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Synthesis of fullerenes from carbon powder by using high power induction thermal plasma

C. Wang*[,a], T. Imahori[a], Y. Tanaka[a], T. Sakuta[a], H. Takikawa[b], H. Matsuo[c]

[a] *Department of Electrical and Electronic Engineering, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan*
[b] *Department of Electrical and Electronic Engineering, Toyohashi University of Technology, Toyohashi, Aichi, 441-8580, Japan*
[c] *Department of Electrical and Electronic Engineering, Shizuoka University, 3-5-1 Jouhoku, Hamamatsu, Shizuoka, 432-8561, Japan*

Abstract

Radio frequency (rf) inductively coupled thermal plasma (ICTP) was used to fabricate fullerenes (C_{60},C_{70}, etc.) by direct evaporation of carbon powder injected into the plasma. Spectroscopic observation of the plasma was made for molecular band spectra of C_2 and atomic lines of C. The formation of fullerenes C_{60} and C_{70} as well as higher fullerenes were checked and recognized by high performance liquid chromatography (HPLC) and time-of-flight mass spectrometer (TFMS). The suitable conditions for the synthesis of fullerenes within the experimental conditions adopted were 10-kPa plasma pressure, with a considerably higher flow rate of approximately 150 l/min for mixed-gas condition of Ar, He and CO_2, with carbon powder of average diameter 20 μm. The results showed that the productivity of fullerenes has a relation to the intensity of C_2 molecular and C atomic spectra from the induction plasma. Mixing of Si with C particles has a kind of role in enhancing the synthesis rate of fullerenes C_{60}, as well as the higher order fullerenes.

Keywords: Inductively coupled thermal plasma; Fullerenes; Carbon; Silicon

1. Introduction

Since the macroscopic properties of C_{60}, formed in a low-pressure carbon arc, were discovered by Kratschmer [1], several experiments have been carried out for synthesis of C_{60} [1–3]. Smalley et al. produced fullerenes in a carbon electrode arc in the pressure range of 0.01–0.1 MPa [4]. Peters reported that fullerenes could be produced by induction heating of a graphite rod in helium gas circumstances [5]. Yoshida et al. reported a novel method for C_{60} synthesis by using a hybrid plasma [6], which consisted of dc plasma and rf plasma at atmospheric pressure, and indicated that fullerenes could be formed in such high temperature thermal plasma conditions from injected carbon powder in pure argon gas [7].

In this paper, an attempt was made to use rf-ICTP for the production of fullerenes, under several gaseous conditions of Ar, CO_2 and He, which were found to be adequate gases for fullerene synthesis in a conventional arc discharge method [8]. The wide and high temperature field in the rf thermal plasma is adequate for fast evaporation of cold powder injected into it, and then a relatively low temperature field of approximately several thousand Kelvin in the downstream portion of the plasma is effective for a high rate quenching of atomic and molecular particles into fullerenes. As the high temperature zone is very wide, and carbon powders are continuously injected into the torch, high rate synthesis of fullerenes could be expected. Spectroscopic observation of the plasma was made for molecular band spectra of C_2 as well as for the C atomic lines. This is because the intensities of C_2 molecular lines were quite strong in the usual operating condition, together with that of C atomic lines, in a conventional vacuum arc method [9,10]. Another trial here is to introduce

* Corresponding author. Tel.: +81-76-234-4845; fax: +81-76-234-4846.
E-mail address: 4128wang@ec.t.kanazawa-u.ac.jp (C. Wang).

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