Growth and Structural Analysis of Gallium Oxide Films on Ru(0001)/Al_2O_3(0001) for Low-Power Electronics

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Gallium oxide is a wide band gap semiconductor with diverse applications in high power electronics [1], oxygen sensors [2], and ultra-violet devices [3]. This study focuses on the growth and structural characterization of gallium oxide on a Ru(0001) substrate. We aim at determining the conditions required for a successful growth of β-Ga_2O_3 on this substrate, specifically for low-power electronics and lateral configuration resistive switching devices [4] at low cost.

To achieve that, we deposited crystalline Ru(0001) films by radio frequency (RF) sputter deposition on Al_2O_3 (0001) wafer substrates. The gallium oxide films were deposited subsequently on the Ru films using plasma-assisted molecular beam epitaxy (PAMBE) and RF sputtering at different temperatures. For characterization, we employed reflection high-energy electron diffraction (RHEED), X-ray photoelectron spectroscopy (XPS), low-energy electron microscopy (LEEM) and diffraction (LEED), atomic force microscopy (AFM), transmission electron microscopy (TEM), and X-ray diffraction (XRD).

PAMBE at 500℃ allowed for epitaxial growth of (-201) oriented β-Ga_2O_3 on Ru(0001) as confirmed by RHEED and XRD measurements. The quality of the films was improved upon annealing at 800℃. This step forms large surface terraces separated by step bunches as observed in LEEM, LEED, and AFM.

As an alternative growth method, sputter-deposited gallium oxide on Ru was studied. Prepared at 400℃, these films showed poly-crystalline β-Ga_2O_3 films with rotational mosaics of (-201) surface orientation as found in XRD and TEM. The stoichiometry of these Gallium oxide films and the concentration of oxygen vacancies were investigated by in-situ XPS. Our results show the presence of oxygen vacancies and an according Ga-Ga metallic bonding. AFM measurements showed that the surface roughness of the films increased with annealing temperature in the range from RT to 400℃, reflecting the presence of successively larger crystallites.

To explore the resistive switching characteristics of the films, we employed electrodes with different work functions (Al and Ag). The sample grown by PAMBE exhibited minimal defects and excellent crystalline quality, resulting in a consistent current response. Conversely, the gallium oxide film deposited through sputtering displayed a good ON/OFF ratio of 10^4 between high and low resistive states, demonstrating long retention (10^4 secs) and good endurance. This makes it a promising low-cost prototype for future non-volatile technology.

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