Effects of Dielectric Barrier Discharge Treatment Conditions on the Uprightness of Carbon Nanofibers

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***Abstract*—Dielectric barrier discharge (DBD) treatment is one of the methods used to make carbon nanofibers stand up on substrates. Upright carbon nanofibers are used as field emission materials. We have used twisted carbon nanofibers (CNTws) as field emission materials and treated printed CNTws on substrates using DBD. In this report, we examine the effects of DBD conditions on the uprightness of the CNTws. The DBD experimental parameters were as follows: 1) N_2/He gas mixture ratio, 2) pulse frequency, and 3) Pt coating on the CNTw surface. The lengths of upright CNTws from the substrate surface and from the surface of a printed CNTw dot were measured using scanning electron microscopy. N_2 gas was shown to be crucial for generating streamer discharges and making the CNTw stand up on the substrate. As the pulse frequency increased, the lengths of the upright CNTws and their number density increased. This is explained by an increase in the number of streamers; the streamers move about over the substrate surface. Pt coating lowered the onset voltage for field emission from the CNTws although the number of upright CNTws was less than that without the Pt coating.**

***Index Terms*—Dielectric barrier discharge (DBD), field emission, helical carbon nanofiber, metal coating, uprightness.**

I. Introduction

DIELECTRIC barrier discharge (DBD) is a type of atmospheric pressure plasma and can be used to treat large areas [1]–[8]. Two different modes of DBD have been confirmed. In "glow mode," the electric field between the electrodes is almost uniform. "Filamentary mode" consists of many short-lived streamers between the electrodes, and the streamers have a strong and nonuniform electric field at their head [1], [9]. DBD is used in many applications, including ozone generation, deposition of thin films, and sterilization of biological samples [9].

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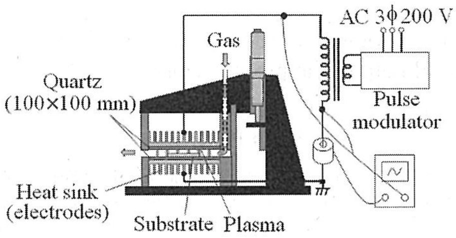

Fig. 1. Dielectric barrier discharge apparatus.

We have developed another application of DBD: making nanofibers stand up. We have found that a nanofiber lying on a substrate could be made to stand up perpendicular to the substrate [1], [2]. This is attractive for field emitters (FEs). Carbon nanomaterials, including nanotubes (CNTs) [10], [11], graphene [12], [13] and nanotwists (CNTws) [1], [2], [14], have been used as field emission materials. A CNTw is a double helix of carbon nanofibers and does not have an inner diameter. The diameter of a CNTw is about ten times that of a multiwalled CNT. A CNTw is expected to have high resistance against ion bombardment and a long lifetime because of its large thickness. In our laboratory, CNTws can be grown at a production yield of $\sim$2 g/h using a Ni/Sn binary catalyst and C_2H_2/N_2 gas mixture [14]. This is suitable for making CNTw pastes and screen-printing on substrates in industrial FE fabrication. The DBD treatment for making CNTws stand up is a noncontact method and capable of changing its area freely, unlike tape treatments [1], [15], [16]. However, the mechanism of achieving CNTw uprightness on a substrate is still under consideration. In this paper, we try to determine the relation between CNTw uprightness and the DBD experimental conditions.

The experimental conditions examined were as follows: 1) N_2/He gas mixture ratio, 2) pulse frequency, and 3) Pt coating on CNTw surface. The experimental purpose of each condition was as follows: 1) observation of the changes in the state of upright CNTws between "glow mode" and "filamentary mode" [17], 2) effect of pulse frequency on plasma state, and 3) effect of metal coating. The lengths and number densities of the upright CNTws were evaluated by scanning electron microscopy (SEM).

II. Experimental Methods

A. Synthesis of CNTws

CNTws were synthesized by catalytic chemical vapor deposition (CVD). Briefly, Ni and Sn liquid catalysts (Kojundo Chemical Laboratory, Saitama, Japan) were dropped on a graphite