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Accurate Evaluation of Inversion-Layer Mobility and Experimental Extraction of Local Strain Effect in sub-μm Si MOSFETs

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1. Introduction

Accurate evaluation of inversion-layer mobility in short channel MOSFETs has been a major concern, not only from the viewpoints of device physics and modeling, but also for the purpose of characterizing strained channel devices. Although there are a few reports on the mobility extraction in the sub-100 nm regime [1,2], the measurement method is not sufficiently reliable yet, in terms of the physical understanding of carrier transport in small devices.

This paper proposes an accurate and reliable method for the mobility extraction in short channel MOSFETs, which is based on the split-*CV* measurement [3]. In addition, our method is applied to a local strained channel MOSFET with a capping stressor, which shows a significant mobility enhancement with decreasing the gate length L_g.

2. Mobility Extraction Method

The devices used in this measurement were simple *n*-MOSFETs without any special processes affecting the mobility. The oxide thickness T_{ox} was 5 nm and the substrate impurity concentration N_{sub} was 10^{15} cm^{-3}.

The proposed method, based on the split-*CV* measurement, is summarized in Fig.1. It was confirmed that the reduction of channel carrier density N_s near the drain is almost negligible, even at L_g=1 μm.

There are three main difficulties in the mobility measurement for short channel MOSFETs. As shown in Fig.2, the value of total capacitance becomes very small, which makes it difficult to conduct an accurate *CV* measurement. The small total capacitance also indicates that the influence of parasitic capacitance becomes relatively significant, because the parasitic capacitance is not scaled with L_g. Moreover, the effective channel length L_{eff} has to be determined correctly, because L_{eff} can no longer be approximated as L_g. For the accurate measurement, therefore, it is necessary to consider (i) the accuracy of *CV* measurement, (ii) the influence of parasitic capacitance and (iii) the determination of effective channel length.

(i) Accuracy of CV Measurement

Since the measured gate-to-channel capacitance C_{gc} is proportional to L_g x W_g, a long channel width W_g of 100μm was used in the present study. Furthermore, the influence of series resistance in short channel MOSFETs is so negligible that the measurement frequency as high as 1 MHz can be employed, which improves the accuracy in the C_{gc}-V_g measurement [4]. Consequently, the accurate C_{gc} curve on the order of sub-pF was obtained, even at L_g=1 μm (Fig.3).

(ii) Influence of Parasitic Capacitance

As shown in Fig.4, the normalized C_{gc} curve at L_g=1 μm agrees well with those at L_g=10 μm and 100 μm, suggesting that the influence of parasitic capacitance can be still neglected, even at L_g=1 μm.

(iii) Determination of Effective Channel Length

Effective channel length is defined as $L_{eff} = L_g - \Delta L_g$, where ΔL_g is a channel length reduction. As is widely accepted, ΔL_g is no longer negligible in short channel MOSFETs. In the present study, L_{eff} was simply determined from the $1/I_d$ - L_g plots in the long channel regime (L_g=7-10 μm), as shown in Fig.5.

3. Result and Discussion

Figure 6 shows that the determination of L_{eff} can strongly affect the mobility extraction in the short channel regime, and that the extracted mobility as a function of effective normal field E_{eff} is on the same curve, independent of L_g, as a consequence of using correct L_{eff} (Fig.6 (b)). This result is reasonable under the framework of universal mobility, indicating that our measurement method is accurate and reliable.

The applicability of our method to the sub-μm device is briefly discussed. We think that the determination of L_{eff} will be more critical and influential to the mobility extraction, rather than the difficulties concerning the C_{gc}-V_g measurement. In the present study, very simple method for determining L_{eff} was employed. When more advanced techniques such as the shift-and-ratio method [5,6], which can also incorporate the influence of parasitic resistance, are used, our measurement method will be available for deep sub-μm MOSFETs.

4. Experimental Extraction of Local Strain Effect

The proposed method was applied to *p*-MOSFETs with a compressive capping layer (Fig.7). As shown in Fig.8, mobility enhancement becomes significant with decreasing L_g. This is the first observation of local strain effect in terms of L_g dependence of effective mobility. It is also noted that hole mobility is uniformly enhanced in the entire E_{eff} region. Similar behaviors have been observed in the SiGe S/D and the mechanical bending experiments [7,8], though the measurement method was not disclosed in the case of the former experiment. A quantitative agreement with the transconductance G_m enhancement (Fig.9) suggests that our mobility results are reasonable.

5. Conclusion

We proposed an accurate and reliable measurement method for the mobility extraction down to the sub-μm region, as a consequence of correctly determining effective channel length. Furthermore, the direct experimental evidence of mobility enhancement was obtained in a local strained channel device by means of our method. In conclusion, our method will be a useful tool for characterizing short channel as well as strained channel MOSFETs.

References

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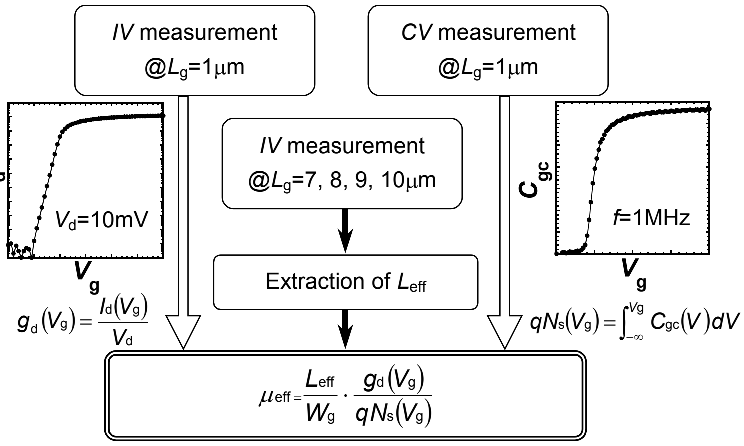

Fig.1 Flow of mobility extraction measurement for short channel MOSFETs.

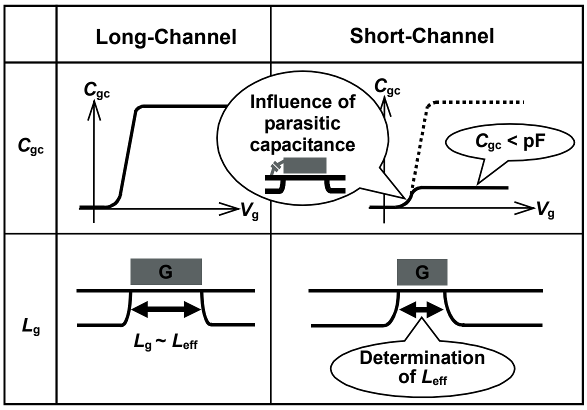

Fig.2 Schematic diagram showing three difficulties in split-CV measurement for short channel MOSFETs.

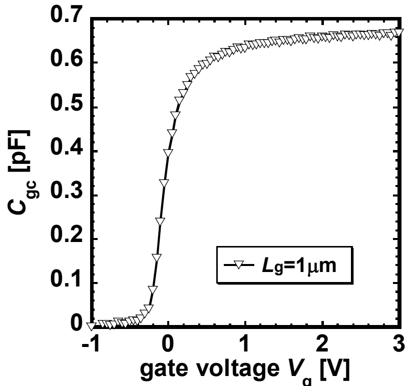

Fig.3 C_{gc}-V_g characteristics at L_g=1μm (W_g=100μm).

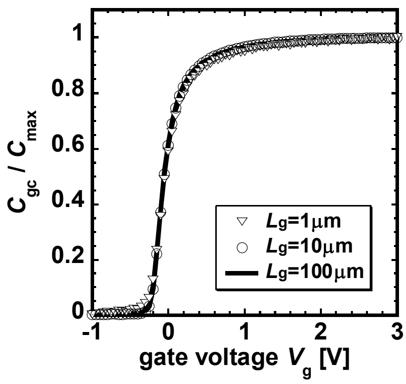

Fig.4 Normalized C_{gc}-V_g characteristics at L_g=100, 10, 1μm. The influence of parasitic capacitance can be still neglected, even at L_g=1μm.

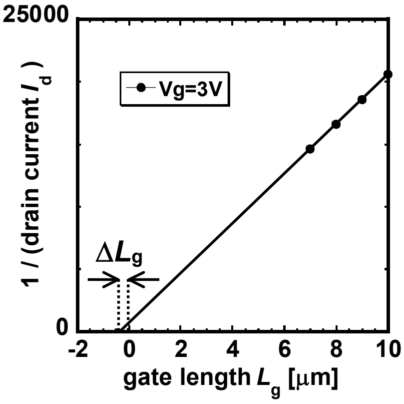

Fig.5 1/I_d- L_g plots for L_{eff} determination. L_{eff} is defined as L_g - ΔL_g, where ΔL_g can be obtained from the x-axis intercept of the observed straight line.

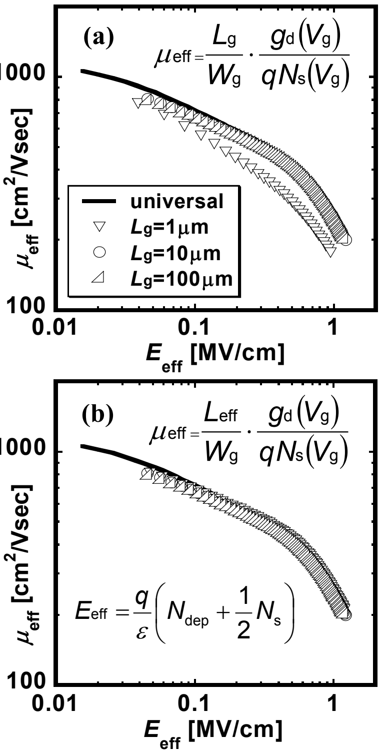

Fig.6 Inversion-layer mobility as function of E_{eff} for L_g=100, 10, 1μm (a) before and (b) after L_{eff} determination. The determination of L_{eff} can strongly affect the mobility extraction in the short channel regime.

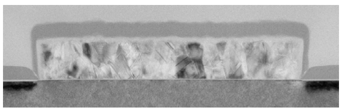

Fig.7 TEM cross-section image of local strained channel MOSFET with capping layer.

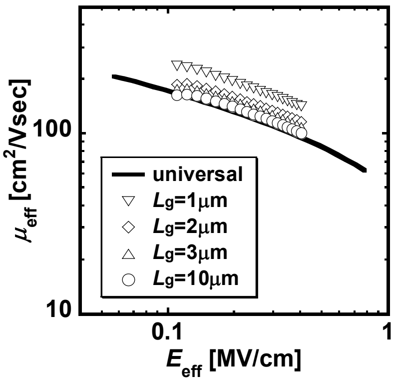

Fig.8 Inversion-layer mobility as function of E_{eff} for p-MOSFETs with compressive capping layer. This is the first observation of local strain effect in terms of L_g dependence of effective mobility.

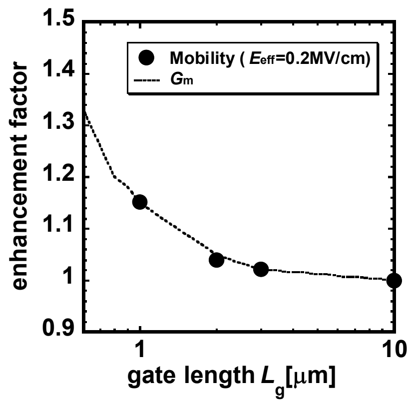

Fig.9 Enhancement factor of mobility and G_m. The mobility enhancement is in quantitative agreement with the G_m enhancement.