

Ternary GaN Based HEMT for High Frequency Application

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Abstract

To achieve high performance in HEMT devices such as high power gain cut off frequency and high current gain cut off frequency and to get maximum drain current and transconductance. By using lattice matched quaternary barrier such as In AlGaIn and re-growing the ohmic contacts in HEMT device. To reach high f_{max} we have to combine a low gate recess technology, scaled device geometry and recessed source and drain ohmic contact to simultaneously enable minimum short channel effect. Short channel effect will lead to current leakage in the device. This effect can be suppressed with the help of barrier and back barrier.

1. Introduction

Nowadays, the reported output power density of GaN 30-40 W/mm is more than ten times higher than that of GaAs based transistors. So the device size is reduced. Impedance matching is very easy in small devices and so losses in the device get reduced. To increase the performance of GaN HEMTs at millimeter-wave frequencies (30–300 GHz). One of the key challenges to achieve high-gain millimeter-wave power amplification is to increase the maximum power-gain cutoff frequency (f_{max}). f_{max} is the maximum frequency at which the Transistor still provides a power gain and can be expressed as

$$f_{max} \approx \frac{ft}{2\sqrt{(Ri + Rs + Rg)/(2\pi ft)RgCgd}}$$

Where ft is the current-gain cutoff frequency and Cgd is the gate-drain (depletion region) capacitance, while Ri , Rs , Rg , and Rds represent the gate-charging, source, gate, and output resistance, respectively.

2. Literature Review

1. Fundamentals of HEMT
2. GaN based HEMT
3. Techniques that can be used to improve the cut off frequency of the device

1. Fundamentals of HEMT

The high electron mobility transistor (HEMT), which is also named as heterostructure field-effect transistor (HFET), modulation doped field-effect transistor (MODFET), two-dimensional electron gas field-effect transistor (TEGFET), or selectively doped heterostructure transistor (SDHT), was invented about 20 years ago. The first HEMT device was reported in 1980, after the successful growth of modulation doped AlGaAs/GaAs heterostructure. By employing two semiconductor materials with different band-gaps, an electron potential well is formed at the hetero-interface between AlGaAs and GaAs. The electrons are confined in this potential well to form a two-dimensional electron gas (2DEG). Due to the two-dimensional feature of the electrons in this conduction

channel, the carrier mobility can be enhanced remarkably. The first generation of HEMT structure was constructed in lattice-matched GaAs- based AlGaAs/GaAs system, which has been widely studied and used in radio-frequency (RF), microwave and millimeter wave applications. Additional material systems, including pseudo-morphic HEMT (i.e. with InGaAs channel in GaAs-based material system) and InP-based InAlAs/InGaAs have also been studied to achieve higher operating frequencies and lower noise.

2. GaN based HEMT

GaN HEMTs have attracted attention due to their high-power performance. HEMT transistors are able to operate at higher frequencies than ordinary transistors, up to millimeter wave frequencies, and are used in high-frequency products such as satellite television receivers, voltage converters, and radar equipment.

Piezo-electric polarization in nitrides have been found to be ten times higher than in arsenides. These two charge accumulation mechanisms result in very high polarization based electron density in GaN-based hetero-structures very near to the interface. This two Dimensional Electron Gas (2DEG) forms even without any significant doping. The absence of doping and spatial separation of channel electrons from ionized donors leads to the reduction of ionized impurity scattering and, consequently, an increase in electron mobility. A higher mobility and electron density leads to higher output current density. Nowadays, the reported output power density of 30-40 W/mm is more than ten times higher than that of GaAs based transistors. Thus, for the same output power, device size can be reduced by the same factor using GaN. The polarization field in the nitride-based heterostructures comes from two parts, the spontaneous polarization and the piezoelectric polarization. Due to the noncentral symmetry, nitrides exhibit a macroscopic spontaneous polarization field along the hexagonal c-axis in the wurtzite lattice.

In addition, nitrides have a strain induced piezoelectric polarization, which is much higher than that in the traditional III-V semiconductors. The direction of the polarization field in nitrides depends on the polarity of the crystal, that is, whether it's Ga-faced or N faced. Almost all MOCVD-grown nitrides are Ga-faced, while the nitrides grown in MBE system are usually N-faced. With the assistance of the polarization field, a polarization charge

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density of 10^{13} cm^{-2} can be achieved in a strained- $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}/\text{relaxed-GaN}$ system.

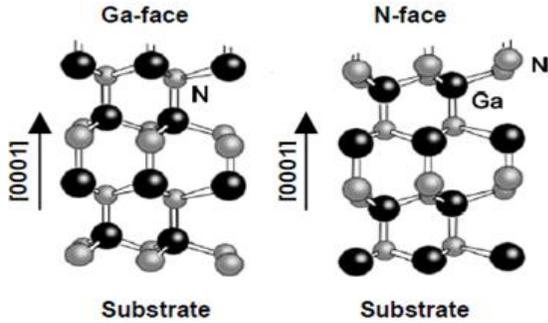


Fig: 1. GaN Crystal Structure

3. Techniques that can be used to improve the cut off frequency of the device

3.1. Device grown on semiconducting material

If the device is grown on a semiconducting material the device internal capacitance and resistance, so that the current and power gain cut off frequency get improved. SiC is excellent material. Fortunately, the high thermal conductivity of SiC substrates (330 W/m K) allows these high power densities to be efficiently dissipated for realistic drain efficiencies, preventing the extreme channel temperatures that would result due to self-heating with other substrate technologies.

3.2. Low-damage gate-recess technology

In field-effect transistors, the short-channel effects play an important role in the high-frequency characteristics. However, improvement of the short-channel effects has been seldom a path to improve the high-frequency performance in GaN HEMTs. In this letter, we applied a low-damage gate-recess technology to effectively suppress the short-channel effects. The resultant HEMT showed excellent output characteristics. Channel length depend on gate length. To increase the speed of the device gate as a greater influence. The type of gate, size of gate the used is very much important.

3.3. Regrowing ohmic contact

Mainly regrowing the ohmic contact is concept used in HEMT in order to reduce the on-resistance of the device. If the device ohmic contact layer is regrown with silicon nitride, silicon oxide etc., with few nm thickness. And on-resistance, and sheet resistance is very much reduced. It is reported a value of below 0.06 ohm.mm .

3.4. Passivation

It can done by using substrate such as SiC or SiN material among that SiN shows excellent results. The downscaling of the gate length in nitride-based high-electron mobility transistors (HEMTs) has proven challenging because ultrathin-barrier AlGaIn/GaN structures are impaired by strong surface depletion effects or by physical etch damage in recessed gate structures. AlInN barrier layers have evolved as a promising alternative for the implementation of thin-barrier GaN HEMTs with high 2-D electron gas channel densities because they are subject to weaker surface depletion effects than AlGaIn/GaN

structures. AlInN/GaN HEMTs have been demonstrated with barriers as thin as 3 nm, opening the possibility to maintain favorable gate aspect ratios

LG/dGC down to extremely short gate lengths. Advances in growth techniques allowing the realization of AlInN/GaN HEMT structures with very low channel sheet resistances were followed by the demonstration of increasingly attractive cutoff frequencies on both Si and SiC substrates. Additionally, the predominance of spontaneous over piezoelectric polarization in AlInN/GaN HEMTs makes them less sensitive to potential reliability limitations involving stress-related mechanisms. By selectively removing the SiN passivation film around the gate electrode to minimize parasitics. While the characterization of such unpassivated transistors may be of interest for demonstrations of the ultimate transistor performance with a reduced total gate capacitance $CGS + CGD$, it remains that practical transistors must however be passivated for reliability reasons, as well as to control the effects of surface states.

3.5. Experiment

Here the ternary GaN based HEMT is designed with Technology Computer-Aided Design (TCAD) refers to using computer simulations to develop and optimize semiconductor processing technologies and devices. TCAD simulation tools solve fundamental, physical, partial differential equations, such as diffusion and transport equations for discretized geometries, representing the silicon wafer or the layer system in a semiconductor device. This deep physical approach gives TCAD simulation predictive accuracy. TCAD simulations are used widely in the semiconductor industry. As technologies become more complex, the semiconductor industry relies increasingly more on TCAD to cut costs and speed up the research and development process. In addition, semiconductor manufacturers use TCAD for yield analysis that is, monitoring, analyzing, and optimizing their IC process flows, as well as analyzing the impact of IC process variation

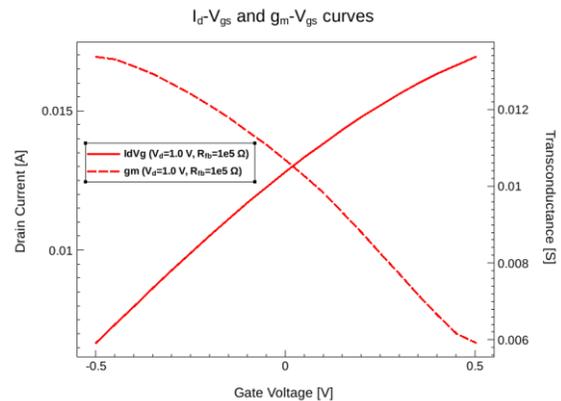


Fig: 2. Gate voltage Vs drain current and Transconductance

Here on a Substrate of 0.04 nm thick SiC HEMT is grown. Nuclear layer of 100 nm AlN is grown and $1.8 \text{ }\mu\text{m}$ GaN thick buffer is present at the top of it. Thickness of barrier is 10 nm AlGaIn and Channel is formed by 55 nm GaN (UID). spacer layer of 1 nm AlN is used in order to

separate barrier and channel. Metal gate of 40 nm foot print is used in order to reduce channel length as well as increase the speed.

Here ternary HEMT have given best result of f_t of 75 GHz and f_{max} of 675 GHz is attained.

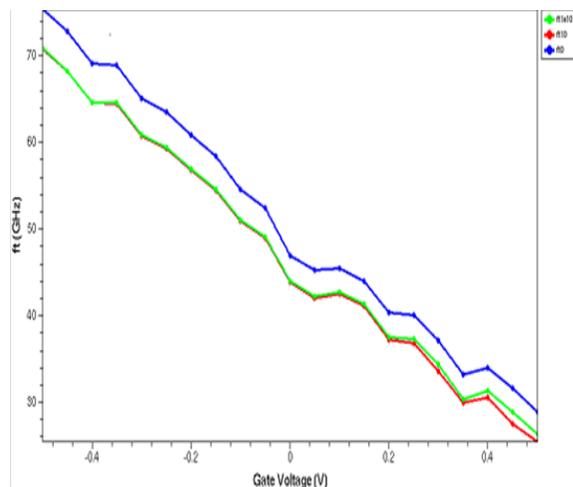


Fig: 3. Gate voltage Vs current gain cut off frequency

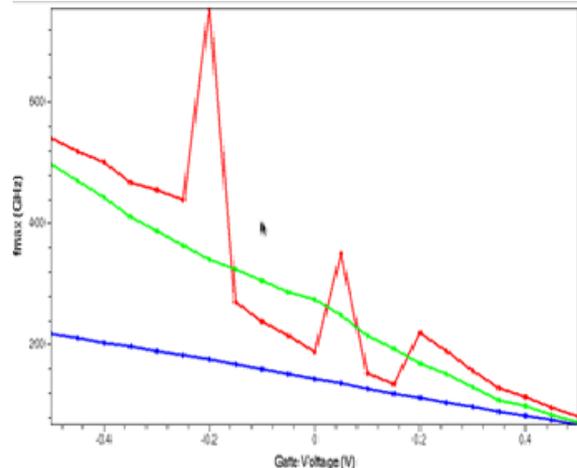


Fig: 4. Gate voltage Vs power gain cut off frequency

4. Conclusion

In this paper by altering the barrier thickness and UID GaN material current gain cut off frequency of about 75 GHz and power gain cut off frequency of about 675 GHz is achieved. Drain current of the device is about 0.015A and transconductance of about 0.015 S is attained.

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