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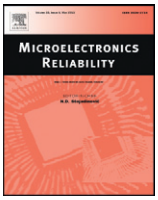

Comparison of electrical characteristics between AlGaN/GaN and lattice-matched InAlN/GaN heterostructure Schottky barrier diodes

Jian Ren, Dawei Yan, Yang Zhai, Wenjie Mou, Xiaofeng Gu *

Key Laboratory of Advanced Process Control for Light Industry (Ministry of Education), Department of Electronic Engineering, Jiangnan University, Wuxi 214122, China

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ABSTRACT

Lattice-matched Pt/Au–$In_{0.17}Al_{0.83}N$/GaN hetreojunction Schottky barrier diodes (SBDs) with circular planar structure have been fabricated. The electrical characteristics of InAlN/GaN SBD, such as two-dimensional electron gas (2DEG) density, turn-on voltage, Schottky barrier height, reverse breakdown voltage and the forward current-transport mechanisms, are investigated and compared with those of a conventional AlGaN/GaN SBD. The results show that, despite the higher Schottky barrier height, more dislocations in InAlN layer causes a larger leakage current and lower reverse breakdown voltage than the AlGaN/GaN SBD. The emission microscopy images of past-breakdown device suggest that a horizontal premature breakdown behavior attributed to the large leakage current happens in the InAlN/GaN SBD, differing from the vertical breakdown in the AlGaN/GaN SBD.

1. Introduction

For many years, AlGaN/GaN high electron mobility transistors (HEMTs) have attracted intensive attention due to their importance for high power/temperature applications [1–3]. However, the lattice mismatch induced strain in the AlGaN barrier layer greatly degrades the reliability of the associated devices [4,5]. Using lattice-matched $In_{0.17}Al_{0.83}N$ barrier layer is currently the most effective solution to this problem since it is free from initial stress [6]. Moreover, some other advantages, such as higher spontaneous polarization coefficient, lower free surface potential of InAlN, good chemical and thermal stability, make lattice-matched InAlN/GaN HEMTs a promising candidate for applications from power condition to microwave communication [7]. So far, extensive researches about the frequency and power performance of lattice-matched InAlN/GaN HEMTs have been reported [8,9]. However, little attention has been paid to the electrical characteristics of lattice-matched InAlN/GaN heterostructure Schottky barrier diode (SBD), even though these characteristics, including two-dimensional electron gas (2DEG) density (n_{2D}), turn-on voltage (V_{on}), Schottky barrier height ($q\Phi_b$), reverse breakdown voltage (V_b) and the forward current transport mechanisms, are valuable for device performance and reliability. Despite the high breakdown voltage in theory, a premature breakdown behavior often occurs and seriously hinders the applications of InAlN/GaN devices in operating at high voltage range. To reduce the probability of the premature breakdown, it is essential to further investigate the relevant breakdown characteristics and understand the breakdown mechanism. Due to the similar structure and material characteristics between InAlN/GaN and AlGaN/GaN heterostructure, comparing the electrical characteristics of InAlN/GaN SBD with an AlGaN/GaN SBD is of great importance to further improve the performance of GaN-based heterostructure devices.

In this work, lattice-matched Pt/Au–$In_{0.17}Al_{0.83}N$/GaN hetreojunction SBDs with circular planar structure were fabricated. The electrical characteristics of InAlN/GaN SBD are investigated and compared with an AlGaN/GaN SBD by measuring current–voltage (I–V) and capacitance-voltage (C–V) characteristics. Based on the emission microscopy (EMMI) images, two different breakdown mechanisms are observed and analyzed in InAlN/GaN and AlGaN/GaN SBDs.

2. Experiments

The epiwafers of InAlN/GaN and AlGaN/GaN heterostructure SBDs investigated in this work were both grown by metal–organic chemical vapor deposition on the *c*-plane sapphire substrate. The InAlN/GaN heterostructure includes a 3 μm i-GaN layer, a 2 nm AlN spacer and an 18 nm i-$In_{0.17}Al_{0.83}N$ barrier layer. The AlGaN/GaN heterostructure consists of a 1.6 μm i-GaN buffer layer and an 18 nm i-$Al_{0.27}Ga_{0.73}N$ barrier layer. The electrode structure consists of a circular Schottky dot of ~100 μm in diameter separated radially by ~10 μm from the Ohmic contact. Standard lithography process and lift-off technique were used to pattern the Pt/Au (Ni/Au for AlGaN/GaN) Schottky contact dots. Ohmic contact were formed by annealing a Ti/Al/Ni/Au (Ti/Al/Ti/Au for AlGaN/GaN) metal stack using rapid thermal annealing in N_2 at 870 °C for about 30 s. Two $100 \times 100\ \mu m^2$ pads were deposited to obtain reliable contacts between the test probe and underlying electrodes. A

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* Corresponding author.
E-mail address: xgu@jiangnan.edu.cn (X. Gu).

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150-nm-thick silicon nitride film was deposited on the sample surface as the passivation layer. The *I–V* and *C–V* characteristics of SBDs were measured using a Keithley 4200 SCS semiconductor parameter analyzer and a MAC3C SHIMAX digital temperature controller. The light emission from the device surface was examined by using an EMMI (FA Instruments Crystal Vision 2) for locating the defects accurately.

3. Results and discussion

Fig. 1 shows the room temperature *C-V* characteristics of InAlN/GaN and AlGaN/GaN SBDs under 1 MHz, respectively. By integrating the measured *C–V* curve from V_T to 0 V, we can obtain the zero-bias n_{2D} by [10].

$$n_{2D}(0) = \frac{1}{eA}\int_{V_T}^{0} C(V)dV, \tag{1}$$

where e is the electron charge, $A \sim 7.85 \times 10^{-5}$ cm^2 is the effective contact area, V_T is the threshold voltage and can be calculated by integrating the *C–V* curve (shown in the inset of Fig. 1). The calculated values of zero-bias n_{2D} in AlGaN/GaN and InAlN/GaN Schottky SBDs are ~6.38×10^{12} cm^{-2} and ~1.27×10^{13} cm^{-2}, respectively. Obviously, even in the absence of piezoelectric polarization, the higher spontaneous polarization coefficient of InAlN barrier can produce a two times higher n_{2D} than AlGaN barrier.

Fig. 2 shows the room temperature *I–V* characteristics of AlGaN/GaN and InAlN/GaN SBDs, respectively. As can be seen, the reverse saturation current of InAlN/GaN SBD is almost three orders of magnitude higher than that of AlGaN/GaN SBD. Meanwhile, the turn-on voltages determined for AlGaN/GaN and InAlN/GaN SBDs are 2.5 V and 4.5 V, respectively, as shown in the inset of Fig. 2. The significantly higher reverse leakage current and turn-on voltage indicate that the InAlN/GaN SBD has higher power dissipation than AlGaN/GaN SBD. In addition, similar increase trend of current as a function of the forward bias can be observed from Fig. 2. At lower bias (region I), the current increases exponentially with the applied voltage; while at higher bias (region II), the current increases slowly due to the significant series resistance effect.

Based on the reported work on AlGaN/GaN SBDs [11,12], the forward-low-bias current (region I) is mainly attributed to the trap-assisted tunneling (TAT), while the forward-high-bias current (region II) is governed by the thermionic emission (TE) mechanism. To obtain the Schottky barrier height from the forward current characteristics, the TE and TAT models are employed to fit the experimental data. In general, the TE current (I_{TE}) is given by [13].

$$I_{TE} = I_0 \exp\left[\frac{q(V - IR_S)}{kT}\right], \tag{2a}$$

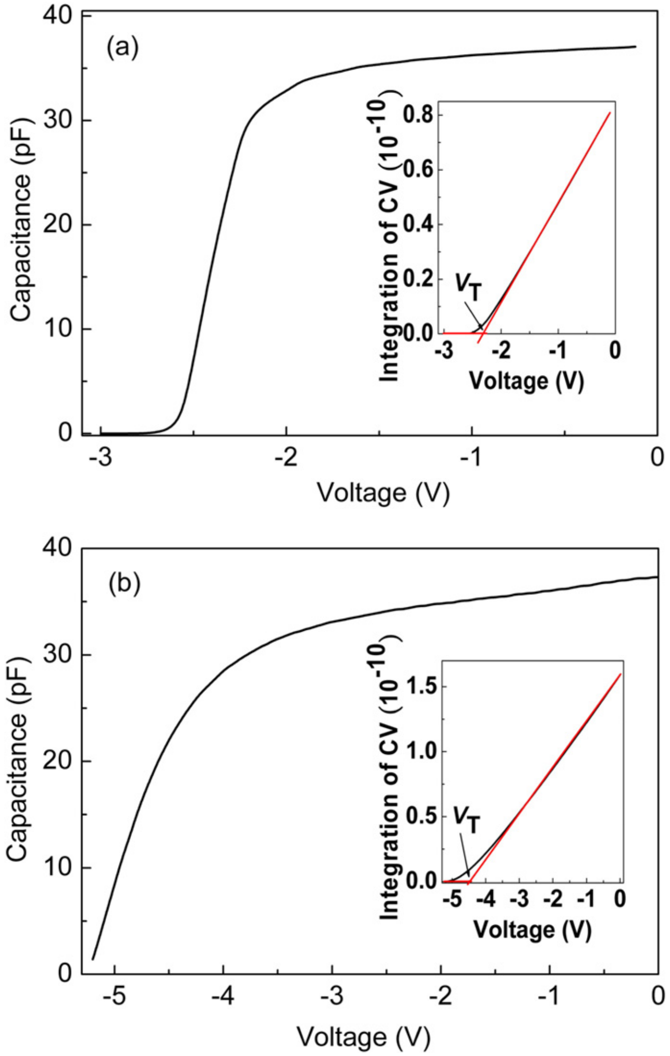

Fig. 1. *C–V* characteristics of (a) AlGaN/GaN and (b) InAlN/GaN SBDs measured at room temperature (1 MHz), with the V_T plotted in the inset.

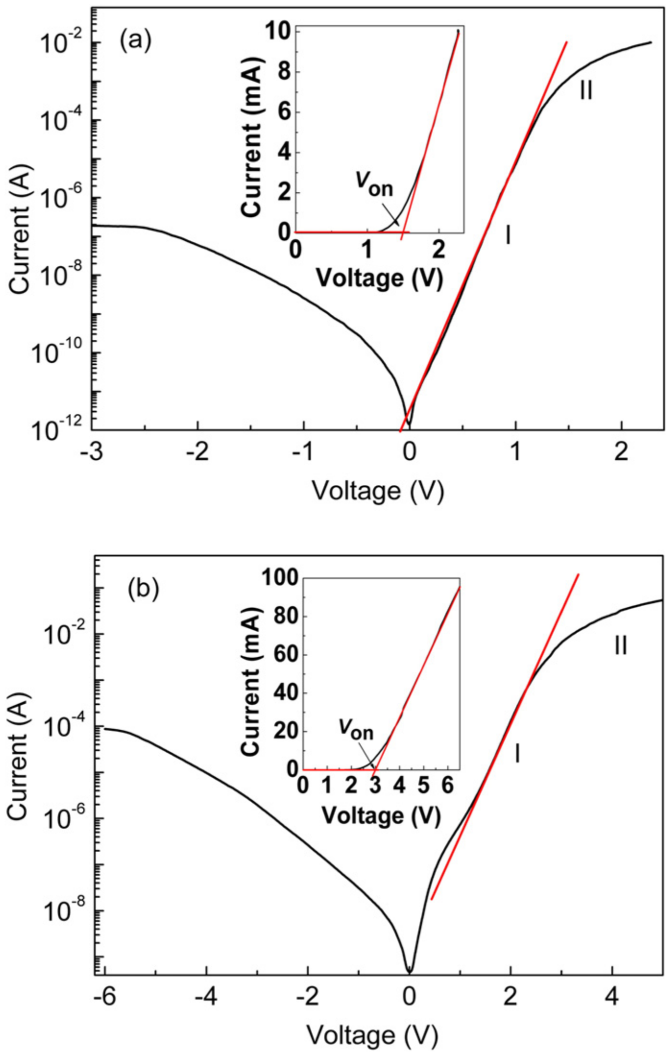

Fig. 2. *I–V* characteristics of (a) AlGaN/GaN and (b) InAlN/GaN SBDs measured at room temperature, with the V_{on} plotted in the inset.