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Noticeable Enhancement of Edge Effect in Short Channel Characteristics of Trench-Isolated MOSFETs

Toshiyuki Oishi, Katsuomi Shiozawa, Akihiko Furukawa, Yuji Abe and Yasunori Tokuda

Advanced Technology R&D Center, Mitsubishi Electric Corporation,
4-1 Mizuhara, Itami, Hyogo 664-8641, Japan
Phone: +81-727-84-7475, Fax: +81-727-80-2675, E-mail: tohishi@lsi.melco.co.jp

Abstract

We defined anomalous channel length dependence on the V_{th} of trench-isolated MOSFET by devising a gate structure. This phenomenon of trench edge effect on MOSFETs being enhanced around the onset of the short channel effect is clearly interpreted in terms of the three-dimensional mixing of narrow and short channel effects.

Introduction

Trench isolation is indispensable for keeping or enhancing the drivability of MOSFETs with a very narrow and short channel, because of less lateral extension of the field oxide as compared with the LOCOS isolation [1]. The electric field concentration at the trench edge, however, significantly influences MOSFET characteristics such as threshold voltage (V_{th}) and leakage current. Especially, it is expected that the edge effect degrades the narrow channel characteristics, so many studies on the channel width (W) dependence on the V_{th} have been performed [2]. On the other hand, there have been few investigations combining the short channel effect (the channel length (L) dependence on the V_{th}) with the edge effect [3], and no clear conclusions have been obtained, since the investigations have mainly depended on simulation.

In this paper, we clearly demonstrate that the trench edge effect on MOSFETs is enhanced around the onset of the short channel effect and this phenomenon is explained by three-dimensional mixing of the short and narrow channel effects.

Experiment

Figure 1 shows schematically the layouts of the two types of trench-isolated MOSFETs with the different gate structures which were used in this work. The MOSFET with an I-shaped gate structure (a), which is the generally used type, may be affected by the trench isolation edges at both the channel sides, while the MOSFET with an H-shaped gate structure (b), which was fabricated as a reference, contains no isolation edges in the current flow region. Two types of wafers with different trench edge shapes as shown in Fig. 2 were used to fabricate the n-channel MOSFETs. The gate oxide thickness and trench depth are 6 nm and 0.3 μm, respectively [4,5].

In advance, we had confirmed that the MOSFET characteristics for the H-shaped gate are the same for wafers with different trench edge shapes. In comparing the I-shaped gate MOSFETs with the H-shaped gate MOSFETs of the same channel length, therefore, we can define the trench edge effects.

Results and Discussion

Figure 3 shows the subthreshold characteristics of the I- and H-shaped gate MOSFETs with the deeper dips (Fig. 2 (a)) for the three L values. Intuitively thinking, the V_{th} difference may become smaller for the shorter channel length, because the short channel effect may be suppressed for the I-shaped gate MOSFET, also the V_{th} for the I-shaped gate MOSFET may be smaller than that for the H-shaped gate MOSFET, due to the electric field concentration at the trench edge [6]. The experimental result that the V_{th} difference between the I- and H-shaped gate MOSFETs is largest for the middle channel length of 0.26 μm, however, is not in agreement with the above simple expectation. For the MOSFETs with the smaller dips (Fig. 2 (b)), the same tendency was obtained as shown in Fig. 4, though the difference is smaller due to the weaker edge effect.

To investigate this strange phenomenon in detailed, Figs. 5 and 6 show the V_{th} values for the I- and H-shaped gates and the V_{th} difference between the I- and H-shaped gates (ΔV_{th}), respectively, as a function of L for the MOSFETs with the deeper dips. As expected, the V_{th} for the I-shaped gate MOSFET is smaller than that for the H-shaped gate MOSFET (Fig. 5). However, it should be noted that ΔV_{th} anomalously depends on L (Fig. 6). That is, ΔV_{th} gradually increases as L decreases and suddenly decreases around an L value of 0.26 μm, which is the appearance point of the short channel effect as seen in Fig. 5.

To interpret this enhancement of the trench edge effect around the onset of the short channel effect, we estimated the surface potential (ψ), which may be used as a current flow standard since a higher ψ gives a lower electron barrier height. A three-dimensional analysis [7] was performed for the structure illustrated in Fig. 7 (a). As shown in Fig. 7 (b), ψ hardly depends on z at the channel center region (0.15 μm< z < 5 μm), whereas ψ rapidly increases near the channel edge (i.e. as z approaches 0), which should be due to the trench edge effect. In Fig. 7(c), L dependence of ψ is shown for the channel center (z =5 μm) and near edge (z =0.02 μm), which should qualitatively correspond to the H- and I-shaped gate MOSFETs, respectively. Figure 7 (d), furthermore, indicates the ψ difference ($\Delta\psi$) as a function of L, which properly corresponds to the experimental data of ΔV_{th}-L curve of Fig. 6. From the calculation, we conclude that ψ is strongly modulated by the trench edge effect, so that the V_{th} is noticeably modified around L of the appearance point of the short channel effect.

Conclusion

We clearly show that the trench edge effect, which is more significant for the deeper trench edge dips, on the MOSFET is enhanced around the appearance point of the short channel effect by comparison with the characteristics of the MOSFET with a devised gate structure. To interpret this noticeable short channel effect, a three-dimensional mixing incorporating the short channel effect and the narrow channel effect should be taken into account. The present results suggest that the influence of the trench edge, for example, an undesirable hump in the subthreshold characteristics, can be checked by measuring the MOSFET with a channel length around the onset of the short channel effect.

References

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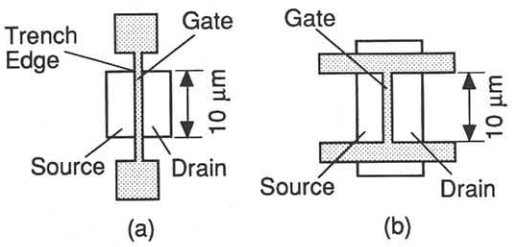


Figure 1. Top views of MOSFETs with (a) I-shaped gate and (b) H-shaped gate. H-shaped gate MOSFET has no trench edge.

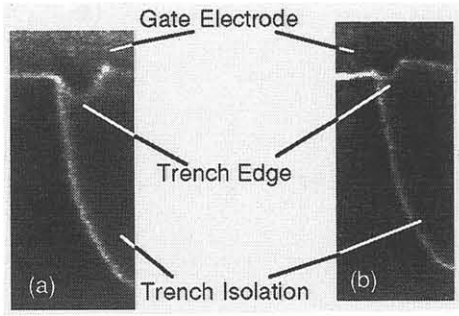
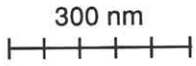


Figure 2. Cross sectional views of trench isolation edges with (a) deep dip and (b) small dip. Deeper dip more strongly affects to the MOSFET characteristics.



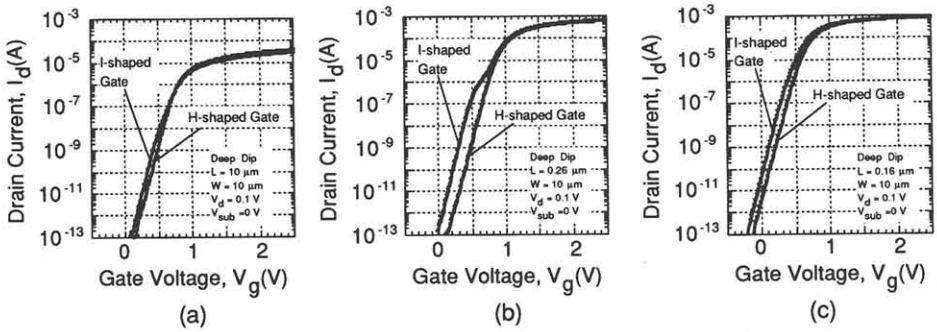


Figure 3. Subthreshold characteristics of I-shaped gate and H-shaped gate MOSFETs with deep dips for various gate lengths, L: (a) 10 μm, (b) 0.26 μm and (c) 0.16 μm. Edge effect, that is, difference between two type of MOSFET is enhanced at L of 0.2 6 μm.

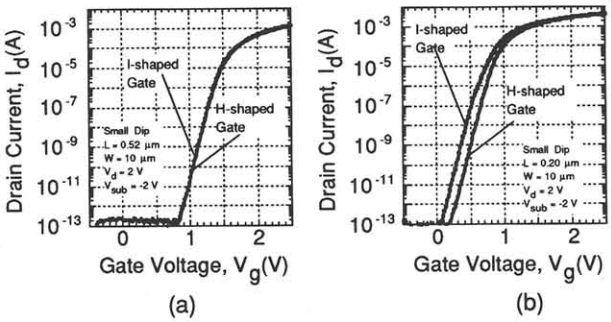


Figure 4. Subthreshold characteristics of I-shaped gate and H-shaped gate MOSFETs with small dips for various gate lengths, L: (a) 0.52 μm and (b) 0.2 μm. Although edge effect is suppressed at L of 0.52 μm, it appeares at L of 0.2 μm.

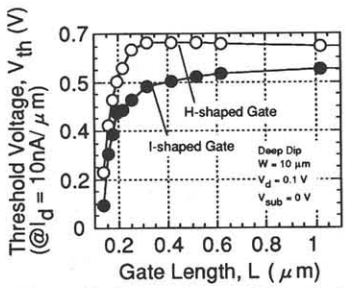


Figure 5. Dependence of threshold voltage, V_{th}, on gate length, L.

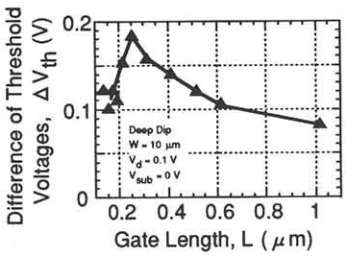


Figure 6. Differences in the threshold voltage of MOSFET with deeper dip, ΔV_{th}, as a function of gate length, L. Trench edge effect indicating as ΔV_{th} strongly depends on L.

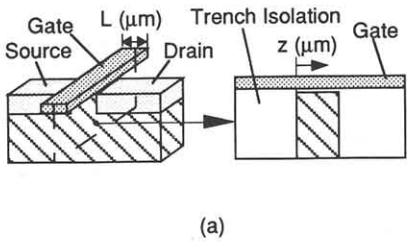


Figure 7(a). Structure for three-dimensional analysis. The left hand figure shows a plan view and the right one shows a cross sectional view along the channel width of the MOSFET.

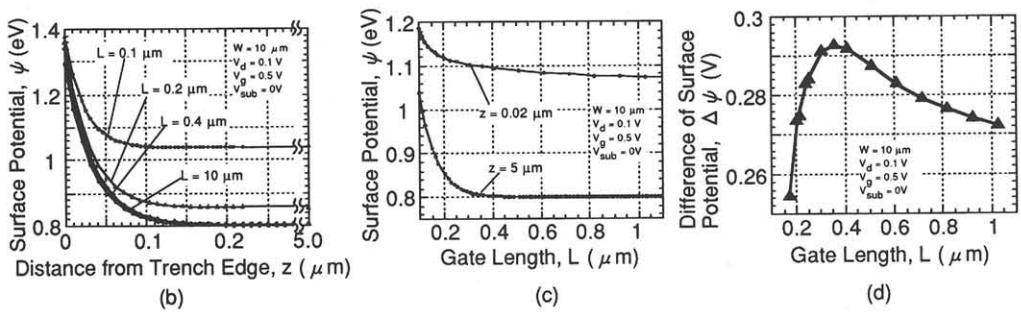


Figure 7(b)-(d). Results of analysis to clarify trench edge effect in experimental data. (b) shows surface potential, ψ, as a function of distance from trench edge, z. (c) shows L dependence of ψ. (d) shows differnce of surface potential, $\Delta\psi$, as a function of L. By these results, experimental data in Fig. 6 can be explained consisitently.