A new approach to determinate parasitic elements of GaN HEMT by COLD FET S-Parameter

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Abstract: A simplified approach to the parasitic elements of 2-gate figures GaN HEMT is introduced by pinch-off COLD FET S-Parameter. When extracting the parasitic parameter at pinch-off state, intrinsic circuit can be ignored as no current flows through it. As a result, if only taking extrinsic part into account, equivalent circuits constructed at different frequencies can extract different parasitic elements. With parasitic parameters from this approach, the simulation result of equivalent circuits agrees very well with experiments.

Keywords: Parasitic elements, GaN HEMT, COLD FET S-Parameter.

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1. Introduction

The development of GaN HEMT is very fast in the last years. Much effort has been put into developing accurate small-signal simulation models for GaN HEMT. It has been shown [1, 2] that the values of elements obtained for the intrinsic FET depend on the extrinsic ones. This implies that extrinsic elements must be extracted with a high degree of accuracy. The parasitic elements are usually determined from cold FET measurements. As Diamant and Laviron have suggested [3], the S-Parameter measurements at zero drain bias voltage can be used for the evaluation of device parasites because the equivalent circuit is much simpler. The standard procedure is based on the measured S-Parameter. First, the S-parameter is converted to Y-parameter. Then the Y-Parameter is taken into the extrinsic components' expression, the circuit elements of the GaN HEMT can then be calculated using analytical equations. The device used in this paper is shown in Fig. 1. It is a 2-figure GaN HEMT made in Nanjing Electronic Devices Institute.

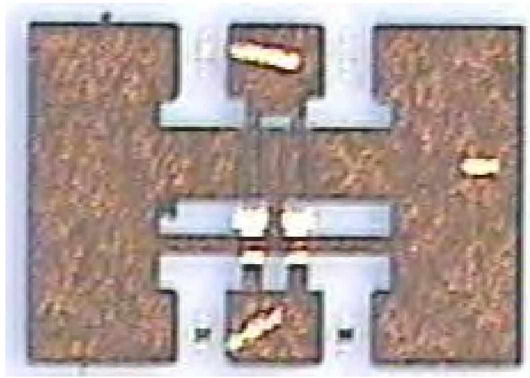

Fig. 1 Micro photo of 2-finger GaN HEMT

2. Parasitic capacitance

Parasitic capacitance is determined by the Y parameter at low frequencies (<5 *GHz*) with cut-off condition (Vds=0, Vgs<Vth). And the equivalent circuit is shown in Fig. 2.

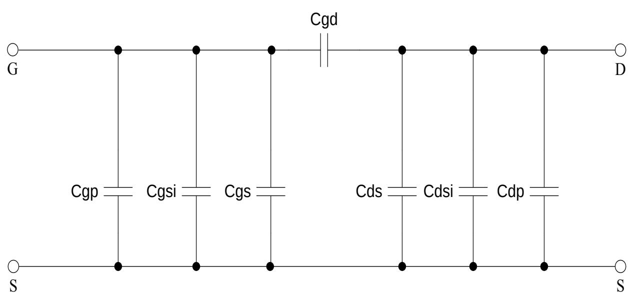

Fig. 2 The equivalent circuit of low-frequency cut-off condition (Vds=0, Vgs<Vth)

At low frequencies, the imaginary part of Y parameters can be expressed as,

$$I_m(Y_{11}) = jw(C_{gsi} + C_{gp} + C_{gs} + C_{gd}) \tag{1}$$

$$I_m(Y_{12}) = I_m(Y_{21}) = -jwC_{gd} \tag{2}$$

$$I_m(Y_{22}) = jw(C_{dp} + C_{dsi} + C_{ds} + C_{gd}) \tag{3}$$

When GaN HEMT is at pinch-off status, the depletion layer is symmetrical. Moreover, the parasitic capacitance of the electrode is approximately equal. Thus we can use the following approximations,

$$C_{gd} = C_{gs} = -\frac{I_m(Y_{12})}{w} \tag{4}$$

$$C_{gp} = C_{dp} \tag{5}$$

$$C_{gp} = C_{dp} = \frac{I_m(Y_{11}) + 2I_m(Y_{12})}{4w} \tag{6}$$

The result of experiments shows that Cgsi and Cdsi are small. Thus they can be approximately equal. As a result,

$$C_{ds} = \frac{I_m(Y_{22})}{w} - \frac{I_m(Y_{11}) + 2I_m(Y_{12})}{w} \tag{7}$$

And,

$$C_{gsi} = 3C_{gp} \tag{8}$$

$$C_{dsi} = 3C_{dp} \tag{9}$$

3. Parasitic inductance

At low frequencies (<5 *GHz*), parasitic inductance and parasitic resistance are extremely sensitive to the S-Parameter， so it is difficult to extract them accurately. Thus the determination job is operated at high frequencies (>5 *GHz*). Then the value of parasitic inductance is extracted at the bias point, Vds=0, Vgs=0. Taking into account of the symmetrical structure of HEMT device, the equivalent circuit is shown in Fig. 3.

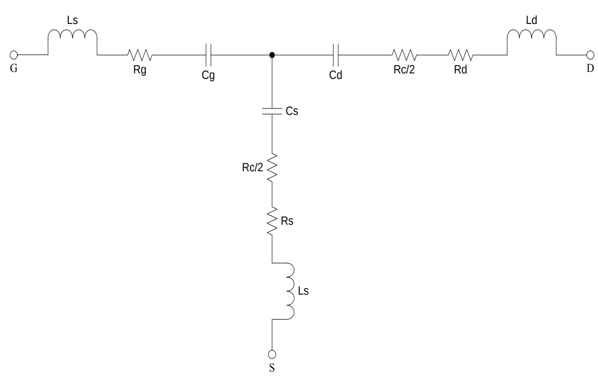

Fig. 3 The equivalent circuit of GaN HEMT at high frequencies when Vds=0 and Vgs=0

The Z-Parameter of circuit is given by,

$$Z_{11} = R_s + R_g + R_{c/2} + j[w(L_s + L_g) - \frac{1}{wC_g} - \frac{1}{wC_s}] \tag{10}$$

$$Z_{12} = Z_{21} = R_s + R_{c/2} + j[wL_s - \frac{1}{wC_s}] \tag{11}$$

$$Z_{22} = R_d + R_s + R_c + j[w(L_s + L_d) - \frac{1}{wC_s} - \frac{1}{wC_d}] \tag{12}$$

Besides,

$$I_m(Z_{12}) = wL_s - \frac{1}{wC_s} \tag{13}$$

It is derived that ωIm(Z12) and ω2 fit straight line with a slope of Ls.

Similarly,

ωIm(Z22-Z11) and ω2 fit straight line with a slope of Ld.

ωIm(Z11-Z12) and ω2 fit straight line with a slope of Lg.

Thus, at high frequencies, Ls, Ld and Lg are shown respectively as following,

$$L_s = \frac{I_m(Z_{12})}{w} \tag{14}$$

$$L_d = \frac{I_m(Z_{22})}{w} - L_s = \frac{I_m(Z_{22} - Z_{12})}{w} \tag{15}$$

$$L_g = \frac{I_m(Z_{11})}{w} - L_s = \frac{I_m(Z_{11} - Z_{12})}{w} \tag{16}$$

4. Parasitic resistance

Two methods have been used to obtain Rd, Rs and Rg. The first one is based on the measurements of DC characteristics and the second one is based on COLD-FET S-Parameter [4]. The method presented in this paper is based on the S-Parameter at zero bias. The equivalent circuit is shown in Fig. 4.

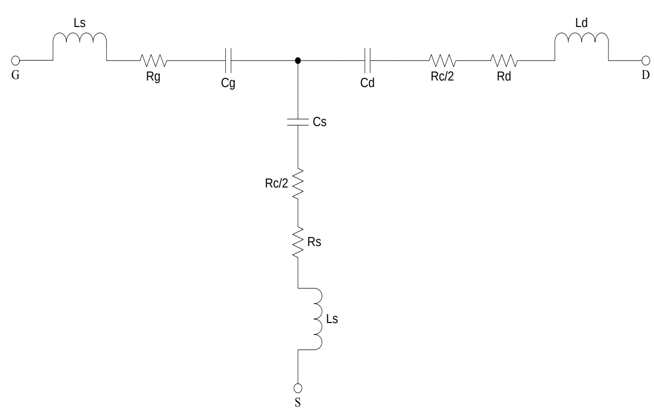

Fig. 4 Equivalent circuit of high frequency (>5 *GHz*) at zero bias

The parasitic resistance R is generated by fitting the real part of Z Parameter. From (10), (11) and (12),

$$R_e(Z_{11}) = R_s + R_g + R_{c/2} \tag{17}$$

$$R_e(Z_{12}) = R_s + R_{c/2} \tag{18}$$

$$R_e(Z_{22}) = R_s + R_c + R_d \tag{19}$$

Combining with the pinch-off Z-Parameter, we have,

$$R_s = R_e\left(Z_{12}\right) = R_e\left(Z_{21}\right) \tag{20}$$

$$R_g = R_e\left(Z_{11} + Z_{12}\right) = R_e\left(Z_{11}\right) - R_s \tag{21}$$

First, we take Z-Parameter at zero bias into (17), (18) and (19). Second, we take pinch-off Z-Parameter into (20) and (21), then we can deduce the Rd. We can also extract parasitic resistances by utilizing the measured S-Parameter by the previously mentioned approach.

5. Conclusions

All the value of parasitic elements are deduced (Table 1) according to the above discussion. Then we take those values into the equivalent circuit of pinch-off cold device and simulate the circuit in a wide band (from 0 *GHz* to 20 *GHz*). We can compare the simulated S-Parameter curves with the measured S-Parameter to verify the consistency. As it can be seen in Fig. 5 and Fig. 6，the simulated curves agree well with the measured ones in a broad frequency band.

A concise approach for determining the parasitic elements of a 2-figure GaN HEMT has been proposed and analyzed. This method consists in a direct determination of all the FET parasitic elements. The knowledge of these parasitic elements will help us determine the intrinsic small-signal parameters. Compared with the conventional method, the method based on S-Parameter can be used in a broad frequency range.

Tab. 1 The value of parasitic elements

C_{dp}=4.53 *fF*	L_d=36.43 *pH*
C_{gp}=4.53 *fF*	L_s=5.27 *pH*
C_{dsi}=9.62 *fF*	R_g=3.89 *Ω*
C_{gsi}=19.73 *fF*	R_d=2.32 *Ω*
L_g=36.43 *pH*	R_s=2.18 *Ω*

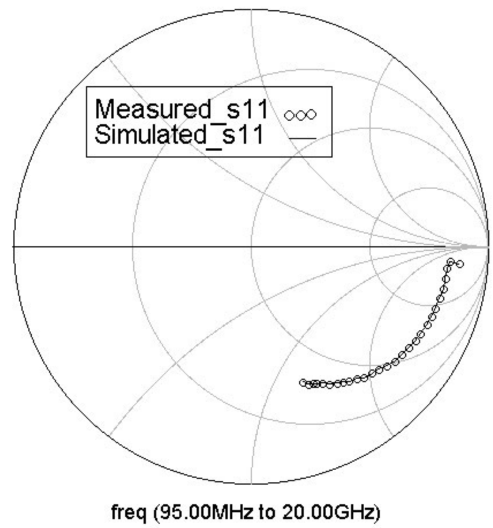

Fig. 5 Measured and simulated S11-Parameter

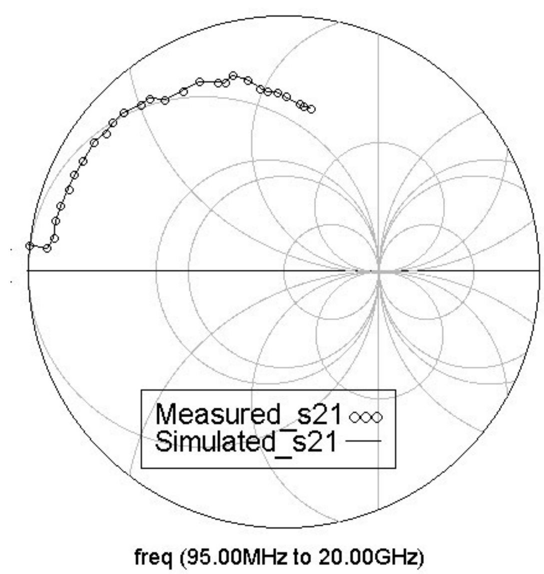

Fig. 6 Measured and simulated S21-Parameter

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