Press Release

Keio University

国立大学法人 東京学芸大学 Tokyo Gakugei University

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Pure and Efficient Single-photon Source Based on Carbon Nanotubes for Quantum Cryptography

―Theoretical discovery of a technique to attain a high-performance single-photon source at room temperature and in the telecommunication wavelength band―

Associate Professor Hideyuki Maki of the Keio University Faculty of Science and Technology, Department of Applied Physics and Physico-Informatics and his collaborators have demonstrated for the first time that a single-photon source that can generate single photons with both high purity and high efficiency at room temperature is theoretically possible through the use of single-walled carbon nanotubes.

Single photons, in which the number of photons contained in a pulse is restricted to one, have recently been attracting attention in quantum information devices such as those for quantum cryptography. To realize highly integrated general-purpose quantum information devices, there is a need for a single-photon source that can generate highly pure and highly efficient single photons at room temperature in the telecommunication wavelength band. To date, Professor Maki's research group has experimentally demonstrated the first single-photon source at room temperature and the telecommunication wavelength using carbon nanotubes, which thereafter has led to research in this area being carried out worldwide. However, it is difficult to generate single photons with both high purity and high efficiency with the current single-photon source, and the development of a technique that can fulfil both of these conditions for practical applications in quantum information devices is highly sought after. In this study, the functionalization of short suspended carbon nanotubes was theoretically demonstrated for the first time as a technique that can generate single photons with both high purity and high efficiency from carbon nanotubes. From this, it became apparent that carbon nanotubes can be used to develop uncooled, high-performance single photon elements in the telecommunication wavelength band, and through the use of this technology, there are expectations that the development of next generation quantum information elements, including general-purpose quantum cryptographic elements with on-chip integration capabilities, will be promoted.

This research was jointly carried out with Associate Professor Yutaka Maeda of Tokyo Gakugei University.

The outcomes of this research were published on the online issue of ACS Applied Nano Materials, a scientific journal published by the American Chemical Society (ACS), on December 27, 2019.

１．Background of research

Single photons, in which the number of photons contained in a pulse is restricted to one, have recently been attracting attention in basic research fields related to quantum mechanics as well as in quantum information fields such as quantum cryptography, where single photons can be used to detect eavesdropping and thereby provide complete security. In order to make this technology widely and universally popular in the future, it is essential to produce inexpensive and highly integrable quantum information devices. It is also desirable to develop a single-photon source that is highly integrable on silicon chips, which can be combined with elements such as an optical integrated circuit called silicon photonics. Carbon nanotubes are a new material with unique physical, chemical, and mechanical properties derived from their one-dimensional structure, and they are attracting attention as a novel material that can lead to the production of various devices that cannot be created using traditional semiconductor materials. In its research up to now, Professor Maki's group has led the way, successfully developing a single-photon source at room temperature that is in the telecommunication wavelength band using carbon nanotubes. However, although highly pure single photons can be experimentally realized, at present, there remains a problem in that the generation efficiency of single photons is low. In order to apply them to quantum information devices such as quantum cryptographic elements, there is a need to establish a new technique that can generate single photons with both high purity and high efficiency from a single-photon source.

２．Content of research and results

In this study, a method to functionalize short suspended carbon nanotubes was devised as a new technique, and when single photon generation through this technique was theoretically explained, it was found that extremely high single photon generation efficiency could be achieved while maintaining the high single photon purity that had been reported to date. It was discovered that for extremely short suspended carbon nanotubes of the order of 100 nm in length, high single photon generation efficiency can be obtained while maintaining extremely high single photon purity from localized excitons at room temperature by functionalizing the localization site of the excitons. Mechanisms were also explained in detail, showing that in short carbon nanotubes, residual free excitons are annihilated through end quenching of the excitons and exciton-exciton annihilation, and that even under high excitation, highly pure and highly efficient single photon generation is possible from localized excitons.

Because these underlying techniques, including suspended carbon nanotubes and functionalizing techniques, have already been established experimentally in the field of carbon nanotubes, the technique presented in this research is practicable. The high-performance single-photon source based on this method of using carbon nanotubes will be a new technique that will lead to the development of inexpensive and highly integrated general-purpose quantum information devices in the field of quantum information, which includes quantum cryptography. In the future, it is thought that quantum optical devices will become denser and increasingly chip-based. It is therefore believed that a high-performance single-photon source using carbon nanotubes that can operate with silicon photonics at room temperature will contribute to the development and growth of inexpensive and general-purpose quantum information devices.

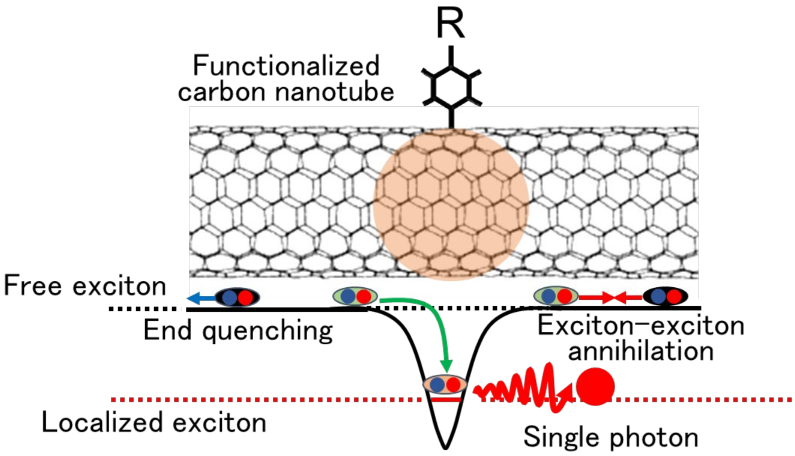

Figure 1　Top: Schematic diagram of a short functionalized carbon nanotube.
Bottom: Schematic diagram in which excitons are localized in molecules and single photons are generated.

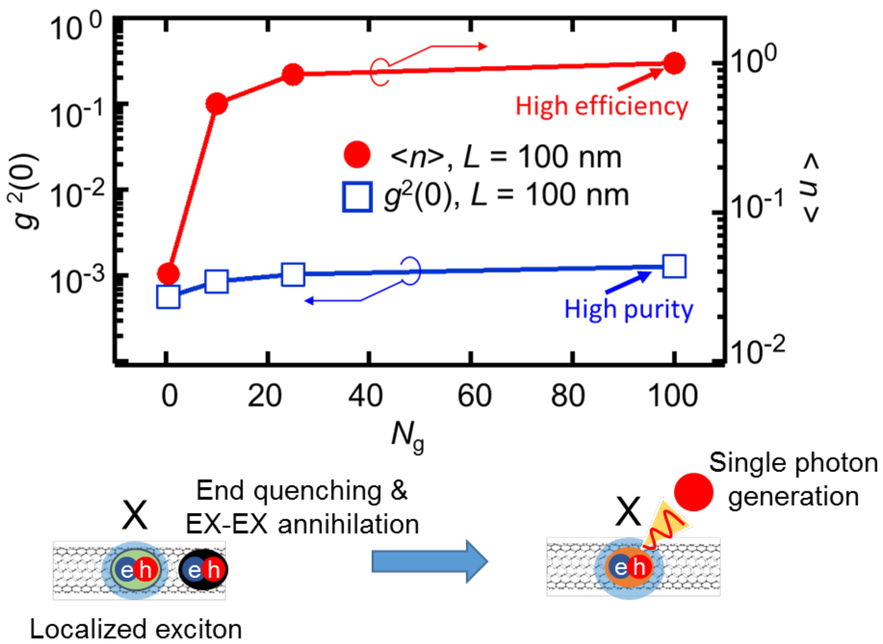

Figure 2　Top: Results of single photon generation characteristics for suspended functionalized carbon nanotubes (CNT) with lengths of 100 nm under various excitation conditions. It can be seen that high purity and efficiency can be obtained under high excitation conditions for carbon nanotubes with a length of 100 nm.

Bottom: Single photon generation mechanism of short functionalized carbon nanotubes (CNT). A single photon is obtained from a localized exciton because at the same time as when an exciton is localized in the functionalized portion, the extra excitons are nonradiatively annihilated through end quenching and exciton-exciton annihilation.

＜Details of original paper＞

"Pure and Efficient Single-Photon Sources by Shortening and Functionalizing Air-Suspended Carbon Nanotubes"

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※Please direct any requests or inquires to the contact information provided below in advance.

・Inquiries about research

Keio University Faculty of Science and Technology, Department of Applied Physics and Physico-Informatics, Associate Professor Hideyuki Maki

Tel: +81-45-566-1643 E-mail：maki@appi.keio.ac.jp http://www.az.appi.keio.ac.jp/maki/

・Inquiries about press release

Keio University Office of Communications and Public Relations (Murakami)

Tel: +81-3-5427-1541 Fax: +81-3-5441-7640

E-mail: m-pr@adst.keio.ac.jp https://www.keio.ac.jp/en/

Tokyo Gakugei University General Affairs Department Public Relations Division

Tel: +81-42-329-7116 Fax: +81-42-329-7878

E-mail：kouhouty@u-gakugei.ac.jp http://www.u-gakugei.ac.jp/