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RESEARCH ARTICLE

Study of 2-DEG Channel asa Cavity Resonator for THz Applications

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Manuscript Info ***Abstract***

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In this paper the 2-dimensional electron gas channel formed in n-AlGaN/GaN based High electron mobility transistor has been discussed with its 2DEG sheet electron density. Due to increase the attention toward the tera hertz(THz) applications the effects of plasma waves (which can exist in the gated two-dimensional electron gas with linear dispersion law) in the 2DEG channel has been summarized. The presence of plasma waves in 2DEG can cause the 2DEG channel behaves as cavity resonator with resonant frequency in the THz range. The fringingeffect which limits the resonant plasma frequency has been discussed in detail. The effect of fringing on the 2-dimensional gas channel sheet electron density and 2DEG cavity resonator frequency(THz) has been displayed.

Introduction

The motivation behind the study of III-V nitride based devices was clear that these AlGaN/GaN nitride based devices are best for High speed applications, high mobility, high peak saturation velocity and also for essential radiation hardness(Vivek K. De and James D. Meindl, 1993). When the polarization (spontaneous and piezoelectric) effects has been studied in AlGaN/GaNthen an interface charges due to abrupt divergencein the polarization at AlGaN/GaN the heterointerface has been found which is not seen in GaAs based devices, which leads to higher 2DEG density and resulting into a high speed device. The terahertz (THz) frequency spectrum has many of its useful applications for communication in the free-space media, sensor,in the field of biomedicine and in searching for secreted explosivesand obscured missiles. The imaging at the terahertz frequency may also be useful for industrial practices, such as review of packaging density and quality control(S .M. Sze and Kwok K. Ng. 1981).

HEMT Device Structure with Its Gated Portion Equivalent Block Diagram Representation

The AlGaN/GaNheterostructure shown in Figure 1has been grown using the metal organic chemical vapor deposition(MOCVD) technique. The 2DEG channel has been formed at the heterointerface between the AlGaN narrow band gap and GaN wide band gap semiconductor layers. Voltage V(t) = $V_g + \delta V e^{iwt}$ which was applied between the gate contact and drain contact contains dc and ac componentwith amplitudes V_g, δV respectively and ac signal frequency *w*(H R Chen, W T Chen, M K Hsu, S W Tan and W S Lour. 2005).

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The block diagram representation of gated portion shown Figure 2including all parameters as capacitance, resistance and inductance has beenused to calculate the 2DEG density Σ beneath the gated portion(Figure 3)and cavity resonator frequency Ω function V_g (Figure 4) . When the voltageV(t) applied between the gate and drain contacts, 2DEG sheet density Σdepends on the gate bias voltage changes by relation as(**Kumar, V.2003)**

$$\Sigma = \Sigma_0 + \frac{\epsilon\epsilon_0 V_g}{e d_g} = \Sigma_0\left(1 - \frac{V_g}{V_{th}}\right) \quad (1)$$

Where $\Sigma_0$has been taken as the 2DEG sheet density when the gate voltage, $V_g = 0$ and $V_{th}$is the threshold voltage.

The 2DEG channel formed under the gated length L$g$can work as a resonant cavity for the plasma waves with the fundamental resonant frequency

$$\Omega = \frac{\pi}{2L_g}\sqrt{\frac{e^2\Sigma d_g}{\epsilon\epsilon_0 m^*}} \quad (2)$$

Here e, m*are taken as the charge of electron and effective mass of electron respectively and ϵ_0 is the dielectric constant of air, ϵ dielectric constantof the layer separating 2DEG channel and gate portion and dg taken thethickness of the layer(MICOVIC, M., et al. 2000).

The Influence of Fringing Effect on the 2DEG Channel

The fringing which is the extension of gate contact due to the nonideality of the gate contact 2DEG capacitanceas shown in Figure 5. Due the fringing effect the 2DEGchannel parameters has been changed. In Figure 5reference point x =0 coincides with the boundary of the gate contact, in this way that points with -Lg< x < 0 correspond to the 2DEG channel beneath the gate contact and x > 0 correspond to the ungated 2DEG channel region subjected to the fringing electric field.

The thickness of the 2DEG channel is assumed to be negligibly small. The distribution of fringing electric field at the 2DEG channel surface is similar to that in the middle plane of the fringed parallel plate capacitor with plate length L$g$and separation 2dg. The fringing electric field distribution can be found from relation and displayed in Figure 6.

$$E(\xi) = \frac{V_g}{L_g}\frac{1}{1+\exp(\xi)} \quad (3)$$

Where ξ a constant and Vg is the gate voltage.The distribution of the electric field in the structure with the gate contact extended in the direction x > 0 in such a way that separation between thegate contact and 2DEG surface varies as d^{fr}= dg(1+exp ξ). Furthermore, the ungated part of 2- dimensional electron gas channel subjected to the fringing electric field can be behaved in the same way as its gated portion.

The Influence of Fringing Effect on the 2DEG Channel Sheet Electron Density

Due to the fringing effect the ungated part of 2- dimensionalelectron gas channel subjected to the fringing electric field(Figure 6) andworks in the similar manner as the its real gated portion does(HU, X., et al.2000). So in theungated region the 2DEG sheet electron density equation is given as

$$\Sigma^{fr} = \Sigma_0^{fr} + \frac{\epsilon\epsilon_0 V_g}{ed_g(1+\exp(\xi))} \quad (4)$$

Where Σ_0^{fr} has been taken as 2DEG sheet electron density in the fringed region when thegate voltage, Vg = 0.

Now from Figure 3and Figure 7effect of fringing can be seen which is quite notable.

The Influence of Fringing Effect on the 2DEG Channel Cavity Resonator Frequency

There are several factors which reduces the the fundamental resonant frequency, fringing effect is one of them. It was clear from equation(1) that as we scaling down the gate length the the increase in cavity fundamental resonant frequency has been found out(RyosukeYamase, Takao Maeda, Irina Khmyrova, Elena Shestakova, EvgenyPolushkin, Anatoly Kovalchuk, Sergei Shapoval, 2012). In the presence of fringing effects cavity fundamental resonant frequency,

$$f^{fr} \approx \frac{f_0}{1+\frac{4d_g}{\pi L_g R_v}\left(\sqrt{1+\frac{\pi R_v L_{fr}}{2d_g}}-1\right)+\chi} \quad (5)$$

$$\chi = \frac{2d_g}{\pi L_g}(1+\ln\frac{4}{R_v} - 2\sqrt{\frac{2d_g}{\pi R_v L_{fr}}})$$

$$R_v = \frac{V_p^0}{V_g - V_{th}^0} \quad (7)$$

$$L_{fr} = \frac{d_g}{\pi}(1+\xi_2+exp\xi_2) \quad (8)$$

For δ doped High electron mobility transistor,

$$V_p = \frac{e\Sigma_d d_d}{\epsilon\epsilon_0}$$

Where f_0 is the fundamental frequency when no fringing takes place and given as $f_0 = \Omega/2\pi$, $V^0_{th}$is the threshold voltage at $Vg = 0$, ξ_2 is a adjustment parameter. Thus impact of fringing effect on 2- dimensional electron gas channel cavity fundamental resonant frequency has displayed in Figure 8and compared with Figure 4.

Conclusion

The 2DEG channel has been studied for various point of view as 2DEG sheet density and terahertz (THz) cavity resonator. From the discussion it was found out that 2- dimensional electron gas channel has approximately $50/2\pi$THz frequency at 10V gate voltage after neglecting fringing effect and approximately $7.3/2\pi$THz frequency at the same gate voltage after having fringing effect into consideration.

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RyosukeYamase, Takao Maeda, Irina Khmyrova, Elena Shestakova, EvgenyPolushkin, Anatoly Kovalchuk, Sergei Shapoval, 2012. Study of fringing effects in multi-cantilever HEMT-based resonant MEMS, InternationalJournal of Applied Electromagnetics and Mech.38: 2-3

Figure 1:Schematic diagram showing 2DEG layer in AlGaN/GaNheterostructure

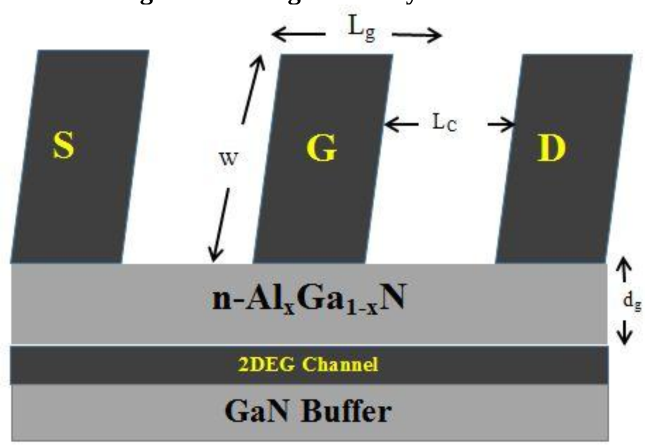

Figure 2: The block diagram representation of gated portion of above Figure 1

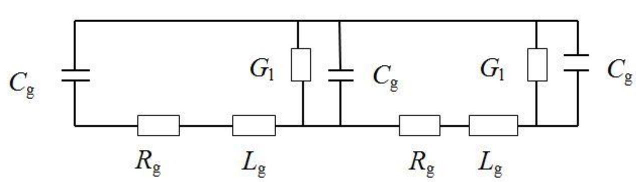

Figure 3:The plot showing the 2DEG density Σ beneath the gated portion function of gate voltage

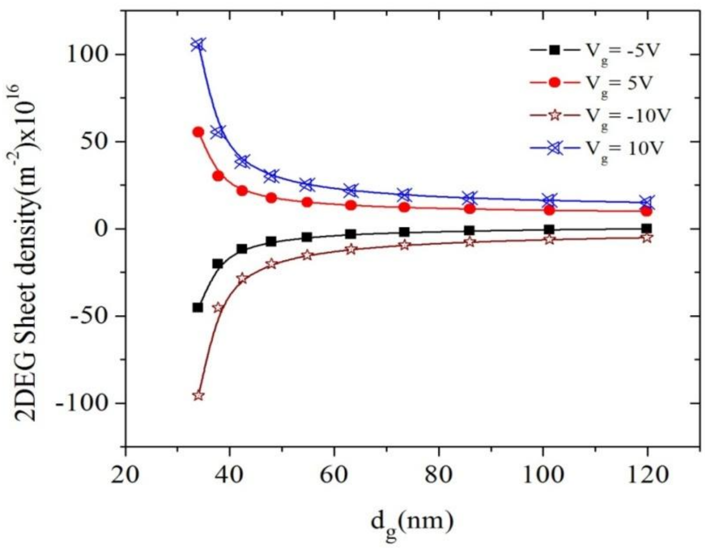

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Figure 4:The 2DEG channel as a cavity resonator frequency Ω function of gate voltage Vg

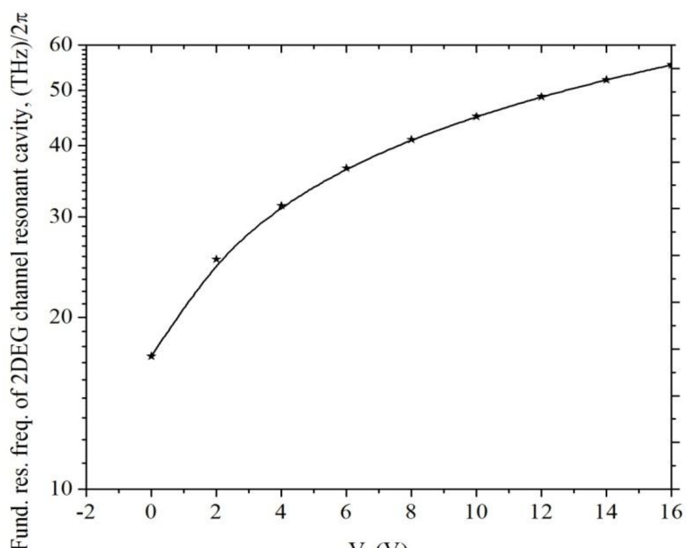

Figure 5: Plot showing the fringing effect in high electron mobility transistor at the gate contact

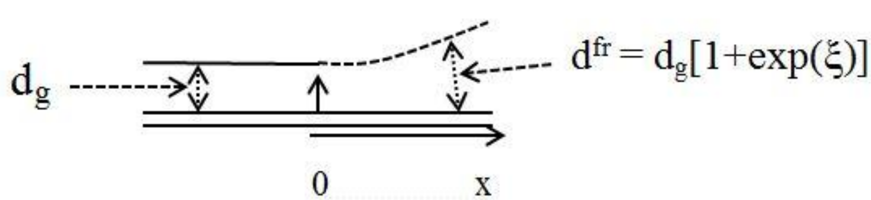

Figure 6:Plot showing the fringing electric field distribution

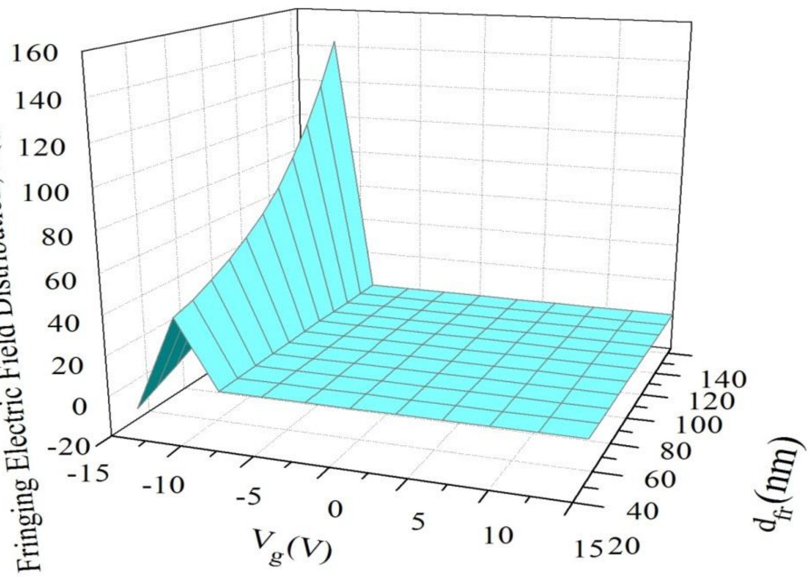

Figure 7: The effect of fringing on 2DEG channel sheet electron density