations of novel quantum state and exotic quantum matter.

High-resolution imaging equipment of microwave electric field: Rydberg sensing techniques based on schemes of quantum interference effects can be exploited in precision measurement. By utilizing Mach–Zehnder interferometry and quantum superhet techniques, a sensitivity of few tens of $nVcm^{-1}Hz^{-1/2}$ has been achieved in the microwave amplitude measurement, which is a significant improvement compared to the standard approach based on Autler–Townes splitting of Rydberg atoms. The sensitivity can be further improved by noise suppression, which is our next goal. Furthermore, we also develop devices with high spatial imaging resolution of microwaves.

Single Molecular Quantum Coherent Spectrometer: The single molecular quantum coherence is about single molecular coherent superposition state and its evolution with the help of ultrafast laser spectrum. It allows us to extract the material composition, structure and the dynamic property at single molecule level. We aim to study the quantum dynamics of single molecules based on preparing and controlling the coherent superposition state by controlling the exciting laser spectrum, effectively manipulating the electronic coherent characteristics through an external electric field. A single molecular quantum coherent spectrometer will be developed, which will provide the quantum information for the single molecular science, promising innovative applications in quantum information processing, molecular electronics as well as single molecular probe.

Highly Sensitive Trace Gas Detection Based on Laser Spectroscopy: A series of sensitive gas sensor based on photoacoustic spectroscopy (PAS), such as NO_2, H_2S, CO sensors, were developed to meet the requirements of environmental monitoring, industrial process control and power system failure. One of the ongoing projects is to realize a sensitive gas sensor on a chip by combining PAS technique with micro-electromechanical system. The other ongoing project is to develop an ultrasensitive NICE-OHMS spectrometer to measure the atmospheric sample by adopting an EDFL or WGM semiconductor laser.

Development of Spontaneous Speckle Reduction Module: A new laser speckle reduction module has been designed and fabricated using micro fabrication process based on the theoretical study of the relationship between laser coherence and speckle effect. This module is efficient for speckle reduction, and it shows the advantages over the other speckle reduction methods because it is motionless and compact. In cooperation with our industry partners, the module has been integrated into laser projectors for the applications of cinema projection and engineering projection etc.