III-D Development of High-Precision Coherent Control and Its Application

Coherent control is based on manipulation of quantum phases of wave functions. It is a basic scheme of controlling a variety of quantum systems from simple atoms to nanostructures with possible applications to novel quantum technologies such as bond-selective chemistry and quantum computation. Coherent control is thus currently one of the principal subjects of various fields of science and technology such as atomic and molecular physics, solid-state physics, quantum electronics, and information science and technology. One promising strategy to carry out coherent control is to use coherent light to modulate a matter wave with its optical phase. We have so far developed a high-precision wave-packet interferometry by stabilizing the relative quantum phase of the two molecular wave packets generated by a pair of fs laser pulses on the attosecond time scale. We will apply our high-precision quantum interferometry to gas, liquid, solid, and surface systems to explore and control various quantum phenomena.

III-D-1 Space- and Time- Resolved Observation of Molecular Wave-Packet Interference on Femtosecond and Picometric Scales

KATSUKI, Hiroyuki[1]; CHIBA, Hisashi[1]; OHMORI, Kenji[1]; GIRARD, Bertrand[2]; MEIER, Christophe[2]
([1]IMS and CREST/JST; [2]Univ. Paul Sabatier)

We have developed a brand new method to observe molecular wave-packet interference in the time- and space-resolved fashion. It has been applied to the half revival of the vibrational wave packet in the iodine molecule. The observed temporal evolution of the interference has been well reproduced by the quantum mechanical calculation. We have succeeded in observing the quantum nodal structures which take place at a spatial resolution of less than 1 pm, and are created and dynamically changed on the femtosecond timescale. To our knowledge, this is for the first time that the dynamical matter-wave interferences are observed on the femtosecond time scale and picometric length scale.

III-D-2 Real-Time Observation of Phase-Controlled Molecular Wave-Packet Interference

KATSUKI, Hiroyuki[1]; HOSAKA, Kouichi[1]; CHIBA, Hisashi[1]; OHMORI, Kenji[1]; HONDA, Masahiro[2,3]; HAGIHARA, Yusuke[2,3]; FUJIWARA, Katsutoshi[3]; SATO, Yukinori[2,3]; UEDA, Kiyoshi[2,3]
([1]IMS and CREST/JST; [2]CREST/JST; [3]Tohoku Univ.)

We have controlled quantum interference of vibrational wave packets (WP's) in the iodine molecule by using a pair of phase-locked fs pulses, and the real time evolution of that interference has been observed. The real-time evolution shows a clear dependence on the inter-pulse delay $\tau_{control}$ between the locked pulses highly stabilized on attosecond time scale. We have also measured a population code, which is a population ratio among the vibrational eigenstates within a WP. The population code also shows a clear dependence on $\tau_{control}$. The ordinary frequency domain interpretation based on the spectral interference of locked pulses may be useful to elucidate population codes, but is no longer suitable for the present real-time observation. Moreover, the real-time evolution has allowed us to obtain additional phase information unable to be obtained from population codes. The combination of a population code and real-time evolution is useful to obtain both phase and amplitude information stored in a WP, which is indispensable for developing novel quantum technologies such as atom- and molecule-based information processing. All these features provides basis for opening new perspective of coherent control in a wide variety of quantum systems.

III-D-3 Development of Quantum Gate Operations with Vibrational Eigenstates of Molecules

HOSAKA, Kouichi[1]; CHIBA, Hisashi[1]; KATSUKI, Hiroyuki[1]; OHMORI, Kenji[1]; TERANISHI, Yoshiaki[2,3]; OHTSUKI, Yukiyoshi[2,3]
([1]IMS and CREST/JST; [2]CREST/JST; [3]Tohoku Univ.)

We have numerically studied quantum gate operations with the iodine molecule, based on the free temporal evolution of the vibrational wave packet and the high-precision wave-packet interferometer. The fidelities of the gate operations are found to be very high, and the proposed experimental scheme is feasible with our present experimental techniques.