Ultimate Quantum Measurements for Quantum Dynamics

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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 backaction. 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 photoluminescence phenomena in nitrogen vacancy center in diamond and in the semiconductor microcavity.

1. Quantum Measurement Sensitivity without Squeezing Technique[1–4)]

As alluded before, our aim is to capture quantum dynamical phenomena. Capturing some phenomena needs to carry out the measurement. The conventional quantum measurement technique has huge measurement backaction. The measurement backaction prevents us chasing quantum dynamics like the classical trajectory. On the other hand, reducing the measurement backaction needs the tiny coupling between the target and probe quantum systems. However, under this situation, the signal in the probe system is also tiny small, that is, it is difficult to capture information. To resolve this problem, the squeezing technique was proposed and was experimentally implemented. However, this technique is practically difficult to be implemented. Our proposal is to use the weak measurement initiated by Aharonov, Albert, and Vaidman without squeezing technique. The profound meaning and interpretation of the weak measurement is seen in the review paper.[3)] The key of this method is to take the post-selection of the target system. Due to this effect, tiny probe signal can be amplified. In the original proposal by Aharonov, Albert, and Vaidman, the amplification factor is infinite by the approximation method. However, the effect measurement backaction is simultaneously amplified. When the probe state is Gaussian to be used in the original proposal, we have analytically shown the upper bound of the amplification factor. We have analytically derived the probe state to maximally amplify the signal by the variational method.[1,2)] By this optimal probe state, the amplification factor has no upper bound. Our result tells us the infinitely amplified single under the known coupling between the target and the probe. However, in this result, we ignore the physical implementation. As the preliminary result, we demonstrate the single effect for the Laguerre-Gauss modes.[3)]

2. Discrete Time Quantum Walk as Quantum Dynamical Simulator[5–10)]

The discrete time quantum walk is defined as a quantum mechanical analogue of the classical random walk but is not the quantization of the classical random walk. This mathematical description is very simple but leads to many quantum dynamical phenomena. This is a toy model to better understand the quantum dynamics. Also, this has recently been various experimental demonstrations in the ultracold atoms in the optical lattice, trapped ions, and optical systems. Recently, we propose the physical implementation in the solid-state system using the nitrogen-vacancy centers in diamond and superconducting qubit.[10)] We have analytically shown that the one- and two-dimensional discrete time quantum walks can be taken as the quantum dynamical simulator,[8)] which concept is to emulate some classes of the differential equations, for example, the Dirac equation. Our approximation is used from the discrete lattice to continuous line for the large time steps of the discrete time quantum walk. This mathematical treatment is so powerful like the relationship between the cellular automaton and the integrable system.

3. Photoluminescence Phenomenon from Solid-State System[11)]

A method to measure some physical properties by light is widely used in physical, chemical, and biological systems. Therefore, laser science has been developed along with our demands from science and technology. A single photon source is expected as the low power laser source and the quantum communication tool. A nitrogen vacancy center in diamond and a quantum dot in a semiconductor system are the promising candidate of the single photon source. Especially, a nitrogen vacancy center in diamond has been attracted since this is run at room temperature. For an application as the highly controlled photon source, the photoluminescence process in the nitrogen vacancy center in diamond needs to be well understood. This system has the $S = 1$ electronic spin with the hyperfine structure 2.87 GHz. Furthermore, inserting a magnetic field, the different magnetic states are separated due to the Zeeman shift. Since this electronic spin is highly localized, the local magnetic field evaluation is needed. We have shown the method to evaluate the local magnetic field from the conventional confocal microscopy. Also, the nitrogen vacancy center in diamond is a candidate of the quantum memory. Since a lifetime of the nuclear spin of a ^{13}C atom nearly located in the nitrogen vacancy spot is long (~ sec order), the perfect quantum state transfer is needed. However, we have proposed the simple spin transfer scheme under the dissipative situation.[10)] As the next step, we will study the photoluminescence process from the nitrogen vacancy center in diamond.

As the current activities of our group, we are studying the photoluminescence processes of the quantum dots and the exciton-polariton Bose-Einstein condensations in the two dimensional electronic gas of the semiconductor. Experimentally, we measure the photoluminescence by the confocal microscopy. These materials are expected to be used as the classical optical devices; the optical switching, collaborated with the various experimentalists.[11)]

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