# Carbon nanotube nanostructures with molecular heterojunctions

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The single-wall carbon nanotube (SWCNT) is an attractive building block for small quantum nanodevices because of its extremely small diameter. Until now, the single quantum dots have been realized simply by depositing metallic contacts on top of the individual SWCNT. In this case, the Schottky barriers are likely formed at the SWCNT/metal interfaces, which work as tunnel barriers to confine electrons in between the contacts. Interesting artificial atom behaviors have been observed [1], which has shown the SWCNTs are suitable for quantum nanodevices, such as quantum bits (qubits) and single electron devices [2]. Larger energy scales associated with the quantum dot could make it possible to achieve a robust (higher temperature) operation of the quantum-dot devices and higher-frequency quantum response even in a range of THz [3]. However, it is not always easy, in practice, to fabricate reliable and reproducible single quantum dots because of difficulties in the device fabrication process in which the standard semiconductor processing techniques are simply applied to the SWCNT. Besides, the present processes are not applicable to fabricate complex nanostructures based on the SWCNTs. Unique processes to the SWCNT need to be developed. We use SWCNT/Molecule heterojunctions to fabricate the complex quantum nanostructures based on SWCNTs. The edges of the SWCNT are easily modified in acid to put –COOH groups which can be used to connect with collagen model peptide molecules that are also modified with a same chemical group. All the processes are carried out in liquid, and structures are dispersed on a substrate for further characterization and device fabrications. In this presentation, we are going to show two examples of nanostructures for the quantum effect study and devices.

## 1. Exciton emission and its coherent control in a SWCNT single quantum dot

We have succeeded in obtaining photoluminescence from the individual SWCNT quantum dot, a finite length (~100nm) SWCNT with both ends terminated by molecules. The density of states along the SWCNT was measured with the scanning tunneling spectroscopy (STS) method, and discrete energy levels with excited states were identified. The photoluminescence excitation spectroscopy was carried out for the single SWCNT quantum dot, and the luminescence between the discrete levels was observed. When the excitation energy was set to the ground state transition, the emission peak splitted as the excitation power was increased. This is the Rabi splitting. In the weak excitation regime, the exciton interference was observed in the pump-probe measurements at liquid helium temperatures. The oscillations persisted over 1ns, which is longer than the measurement done in the InGaAs self-assemble quantum dot. An indication of the Rabi oscillation was observed in stronger excitation conditions. The experimental observation indicates that the excitons in the SWCNT quantum dot are attractive for their coherent control or exciton quantum bits (qubits).

## 2. Ballistic electron wave interference in individual SWCNT rings

SWCNTs are also interesting in term of electron wave interference study and related devices because they show one-dimensional and ballistic transport. We have fabricated individual SWCNT rings by chemically connecting both ends of the SWCNT. Standing wave patterns were observed in the scanning tunneling microscope (STM) images at liquid Nitrogen temperatures, and their wavelengths changed as the tip voltage was changed. This indicates that the standing wave can be built when the injected electron energy (wave length) meets boundary condition set by the ring where the bonding part is likely to work as a pinning center. We have also fabricated metallic contacts to the ring and observed Aharanov-Bohm (AB) conductance oscillations as the magnetic field was swept. The remarkable observation was that the amplitude of the oscillations was as large as ~80%, much larger than the AB oscillations which have been observed in a diffusive metal. The huge oscillations were observed up to ~10K, showing the long coherence in the SWCNT.

## References

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