Electron-stimulated formation of the AlN crystalline structure on the reconstructed (√31 × √31) R±9° sapphire surface

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III-nitrides are direct-gap semiconductor materials with a band gap of 0.7 eV (InN) and 3.4 eV (GaN) to 6.2 eV (AlN). III-nitride low-dimensional structures (quantum wells, superlattices and quantum dots) are of considerable interest due to their possible practical applications for creating light-emitting devices and photodetectors. III-nitride heterostructures with two-dimensional electron gas are actively used to create high-power microwave and power transistors. No less relevant at the moment is the use of III-nitrides in the form of graphene-like layers (g-AlN and g-GaN) in spintronics and electronics. To date, the most widely used substrate for the III-nitrides epitaxial growth is sapphire (α-Al_2O_3). It is believed that when high-temperature (over 1150 °C) heating the sapphire substrate, decomposition of the surface layers of Al_2O_3 occurs with oxygen desorption and the formation of metallic aluminum [1,2]. The high resolution AFM images of the initial Al_2O_3 surface and after high-temperature annealing are shown in Fig. 1a,b. In this case, a reconstruction transition occurs (1 × 1) - (√31 × √31) R±9° [3]. The sapphire reconstructed surface (√31 × √31) R±9° is stable and improves the adhesion of growth components [1]. This work is devoted to the study of the fast electrons effect (E ~ 11 keV) on the crystalline AlN formation on the reconstructed (√31 × √31) R±9° sapphire surface. It was established experimentally that the reconstructed (√31 × √31) R±9° sapphire surface under an ammonia flux nitrided at low speed compared to the unreconstructed sapphire surface (1 × 1), but in the presence of an electron beam the nitridation process rate increases. The order-disorder reconstruction transition (√31 × √31) R±9° - (1 × 1) (the diffraction pattern in Fig. 1e is replaced by 1d with subsequent accelerated nitridation of the disordered sapphire surface (1x1) occurs. Since the reconstructed surface, is said to enriched with metallic aluminum, it was fair enough to assume that the reconstruction (√31 × √31) R±9° contributes to the nitridation process due to the high chemical activity of metallic aluminum, but this contradicts our experimental data. A series of experiments was carried out on deposition of 1-2 monolayers of metallic aluminum on the surface of sapphire to reproduce the reconstruction (√31 × √31) R ± 9 ° proposed in [1,2,4]. As a result, it was found that when aluminum is deposited at a temperature above 800 °C (this temperature is much lower than the reconstruction formation temperature (√31 × √31) R±9°), all the adsorbed aluminum desorbs from the surface and the crystalline phase of aluminum does not form. After reducing the substrate temperature to 200 °C, deposition of aluminum on the sapphire surface led to the formation of crystalline aluminum with a 30° unit cell rotation relative to the sapphire unit cell, however, no reconstruction reflexes were detected in the diffraction pattern (Fig. 1f). These experimental results refute early work, representing the reconstructed (√31 × √31) R±9° sapphire surface in the form of 1-2 monolayers (111) of monocrystalline aluminum. It can be assumed that the reconstructed surface does not consist of metallic reactive aluminum, but is formed as oxides of partially reduced aluminum (Al_2O and AlO) with the formation the more stable ordered phase [5]. The formation of the crystalline AlN phase under the high-energy electrons action in this case can be explained by the fact that the electron beam initiates electron-stimulated desorption of oxygen from the sapphire surface and accelerates the nitridation reaction.

This work was supported by RFBR grants No. 18-52-00008 and 17-02-00947.

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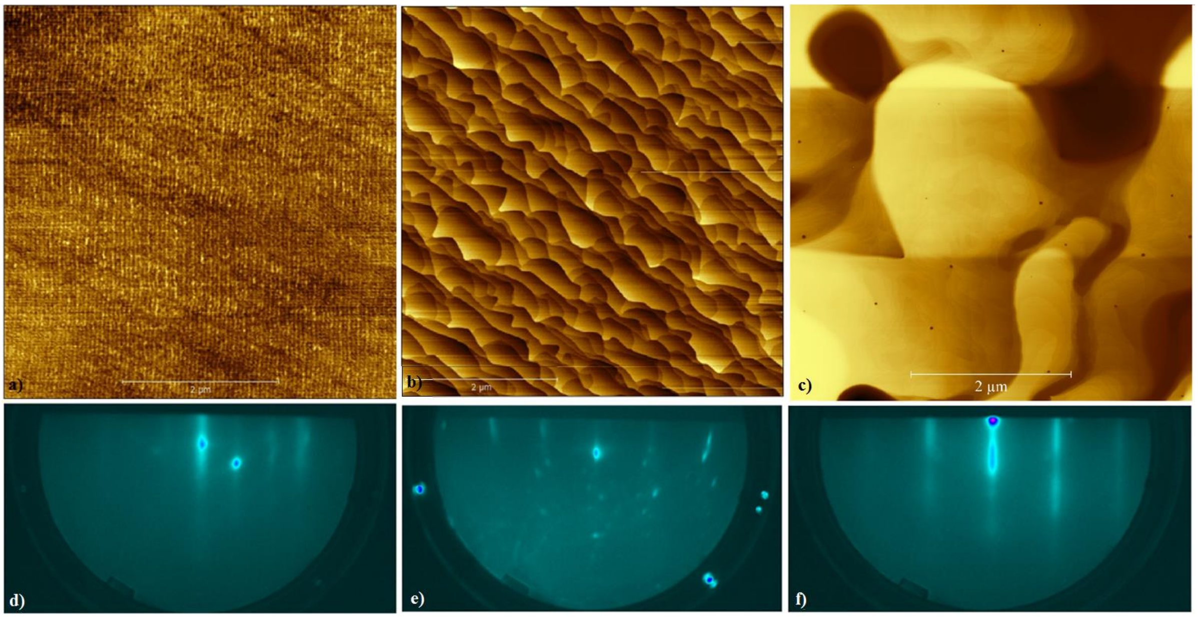

Figure 1 High resolution AFM images of 5x5 µm and diffraction patterns of the initial α-Al2O3 surface close to the symmetric azimuth [11–20] - a) and d); reconstructed (√31 × √31) R±9° surface of α-Al2O3 after high-temperature annealing (1150 °C) - b) and e); crystalline Al close to the symmetric azimuth [10–10] - c) and f). The scale along the z axis for a) and b) is 2nm, for c) is 20nm.