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Formation and Deformation of Multiwall Carbon Nanotubes in Arc Discharge

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Running arcs under both vacuum and low pressure and a jumping arc under vacuum were generated with a pure graphite cathode for 1–3 s upon applying a magnetic field. For the running arcs under both vacuum and low pressure, multiwall carbon nanotubes (MWNTs) were observed only at the cathode spot craters where the arcs were extinguished by switching the power off. At the crater where the cathode spot had run over, nanotubes were hardly observed. For the jumping arc in vacuum that was self-extinguished, only a few nanotubes were observed at the cathode spot craters. No nanotubes were observed on the surface outside the cathode spot crater for all arcs. These results revealed that the nanotubes are formed, as well as destroyed, by the cathode spot. The process of nanotube formation and deformation is discussed, taking into account the cathode spot activity and electron emission.
KEYWORDS: multiwall carbon nanotubes, running arc, jumping arc, magnetic field, formation process

1. Introduction

The investigation of the growth mechanism of carbon nanotubes focuses a significant amount of attention on the chemical point of view, since the nanotube has a unique structure and growth control must be achieved. On the other hand, the fact that multiwall carbon nanotubes (MWNTs) are formed on a graphite (C) cathode surface with electric arc discharge is of essential importance with regard to the physics of arc plasma electric discharge. The authors were the first to reveal that MWNTs are observed only at the cathode spot crater of the graphite cathode in a low-pressure arc with a C-molybdenum (Mo) heteroelectrode system.[1] This result indicates that the MWNTs are produced by the cathode spot of graphite. Then, they employed a cathodic vacuum arc with a graphite cathode and an inert anode.[2] The MWNTs have likewise been observed at the C-cathode spot crater. This is further evidence that the graphite cathode spot essentially produces the MWNTs. Moreover, the potential of the use of the cathodic vacuum arc for preparing fine particles covered with nanotubes, like sea urchins, and for depositing diamond-like carbon thin film with embedded nanotubes, was presented.[2]

In the present study, in order to reveal when and where the MWNTs are formed, new experiments were conducted. The cathode spot on graphite in vacuum and under low pressure was intentionally driven by applying an external magnetic field. Then, the cathode surface was microscopically observed. Based on the experimental results, the formation and deformation processes of MWNTs in arc discharges with a graphite cathode were considered.

2. Experimental

The apparatus of a running arc in vacuum (cathodic running arc) is depicted in Fig. 1(a). The term running arc implies that the cathode spot is driven by a magnetic field and the cathode spot creates a continuous crater on the cathode surface. The graphite cathode (approximately 10 mm wide, 15 mm long, 1 mm thick; purity 99.998%) was placed in a cylindrical vacuum chamber (SUS304; 300 mm long, 200 mm diameter). The chamber acted as the anode. Two permanent-magnet plates were placed on both sides of the cathode in order to apply a parallel magnetic field on the cathode surface. The arc was ignited by a mechanical triggering system with a Mo trigger electrode (3 mm diameter). When the trigger electrode was brought into contact with the cathode and withdrawn, an electric spark was ignited between the cathode and the trigger electrode. This spark induced the cathodic arc between the cathode and the anode. After the desired discharge period, the arc was extinguished by switching off the power supply. The experimental conditions were as follows: arc current I, dc 50 A; base pressure, 0.005 Pa; helium (He) gas pressure, 0.5 Pa; magnetic flux density at the center of the cathode B, approximately 4 mT; discharge time, 1–2 s. The cathode spot motion was observed using an 8-mm video camera.

The apparatus of a low-pressure running arc is depicted in Fig. 1(b). The graphite plate (approximately 10 mm wide,

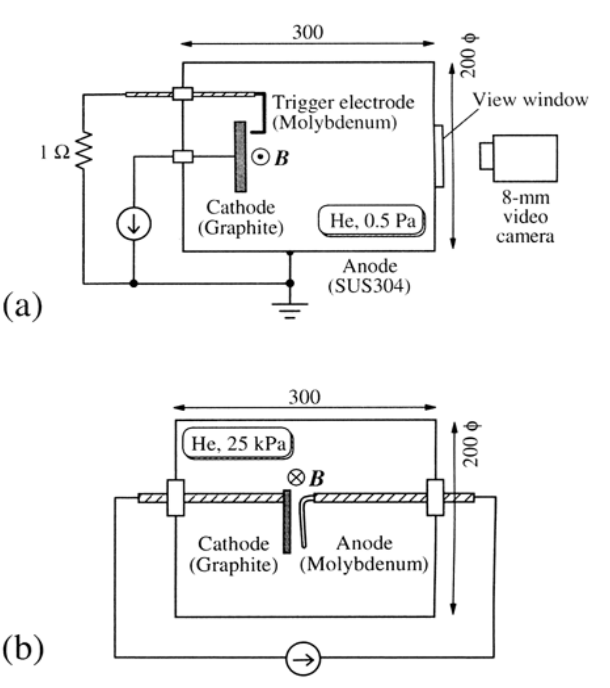

Fig. 1. Schematic diagrams of arcs under applied magnetic field. (a) Cathodic vacuum arc with C cathode and inert anode. (b) Low-pressure arc with heteroelectrode system (C cathode and Mo anode). B denotes magnetic flux density.