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Preparation and structural properties of YBCO films grown on GaN/*c*-sapphire hexagonal substrate

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ABSTRACT

Epitaxial YBCO thin films have been grown on hexagonal GaN/*c*-sapphire substrates using DC magnetron sputtering and pulsed laser deposition. An MgO buffer layer has been inserted between the substrate and the YBCO film as a diffusion barrier. X-ray diffraction analysis indicates a *c*-axis oriented growth of the YBCO films. Φ-scan shows surprisingly twelve maxima. Transmission electron microscopy analyses confirm an epitaxial growth of the YBCO blocks with a superposition of three *a*–*b* YBCO planes rotated by 120° to each other. Auger electron spectroscopy and X-ray photoelectron spectroscopy reveal no surface contamination with Ga even if a maximum substrate temperature of 700 °C is applied.

1. Introduction

Recently, the field of new electronics based on III-V and III-N semiconducting materials with their main representatives such as GaAs, AlAs, GaN, AlN has rapidly developed. These materials seem to be usable in the design of new sub-millimeter wave devices and MEMS structures [1]. Active and passive elements based on these materials are very efficient at a temperature of liquid nitrogen (77 K). This gives a possibility of the integration of passive high-temperature superconductor (HTS) devices with active GaAs and GaN devices in the form of millimeter wave devices. A direct growth of the HTS thin films on the GaAs, however, may not only produce a film with a suppressed critical temperature but it can cause a damage to the GaAs substrate as well [2,3]. This is the reason to examine the possibilities of the YBCO deposition on the hexagonal GaN substrate in more detail. The III-N material systems have the advantage of the wide gap. The GaN as one of the basic representative of this group is widely studied nowadays. This material has two thermodynamically stable phases: a cubic and a hexagonal (wurtzite) phase. The latter one was found as more suitable for semiconducting elements due to less concentration of defects in the GaN layer [4,5].

In this paper we report the preparation and study of the properties of the YBCO films prepared by pulsed laser deposition (PLD) and sputtering techniques on the MgO buffered semiconducting hexagonal GaN/*c*-sapphire substrate.

2. Experimental

GaN/*c*-sapphire wafers were chemically cleaned in the H_2O:NH_4OH = 10:1 solution for 30 s before placing to the heater in the growth chamber. Prior to the MgO growth, the GaN substrates were heated to the heater temperature T_H of 650 °C for 5 min in the growth chamber at a pressure of ~10^{-4} Pa. The MgO deposition was done at the T_H = 600 °C and a partial oxygen pressure of ~10^{-2} Pa. The typical deposition rate was 0.1 nm/s. The ex situ deposition of the YBCO films was realized using DC magnetron sputtering or PLD. Using PLD, the YBCO films were grown at the T_H = 760 °C. An excimer laser was used for 10 min at a pulse rate of 5 Hz, laser energy of the density of 1 J/cm^2 and at an oxygen pressure of 40 Pa. The deposition was followed by slow cooling (20 °C/min) at an oxygen pressure of 10^4 Pa. In the case of high pressure DC sputtering,

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the substrate was localized into a hollow of the heating coil to avoid the gradient temperature between the surface and the backside of the substrate. The sputtering was performed at a temperature of 700–710 °C in oxygen at a pressure of 150 Pa for 2–3 h.

The crystallographic orientation perpendicular to the film surface was determined using an HZG4 diffractometer (standard θ–2θ scan in Bragg–Brentano geometry with $\lambda = 0.15406$ nm for Cu Kα radiation) and using a diffractometer BRUKER AXS D8 DISCOVER with rotating Cu anode. In plane orientation was established by the sample rotation around the axis perpendicular to the sample surface (Φ-scan). The microstructure of the YBCO films was investigated by transmission electron microscopy (TEM) Jeol 1200EX. Cross-section view TEM sample was prepared in the conventional way with a final ion milling process.

Auger electron spectroscopy (AES) depth profiling was carried out in a Varian Auger electron spectrometer equipped with a cylindrical mirror analyzer (CMA) and EX 05 VG ion gun. A primary electron beam was used with the energy of 3 keV and the incident angle of 20° with respect to the surface normal. The sputtering was achieved by scanned Xe^+ ion beams with the energy of 1 keV and 60° of incidence with respect to the surface normal. The energy resolution of the CMA was $\Delta E/E = 0.3\%$.

X-ray photoelectron spectroscopy (XPS) spectra were obtained in an ESCALAB 210 spectrometer (Vacuum Generators), with a base pressure in the range of 10^{-8} Pa. A hemispherical electron energy analyzer working in the pass energy constant mode at a value of 50 eV was used. Unmonochromatized Al Kα radiation (1486.6 eV) was used as an excitation source. Successive spectra were recorded after sputtering treatments with Ar^+ ions of 3.5 keV of kinetic energy, impinging the surface sample at normal incidence.

The temperature dependence of the resistance was measured using a standard DC four-probe technique in a temperature range of 4.2–340 K. The films were analyzed by microwave absorption measurements using magnetic modulation absorption (MMMA), where the superconducting film is placed in a cavity resonator filled with the sapphire rod [6,7].

3. Results and discussion

The X-ray diffraction (XRD) patterns of the prepared MgO buffer film on the GaN substrate have shown, as we supposed (Fig. 1), only (1 1 1) orientation similarly to [8]. So, we expected rather a polycrystalline character of the ex situ grown YBCO film. However, the XRD pattern shows surprisingly only (0 0 l) peaks belonging to the *c*-axis oriented YBCO film (Fig. 2). Such a pattern is characteristic rather for the YBCO films grown on a (0 0 l) oriented cubic buffer layer. This was the reason why we investigate the growth of the YBCO in the *a*–*b* plane. Φ-scan (Fig. 3) reveals twelve maxima belonging to the YBCO film and to the MgO buffer layer too, instead of the expected random orientation in the *a*–*b* plane.

TEM analysis was applied to clear up such a behavior. Selected area diffraction (SAD) pattern shows (Fig. 4) an epitaxial growth of the MgO buffer layer on the top of the GaN (Fig. 4c). On the other hand, the SAD taken from the YBCO thin film shows (Fig. 4d) random character of the growth at first sight. However, a detail examination confirms that this SAD pattern is practically identical with the schematic SAD pattern of the superposition of three single crystalline pattern rotated by 120° (Fig. 4a and b). Such oriented grains (blocks) create wide angle boundaries with each other. This fact can have an impact on the electrical properties of the prepared YBCO films.

Indeed, the measured resistance versus temperature (*R*–*T*) characteristics exhibit a broad transition into the superconducting state at both methods of the YBCO film preparation. However, the onset temperature values (T_{ON}) give an evidence that the grains itself are not degraded (Fig. 5).

To receive more complex information about the bulk properties of the films a method of temperature dependence of microwave losses was applied [6,7]. MMMA study exhibits the existence of Josephson losses (JL) in intergranular weak link medium from the bottom of the transition to 4.5 K (the range is marked in Fig. 5). This is an evidence of the presence of wide angle boundaries between

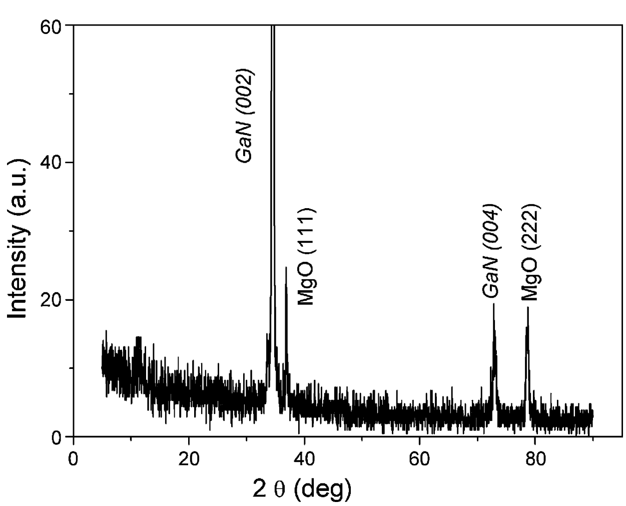

Fig. 1. XRD pattern of the MgO film deposited on the GaN/*c*-sapphire substrate.

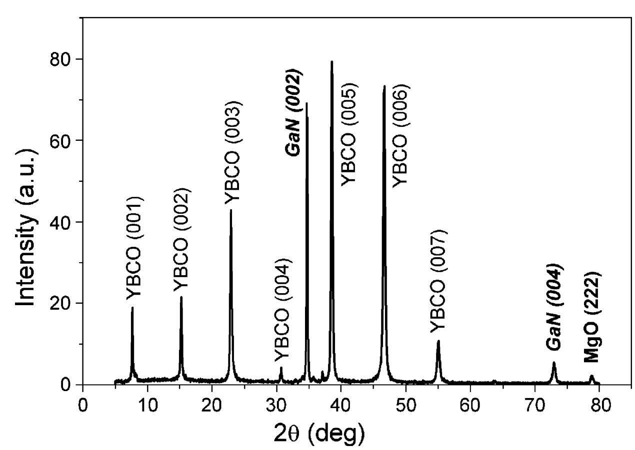

Fig. 2. XRD pattern of the YBCO film deposited on MgO/GaN/*c*-sapphire substrate.

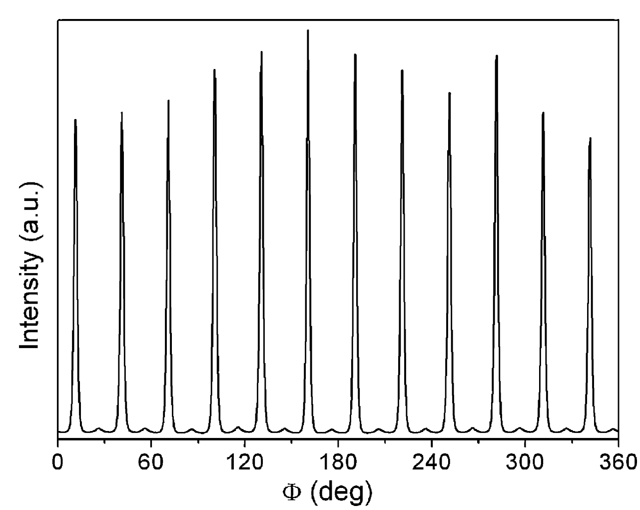

Fig. 3. Φ-scan of the 100 nm thick YBCO film on the MgO/GaN/*c*-sapphire substrate.