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Control of growth mode in diamond (111) homoepitaxy by microwave plasma CVD
マイクロ波プラズマCVDによるダイヤモンド(111)ホモエピタキシーの成長モードの制御

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Crystal growth process of diamond (111) homoepitaxy by microwave plasma-enhanced chemical vapor deposition was investigated on characterizing areas by ex-situ atomic force microscopy. The evolution of surface morphology during the diamond homoepitaxy was visualized utilizing a mesa of mesa-structure-patterned surface as a marker. Depending on the methane concentration in the gas phase we found a variety of growth modes; lateral, two-dimensional island and three-dimensional growth. The lateral growth formed 100 × 100 μm^2 step-free surfaces of (111) diamond. This growth technique will be a key to realize high quality diamond devices.

1. Introduction

Diamond device is expected to be one of the next-generation semiconductor devices, such as high-power electronic, optoelectronic, biotechnological and quantum computing devices, because of superior physical, chemical and electronic properties. For fabrication of diamond device, homoepitaxial diamond films are grown mostly on (100) and (111) substrates by microwave plasma-enhanced chemical vapor deposition (MPCVD). However, its growth mechanism is not clearly understood. To elucidate the growth mechanism, both vapor phase reaction and surface reaction need to be studied. Observation of the growth surface is crucial for the elucidation of the growth mechanism, since the growth process influences the morphology of growth surface. To clarify the growth mechanism, in-situ observations for Si, Ge and GaAs have been carried out, but in-situ observation of diamond growth during MPCVD process is extremely difficult, because of high temperature (800 ~ 1100°C), high pressure (25 ~ 150 Torr) and hydrogen plasma environment. Therefore, other techniques for surface observation are important for clarification of diamond growth mechanism, instead of in-situ observation. In this study, we use ex-situ atomic force microscopy (AFM) to investigate the surface morphology of homoepitaxial diamond (111) films grown by MPCVD, and examine growth modes in the diamond homoepitaxy.

2. Experimental

Using MPCVD system with 0.05% CH_4 diluted in H_2, diamond films were deposited on single-crystalline diamond (111) substrates whose surfaces were patterned with mesa structures. The mesa structures were fabricated by electron beam lithography and inductive-coupled plasma etching. The total pressure and microwave power were maintained at 50 Torr and 1200 W, respectively. The substrate temperature was around 900°C. The morphology of diamond surfaces on mesas before and after the MPCVD growth was observed with ex-situ AFM in air. We judged the growth modes from the surface morphology of diamond films on mesas.

3. Results

Figure 1 and 2 show AFM images of mesas of dimension 1 × 1 μm^2 before and after the MPCVD growth at 0.05% CH_4/H_2 ratio for 1 h, respectively. The substrate surface before growth was rough, which was induced by surface mechanical polishing. On the other hand, the mesa top surface after growth was atomically flat, which was composed of single bi-atomic layer steps and an atomically flat equilateral triangular island [1]. The heights of the steps were approximately 0.21 nm, which corresponds to the theoretical height of single bi-atomic layer (111) step. Accordingly, this growth mode is experimentally identified as two-dimensional island growth.

In this presentation, we will systematically discuss the relationship between growth modes including two-dimensional island growth as well as lateral and three-dimensional growth, and CH_4 concentrations, and we will also demonstrate the lateral growth of 100 × 100 μm^2 step-free surfaces, which are perfectly flat surfaces without any atomic steps and islands on (111) diamond [2,3]. We are sure that this growth technique will be a key to realize high quality electronic interfaces and devices.

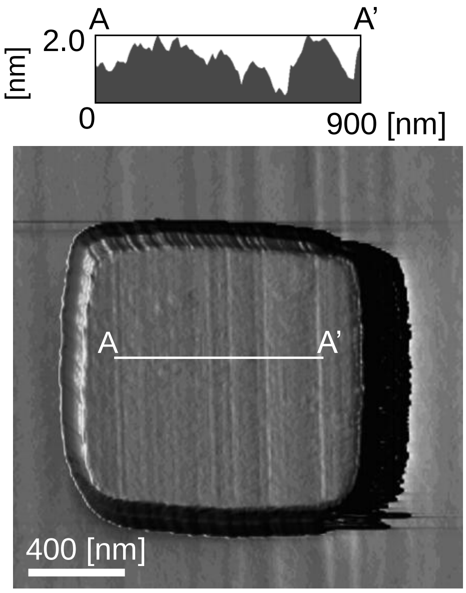

Fig. 1. Three-dimensional and cross-sectional AFM images of a mesa of dimension 1 × 1 μm^2 before the MPCVD growth.

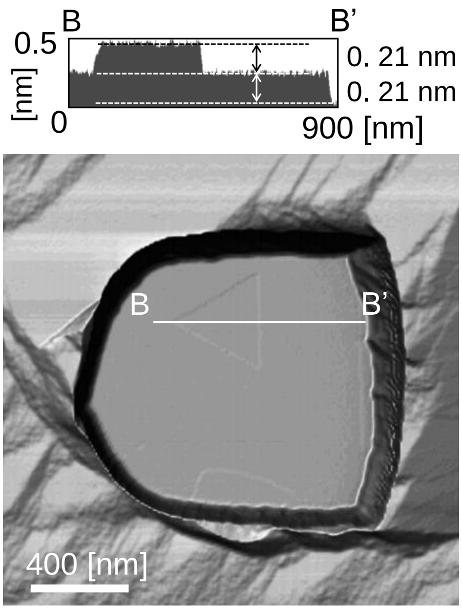

Fig. 2. Three-dimensional and cross-sectional AFM images of a mesa of dimension 1 × 1 μm^2 after the MPCVD growth at 0.05% CH_4/H_2 ratio for 1 h.

Acknowledgments

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