Transactions of the Materials Research Society of Japan 25 [3] 873-876 (2000)

Carbon Nanotube Growth at Cathode Spot in Vacuum Arc

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Multi-wall carbon nanotubes were fabricated in cathodic vacuum arc, in which the pure graphite was used as a cathode and stainless-steel vacuum chamber was used as an anode. First, the arc with a constant current of 50 A was ignited for approximately 0.8 s without magnetic field and the cathode spot motion was recorded by a video. After the discharge, the crater created by the cathode spot was microscopically observed. Numerous carbon nanotubes were observed at the position where the arc might be extinguished. Then the arc was ignited with an external magnetic field parallel to the cathode surface for approximately 1.6 s in order to drive the cathode spot to retrograde direction and to specify the extinguished position of the arc. Again numerous nanotubes were observed at the extinguished position. The nanotubes were hardly observed at other area. These results indicate that two different processes on the nanotube growth in cathodic vacuum arc can be possibly considered.

Keywords: multi-wall carbon nanotube, cathodic vacuum arc, cathode spot, magnetic field

1. INTRODUCTION

Since the carbon nanotube was found in the cathode deposit in arc discharge [1], numerous numbers of researches have been concentrated on the low-pressure arc with homoelectrode system, namely graphite (C) cathode and C anode [2], [3]. However, the formation mechanism of carbon nanotube in the carbon arc method is still unclear.

Recently, the authors have utilized the low-pressure arc with the heteroelectrode system, and shown that the multi-wall carbon nanotubes (MWNT) were synthesized by the cathode spot and that anodic phenomena is not essential to produce MWNT in carbon arc method [4]. Consequently they have employed the cathodic vacuum arc, in which the anode is inert, and it has been found that the cathodic vacuum arc also produces MWNT at the crater that produced by the cathode spot [5], [6]. Moreover, potential of the cathodic arc to produce the macrodroplets having nanotubes, called nanotube sea urchin, and diamond-like carbon (DLC) film embedding MWNT were demonstrated [6]. However, in the previous studies, they have not paid attention on the cathode spot movement.

In the present study, first, the crater produced by the cathode spot in a vacuum arc without magnetic field was more carefully observed than previously. Then the cathode spot crater was created when the magnetic field parallel to the cathode surface was applied in order to drive the cathode spot and to specify the crater site. From these experiments, the position and timing of MWNT growth were identified.

2. EXPERIMENTAL

Experimental setup is shown in Fig.1. A cathode of pure graphite plate (approximately, 10 mm × 15 mm, 1 mm thick) was placed in the cylindrical vacuum chamber (200 mm in diameter, 300 mm in length), which was made of stainless steel (SUS304) and used as an anode. Two permanent magnet plates sandwiched the cathode plate in order to apply the magnetic field parallel to the cathode surface. The chamber was once evacuated down to 0.01 Pa by a turbomolecular and rotary pump, and then helium (He) gas was filled until the pressure became 0.5 Pa. The arc was ignited using a mechanical