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Epitaxial growth of anthracene single crystals on graphite (0 0 0 1) substrate with physical vapor growth technique

Sadaharu Jo, Hitoshi Yoshikawa, Akane Fujii, Mitsuru Takenaga *

Department of Materials Science and Environmental Engineering, Tokyo University of Science, Yamaguchi, 1-1-1 Daigaku-Dori, Onoda, Yamaguchi 756-0884, Japan

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Abstract

The epitaxial growth of an anthracene/graphite (0 0 0 1) system was performed using the physical vapor growth technique. Most anthracene single crystals had the clear tendency to form the epitaxial orientation relationships $[0\,1\,0]_{anthracene}//[2\,\bar{1}\,\bar{1}\,0]$, $[\bar{1}\,2\,\bar{1}\,0]$, or $[1\,1\,\bar{2}\,0]_{graphite}$, $(1\,0\,0)_{anthracene}//(0\,0\,0\,1)_{graphite}$, and a few, $(0\,0\,1)_{anthracene}//(0\,0\,0\,1)_{graphite}$. The layer structure of each (0 0 1) plane of an anthracene single crystal appeared on lateral planes with a high periodicity, which caused epitaxy with the highly periodic atomic arrangement of a graphite (0 0 0 1) substrate.

Keywords: Epitaxy; Growth; Interface state; Surface structure; Morphology; Roughness and topography; Graphite; Aromatics; Stepped single crystal surfaces; Metal–semiconductor interfaces

1. Introduction

In recent years, significant developments in the field of organic semiconductors have been conspicuous, such as light-emitting diodes, field-effect transistors, solar cells, and so forth [1–5]. Mainly, for developments of such advanced fields, considerable interest has been concentrated on deposited ultrathin films. However, high-quality single crystals have also attracted considerable attention from researchers in the construction of new organic devices. For the growth of organic single crystals, the melt growth technique is standard, but the physical vapor growth technique is also effective. Two types of systems are generally recognized, which are the perfectly sealed system and the opened system with carrier gases. Karl succeeded in the growth of 10-mm-sized anthracene single crystals using the latter type with carrier

* Corresponding author. Tel./fax: +81 836 88 4564.
E-mail address: taken@ed.yama.tus.ac.jp (M. Takenaga).

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gases [6]. Moreover, a horizontal arranged system had been performed by Laudise et al., and they succeeded in the growth of thiophene-oligomers, pentacene, tetracene, anthracene, and so forth [7]. The new physical vapor growth technique proposed by Kloc et al. [8] has several special features; 10-mm-sized crystals can be obtained using only 10–30 mg of the source material [8]. Moreover, the handling of samples is very easy for experimentalists, which is very important because the organic single crystals are so fragile that experimentalists must be cautious in handling the samples to prevent stresses, such as strains, defects, and deformations. Superpurification can be performed during the growth due to the differences in vapor pressures peculiar to each material.

Using the above-mentioned special features, we suggest the epitaxial growth of anthracene/graphite (0001) by the physical vapor growth technique with the horizontally arranged system. It is indeed confirmed that thin solid films with some periodic structures can be formed on a substrate using a high-vacuum system, but the physical vapor growth technique with the horizontally arranged system is also applicable for the achievement of quasi-statistical conditions for epitaxial growth. Moreover, using this technique, many epitaxially oriented single crystals can be easily obtained, called as epitaxial single crystals in this paper. This system enables the construction of all-organic semiconductor devices.

2. Experimental

A schematic drawing of the horizontally arranged system for the physical vapor growth is indicated in Fig. 1. A reaction tube, a crystal growth tube, a source boat, a resistance wire and a band heater were set for constructing the furnace. The lengths and diameters of the reaction tube and crystal growth tube are 500 and 30 mm, and 250 and 25 mm, respectively. Small tubes with a diameter of 5 mm were set at both edges of the reaction tube for inflow and outflow of carrier gases. The reaction tube was surrounded by the resistance wire at an equal distance, which maintained the desired temperature in the furnace. The band heater was placed at the boat to establish the temperature gradient for the source material. Temperature gradients for the physical vapor growth were provided by supplying some current to the resistance wire and the band heater. A newly cleaved graphite (0001) substrate was set at the crystal growth area. The graphite crystal of our use is a highly oriented pyrolytic graphite (HOPG) with a newly cleaved (0001) plane. The evaporation temperature was set at 100 °C and the growth time was set at 500 h. After the physical vapor growth, the substrate with anthracene single crystals was carefully removed from the furnace, and morphological and geometrical investigations were performed by optical microscopy and X-ray diffraction.

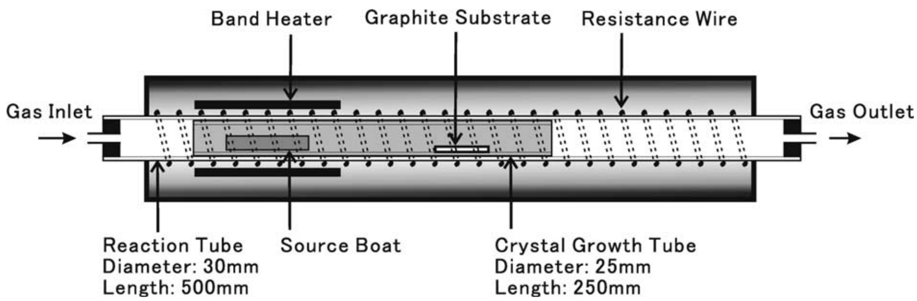

Fig. 1. Schematic drawing of our physical vapor growth apparatus. A reaction tube, a crystal growth tube, a source boat, a resistance wire and a band heater were set for constructing the furnace. The lengths and diameters of the reaction tube and crystal growth tube are 500 and 30 mm, and 250 and 25 mm, respectively. The reaction tube was surrounded by the resistance wire at an equal distance. The band heater was placed at the boat to establish the temperature gradient. A graphite substrate was set at the crystal growth area.