Development of High-Precision Coherent Control and Its Applications

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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 femtosecond 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.

1. Strong-Laser-Induced Quantum Interference[1)]

Molecules are expected to be promising information devices. Theoretical proposals have been made for logic gates with a molecular wave packet modulated by a strong femtosecond laser pulse. However, it has not yet been observed how this changes the population of each eigenstate within the wave packet. Here we demonstrate direct observation of the population beating clearly as a function of the delay of the strong laser pulse. The period is close to the recurrence period of the wave packet, even though a single eigenstate should have no information on the wave-packet motion. This unusual beat arises from quantum interference among multiple eigenstates combined on a single eigenstate. This new concept, which we refer to as 'strong-laser-induced interference,' is not specific to molecular eigenstates, but universal to the superposition of any eigenstates in a variety of quantum systems, being a new tool for quantum logic gates, and providing a new method to manipulate wave packets with femtosecond laser pulses in general applications of coherent control.

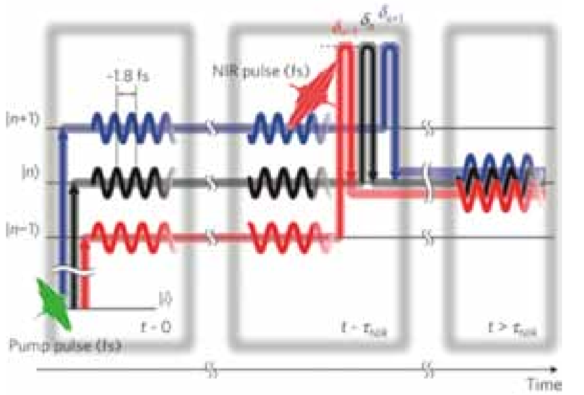

Figure 1. Starting from a common initial state *i*, there are multiple pathways given by the pump and strong near-infrared (NIR) laser pulses to the common final state *n*. Those multiple pathways interfere with each other. The amounts of phase shifts during the NIR pulse are indicated as δ_{n-1}, δ_n, and δ_{n+1}.

2. Optical Manipulation of Coherent Phonons in Superconducting $YBa_2Cu_3O_{7-\delta}$ Thin Films[2)]

The coherent phonons of $YBa_2Cu_3O_{7-\delta}$ are believed to be strongly coupled to its superconductivity. Controlling the phonons below its transition temperature, therefore, may serve as a promising scheme of the control of superconductivity. Here we demonstrate optical manipulation of the Ba–O and Cu–O vibrations in a thin-film $YBa_2Cu_3O_{7-\delta}$ below its transition temperature using a pair of femtosecond laser pulses. The interpulse delay is tuned to integral and half-integral multiples of the oscillation period of a specific phonon mode (Ba–O or Cu–O vibration) to enhance and suppress its amplitude, respectively.

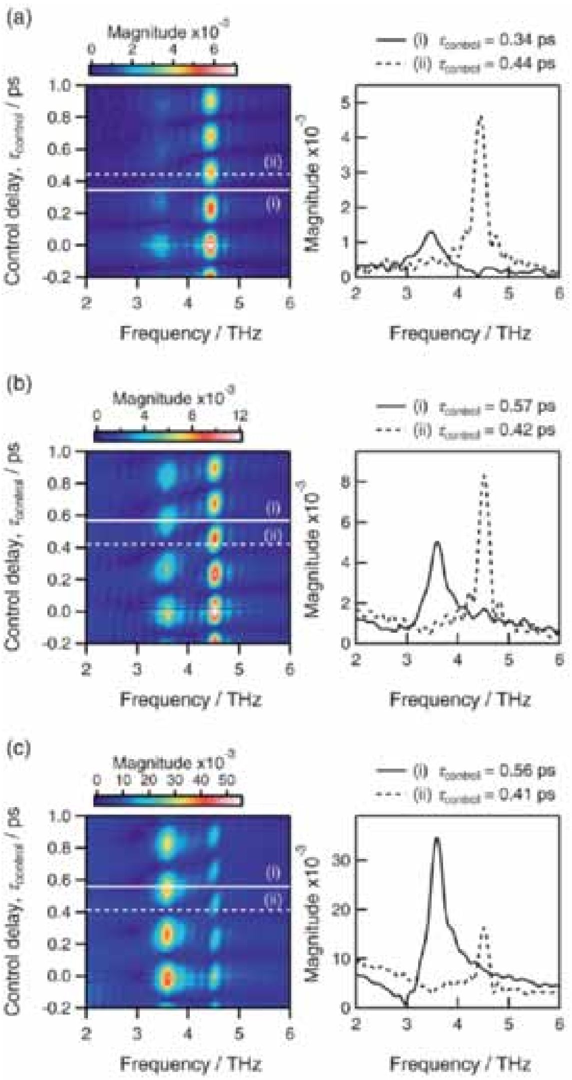

Figure 2. Fast-Fourier-transform of the temporal evolutions of the coherent phonons induced by a pair of femtosecond laser pulses in $YBa_2Cu_3O_{7-\delta}$ thin films with temperatures (a) 296 K, (b) 78 K, and (c) 8 K. They are plotted as functions of the interpulse delay $\tau_{control}$ in the left column. The right column shows cross sections along the solid (i) and broken (ii) lines in the left column at each temperature.

References

1) H. Goto, H. Katsuki, H. Ibrahim, H. Chiba and K. Ohmori, *Nat. Phys.* **7**, 383–385 (2011).
   Highlighted by Nat. Phys. **7**, 373–374 (2011).
   Highlighted by Nat. Photonics **5**, 382–383 (2011).
2) Y. Okano, H. Katsuki, Y. Nakagawa, H. Takahashi, K. G. Nakamura and K. Ohmori, *Faraday Discuss.* **153**, 375–382 (2011). (invited paper).

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