Ka band High RF performance AlGaN/GaN HEMTs

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Abstract. To realize high RF performance AlGaN/GaN high electron mobility transistor (HEMT), two SiNx passivation layers were respectively grown on the surface of AlGaN/GaN epi wafer by inductively coupled-plasma chemical vapor deposition (ICP-CVD) and plasma enhanced chemical vapor deposition (PECVD). The two-stage passivation can effectively suppress the current collapse and decrease the parasitic parameters. To verify the performance improvement, a 6 × 50 μm GaN HEMT device was fabricated and measured. The device shows a maximum drain current of about 1067 mA/mm and a maximum transconductance of about 433 mS/mm, the cut-off frequency (fT) of 45.4 GHz at a gate bias of -1.5 V and a drain bias of 20 V. The device shows a power density of 3.7 W/mm, a power-added efficiency (PAE) of 46.5% and power gain of 8.5 dB by load-pull measurement. In addition, a 34-36 GHz GaN monolithic microwave integrated circuit (MMIC) was fabricated, which exhibits an output power of about 41.5 dBm, a PAE of 20% and a gain of 15.5 dB.

1. Introduction
HEMTs guiding currents by two-dimensional electron gas have been regarded as a promising candidate for high frequency power amplification [1, 2]. Owing to the excellent material properties of GaN, such as wide band gap (3.4 eV), high breakdown field and an extremely high saturated electron velocity, the GaN-based power HEMTs involving AlGaN/GaN, have drawn much more attention in the past decades [3, 4]. In late 1990s, GaN-based HEMTs have demonstrated much larger power application. Additionally, the GaN-based HEMTs show special advantages of high temperature tolerance and radiation hardness. Thereby, the GaN-based HEMTs possess great potential applications in the fields of high frequency, high power and high temperature. At present, AlGaN/GaN-based HEMTs have attracted many attentions [5, 6]. Recently, the research about the GaN microwave devices in the band of L, S, C, X and Ka were hot topics [7, 8]. However, surface passivation is one of the most important limits to the realization of high frequency and high power AlGaN/GaN HEMTs [9-
Generally, the surface and crystalline defects always lead to electron traps that dramatically degrade the RF performance [12].

In this paper, SiN passivation approach based on ICP-CVD and PECVD techniques was utilized to reduce the electron trapping effect and improve the performance of AlGaN/GaN HEMT devices. In addition, the PECVD SiN layer was selectively removed by dry etching technique based on the etching rate difference between the two layers grown by ICP-CVD and PECVD. Based on this fabrication approach, a 6 × 50 μm GaN HEMT and a 34-36 GHz GaN MMIC were successfully achieved. Then, the performances of the fabricated devices were investigated systematically. The results indicated that the fabricated devices and MMIC show excellent performances and have wide application prospects.

2. Device structure and fabrication

The Fig. 1 shows the cross section of an AlGaN/GaN HEMT. The device consists of SiN passivation layer, GaN capping layer, AlGaN barrier layer, GaN buffer layer, SiC substrate, and the source (S), gate (G), drain (D) contacts. To improve the performances, the gate-close-to-source structure and T-shaped gate with sloping sides, were utilized in the HEMT.

![Figure 1. Structure of the AlGaN/GaN HEMT](image)

To fabricate the HEMT devices, the epitaxial layers involving i-GaN buffer layer, AlGaN barrier layer and GaN capping layer were grown on SiC substrate by MOCVD successively. The source and drain ohmic contacts were fabricated by evaporating Si/Ti/Al/Ni/Au layers and following the rapid thermal annealing in nitrogen ambient. A 1500 Å high-density SiNx layer was deposited by ICP-CVD at 350°C. The gate contact was fabricated by evaporating Ni/Au layers. For device isolation, the active region of the device was patterned and defined by ion implantation using B+. The T-shaped gate was made by techniques of step-and-scan lithography, deposition and etching. The drain and source metal layers were thicken by electroplating process to meet the requirement of high power. Finally, the thinning and through-hole grounding processes to the back of the wafer were performed. Using to these processes, we fabricated a series of HEMTs with gate width of 6 × 50 μm.

To fabricate the 34-36 GHz MMIC, the capacitance was fabricated by using the MIM process. A 150-nm-thick SiNx was deposited by PECVD as the dielectric layer of the capacitance. Then, Ni/Cr resistances were fabricated. Because the PECVD SiNx layer above the gates could enlarge the parasitical parameter of gate capacitance, the PECVD SiNx layer should be removed. Compared with PECVD SiNx, the ICP-CVD SiNx film is harder with better quality due to the high-density plasma in the ICP-CVD produced by two high-power RF sources. The dry etching rate with SF6 plasma of the hard ICP-CVD SiNx film is 1/4 of that of the PECVD SiNx film. Based on the different etching rates, the PECVD SiNx on the T-shaped gate can be selectively removed, as shown in. Fig. 2 shows optical microscope image of a fabricated 6× 50 μm HEMT.
Figure 2. Optical microscope image of fabricated 6 × 50 μm HEMT.

The remained ICP-CVD passivation layer can protect the surface of GaN/AlGaN, even when the PECVD SiNx passivation was removed. Additionally, the low capacitance of gate and source is conducive to the high-frequency performance of HEMT. It should be noted that, the intrinsic parameters of capacitance would be further decreased if the passivation layers were removed completely. However, the performance of device might become unstable because of the well-known phenomena of current falling.

3. Measurements and discussions

To investigate the device performance of the fabricated GaN-based HEMT, pulsed I-V measurements were performed on different conditions, as shown in Fig. 3 (a). A pulse width of 1 μs with a duty cycle of 0.1% was applied to both the gate and drain voltages. The output current drops from 1.067 A/mm (Vgsq = 0 V, Vdsq = 0 V) to 1.003 A/mm (Vgsq = -3 V, Vdsq = 15 V) at the point of (Vgs = 1 V, Vds = 5 V). The current collapse is about 6 %.

Figure 3. Pulsed I-V characterizations of the fabricated HEMT: (a) Drain current density at several different conditions. (b) Drain current density and transconductance of the fabricated HEMT at a gate bias of -3 V and a drain bias of 15 V.

The device exhibits a maximum drain current density of about 1067 mA/mm and a maximum transconductance (Gm) of 433 mS/mm at a gate bias of -3 V and a drain bias of 15 V, as shown in Fig. 3 (b).
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Fig. 4 and Fig. 5 show the load-pull measured results of the transistor at 29 GHz. The DC conditions were Vds = 20 V and Vgs = -2.5 V. At room temperature, the 300(6×50) am device shows PAE of 46.5 %, an power gain of 8.5 dB and a power of about 30.5 dBm, so the power density was 3.7 W/mm.
4. Conclusion
A SiNx passivation method based on ICP-CVD and PECVD techniques was utilized the RF performances of HEMTs for Ka-band amplifiers. The proposed passivation approach can effectively suppress the current collapse and decrease the parasitic parameters of GaN HEMT. The fabricated $6 \times 50 \mu m$ GaN HEMT shows a maximum drain current of about 1067 mA/mm, a maximum transconductance of about 433 mS/m, a power density of 3.7 W/mm, a PAE of 46.5 % and a power gain of 8.5 dB. The 34-36 GHz GaN MMIC exhibited an output power saturation of about 41.5 dBm, a PAE of 20% and a gain of 15.5 dB. Thus, the proposed technique can be used in the Ka-band MMIC.

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