GaN-Based Schottky Varactors for High-Power RF Applications

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1. Introduction

High performance AlGaN/GaN high electron mobility transistors (HEMTs) have been successfully employed for high power RF applications. Most of the recent researches focused on GaN-based power amplifiers (PAs) and low-noise amplifiers (LNAs) [1][2]. For typical RF front-end applications, voltage-controlled oscillators (VCOs) are also of great importance for reference signal generation. However, little has been reported on VCOs using GaN HEMT technology [3]. One of the main obstacles of GaN-based VCOs is the realization of high-Q varactor in this technology.

It is well known that a high quality-factor LC tank is critical for high performance VCOs. In CMOS technology, the accumulation-mode MOS varactors have a relatively higher quality factor compared with that of the spiral inductors in the GHz range. As a result, the varactors usually are not the dominant factor of the LC tank. On the other hand, it is difficult to obtain a high-Q schottky varactor on the basis of GaN process [4][5], which becomes the main reason to limit the overall Q-factor of the LC tank. In this work, we investigate the effects of the gate and body leakage currents and the device geometry on GaN-based varactors, which provide guidelines of achieving high-Q varactors for high performance and high power GaN-based VCOs.

2. Device Design and Fabrication

The device structure of the modulation-doped AlGaN/GaN heterostructure grown on semi-insulated silicon substrate is shown in Fig. 1. Device isolation was achieved by dry etching using Cl₂/Ar gas mixture, and the body ohmic contacts were then formed with Ti/Al/Ti/Au using rapid thermal annealing at 750°C for 30 seconds in a N₂ ambient. The alloy Ni/Au was deposited to form the schottky gate contact. Finally, a silicon nitride layer was deposited for surface passivation.

Fig. 2 shows the layouts of the AlGaN/GaN schottky varactors with different geometries. For each device, the gate length is 2 μm and the gate (G) to body (B) spacing LGB is also 2 μm. Three different designs including one-, two-, and four-finger devices were realized. For a fair comparison, the total width of the three types of devices is all 100 μm. Previous studies suggest that the etching process can induce damage especially underlying the gate finger across the edge of the mesa region [5]. Most importantly, the etching damage can also introduce traps resulting in higher leakage current and lowering the varactor quality factor. This effect should be geometry-dependent and thus can be investigated by using the test devices with different finger numbers.

3. Results and Discussion

All the tested devices were measured with RF ground-signal-ground (GSG) probes and the open-pad de-embedding procedure was employed to remove the probing pad parasitics. Fig. 3 shows the measured C-V characteristics at different frequencies including 900 MHz, 1.8 GHz, 2.4 GHz, and 3.0 GHz. As can be seen, the schottky varactors have a wide tuning range higher than 4 under the change of the gate bias VG. The capacitance is tunable when VG varies in the range from ~3.0 V to ~4.5 V, which implies that the 2DEG channel starts to deplete and the depletion region increases with a more negative VG applied. In addition, as the finger number changes from 1 to 4, the capacitance especially under higher VG (~0 V to ~3.5 V) increases obviously even the total finger width is identical for the three cases. This can be attributed to the increased fringing and substrate capacitances for the varactor with more fingers.

Fig. 4 shows the Q-factors of the schottky varactors at different frequencies. The results indicate that the one-finger device shows a higher Q-factor than the other two types. Also, a notch is observed at around VG of ~4.0 V and the Q-factor drops obviously as the frequency increases when VG > ~4.0 V. The observed trends can be explained by the corresponding gate and body leakage currents IG and IB respectively as presented in Fig. 5. With more finger numbers, both IG and IB increase due to the additional traps from the gate fingers across the mesa region and the buffer layer. The effective gate and body resistances, connecting in parallel to the gate capacitance and body capacitance respectively, become smaller leading to the reduction of Q-factor.

As also shown in Fig.5, the body leakage current IB is much higher than the gate leakage current IG and is the dominant factor of the Q-V characteristics when VG > ~4V. The Q-factor maintains as a constant as VG varies from 0 to ~3V, which is consistent with the trend of IG. As VG < ~3V, the 2DEG channel starts to deplete and the capacitance decreases rapidly resulting in the obvious drop of the Q-factor. Finally, the 2DEG channel is fully depleted when VG < ~4V. Under this condition, the leaky path from the body is closed due to the fully depleted channel; IB decreases rapidly and the Q-factor increases again. The gate leakage becomes important and thus the one-finger device with the smallest IG presents the highest Q value.

4. Conclusion

In this study, the Q-factors of GaN-based schottky varactors with different geometries were investigated. We found that the Q-factor strongly depended on the leakage current from the mesa damage during the process. The varactor with only one-finger has higher Q-factor compared with the varactors with more finger numbers. This study provided information to further enhance the Q-factor of GaN schottky varactors for RF VCO applications.
Fig. 1 Layer structure and equivalent circuit model of the AlGaN/GaN Schottky varactor.

Fig. 2 Varactor layouts with different finger numbers:
(a) one-finger (b) two-finger (c) four-finger device. The total width is 100 μm in each case.

Fig. 3 C-V characteristics at (a) 900 MHz (b) 1.8 GHz (c) 2.4 GHz and (d) 3.0 GHz.

Fig. 4 Q-V characteristics at (a) 900 MHz (b) 1.8 GHz (c) 2.4 GHz and (d) 3.0 GHz.

Fig. 5 $I_D$ and $I_G$ as a function of gate bias.

References