Formation of Quantum Emitters in Air-Suspended Carbon Nanotubes Using Vapor-Phase Reaction

Daichi Kozawa[1], Xiaojian Wu[2], Akihiro Ishii[1,3], Jacob Fortner[2], Keigo Otsuka[3], Rong Xiang[4], Taiki Inoue[4], Shigeo Maruyama[4,5], YuHuang Wang[2,6], Yuichiro K. Kato[1,3]

[1] Quantum Optoelectronics Research Team, RIKEN Center for Advanced Photonics
[2] Department of Chemistry and Biochemistry, University of Maryland
[3] Nanoscale Quantum Photonics Laboratory, RIKEN Cluster for Pioneering Research
[4] Department of Mechanical Engineering, The University of Tokyo
[5] Energy NanoEngineering Laboratory, National Institute of Advanced Industrial Science and Technology (AIST)
[6] Maryland NanoCenter, University of Maryland
E-mail: daichi.kozawa@riken.jp

High quality carbon nanotubes such as an air-suspended will lead to improve single photon properties. Air-suspended SWCNTs are an ideal platform as a single photon emitter because they exhibit brighter photoluminescence than liquid-dispersed SWCNTs [1,2]. Such SWCNTs keep their length and pristine surface, which leads to suppress end quenching often observed in liquid-dispersed SWCNTs [3]. Introducing color centers, however, requires to disperse SWCNTs in solution [4–7]. This process results in contaminating tube surface and quenching photoluminescence due to an interaction between SWCNTs and surrounding environments [8]. Air-suspended SWCNTs are ideal as a host of color centers, but directly immersing air-suspended SWCNTs in water inevitably destroys the suspended structures due to the high surface tension of the solvent. To use the excellent optical properties of the air-suspended carbon nanotubes with color centers, an intelligent design of chemical reaction is required without compromising the air-suspended structure.

In this presentation, we propose a vapor-phase reaction in air-suspended SWCNTs, where adsorbing precursor vapor with a weak mechanical perturbation preserves the suspended structures [9]. We present the formation of color centers in air-suspended SWCNTs using the vapor-phase reaction and evaluate the photoluminescence properties of the functionalized SWCNTs. We use confocal spectroscopy to measure photoluminescence spectra and time-resolved photoluminescence, focusing at individual carbon nanotubes. We build a theoretical model considering the strain along the curvature of SWCNT and relate diameter-dependent photoluminescence properties to the chemical reactivity. We also describe the diameter dependence of trapping potential at the sp^3 defect by statistically analyzing emission energies. We estimate formed defect density from the change in photoluminescence intensity by the functionalization.

Acknowledgments

This work was supported in part by RIKEN (Special Postdoctoral Researcher Program), MIC (SCOPE 191503001), JSPS (KAKENHI JP15H05760, JP18H05329, JP20K15112, JP20K15137, JP20H02558), and MEXT (Nanotechnology Platform JPMXP09F19UT0077). We thank the Advanced Manufacturing Support Team at RIKEN for technical assistance.

References

[1] S. Moritsubo, T. Murai, T. Shimada, Y. Murakami, S. Chiashi, S. Maruyama, and Y. K. Kato, Phys. Rev. Lett. **104**, 1 (2010).
[2] A. Ishii, M. Yoshida, and Y. K. Kato, Phys. Rev. B **91**, 125427 (2015).
[3] N. Danné, M. Kim, A. G. Godin, H. Kwon, Z. Gao, X. Wu, N. F. Hartmann, S. K. Doorn, B. Lounis, Y. Wang, and L. Cognet, ACS Nano **12**, 6059 (2018).
[4] M. Kim, X. Wu, G. Ao, X. He, H. Kwon, N. F. Hartmann, M. Zheng, S. K. Doorn, and Y. Wang, Chem **4**, 2180 (2018).
[5] B. J. Gifford, X. He, M. Kim, H. Kwon, A. Saha, A. E. Sifain, Y. Wang, H. Htoon, S. Kilina, S. K. Doorn, and S. Tretiak, Chem. Mater. **31**, 6950 (2019).
[6] X. Wu, M. Kim, H. Kwon, and Y. Wang, Angew. Chemie Int. Ed. **57**, 648 (2018).
[7] H. Kwon, A. Furmanchuk, M. Kim, B. Meany, Y. Guo, G. C. Schatz, and Y. Wang, J. Am. Chem. Soc. **138**, 6878 (2016).
[8] J. Lefebvre, Y. Homma, and P. Finnie, Phys. Rev. Lett. **90**, 4 (2003).
[9] D. Kozawa, X. Wu, A. Ishii, J. Fortner, K. Otsuka, R. Xiang, T. Inoue, S. Maruyama, Y-H. Wang, Y. K. Kato, in preparation.