Report on MERIT long-term overseas dispatch

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Abstract

I have visited Stephen K. Doorn's Laboratory of Los Alamos National Laboratory (LANL) during April 10th to June 5th and performed experiments with the help of Dr. Htoon regarding integration of dopant states of carbon nanotubes and silicon microcavities.

Background and Research Objective

In the recent few years, improvement of optical properties of carbon nanotubes (CNTs) by introducing dopant states on surface of CNTs becomes possible. Using doped CNTs, dramatic increase of emission intensity and single photon emission at room temperature are reported, and therefore such doping technique is regarded as a promising approach to achieve future CNT devices with excellent optical properties. At the same time, integration of CNTs and silicon photonics is also attracting a lot of attention recently as it enables control of radiation properties and thus enhancement of emission intensity becomes possible.

In this project, we try to integrate both the techniques. Doped CNTs are deposited on silicon microcavities, and emission spectra of the devices are measured in order to confirm that the dopant states can be coupled to silicon microcavities and to evaluate the effect of optical coupling, in particular for single photon generation process.

My Research Activities

In advance, two-dimensional photonic crystal (PhC) microcavities on silicon-on-insulator substrates have been fabricated using electron beam lithography and dry etching at the University of Tokyo. Chemical doping process to micelle-wrapped CNTs using diazonium salts is done by Doorn group, and the existence of the dopant states in the sample is confirmed by measuring the emission spectrum.

To obtain coupling devices of the microcavities and the doped CNT sample, we start sample deposition process onto the PhC substrates with spin coating and drop casting methods, but it is found that we cannot obtain appropriate condition for optical coupling in these methods as the deposited density of the sample is not uniform over a substrate, and these processes consume large amount of nanotube solution and PhC substrates. Therefore, with an advice from Dr. Htoon, I newly construct a micro-manipulation system and try micro-deposition of the sample. The micro-manipulation system consists of an optical microscope, a micro-manipulator, and a micro-pipette connected to a micro-syringe as shown in Fig. 1. The deposition area can be changed by replacing the micro-pipette with various tip diameters ranging from 0.1 μm to 10 μm, and finally we find that relatively large area deposition over tens of microcavities can form a smooth gradient of doped CNT density, so that we

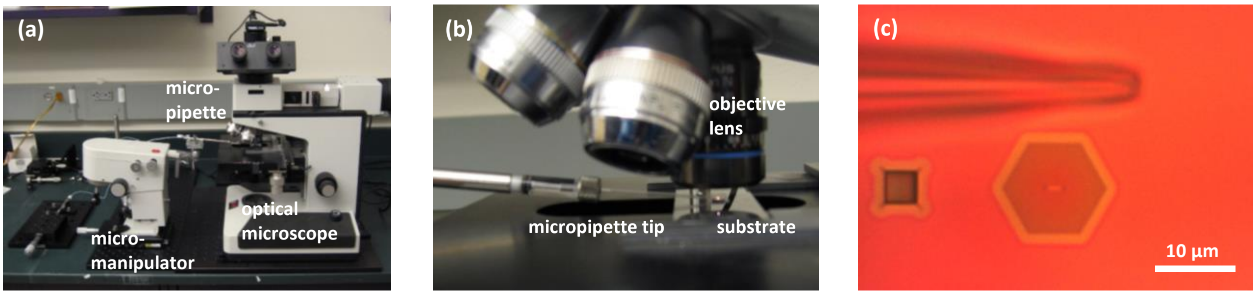

FIG. 1. Micromanipulation system for CNT deposition on PhC nanocavities. (a) Overall picture of the system. (b) Micropipette tip approaching to a substrate under an objective lens with a long working distance (3.4 mm). (c) Optical microscope image taken with this system. The inner diameter of the tip is 1.0 µm. In this image, the tip is slightly defocused in order to avoid a direct contact to the substrate.

can obtain devices with a good coupling between doped CNTs and a microcavity.

For the CNT deposited cavities, optical measurements are performed in a home-build optical measurement system. A continuous-wave Ti:Sapphire laser with wavelength of 820 nm is used for excitation, and the laser is focused on a substrate through an objective lens. Photoluminescence from a sample is detected by InGaAs detector array attached to a spectrometer. In the photoluminescence spectra, emission from intrinsic (undoped) region of CNTs appears as a sharp peak at 1000 nm, while emission from dopant states is observed as broader peaks around 1280 nm. As we have designed the cavity resonant wavelength to match the dopant state emission, dopant states of nanotubes are able to be coupled to the cavity under an appropriate condition of deposition, and we obtain very sharp peaks around the emission wavelength of the dopant states in some devices, successfully.

As a future plan, we are planning to perform radiation lifetime measurements and single photon generation experiments with pulsed laser and single photon detectors, for quantitative evaluation of the optical coupling effects in these devices.

Life in Los Alamos

LANL is known as one of the largest science institution in the world, so I have experienced the great environment and state-of-the-art technologies for scientific researches. Everyone working in the lab is very friendly, so I was able to work there without any troubles. The city of Los Alamos is very quiet, safe, and convenient place for working in LANL. The room I rent is located near the lab, and the house owner and roommates are really kind persons, so I spent comfortable and enjoyable time. In particular, playing with two dogs in the house is one of the most pleasant time during my stay.

Acknowledgements

I would like to express my gratitude to Dr. Doorn and Dr. Htoon for all the supports during my stay in LANL. I would also like to thank Dr. Hartmann and Dr. He, postdoc researchers of LANL, for their kind help, and Mr. Machiya and Mr. Kimura, master students in our lab, for the help of fabrication process of silicon microcavities. Finally, I am grateful to MERIT for giving me such a great opportunity of this long-term overseas dispatch.