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Sub-0.1㎛ MOSFET의 게이트전압 종속 캐리어 속도를 위한 정확한 RF 추출 방법

(Accurate RF Extraction Method for Gate Voltage-Dependent Carrier Velocity of Sub-0.1㎛ MOSFETs in the Saturation Region)

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요 약

Sub-0.1㎛로 스케일이 감소함에 따라 기생 저항 효과가 크게 발생되는 dc Ids 측정 데이터 없이 측정 S-파라미터로부터 얻어진 RF Ids를 사용하여 벌크 MOSFET의 포화영역에서 게이트 전압 종속 유효 캐리어 속도를 추출하는 새로운 방법이 개발되었다. 이 방법은 바이어스 종속 기생 게이트-소스 캐패시턴스와 유효 채널 길이의 복잡한 추출 없이 포화영역의 유효 캐리어 속도를 추출할 수 있게 한다. 이러한 RF 기술을 사용하여 벌크 포화 속도를 초과하는 전자 속도 overshoot 현상이 0.065㎛ 게이트 길이의 벌크 N-MOSFET에서 관찰되었다.

Abstract

A new method using RF Ids determined from measured S-parameters is proposed to extract the gate-voltage dependent effective carrier velocity of bulk MOSFETs in the saturation region without additional dc Ids measurement data suffering parasitic resistance effect that becomes larger with continuous down-scaling to sub-0.1㎛. This method also allows us to extract the carrier velocity in the saturation region without the difficult extraction of bias-dependent parasitic gate-source capacitance and effective channel length. Using the RF technique, the electron velocity overshoot exceeding the bulk saturation velocity is observed in bulk N-MOSFETs with a polysilicon gate length of 0.065㎛.

Keywords : MOSFET, CMOS, RF, carrier velocity, device modeling, S-parameter, parameter extraction

Ⅰ. INTRODUCTION

As successful down-scaling of channel length is continued below 0.1㎛ for MOSFETs, accurate values of experimentally determined effective carrier velocity v_{eff} in the saturation region are very important to determine the intrinsic speed and carrier transport behavior in the channel region. Generally, the gate-voltage dependent v_{eff} is extracted by the following equation[1]:

$$v_{eff} = \frac{I_{ds}}{WQ_{in}}$$

$$= \frac{I_{ds}}{W\int_0^{V_{gs}} C_{gsd}'(V_{gs}')dV_{gs}'}$$

$$= \frac{I_{ds}}{\int_0^{V_{gs}} [C_{gsd}(V_{gs}')/L_{eff}]dV_{gs}'} \qquad (1)$$

where L_{eff} is the effective channel length, W is the

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channel width and C_{gsd}'(= C_{gsd}/WL_{eff}) is the gate-source-drain capacitance between gate and tied source and drain at V_{ds}=0V per unit channel area. However, the measurements of C_{gsd} at V_{ds}=0V using a very long-channel test device lead to velocity extraction errors, because the actual incremental charge dQ_{in} in the saturation region becomes smaller than that of $C_{gsd}dV_{gs}$ at V_{ds}=0V. An another method using dQ_{in} at high V_{ds} is reported[2], but dQ_{in} nomalized by Cox is still overestimated where Cox is the oxide capacitance per unit channel area. Recently, a novel method[3] using $g_{mi}/(WC_{gsi}') = g_{mi}/K$ at high V_{ds} where g_{mi} is the intrinsic transconductance, C_{gsi}' is the intrinsic gate-source channel capacitance per unit channel area, and K is the slope of the plot of C_{gs} versus L_{poly} is reported to avoid the errors in the traditional ones. However, this method produces the local carrier velocity at the point in the channel where $\partial v_{eff}/\partial V_{gs} = 0$ [1,2].

The carrier velocity extracted from $g_{mi}/(WC_{gsi}')$ is overestimated when $\partial v_{eff}/\partial V_{gs}>0$ because $g_{mi}/(WC_{gsi}') = v_{eff} + (Q_{in}/C_{gsi}')(\partial v_{eff}/\partial V_{gs})$ obtained by differentiating (1) in terms of V_{gs}[2]. Thus, the best way to extract the average carrier velocity in the saturation region is to use $I_{ds}/(WQ_{in})$ at high V_{ds} directly.

It is well known that the measured dc I_{ds} is degraded by the reduction of internal V_{gsi} due to the potential drop between source resistance of MOSFETs. This degradation may be negligible in typical submicron MOSFETs, but it becomes much larger due to the increase of I_{ds} per unit width as channel length is scaled down to the sub-0.1㎛ regime. Thus, the previous methods[1~2] using $I_{ds}/(WQ_{in})$ lead to underestimated extraction of v_{eff} due to a degraded dc I_{ds} value in sub-0.1㎛ devices.

Thus, in this paper, a new RF method based on the removal of the I_{ds} degradation effect using measured S-parameters is proposed to extract the effective carrier velocity of actual sub-0.1㎛ bulk MOSFETs accurately in the saturation region.

Ⅱ. NEW EXTRACTION METHOD

S-parameters are measured on typical bulk N-MOSFETs with different polysilicon gate length L_{poly} and 10 gate fingers of 5㎛ unit finger width. To remove RF probe pad parasitics, the accurate de-embedding technique was carried out by subtracting parasitics of open and short test structures from measured device S-parameters[4]. In order to reduce v_{eff} extraction error due to the overestimated Q_{in} in the conventional methods using (1) at V_{ds}=0V, the following equation in the saturation region is used:

$$v_{eff}(V_{gs}, V_{ds}) = \frac{I_{ds}}{\int_0^{V_{gs}} [C_{gsi}(V_{gs}', V_{ds})/L_{eff}]\, dV_{gs}'} \tag{2}$$

where C_{gsi} is the intrinsic gate-source capacitance in the saturation region.

To obtain C_{gsi} and L_{eff} accurately using C-V measurements, the parasitic overlap and fringe capacitance C_{gso} should be subtracted from the extracted gate-source capacitance C_{gs}. However, the accurate determination of C_{gso} that contains the voltage-dependent component is very difficult in sub-0.1㎛ CMOS technology.

In order to extract v_{eff} without the difficult extraction of voltage-dependent C_{gso} and L_{eff}, the following new equation is derived by substituting $C_{gsi} = KL_{eff}$ into (2):

$$v_{eff}\,(V_{gs},\ V_{ds}) = \frac{I_{ds}}{\int_0^{V_{gs}} K(V_{gs}', V_{ds})dV_{gs}'} \tag{3}$$

In (3), K can be obtained by the slope of the plot of C_{gs} versus L_{poly}, because $C_{gs} = C_{gso} + K(L_{poly} - \Delta L)$ where ΔL is the channel length reduction.

Since dc I_{ds} in the saturation region is degraded by source resistance, a RF value of I_{ds}(rf) determined by the following voltage-integral of g_{mi} and the output conductance g_{ds} is used for removing the source resistance effect:

$I_{ds(rf)}(V_{gs}, V_{ds}) =$

$$\int_0^{V_{ds}} g_{ds}(0, V_{ds}')dV_{ds}' + \int_0^{V_{gs}} g_{mi}(V_{gs}', V_{ds})dV_{gs}' \quad (4)$$

In order to extract C_{gs}, g_{mi}, and g_{ds} from the measured S-parameters, a direct extraction technique [5-7] using a small-signal MOSFET equivalent circuit model in Fig. 1 has been applied.

In the high-frequency region, resistances and inductances are extracted from y-intercepts of Z-parameter equations[5] at V_{gs}=0V as a function of ω^{-2}. The drain junction capacitance is determined at V_{gs}=0V using the following low-frequency equation in Fig. 2:

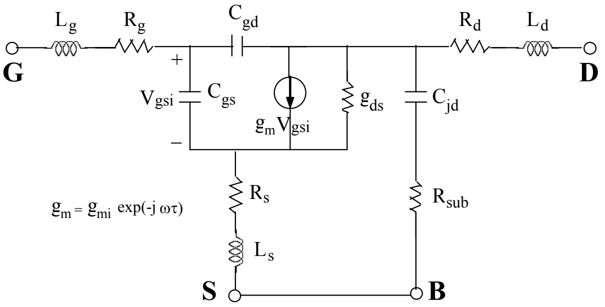

그림 1. 소스와 벌크가 연결된 소신호 MOSFET 등가회로.

Fig. 1. A small-signal MOSFET equivalent circuit with tied source and bulk.

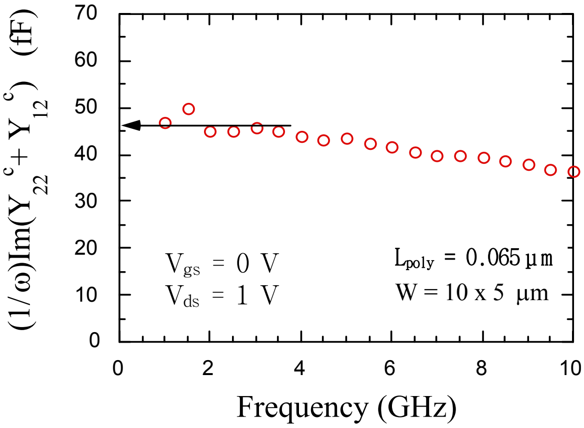

그림 2. 측정된 $(1/\omega)Imag(Y_{22}^c + Y_{12}^c)$ 대 주파수 데이터

Fig. 2. The measured data of $(1/\omega)Imag(Y_{22}^c + Y_{12}^c)$ versus frequency.

$$C_{jd} \approx \frac{1}{\omega} Imag(Y_{22}^c + Y_{12}^c) \quad (5)$$

where Y^c-parameters are obtained by subtracting extracted R_d, R_g, L_d, and L_g from measured S-parameters.

The substrate resistance R_{sub} is determined by k_1/C_{jd}^2 at V_{gs}=0 where k_1 is the slope of $Real(Y_{22}^c + Y_{12}^c)$ versus ω^2 at low-frequencies[6,7]. The values of C_{gs}, g_m, and g_{ds} are extracted by the following equations:

$$C_{gs} = \frac{1}{\omega} Imag(Y_{11}^i + Y_{12}^i) \quad (6)$$

$$g_m = |Y_{21}^i - Y_{12}^i| \quad (7)$$

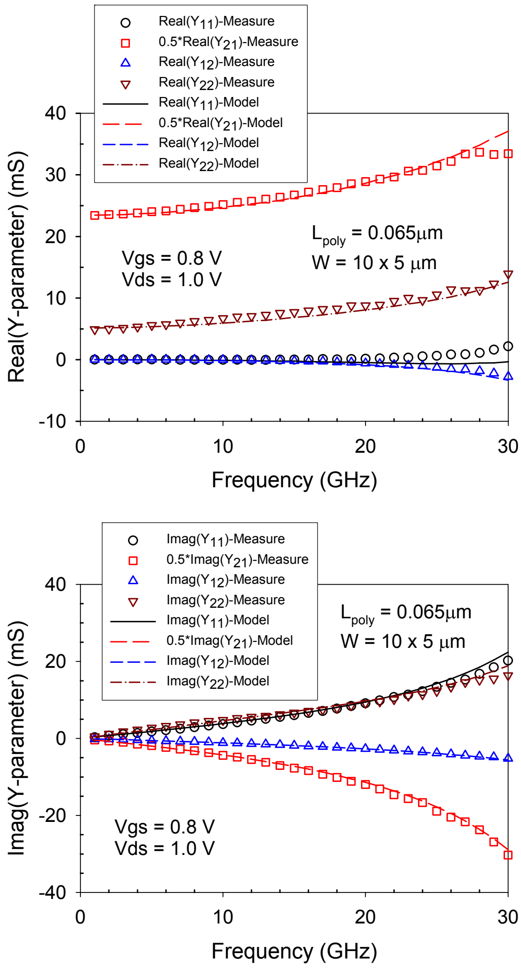

그림 3. Y-파라미터 측정치(symbol)와 모델(lines)값의 비교

Fig. 3. Comparison between and measured (symbol) and modeled (lines) Y-parameters.

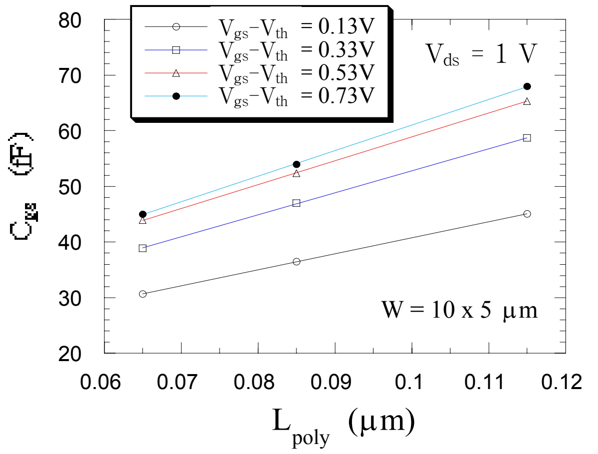

그림 4. 다양한 Vgs - Vth에서 추출된 Cgs 대 Lpoly 데이터

Fig. 4. The extracted data of Cgs versus Lpoly at various Vgs - Vth.

$$g_{ds} = Real(Y^{i}_{22}) \tag{8}$$

where Y^{i}-parameters are obtained by subtracting C_{jd}, R_{sub}, R_s, and L_s from the Y^{c}-parameters sequentially.

The accuracy of the parameter extraction has been demonstrated by observing excellent agreements between measured and modeled Y-parameters up to 30 GHz in Fig. 3. The values of K at various V_{gs} are determined from the slope of the best regression lines for C_{gs} versus L_{poly} in Fig. 4.

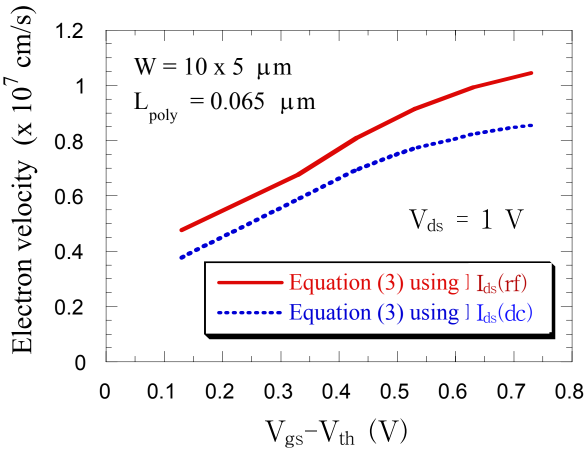

그림 5. 새로운 방법으로 Ids(rf)를 사용하여 추출된 식(3)의 Vgs 종속 veff곡선과 Ids(dc)를 사용한 기존 방법 곡선과의 비교

Fig. 5. The Vgs-dependent curve of veff extracted from the new method of (3) using Ids(rf), compared with the conventional one of (3) using Ids(dc).

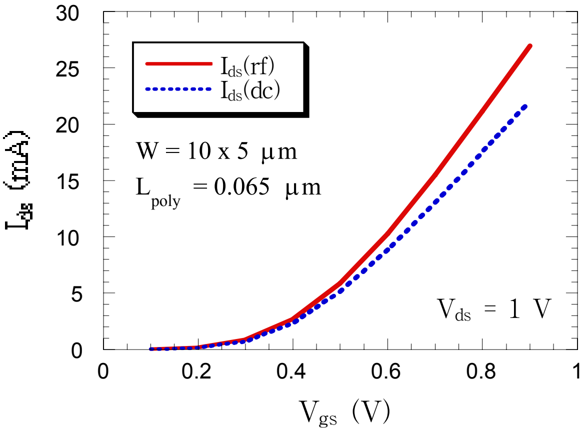

그림 6. 식 (4)의 RF Ids(rf) 데이터와 DC Ids(dc) 데이터를 Vgs 함수로 그린 그래프

Fig. 6. RF Ids(rf) data of (4) and DC Ids(dc) data as a function of Vgs.

Ⅲ. RESULTS AND DISCUSSION

In Fig. 5, gate-voltage dependent data of v_{eff} at L_{poly} = 0.065㎛ obtained from the conventional method of (3) using I_{ds}(dc) are lower than those of the new one using I_{ds}(rf) in (4). The large extraction error of the conventional method is generated by degraded I_{ds}(dc) caused by the potential drop across R_s. Fig. 6 shows the current degradation effect that I_{ds}(dc) is about 19% smaller than I_{ds}(rf) due to the gate-source voltage reduction of $I_{ds}R_s$=0.08V at V_{gs}=0.9V. This indicates the current degradation effect should be eliminated to extract an accurate value of v_{eff} in deep sub-0.1-㎛ devices. It is observed that v_{eff} exceeds the bulk saturation velocity (v_{sat} =10^7cm/s) for bulk N-MOSFETs with L_{poly} = 0.065㎛, because of carrier acceleration due to velocity overshoot near the drain side[1, 8].

Physically, the drain-source saturation voltage V_{ds}(sat) at the drain end of the inversion channel is expressed by $V_{gs} - V_{th}$. Thus, to analyze gate-voltage dependence of velocity in the saturation region, the effect of lateral channel electric field due to the V_{gs} increase should be incorporated together with that of vertical one. In particular, in sub-0.1㎛ bulk N-MOSFETs, the rising rate of lateral channel electric field with $V_{gs} - V_{th}$ becomes larger due to very short channel length. In Fig. 5, the linear increase of v_{eff} at low $V_{gs}-V_{th}$ is primary due to the rise of lateral field, but the reduction of the increasing rate at high $V_{gs}-V_{th}$ is due to velocity saturation and the rise of vertical field. This analysis will be very helpful to understand the gate-voltage dependent behavior of the cutoff frequency f_T and the maximum oscillation frequency f_{max} for deep sub-0.1-μm devices in the saturation region.

Ⅳ. CONCLUSIONS

A new RF method using the RF value of I_{ds} obtained by the voltage-integral of g_{mi} and g_{ds} from measured S-parameters is proposed to extract V_{gs}-dependent v_{eff} of actual sub-0.1μm bulk MOSFETs in the saturation region accurately. This new method is developed to avoid the extraction error in conventional ones due to dc I_{ds} degradation that can't be neglected in sub-0.1μm MOSFETs. This technique based on the slope extraction of C_{gs} versus L_{poly} is more accurate than previous methods, because the difficult extraction of bias-dependent C_{gso} and L_{eff} is not needed. It is observed that electron velocity enhancement exceeding v_{eff} occurs in bulk N-MOSFETs with L_{poly} = 0.065μm.

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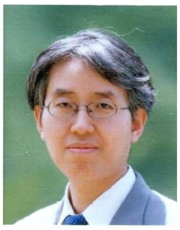
저자소개



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