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Influence of the structural and compositional properties of PECVD silicon nitride as a passivation layer for AlGaN HEMTs

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Maximum RF output power of GaN based HEMTs is significantly less than what can be estimated from its DC characteristics. The responsible current collapse mechanism is generally indicated as DC-to-RF current dispersion or gate lag and is caused by traps located at the semiconductor surface that capture 2DEG-electrons. Surface passivation with high quality plasma enhanced chemical vapour deposition (PECVD) SiN_x reduces gate lag [1].

We have investigated the compositional and structural properties of PECVD deposited SiN_x and relate those to device performance. We have looked at the effect of various PECVD parameters like gas composition (SiH₄/NH₃ ratio and ammonia-free SiN_x), process pressure, plasma power and deposition temperature. The investigated SiN_x layers were deposited on 2 inch Si wafers to ease the characterization and interpretation of the results. Therefore this analysis can only be used as an indirect reference for the investigations of the surface passivation and of the amount of gate and drain leakage currents of the AlGaN HEMTs.

The SiN_x layers were systematically characterized using spectral ellipsometry (400 up to 1700 nm), this measurement gives among others information on the refractive index of the dielectric layer, its band gap, the absorption at 3.44 eV (Si-Si bond). Fourier Transform Infra Red (FTIR) spectroscopy was carried out to determine the H₂-incorporation in the SiN_x layers. For a selection of layers, the effective minority carrier lifetime was measured. Finally strain measurements were also performed.

We have investigated the influence of the following PECVD process parameters:

- Chamber pressure between 150 and 1000 mTorr.
- SiH₄ flow (4 – 20 sccm)
- RF power was varied from 20 up to 150W including a combination of frequencies (13.56MHz and 50 KHz).
- Table temperature was varied for 30 up to 350°C.

The SiN_x layers were characterized by the following techniques:

- Spectral ellipsometry (refractive index, presence of Si-Si bond and optical band gap)
- Fourier Transform Infra red spectroscopy (H₂-incorporation)

- effective minority carrier lifetime
- Measurement of stress/strain

Several SiN_x layers with different values of refractive index, optical band gap, H₂-incorporation and residual mechanical stress have been selected to investigate their passivation capability on small periphery (W_g = 2 x 40 μm, L_g = 2 μm) HEMTs fabricated on undoped Al_{0.25}Ga_{0.75}N/GaN layers grown on a sapphire substrate. The influence of the different SiN_x films on the surface passivation has been investigated using pulsed DC I-V measurements to determine the drain current recovery, and gate and drain leakage currents at pinch-off before and after SiN_x passivation. It has to be noted that all devices have been fabricated in the same way up to the point of surface passivation where the various PECVD layers were investigated.

The best device performance has been obtained with a 100 nm thick SiN_x layer deposited using the following process conditions:

1. SiH₄:NH₃:N₂ = 16:13.4:980 sccm, respectively.
2. RF power (13.56 MHz): 20W
3. Pressure: 650 mTorr
4. Table temperature: 300°C

The corresponding parameters of this SiN_x layer are:

- Refractive index at 2 eV: 1.97
- Extinction coefficient at 3.44 eV: 0.025
- Optical bandgap: 2.78 eV
- Stress: tensile, 390 MPa

One can notice that the high refractive index and the extinction coefficient at 3.44 eV clearly indicate that the SiN_x layer is Si-rich. The optical band gap (2.78 eV) is quite low whereas the commonly used SiN_x to passivate Si-based solar cells should have an optical band gap around 5 eV.

However the optimized SiN_x layer alone was not sufficient to achieve good RF performance of the HEMTs. Best RF device performance was only achieved when the optimized SiN_x layer was used in conjunction with an adequate treatment that consists of a low-power Ar-plasma after the ohmic contacts and cleaning using a NH₄OH solution (1 min) just before the Schottky metallization [2]. The ammonia dip accounted for a substantial gate leakage reduction from 6.7 mA/mm down to 0.4 mA/mm. The best small periphery HEMTs show a drain current density of 450 mA/mm.

References

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