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Polarization-Engineered Enhancement-Mode High-Electron-Mobility Transistors Using Quaternary AlInGaN Barrier Layers

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Group III nitride heterostructures with low polarization difference recently moved into the focus of research for realization of enhancement-mode (e-mode) transistors. Quaternary AlInGaN layers as barriers in GaN-based high-electron-mobility transistors (HEMTs) offer the possibility to perform polarization engineering, which allows control of the threshold voltage over a wide range from negative to positive values by changing the composition and strain state of the barrier. Tensile-strained AlInGaN layers with high Al contents generate high two-dimensional electron gas (2DEG) densities, due to the large spontaneous polarization and the contributing piezoelectric polarization. To lower the 2DEG density for e-mode HEMT operation, the polarization difference between the barrier and the GaN buffer has to be reduced. Here, two different concepts are discussed. The first is to generate compressive strain with layers having high In contents in order to induce a positive piezoelectric polarization compensating the large negative spontaneous polarization. Another novel approach is a lattice-matched Ga-rich AlInGaN/GaN heterostructure with low spontaneous polarization and improved crystal quality as strain-related effects are eliminated. Both concepts for e-mode HEMTs are presented and compared in terms of electrical performance and structural properties.

Key words: AlInGaN, InAlGaN, composition, polarization, HEMT, enhancement mode

INTRODUCTION

Using quaternary AlInGaN barrier layers in GaN-based high-electron-mobility transistors (HEMTs) offers the possibility to realize depletion-mode (d-mode) and enhancement-mode (e-mode) operation.[1–3] By changing the composition and hence the spontaneous and piezoelectric polarization in a pseudomorphically grown AlInGaN layer, one can control the polarization difference between the AlInGaN barrier and the GaN buffer.[4,5] Tensile-strained AlInGaN layers with high Al contents and lattice-matched pure AlInN both generate high two-dimensional electron gas (2DEG) densities.[6,7] Compressively strained AlInN and AlInGaN layers have been used to generate a piezoelectric polarization which compensates a high spontaneous polarization to lower the 2DEG density and realize e-mode operation.[8,9] However, device performance is limited by the inferior crystal quality caused by the high In content. Further, barrier layers under high compressive strain show effects such as relaxation and In pulling, which degrade device characteristics even further and impede process control and reproducibility.[10,11] Here, we present a different approach of a simultaneously lattice-matched and polarization-reduced AlInGaN/GaN heterostructure

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