Visualization of Quantum Dynamical Nature Utilized Quantum Measurements

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Awards

2013 FQXi Essay Contest Fourth Prize
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Due to great development on experimental technologies, it is possible to capture quantum dynamics in some physical and chemical systems. On the other hand, all experiments are in principle open and dissipative systems. Up to now, the well explained experiments are approximated to the equilibrium situation. However, by recent technological development, some experiments reach to a transition from equilibrium to non-equilibrium situations. While there are the well-known tools on the non-equilibrium situations; the linear response theory and the Keldysh Green function method, this analysis cannot basically catch dynamical situations. Our goal is to construct the time-resolved theoretical models included the non-equilibrium situations. However, the quantum measurement theory is needed on measuring quantum dynamics, especially considering the measurement back action. Our current activities are to resolve how sensitive (quantum) measurement can we carry out in principle, to build up some toy models on quantum dynamic and to explain unique quantum-mechanical phenomena using precise quantum-state engineering technology.

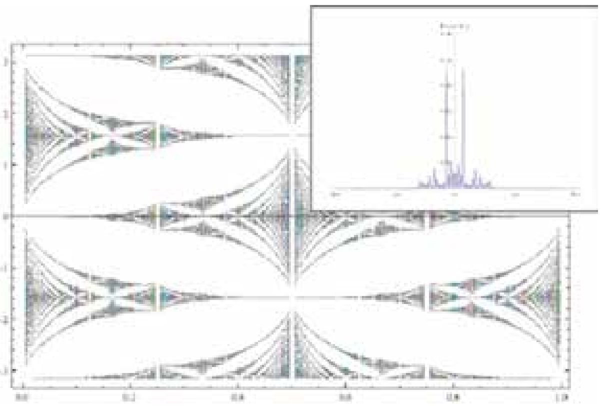

Figure 1. Example of the complex but regular phenomena from the simple law; the discrete-time quantum walk, which is a mathematical toy model to be defined as a quantum-mechanical analogue of the random walk. The probability distribution is depicted in the left top panel. This main distribution is called Hofstadter's butterfly to show the multi-fractal structure.

Selected Publications

- Y. Shikano and A. Hosoya, "Weak Values with Decoherence," *J. Phys. A* **43**, 025304 (15 pages) (2010).
- Y. Shikano and H. Katsura, "Localization and Fractality in Inhomogeneous Quantum Walks with Self-Duality," *Phys. Rev. E* **82**, 031122 (7 pages) (2010).
- A. Noguchi, Y. Shikano, K. Toyoda and S. Urabe, "Aharonov-Bohm Effect in the Tunnelling of a Quantum Rotor in a Linear Paul Trap," *Nat. Commun.* **5**, 3868 (6 pages) (2014).
- H. Kobayashi, K. Nonaka and Y. Shikano, "Stereographical Visualization of a Polarization State Using Weak Measurements with an Optical-Vortex Beam," *Phys. Rev. A* **89**, 053816 (5 pages) (2014).

1. Generation Mechanism and Detection of Coherent Phonon in Bulk Solid[1,2]

Coherent optical phonons in bulk solid system play a crucial role in understanding and designing light-matter interactions and can be detected by the transient-reflectivity measurement. In this paper, we demonstrate spectrally resolved detection of coherent optical phonons in diamond from ultrashort infrared pump–probe measurements using optical bandpass filters. We show that this enhances the sensitivity approximately 35 times in measuring the coherent oscillations in the transient reflectivity compared with the commonly used spectrally integrated measurement. To explain this observation, we discuss its mechanism.

We also investigated the coherent phonon generation mechanism by irradiation of an ultrashort pulse with a simple two-level model. Our derived formulation shows that both impulsive stimulated Raman scattering (ISRS) and impulsive absorption (IA) simultaneously occur, and phonon wave packets are generated in the electronic ground and excited states by ISRS and IA, respectively. We identify the dominant process from the amplitude of the phonon oscillation. For short pulse widths, ISRS is very small and becomes larger as the pulse width increases. We also show that the initial phase is dependent on the pulse width and the detuning.

2. Exciton–Polariton Condensates in High Density Regime[3]

In a standard semiconductor laser, electrons and holes recombine via stimulated emission to emit coherent light, in a process that is far from thermal equilibrium. Exciton–polariton condensates—sharing the same basic device structure as a semiconductor laser, consisting of quantum wells coupled to a microcavity—have been investigated primarily at densities far below the Mott density for signatures of Bose-Einstein condensation. At high densities approaching the Mott density, exciton–polariton condensates are generally thought to revert to a standard semiconductor laser, with the loss of strong coupling. Here, we report the observation of a photoluminescence sideband at high densities that cannot be accounted for by conventional semiconductor lasing. This also differs from an upper-polariton peak by the observation of the excitation power dependence in the peak-energy separation. Our interpretation as a persistent coherent electron–hole–photon coupling captures several features of this sideband whereas many remain elusive. Understanding the observation will lead to a development in non-equilibrium many-body physics.

3. Operational Derivation of Physical Laws[4,5]

The resolution of the Maxwell's demon paradox linked thermodynamics with information theory through information erasure principle. By considering a demon endowed with a Turing-machine consisting of a memory tape and a processor, we attempt to explore the link towards the foundations of statistical mechanics and to derive results therein in an "operational" manner. Here, we present a derivation of the Boltzmann distribution in equilibrium as an example, without hypothesizing the principle of maximum entropy. Further, since the model can be applied to non-equilibrium processes, in principle, we demonstrate the dissipation–fluctuation relation to show the possibility in this direction.

4. Laser Cooling Mechanism of Optomechanics[6]

In the optomechanical cooling of a dispersively coupled oscillator, it is only possible to reach the oscillator ground state in the resolved sideband regime, where the cavity-mode line width is smaller than the resonant frequency of the mechanical oscillator being cooled. In this paper, we show that the dispersively coupled system can be cooled to the ground state in the unresolved sideband regime using an ancillary oscillator, which is coupled to the same optical mode via dissipative interaction. The ancillary oscillator has a resonant frequency close to that of the target oscillator; thus, the ancillary oscillator is also in the unresolved sideband regime. We require only a single blue-detuned laser mode to drive the cavity.

References

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3) T. Horikiri, M. Yamaguchi, K. Kamide, Y. Matsuo, T. Byrnes, N. Ishida, A. Löffler, S. Höfling, Y. Shikano, T. Ogawa, A. Forchel and Y. Yamamoto, *Sci. Rep.* **6**, 25655 (11 pages) (2016).
4) A. Hosoya, K. Maruyama and Y. Shikano, *Sci. Rep.* **5**, 17011 (9 pages) (2015).
5) Y. Shikano, in *It From Bit or Bit From It?* The Frontiers Collection, Springer; Switzerland, Chapter 10, pp. 113–118 (2015).
6) Y.-X. Zhang, S. Wu, Z.-B. Chen and Y. Shikano, *Phys. Rev. A* **94**, 023823 (11 pages) (2016).

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