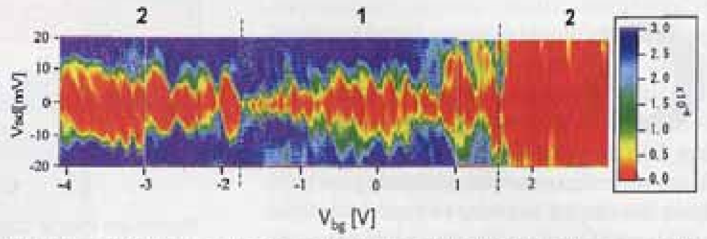
Dawn of the Carbon Device Era

Carbon nanotube devices are another step closer to realization following research in Japan that will enable manufacturers to design and fabricate single-electron transistors. **Chris A. Pomeroy** reports.



Coulomb diamonds observed in a carbon nanoscale peapod quantum dot at *T*=1.5 K. The *z* axis is the differential conductance, the magnitudes of which are indicated on the right side. Dotted lines at V_{bg}= ± 1.7 V indicate boundaries for two different V_{bg} regions for small and large diamonds.

Researchers working under the auspices of the Japan Science and Technology Agency (JST) have succeeded in the injection of single electrons (Coulomb diamonds) into carbon nanoscale peapod quantum dots. Professor Haruyama Junji, chief of the Aoyama-Gakuin Group of the JST Core Research for Evolutional Science & Technology (CREST) Shinohara Team, reported the phenomenon for the dots as encapsulated in a series of C_{60} molecules—forming a structure that looks like a "peapod"—and this is seen leading the way to realization of carbon nanotube (CNT) devices.

The physicists had succeeded in single-electron injection into a carbon nanopeapod quantum dot, encapsulating a series of fullerenes into the inner space within a singled-walled CNT, and found that the individual fullerenes could act as individual quantum dots for single electron confinement by tuning back-gate voltages. With this, the measurement of interaction on ament by tuning back-gate voltages. With this, the measurement of interaction on a single fullerene regime by utilizing CNT as a cavity was made possible. The finding and measurement techniques related thereto will enable manufacturers to design and fabricate single-electron (spin) memory devices using molecules confined in the inner space of CNT.

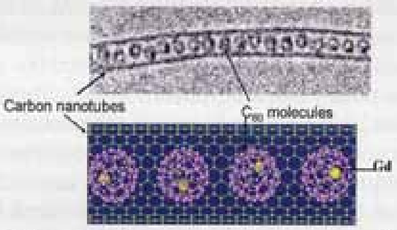
These molecular memories, next-generation devices that consume much less power since they can control flow at the single-electron level rather than requiring a large amount of electrons, may thus herald the dawning of the "Carbon Device Era" wherein nanoelectronics has become commonplace, said Dr. Awano Yuji of Fujitsu who is collaborating with Professor Haruyama. The Shinohara Team under which the Aoyama-Gakuin group is attached is supervised by Nagoya University Professor Shinohara Hisanori, and has brought together researchers from companies in the private sector such as Fujitsu and the Toray group with academics from both public and private universities.

One of the goals of the current research being conducted by the Shinohara Team is realization of the field-effect transistor (FET), which is a type of transistor that relies on an electric field in order to control the shape and with this the conductivity of the "channel" within a semiconductor material. Professor Shinohara, a leading light in terms of research on fullerenes and nanotubes, is the namesake of the nanotube-focused team. Fujitsu, as the main Japanese semiconductor manufacturer involved in this team, is looking to apply the findings and measurements made by the Aoyama-Gakuin Group to enable manufacturing of the FET and nano-electronics devices.

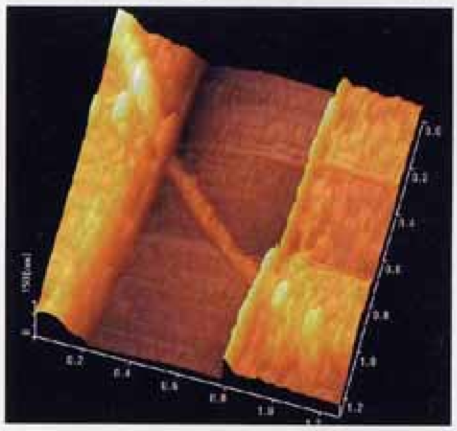
According to Professor Haruyama, it was found that behaviors of the "Coulomb diamonds" representing the charging effect of single electrons are anomalously sensitive to back-gate voltages (V_{bg}), exhibiting two evidently different V_{bg} regions and a large polarity on V_{bg}. The sizes of the diamonds indicate that at low V_{bg}, single electrons are injected on doubly degenerated electron orbitals in the CNT, while single electrons are injected into the individual fullerenes encapsulated in the inner space of the CNT by applying high V_{bg}. Attached to the campus in Kanagawa, the professor has in other research also shown that "entirely end-bonded" multi-walled carbon nanotubes can superconduct at temperatures as high as 12 K, which is a world-highest record and thirty times greater than for single-walled CNTs, as if to back up Dr. Awano's vision for tomorrow.

Part of the "diamond" finding, which additionally highlighted that there is dependence upon the magnetic field, indicates the shell being filled (shell filling) by spin singlet and doubly degenerating the electronic levels thereof. The encapsulated C_{60} molecules indirectly affect this shell filling at low V_{bg} possibly via nearly free electrons. Moreover, it was reported that specified electron correlation in one-dimensional space (the so-called Tomonaga Luttinger liquid) can be observed on the interaction between this shell filling and free spins injected from the electrode. In contrast, they act as individual quantum dots coupled in series within the high V_{bg} region as mentioned above. Said behavior directly contributes to the major overlapping leading to creation of very large diamonds.

Carbon Nano-peapod



TEM image of a carbon nano-peapod encapsulating C_{60} and Gd



AFM image of a bundle of CN peapods placed between source and drain electrodes of the FET

Chris A. Pomeroy is a journalist and columnist specializing in science and technology.