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Dependence on substrate topography of growth of nanosized dendritic structures in an electron-beam-induced deposition process

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Abstract

Nanometer-sized W-dendrites are fabricated on Al_2O_3 substrates with an electron-beam-induced deposition process. Dependence of growth of nanodendrite on surface topography is investigated with transmission electron microscopy. It is confirmed that the nanodendrite grows on convex surfaces but not around a hole on a substrate. These are attributed to different distribution of charges on surfaces with different topographies during electron beam irradiation when charges are produced on the surface due to emission of second electrons. The charges accumulate on convex surface and do not distribute around a hole. Therefore, the nanodendrite grows on the former and not on the latter.

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1. Introduction

Nanostructures, such as carbon nanowires, carbon nanotubes, fullerenes, etc., have been obtained much attention these years. Among methods for fabrication of nanostructures, electron- or ion-beam induced deposition (EBID or IBID) has attracted a great attention. In these methods, gaseous precursors containing elements to be deposited are decomposed by an energetic electron or ion beam in a vacuum chamber, the volatile part in the precursor is pumped out then the non-volatile part remains to form a deposit. Due to the controllability of the beam, zero, one, two, or three-dimensional small-sized objects can be fabricated [1–8]. Conductive substrates have been usually used for obtaining stable growth conditions in these fabrications. The resulted structures are generally compact ones. Recently, by using insulator substrates, W-nanosized branched structures, namely nanowires, nanodendrites

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and nanofractal-like trees, were fabricated with EBID using a precursor, tungsten hexacarbonyl ($W(CO)_6$) in a 200 kV transmission electron microscope (TEM) [9]. The growth of these structures is attributed to a charge-up, a movement and an accumulation of charges on surface. It is anticipated that surface topography of a substrate may influence the growth and the morphology of the grown nanostructure. The aim of the present work is to investigate the dependence of growth of nanobranched structures on topography of a substrate in order to understand the growth process more precisely.

2. Experiment

EBID is performed using TEM, JEM-2010F operated at 200 kV. The field emission gun of the TEM makes the intensity of the electron beam (EB) controllable in a wide range. The base pressure in column is lower than 2×10^{-5} Pa. $W(CO)_6$ powder was introduced into the TEM chamber as a precursor in a way described previously [7]. Crystalline Al_2O_3 thin film samples suitable for TEM observation were used as substrates. They were prepared from commercially obtained wafers by means of dimpling and Ar ion milling. Surfaces of the sample are mirror polished or mechanically polished followed by a 5 keV Ar ion milling. For a 5.5 keV Ar-ion-milled silicon wafer, protuberances on surface has been estimated less than 2 nm [10]. The protuberances on surface of the present sample may be in the same order. The fabricated structures were observed in situ or after the fabrication with a JEM-2010F TEM operated at 200 kV. All the experiments were performed at room temperature.

3. Results and discussions

The growth of nanobranched structures, nanowires, nanodendrites, or nanotrees, depends on intensity of EB in EBID [9]. Dendritic structures are fabricated using mediate EB intensity in the present work. Fig. 1 shows a micrograph of dendrite-like structures grown on an Al_2O_3 substrate in a current density of 3.2 A cm^{-2} (3.2 C cm^{-2} s^{-1}) for 30 s with an EB size of about 800 nm. The edge of the EB is indicated in the figure. The contrast inside the irradiated area is apparently dark. The size of dendrite-like structures is much smaller than the area of EB irradiation. The dendrite shows a tendency to grow at edge of the substrate with a convex surface. The dendrite becomes thinner as the position goes further from the surface of the substrate, which implies that as the dendrite grows longer, EB-induced deposition also takes place at the trunk part. The typical thickness of the tips is less than 3 nm [9]. It is noted that the EB used is defocused and has almost an even current density in the whole irradiated area. An intensity distribution of a defocused EB is shown in the insert, where the beam size is about 300 nm. The intensity distribution of EB in other size is also similar except it is focused. The microstructure and composition of the W-nanodendrites have been characterized elsewhere [9].

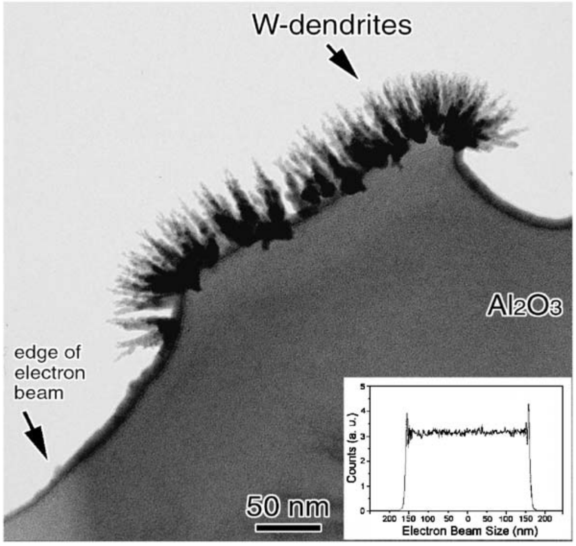

Fig. 1. Nanodendritic deposits grown on the surface of an Al_2O_3 substrate with electron-beam-induced deposition (EBID) with a current density about 3.2 A cm^{-2} for 30 s. Inset: a typical distribution of electron beam.

The fact that the nanodendrite tends to grow only on a part of the surface within the irradiated area indicates that the growth of the dendrite