Abstract #2206, 224th ECS Meeting, © 2013 The Electrochemical Society

Improved Passivation Techniques for AlGaN/GaN HEMTs

T.J. Anderson, A.D. Koehler, M.J. Tadjer, K.D. Hobart, N. Nepal, T.I. Feygelson, B.B. Pate, C.R. Eddy, Jr, F.J. Kub

Naval Research Laboratory
4555 Overlook Ave SW, Washington, DC 20375

AlGaN/GaN high electron mobility transistors (HEMTs) are appealing for high power, high frequency and high power switching applications, however trapped charge in the access region between the gate and drain, depleting the two-dimensional electron gas (2DEG), limits performance and increasing the dynamic on-resistance ($R_{ON,DYN}$). Typically, plasma-enhanced chemical vapor deposition (PECVD) SiN_x is used to passivate AlGaN/GaN HEMT surface states. In this work, we present improved passivation techniques by studying the effects of surface cleaning, passivation material, and deposition method to mitigate current collapse in AlGaN/GaN HEMTs.

The cleaning process before passivation is critical. Typically combinations of oxygen plasma and wet chemical treatments are used. The ex-situ cleaning process before PECVD SiN_X deposition has been optimized to remove carbon from the surface and etch any native oxides. The optimization of the cleaning process has resulted in a 50% reduction in dynamic on-resistance degradation under off-state stress. The use of in-situ SiN_X has also been proposed as a method to create an even cleaner surface [1,2]. An advantage of this process is that the passivation layer can be deposited directly after the barrier layer growth, and is typically of high quality. A systematic study has been performed to investigate the effect of SiN_X thickness and deposition method (in-situ vs PECVD) on device performance.

Recently, AlN has become attractive as a passivation layer for HEMT devices [3]. The development of atomic layer deposition (ALD) and atomic layer epitaxy (ALE) methods for depositing high-quality, low-temperature AlN films has enabled the conformal deposition of AlN on processed HEMTs as passivation material. A particular advantage of the deposition technique is the ability to use in-situ cleaning techniques, thus presenting another method of forming a clean interface. We have investigated thin (4 nm) ALE-deposited AlN films as passivation layers. It was found that as the deposition temperature is increased up to 500 °C, the passivation quality improved relative to conventional PECVD SiN_X films. In particular, there was reduced gate and off-state leakage current, minimal increase in dynamic on-resistance under off-state stress conditions, and little change in the 2DEG properties (mobility, sheet carrier density).

Diamond has been heavily investigated as an integrated heat spreading layer, however it has also recently been reported to have passivation properties as well [4,5]. The high deposition temperature and harsh microwave CVD conditions (750 °C, H_2/CH_4 atmosphere) provide a very clean surface. The current collapse ratio is comparable to PECVD SiN_X, but the thermal conductivity is much higher, resulting in improved device performance as a result of the reduced channel temperature.

In order to quantify passivation and study current collapse under realistic operating conditions, a boost converter circuit was integrated on a probe card. This enables the insertion of devices into a circuit without packaging, allowing for rapid prototyping of the various passivation schemes as well as device geometry effects. An increased circuit efficiency is visible in the better-passivated devices as a result of the larger voltage swing from the reduced current collapse. This circuit enables us to study HEMT performance in the circuit as a function of duty cycle, operating frequency, and input voltage.

1. J. Derluyn, S. Boeykens, K. Cheng, R. Vandersmissen, J. Das, W. Ruythooren, S. Degroote, M.R. Leys, M. Germain, G. Borghs. J. Appl. Phys. 98, 054501 (2005).
2. M.J. Tadjer, T.J. Anderson, K.D. Hobart, M.A. Mastro, J.K. Hite, J.D. Caldwell, Y.N. Picard, F.J. Kub, C.R. Eddy, Jr. J. Electron. Mater. 39, 2452-2458 (2010)
3. S. Huang, Q. Jiang, S. Yang, Z. Tang, K.J. Chen. IEEE Electron Dev. Lett. 34, 193-195 (2013)
4. M.J. Tadjer, T.J. Anderson, K.D. Hobart, T.I. Feygelson, J.D. Caldwell, C.R. Eddy, Jr. F.J. Kub, J.E. Butler, B.B. Pate, J. Melngailis. IEEE Electron Dev. Lett. 33, 23-25 (2012)
5. T.J. Anderson, A.D. Koehler, M.J. Tadjer, K.D. Hobart, T.I. Feygelson, J.K. Hite, B.B. Pate, C.R. Eddy, Jr, F.J. Kub. 2013 CS Mantech Technical Digest

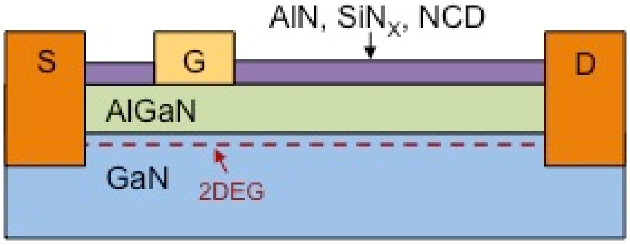

Figure 1. Cross-section of passivated HEMT

Table I. Table of DC parameters for passivation schemes

Passivation	n_s (cm^{-2})	Hall Mobility ($cm^2/(V \cdot s)$)	R_{sh} (Ω/□)	V_T (V)	SS (mV/dec)
Unpassivated	7.12×10^{12}	1703	523	—	—
SiN (100nm)	8.60×10^{12}	1567	463	-3.51	116
300°C AlN (4nm)	8.30×10^{12}	1790	418	-3.12	115
500°C AlN (4nm)	8.55×10^{12}	1765	414	-3.25	76

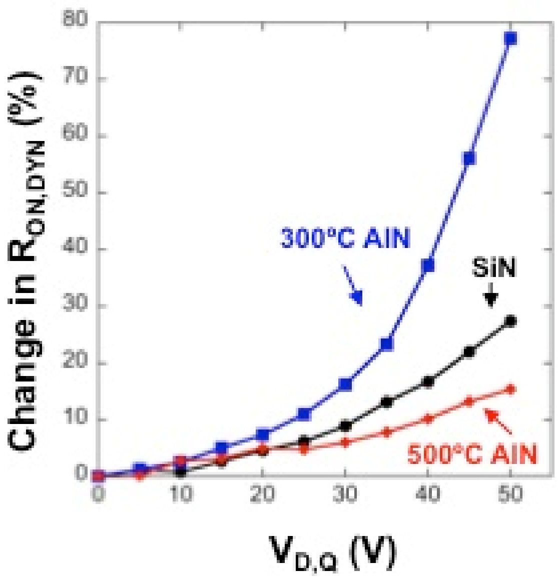

Figure 2. Change in dynamic R_{ON} for various quiescent point drain voltage stress