Optically engineered quantum states in ultrafast and ultracold systems

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The wavefunctions of electrically neutral systems can replace electric charges of the present Si-based circuits, whose further downsizing will soon reach its limit where current leakage will cause heat and errors with insulators thinned to atomic levels. Atoms and molecules are promising candidates for these neutral systems, in which the population and phase of each eigenstate serve as carriers of information. A shaped ultrashort laser pulse can access many eigenstates simultaneously within a single atom or molecule, manipulating the amplitude and phase of each eigenstate individually to write more than one million distinct binary codes in the angstrom space [1-3]. Molecules in particular are now expected to be promising components to develop scalable quantum computers [4]. The development of I/O and logic gates with molecules should be meaningful for us to be prepared for such a future scalable system. It is therefore important to study information processing with molecular eigenstates for both high-density classical information processing and quantum information processing. Here we demonstrate a logic gate based on the temporal evolution of a wavefunction. An optically tailored vibrational wave packet in the iodine molecule implements four- and eight-element discrete Fourier transforms [2]. Our ultrahigh-precision wave-packet interferometry [5-8] has retrieved complete sets of amplitude and phase information stored in the input and output states, verifying the transform has been securely executed with arbitrary real and imaginary inputs. The evolution time is 145 fs, which is shorter than the typical clock period of the current fastest Si-based computers by 3 orders of magnitudes [9]. We have also developed another class of logic gates based on quantum interference among different molecular eigenstates induced by a strong non-resonant femtosecond laser pulse, which is referred to as strong-laser-induced quantum interference (SLI) [3]. These ultrafast approaches are now being applied to cold and ultracold systems such as solid para-hydrogen [10] and laser-cooled atoms and molecules to develop ultrafast quantum information processing.

References

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