Carbon nanotubes and graphenes for building blocks of nanodevices

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Single-wall carbon nanotubes (SWCNTs) and graphenes are grown in a self-assembled manner, and are composed by carbon. The various nanodevices could be realized with these materials due to their unique structural and physical properties. For example, they are suitable for spin-based quantum bit (qubit) with long spin coherence due to small spin orbit interaction and a natural abundance of nuclear spins in the host atom. The talk covers the following topics below.

1) Artificial atom behaviors of the SWCNT quantum dot [1-3]

It is shown that the electrons confined in the SWCNT behave those confined in the one-dimensional hard-wall potential. This makes the degeneracy of the quantum states, independent on the number of electrons or the quantum numbers. In the SWCNT quantum dots, the four or two electron shell structures are observed even with many electrons in the dot. The energy scales associated with the dot fall in a THz range, which is demonstrated by the THz photon assisted tunneling in the SWCNT single quantum dot.

2) Chemical modification of SWCNTs and their molecular scale nanostructures

Two examples of SWCNT-based molecular scale nanostructures are shown. The ring structures were fabricated with both SWCNT ends connected chemically. The scanning tunneling spectroscopy (STS) revealed a standing-wave pattern along the ring at a liquid nitrogen temperature, indicating the ballistic nature of the ring. Another example is SWCNT/molecule heterostructures. The STS study has made it possible to study the density of states and the confinement potential of a SWCNT terminated by molecules at both ends.

3) Coupled quantum dots with graphenes [4]

Graphenes quantum dots are attractive for building blocks of the spin qubit. The coupled quantum dots are basic structures for the spin qubit with a readout mechanism due to the spin blockade mechanism. The dots are formed by etching the triple-layer graphenes into the coupled dot patterns with narrow constrictions for the barriers. The coupled-dot formation has been confirmed by the charge stability diagram of the double dots.

References

[1] K. Ishibashi, S. Moriyama, D. Tsuya, T. Fuse, M. Suzuki, “Quantum-Dot Nanodevices with Carbon Nanotubes”, J. Vac. Sci. Technol. A**24** (4), 1349 (2006)
[2] S. Moriyama, T. Fuse, M. Suzuki, Y. Aoyagi, K. Ishibashi , “Four-electron shell structures and an interacting two-electron system in carbon nanotube quantum dots”, Phys. Rev. Lett. **94**, 186806 (2005)
[3] Y. Kawano, T. Fuse, S. Toyokawa, T. Uchida, K. Ishibashi, “Terahertz photon-assisted tunneling in carbon nanotube quantum dots”, J. Appl. Phys. **103**, 034307 (2008)
[4] S. Moriyama, D. Tsuya, E. Watanabe, S. Uji, M. Shimizu, T. Mori, T. Yamaguchi, and K. Ishibashi, “Coupled quantum dots in a graphene-based two-dimensional semimetal”, Nano Lett. **9**, 2891-2896 (2009)