Dynamically Unpolarized Single-Photon Source in Diamond with Intrinsic Randomness

Naofumi Abe, Yasuyoshi Mitsumori, Mark Sadgrove, Keiichi Edamatsu

Research Institute of Electrical Communication, Tohoku University
E-mail: n-abe@quantum.riec.tohoku.ac.jp

Single-photon sources are essential tools for quantum information technology and testing the foundations of quantum theory. To date, single-photon sources which emit purely polarized single photons (e.g. horizontal polarization and vertical polarization) have been realized in various ways. On the other hand, single-photon sources which emit completely unpolarized single photons are also important for applications such as realizing hardware random number generators and testing the foundations of quantum theory such as the error-disturbance relation for mixed states [1, 2] which are quantum states of unpolarized polarization states. Here, we present a dynamically and statically unpolarized single-photon source using a single nitrogen-vacancy (NV) center in diamond. In particular, we demonstrate a new method for evaluation of dynamical unpolarization using the second order correlation function [3].

NV centers consist of a substitutional nitrogen atom and an adjacent vacancy (Fig. 1(a)). Polarization of emitted photons from a NV center is determined by an excited dipole associated with an excited electronic orbital state. NV centers have two excited electronic orbital states called E_x and E_y. The excited dipoles associated with E_x and E_y are perpendicular to each other and also to the NV axis which is an axis connecting the nitrogen atom and the vacancy (Fig. 1(a)). After excitation from the ground state to E_x or E_y, these excited states immediately reach thermal equilibration at room temperature. Therefore, if excitation and detection are carried out along the NV axis which is oriented along [111], we can observe the unpolarized property of emitted photons from the NV center. To observe this, we use (111) diamond synthesized by a high pressure high temperature (HPHT) method. The excitation by a 532 nm laser and the collection of the phonon sideband emission (650-800 nm) from a single NV center was carried out by a standard confocal microscopy method at room temperature.

Firstly, we carried out quantum state tomography for polarization states of emitted single photons to examine the statically unpolarized property [3]. We obtained Stokes parameters (S_1/S_0, S_2/S_0, S_3/S_0) = (0.057, − 0.003, − 0.004) (for the completely unpolarized case, i.e. the completely mixed state, (0, 0, 0)). The corresponding state fidelity to the completely mixed state was 0.999.

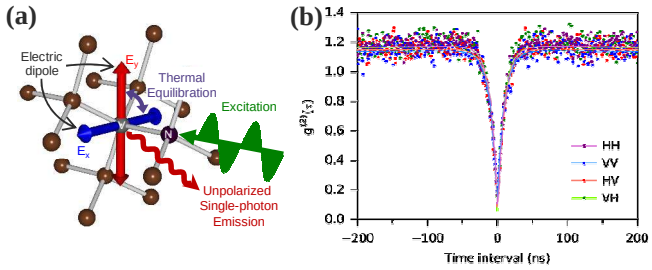

Fig. 1 (a) Structure of a NV center in diamond and electric dipoles associated with E_x and E_y. (b) The measured modified second order correlation function $g_{ij}^{(2)}(\tau)$ [3].

Secondly, we measured the degree of dynamic unpolarization using the modified second order correlation function [3]. The basic setup was a standard Hanbury Brown-Twiss type setup in which the photon stream was divided by the insertion of a non-polarizing beamsplitter (NPBS), and detected at the outputs by a couple of avalanche photodiodes. To measure the degree of dynamic unpolarization, polarizers were introduced just after each outputs of NPBS. We measured the modified second-order correlation function $g_{ij}^{(2)}(\tau)$, where i and j denotes the polarizer settings HH, VV, HV and VH, and H (V) indicates horizontal (vertical) polarization. The $g_{ij}^{(2)}(\tau)$ data we measured at weak excitation (0.20 mW) are shown in Fig. 1(b). The data show that the four $g_{ij}^{(2)}(\tau)$ are identical to each other within experimental accuracy. This result means that emitted photons are dynamically unpolarized, i.e., time adjacent single photons have essentially no polarization correlation.

In conclusion, we demonstrate dynamically and statically unpolarized single photons emitted from a [111]-oriented NV center in diamond. The photon source will be useful in applications testing the foundations of quantum theory.

Acknowledgements

This research was supported in part by JSPS KAKENHI (no. 22244035) and MIC SCOPE (no. 121806010).

References

[1] Masanao Ozawa, arXiv [quant-ph] (2014) 1404.3388
[2] Bülent Demirel *et al.*, Phys. Rev. Lett. **117** (2016) 140402
[3] Naofumi Abe *et al.*, Sci. Rep. **7** (2017) 46722