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Influence of Mesa Edge Capacitance on Frequency Behavior of Millimeter-wave AlGaN/GaN HEMTs

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ABSTRACT

The influence of mesa edge capacitance on the frequency characteristics of AlGaN/GaN HEMTs with 90 nm gate length was studied in this paper. To extract mesa edge capacitances, a small-signal equivalent circuit model considering mesa edge capacitances was provided. Based on the model, the intrinsic gate capacitances of AlGaN/GaN HEMTs with 2×20 μm, 2×30 μm, 2×40 μm, and 2×50 μm gate widths were extracted, respectively. Through linear fitting along gate width for the extracted results and simulations, 8.06 fF / μm^2 of mesa edge capacitances at V_{gs} = -4.5 V and V_{ds} = 8 V in the devices with 2×20 μm gate width was obtained, which can be about 33.2% of the total gate capacitance. Mesa edge capacitances results in a significant drop of current-gain cut-off frequency (f_T), and the effect is more serious in the shorter gate length devices.

Keywords: AlGaN/GaN, HEMT, small-signal, mesa, capacitance.

1. Introduction

High electron mobility and saturation velocity enable AlGaN/GaN high electron mobility transistors (HEMTs) to be very attractive for millimeter wave applications [1]-[3]. Gate-length scaling is one of the main approaches to increase the f_T, and it has been very effective down to about 100 nm. However, for devices of the gate length scales below 100 nm, the delay caused by parasitic components cannot be ignored [4]-[6]. The parasitic components in AlGaN/GaN HEMTs come from source/drain resistance and gate fringing capacitance. The source/drain resistance, which is composed of the access and contact resistance, results in RC parasitic charging delay by coupling with the gate capacitance, and the effects had been highlighted by several papers: K. Shinohara et al [7] reported a f_T/f_{max} of 310/364 GHz in 20 nm gate GaN DH-HEMTs by aggressive lateral scaling of the gate length (L_g) and the source-drain distance (L_{sd}) using a novel self-aligned gate technology and engineering of a thin top barrier layer. Dong Seup Lee et al [8] reported a 30-nm-gate-length device with an on-resistance (R_{on}) of 1.2 Ω•mm, a peak f_T of 300 GHz by applying an $In_{0.15}Ga_{0.85}N$ back barrier to improve the f_T. In the case of the gate fringing capacitance, it increases the total gate capacitance and causes an additional delay. Several components of the gate fringing capacitance have been studied by previous works. Dong Seup Lee et al [6] reported that the thicker Al_2O_3 passivation would increase the fringing gate capacitance, which could be about 30% of the total gate capacitance in the devices with a gate length below 35 nm.

Yan Tang et al [9] reported a 20 nm gate GaN HEMTs with the record-high f_T of 454 GHz through optimizing the epitaxial layer thickness, carrier distribution, and bias control to suppress the fringing gate capacitance. Thus, reducing the fringing gate capacitance is an effective approach to improve the frequency response for short length devices. However, as a component of the fringing gate capacitance, mesa edge capacitance (C_g^{ME}) has not been systematically studied.

In this work, we investigated the impact of the mesa edge capacitance on the frequency characteristics in AlGaN/GaN HEMTs with 90 nm gate length. Firstly, a small-signal model considering mesa edge capacitances was provided, and the intrinsic gate capacitances were extracted. Then, the intrinsic gate capacitances were analyzed as a function of the gate widths. Finally, mesa edge capacitances were obtained and the impact of mesa edge capacitance on the frequency performance of the devices was studied.

2. Device fabrication

The AlGaN/GaN HEMTs were grown by metal-organic chemical vapor deposition on sapphire substrates. The Epitaxial layers consisted of a 1.8 μm of GaN buffer layer, a 22 nm $Al_{0.26}Ga_{0.74}N$ barrier layer, and a 2 nm GaN cap layer. Mesas were formed by using chlorine and inductively coupled plasma (ICP) etching. AlGaN/GaN HEMTs with 4

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