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報 告 番 号	※ 甲　　第　　　　号

主　論　文　の　要　旨

論 文 題 目　Synthesis and Characterization of Flattened CNTs and Graphene Nanoribbons and the FET-Device Fabrication
(平坦化カーボンナノチューブおよびグラフェンナノリボンの合成および評価と FET デバイス作製)

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論　文　内　容　の　要　旨

Size and shape can strongly affect the properties of nanomaterials. It was found that reduction of graphene width down to several tens of nanometers by the fabrication of graphene nanoribbons (GNRs) can open the bandgap of graphene. The development of simple, low-cost mass-produced GNRs is highly necessary for the application of graphene in nanoelectronic devices. For this purpose, a mass production method of GNR analogs, fully flattened carbon nanotubes (FNTs), has been developed. In this method, solution-based extraction of large-diameter carbon nanotubes (CNTs) from multi-wall CNTs was used to produce FNTs, which were formed by spontaneous collapsing of large-diameter (most outer) CNTs. FNTs can be obtained on a bulk scale with a high yield, and the structure and surface morphology of FNTs were fully investigated. We also observed the opening of bandgaps at room temperature and the appearance of subbands in the electronic structure of FNT at 9 K.

FNTs possess a unique low-dimensional inner space with a barbell-like cross section that is expressively different from cylindrical inner space of CNTs. This new kind of inner space enables the alignment of atoms or molecules not only in one-dimensional fashion but also in two-dimensional fashion, producing a brand new class of FNT-based hybrid nanostructures: FNT peapods. The synthesis of FNT-based C_{60} nanopeapods, C_{60}@FNTs, and transmission electron microscopy (TEM)-based structural characterization of a low-dimensional array of C_{60} were performed with consistent images simulation on the basis of the multi-slice method. The structure of this brand new class of nanocarbon materials is quite interesting and fully-characterized with TEM observations. Furthermore, the proposed findings indicate that varieties of atoms and molecules can be intercalated in FNTs, providing the potential of preparing a new class of novel hybrid materials based on FNTs with promising properties.

The combination of precise structural characterization and electronic property measurement is essential for complete understanding of the intrinsic properties of GNRs. New experimental techniques for the fabrication of freestanding GNR devices have been developed, leading to the simultaneous characterization of GNRs' electronic properties and atomic structure. The freestanding devices were assembled in our home-developed TEM holder for in-situ characterization, including Joule heating to purify the graphene and electronic measurements. Using electron beam sculpting and Joule heating in TEM, ~ 10 nm wide GNR structures can be obtained. During the narrowing process, the conductance of GNRs behaved nonlinearly as a function of width, indicating the opening of the bandgap. The observed transport gap of 400 meV is the largest among GNRs measured through transport measurements, and this method can be used to study the intrinsic electronic properties of GNRs. The presented methodology could be used in the future to correlate the electronic properties with a known structure in two dimensional materials such as transition metal dichalcogenides.