Boron nitride formation on highly boron-doped Si(111) surface: AES, EELS and LEED study

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A large number of ion beam assisted deposition (IBAD) and plasma enhanced physical vapour deposition (PEPVD) processes for the preparation of boron nitride (BN) has been reported in the literature. All these deposition methods have been shown to work within the same range of microscopic deposition parameters and therefore to rely on the same basic mechanisms. For the BN films obtained by these techniques the existence of three distinct structural regions is typical. At the substrate interface a thin amorphous layer is formed, followed by the formation of a highly oriented hexagonal boron nitride layer (h-BN) and a top layer is represented by a nanocrystalline cubic boron nitride (c-BN). For the further improvement of the structure of the films it is important to understand the nucleation and growth mechanism of the various phases.

In this work we report the results of a study on air interaction with a boron-modified Si(111) surface depending on the conditions of an air adsorption and a degree of Si(111) surface modification by boron atoms using Auger electron (AES), a electron energy-loss (EELS) spectroscopies and a low energy electron diffraction (LEED). The obtained results demonstrate a new property of the surface giving a possibility to investigate an initial stages of BN formation on the one.

Experiments were carried out in the two-chamber LAS-600 UHV system with a base pressure of 2×10^{-10} Torr. The boron-modified Si(111) surface with ($\sqrt{3} \times \sqrt{3}$) structure was prepared by the high-temperature treatment of a heavily B-doped Si wafer with resistivity of 0.005 Ω cm. Si(111)-B surface with a desired boron concentration was exposed in an air atmosphere introduced into the vacuum chamber through a variable leak valve at a pressure of $(1\div2) \times 10^{-5}$ Torr at the room temperature. In the experiments, the samples have been exposed to both unexcited air and air excited by an operating vac-ion pump. The post-exposed samples were annealed at temperatures in the range from 300 to 1250°C.

The following findings will be presented and discussed.

1. Adsorption of gas species on boron-modified Si(111) surface occurs more readily when the inlet of an air into a vacuum chamber was conducted at the operating vac-ion pump. It is suggested that the main reason of the phenomenon is the change of the air composition as a result of its interaction with electro-magnetic field of the vac-ion pump.
2. The amount of nitrogen adsorbed on a boron-modified Si(111) surface with the ($\sqrt{3} \times \sqrt{3}$) structure at air excited exposure increases with the increasing of boron surface concentration (or, in other words, with the increasing of the degree of Si(111) surface modification by boron atoms), while the dependence for oxygen adsorbed is inversely. No correlation between amount of carbon adsorbed and the boron surface concentration was found. At the air excited adsorption, LEED showed a (1 x 1) pattern and an increased background intensity, indicating disruption of $\sqrt{3}$ registry on the surface.
3. Subsequent annealing of the boron-modified Si(111) surface with the adsorbed gas species stimulates further chemical reactions between adsorbates and surface Si and B atoms. AES and EELS data show a formation of BN islands of both hexagonal and cubic modifications, and a small amount of SiC phase after heating up to 900°C. LEED measurements showed that the (1 x 1) pattern returns back to the ($\sqrt{3} \times \sqrt{3}$) one after the annealing. The reaction between nitrogen and boron atoms becomes noticeable at heating to about of 550°C.
4. A disruption of the BN islands is a thermal activated process with an activation energy of 8.9 ± 0.6 eV and it becomes noticeable at temperatures above of 1150°C.
5. The thin layer of BN can be grown on highly boron-doped Si(111) surface by a three-stage cyclic process involving a segregation of boron atoms from a bulk of the wafer to its surface, adsorption of nitrogen from an air-excited atmosphere at room temperature and subsequent a short heating.