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Effects of H_2O Pretreatment on the Capacitance–Voltage Characteristics of Atomic-Layer-Deposited Al_2O_3 on Ga-Face GaN Metal–Oxide–Semiconductor Capacitors

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Atomic layer deposition (ALD) of Al_2O_3 on Ga-face GaN is studied with respect to the effects of growth saturation, precursor injection sequence, and H_2O pretreatment. A metal–oxide–semiconductor capacitor (MOSCAP) structure is fabricated to measure the capacitance–voltage (C–V) characteristics. The origin of C–V hysteresis is explained by a model considering the different trapping behaviors of interface states and oxide border traps. The interface state density (D_{it}) is extracted as a function of band bending using an ultraviolet (UV)-assisted method. It is found that H_2O pretreatment followed by saturated ALD growth produces the best interface quality, with a reduced D_{it} compared with growth without H_2O pretreatment.

Key words: GaN, Al_2O_3, atomic layer deposition, interface states, traps, hysteresis, MOSCAP

INTRODUCTION

Al_2O_3 has emerged as a suitable gate dielectric for III-nitride-based electronic devices.[1–10] It has a large bandgap and relatively high dielectric constant, and exhibits high thermal and structural stabilities. Al_2O_3 can also be used as a passivation material to improve device output performance.[1–3,7,9,11] The passivation effects are often seen to be better than with the widely used SiN.[1,11] For both applications it is essential to have a low interface state density (D_{it}) between Al_2O_3 and III-nitride semiconductor, and a low oxide trap density within Al_2O_3 itself.

Due to the great chemical versatility and the exceptional control over film uniformity and conformity, atomic layer deposition (ALD) has become the predominant method for depositing Al_2O_3[12–17] and various other dielectrics. In typical thermal ALD of Al_2O_3, trimethylaluminum (TMA) and H_2O precursors are introduced alternately. Each half-cycle reaction is driven by the respective surface chemistry,[12] limiting growth to proceed in a layer-by-layer fashion. Saturated growth is usually preferred in order to get the maximum growth rate and incorporation efficiencies, as well as better run-to-run consistencies. To achieve a low-D_{it} interface at the initial stage of growth, the precursor injection sequence needs to be designed carefully by considering the surface termination and chemical properties of the underlying semiconductor.[15–17] For example, a TMA pretreatment step is found to reduce D_{it} in ALD of Al_2O_3 on As-terminated InGaAs.[15] The As termination favors TMA adsorption and passivation,[16] and prefers the formation of Al–As bonds for the first layer growth.[17] On the other hand, for ALD of Al_2O_3 on Ga-face GaN, it might be advantageous to use H_2O pretreatment and passivate the surface with H_2O adsorption.[1,3]

The Terman method is a standard high-frequency capacitance–voltage (C–V) technique for analyzing D_{it}.[18,19] It relies on the interface states to change occupancy along with the direct-current (DC) bias sweep. By making a point-by-point comparison between a measured C–V curve containing responses from the interface states and a calculated ideal reference curve assuming no interface states, D_{it} can be extracted as a function of band bending. However, the Terman method can grossly

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