Department of Mechanical Engineering	Key words	Nanocarbon, Nanometer-sized materials, Transmission electron microscopy, *In-situ* observation, Solid State Physics, Material properties

Doctor of Engineering / Professor

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Education

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Professional Background

FUJITSU LABORATORIES LTD., Research associate, University of Tsukuba, Lecturer, Nagoya University, Gastprofessor, ETH Zürich, Professor, Fukui University of Technology

Consultations, Lectures, and Collaborative Research Themes

Nanocarbon, Nanometer-sized materials, Analysis /evaluation by electron microscopy, *In-situ* transmission electron microscopy

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Main research themes and their characteristics

Nanocarbon is known as nanometer-sized carbon allotropes, including fullerene, carbon nanotube, graphene, carbyne, and so on. Theoretical studies on nanocarbon have predicted outstanding mechanical, thermal, and electrical properties. In order to apply their properties in nanotechnology and nanoscience, the structures and properties of nanocarbon are experimentally studied by *in-situ* transmission electron microscopy (TEM). *In-situ* TEM throws a new light on the experimental approach to investigate the electrical, mechanical, and optical properties of individual nanocarbon.

「Nanowelding of a Carbon Nanotube to Metal Surface and Measurement of its Electron Field Emission」

A multi-walled carbon nanotube (MWNT) was manipulated in a transmission electron microscope combined with a nanomanipulator, and an MWNT emitter freestanding on a platinum (Pt) surface was fabricated by nanowelding. Figures 1(a)-1(c) show a time-sequential series of high-resolution images of a nanowelding procedure of the MWNT to the Pt surface. In Fig. 1(a), the dark regions at top and bottom show the Pt surface and a Pt particle encapsulated in the MWNT, respectively. The application of voltage to the MWNT brought about a migration of the Pt particle toward the Pt surface with dissolving graphite layers surrounding the Pt particle, as seen in Fig. 1(b). Finally, the Pt particle was bonded to the Pt surface, as shown in Fig. 1(c). Noted that each layer composing the MWNT is directly connected to the Pt particle as indicated by arrows in Fig. 1(c), suggesting that an Ohmic contact forms at the junction between the MWNT and the Pt particle. The MWNT emitter was fabricated by retracting the support plate, as shown in Fig. 1(d). Figure 1(e) shows current-voltage curves measured during field emission from the MWNT emitter seen in Fig. 1(d) at various tip-anode distances in a range from 27 to 442 nm. The Fowler-Nordheim analysis for Fig. 1(e) provided that the field enhancement factor increased with increasing the distance between the MWNT tip and the anode. The present study showed that the freestanding MWNT welded to metal surfaces is the promising single electron emitter for vacuum nanometer-sized electronic devices.

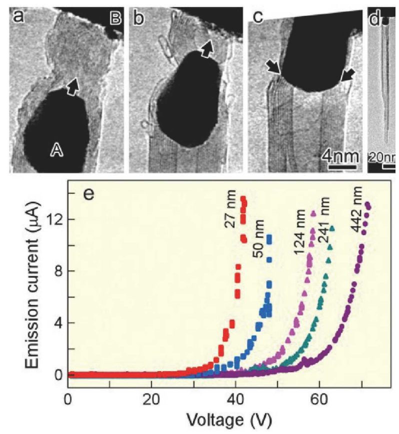

Fig.1 (a)-(c) Time-sequential series of high-resolution images of a nanowelding procedure of an MWNT to a Pt surface (d) Low magnification image of a fabricated MWNT emitter. (e) Current-voltage curves measured during electron field emission from the MWNT of (d).

「Mechanical and Electrical Properties of a Carbon Nanocapsule」

A multi-walled carbon nanocapsule (NC) was compressed by manipulation in a transmission electron microscope, and the structural dynamics were observed *in-situ* with simultaneous measurement of the sub-nanonewton forces acting on the NC. The NC completely dented under a load of 4.6 nN exerted by a nanomanipulator, and recovered to its original shape when the nanomanipulator was retracted. The observations showed that the NC possesses a high toughness for compression. Meanwhile, electrical properties of the NC were studied by *in-situ* TEM. Figures 2(a)-2(c) show a time-sequential series of high-resolution images of a NC junction sandwiching between two gold electrodes at a cycle of contact and separation. Figure 2(d) shows a current-voltage curve for the NC measured at the state observed in Fig. 2(c). The differential conductance of the junction at bias voltages from 0 to 0.20 V corresponded to half of quantized conductance, i.e., 0.5 G_0 where $G_0=2e^2/h$ is the conductance quantum, e is the electron charge, and h is Planck's constant. The present study showed that the NC is quantized metallic conductors and can be utilized for various components for carbon device technologies.

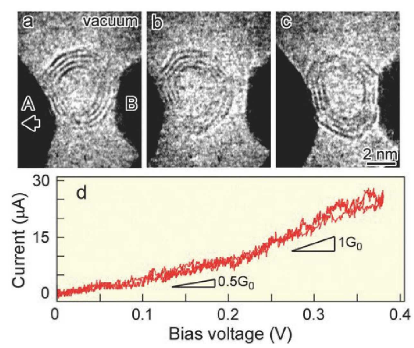

Fig.2 (a)-(c) Time-sequential series of high-resolution images of a NC junction in the cycle of contact and separation. The regions A and B are gold electrodes. (d) Current-voltage curve for the NC junction seen in (c).

Major academic publications

K. Asaka, K. Nishikawa, Y. Saito, Light emission and structural changes in a suspended multiwall carbon nanotube on application of electric current, Diamond and Related Materials, 111, 108175 (2021).

K. Asaka, T. Nakayama, K. Miyazawa, Y. Saito, Structures and field emission properties of heat-treated C_{60} fullerene nanowhiskers, Carbon, 50, 1209-1215 (2012).

K. Asaka, H. Nakahara, Y. Saito, Nanowelding of a multiwalled carbon nanotube to metal surface and its electron field emission properties, Applied Physics Letters, 92, 023114-1-3 (2008).

K. Asaka, T. Kizuka, Atomistic dynamics of deformation, fracture, and joining of individual single-walled carbon nanotubes, Physical Review B, 72, 115431-1-5 (2005).