First demonstration of GaN nanowire-based devices with top-down approach

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The layout of modern field-effect transistors (FETs) is rapidly moving toward three-dimensional structures to reduce the off-state currents and improve the subthreshold characteristics, allowing for the reduction of supply voltage and dynamic power consumption in integrated circuits [1]. The gate-all-around (GAA) structure has been already proven [2] in Si CMOS to effectively suppress short channel effects, thanks to its superior gate electrostatic control. In addition, there is a strong interest in introducing III-V channels to boost FET current drive due to higher mobility and saturation current in comparison with Si. Recently, GaAs and InAs-based III-V GAA FETs were also demonstrated with lateral and vertical type by J. J. Gu *et al*. [3] and C. Thelander *et al*., respectively [4]. Gallium nitride-based devices comprise one of the most promising candidates for high-voltage, high-frequency and high-temperature operation, because of the superior material properties of GaN, such as wide band-gap energy, high breakdown field, and high electron saturation velocity [5]. However, GaN-based GAA FETs have not been realized yet because strong chemical stability and hardness of III-nitride materials make it very difficult to achieve the GAA structure with conventional techniques, such as wet-chemical etching and oxidation processes. Here we report first experimental demonstration of the GaN nanowire-based omega-gate and GAA FETs (including both lateral and vertical type) by top-down approach using reproducible, strongly-anisotropic wet etching in tetramethyl ammonium hydroxide (TMAH) solution, which permits accurate etch-time-based control over size of the GaN nanopattern. Benefiting from the fabricated device structure, we demonstrate the well-behaved on- and off-state characteristics, such as extremely low off-state leakage current, low subthreshold swing close to 60 mV/dec and high normalized maximum current higher than 1 A/mm.

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