行政院國家科學委員會專題研究計畫成果報告

幅射對正反短通道效應之研究
The Effects of Irradiation on the NSCE and RSCE of MOSFETs

計畫編號：88-2215-E-009-029-
執行期限：87年8月01日至88年7月31日

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一、中文摘要:

在本研究計畫中，我們首度發現，經過幅射照射後，金氧半電晶體之正短通道效應及反短通道效應均有被加強之趨勢。此一似乎不合羅輯之有趣現象，在已知文獻中並無報告，我們也首度提出解釋之方法，並經模擬證實。另外，在本計畫中，我們亦首度發現，以氮化之犧牲氧化層亦有減少反短通道效應之效果，此亦為已知文獻中所無者。本計畫之研究結果推翻了傳統思維，認為可設計一稍具反短通道效應之電晶體，而經幅射照射後剛好正反抵消，而達到最佳化之迷思，本計畫之發現，對抗幅射電晶體電路之設計，有重要之貢獻。

關鍵詞：抗幅射、金氧半電晶體、正短通道效應、反短通道效應。

Abstract

In this project, we report, for the first time, the simultaneous enhancement of normal short-channel effect (NSCE) and reverse short-channel effect (RSCE) on MOS transistors. We have proposed a model to successfully explain this intriguing and seemingly contradictory observation. Medici simulation also confirms with our model. Our findings suggest that the conventional thinking of designing transistors with a slight RSCE before irradiation in hope that RSCE will be reduced so an ideal Vth-vs-L curve is achieved after irradiation is therefore impractical. In addition, we also discovered, for the first time, that the use of a nitrided sacrificial oxide is as effective in reducing the RSCE of the resultant transistors. Our findings have important implications in designing MOS transistors for rad-hard applications.

Keywords: rad-hard, MOS transistors, normal short-channel effects, reverse short-channel effects.

二、緣由與目的:

Recently reverse short channel effect (RSCE) has received many attentions. Unlike the normal short channel effect (NSCE) which is the threshold voltage (Vth) lowering with decreasing channel length (L). RSCE depicts instead an increase in Vth with decreasing L [1-6]. RSCE is believed to be due a non-uniform lateral surface channel dopant concentration (C_S) as a result of enhanced boron diffusion near the source/drain (S/D) regions. It has been shown that by nitriding the gate oxide or after-gate re-ox, RSCE in nMOSFETs can be suppressed [7-8]. In this paper we report, for the first time, that RSCE in nMOSFETs can also be effectively suppressed by performing the nitridation on the sacrificial oxide (SO), which is stripped off before growing a pure SiO_2 as the final gate oxide.

The effects of irradiation on Vth-lowering (i.e., NSCE) were reported briefly before [9]. They found that NSCE was enhanced after irradiation for their nMOSFETs that depict minor before-irradiation NSCE. Neither their pre- nor after-irradiation devices depict RSCE. In this paper, we report for the first time the intriguing observations that while the NSCE is enhanced after irradiation on devices which depict minor NSCE before irradiation, the RSCE is simultaneously enhanced after irradiation on devices which depict minor RSCE before irradiation.

三、研究內容:

Both n- and p-channel MOS transistors were fabricated. Our baseline devices (i.e., control) received a standard 25-nm SiO_2 sacrificial oxide growth that was later stripped off before growing a 20-nm final gate oxide. Some wafers were deliberately split to receive an N_2O-annealed 25-nm sacrificial oxide to study its effects. The N_2O-sacrificial oxide was first grown by O_2 oxidation, followed by an N_2O anneal for 15 min at 925°C, to make up a final thickness of 25nm. For radiation study, devices were subjected to a radiation from a cobalt-60 source with 1Mrad(Si) dose, and their characteristics were re-measured.

Threshold voltage: vs. L for all nMOSFETs are plotted in Fig. 1. Before irradiation, SiO_2-devices depict RSCE, while N_2O-devices depict NSCE, suggesting that performing SO in N_2O is also effective in suppressing the enhanced boron diffusion, resulting in a more uniform C_S, thereby suppressing RSCE in nMOSFETs. Our results suggest that, even though the N_2O-SO was stripped off, the nitrogen incorporated at the interface remains, serving to suppress enhanced boron diffusion during later processing.

Threshold voltage depicts an across-the-L reduction after irradiation for all nMOSFETs (Fig. 1), due to the well-known hole trapping (Q_F) after irradiation. More importantly, an interesting and seemingly contradicting phenomenon is observed. Specifically, for the SiO_2-devices that depict minor RSCE, the RSCE is enhanced after irradiation Interestingly, for the N_2O-devices that depict minor NSCE, the NSCE is also enhanced after irradiation. The trend is even more clear by plotting delta Vth (Fig. 2).

Similar trends are also observed in pMOSFETs (Fig. 3). Before irradiation the SiO_2-devices depict NSCE, while the N_2O-devices depict RSCE. Vth depicts an across-the-L increase (i.e., in absolute value) after irradiation for all pMOSFETs. Moreover, for the SiO_2-devices that depict minor NSCE, the NSCE is enhanced after irradiation. In contrast, for the N_2O-devices that depict minor RSCE, the RSCE is also enhanced after irradiation. These trends are even more clear by plotting delta Vth (Fig. 4).

We believe these seemingly contradicting observations can be explained as follows: taking nMOSFETs for example, a more uniform lateral C_S (e.g., N_2O-nMOSFETs), will depict NSCE before irradiation. A uniform hole trapping Q_F reduces C_S uniformly, causing enhanced NSCE after irradiation. However, for nMOSFETs with a non-uniform lateral C_S (e.g., SiO_2-"MOSFETs), boron C_S is higher near the S/D regions, causing RSCE before irradiation. After irradiation, a uniform Q_F attracts uniform n-type electrons in the channel counterdoping the p-type C_S, resulting in a more pronounced differential ratio in the boron C_S between the middle channel and regions near S/D, causing a more pronounced RSCE.

To confirm the above hypothesis, Medici simulations were performed. Simulation results show that for nMOSFETs with a uniform C_S, NSCE is observed before irradiation (Fig. 5). By adding a uniform Q_F, an enhanced NSCE is indeed depicted (Fig. 5). While for nMOSFETs with a non-uniform lateral C_S, RSCE is depicted before irradiation and an enhanced RSCE is indeed depicted after irradiation (Fig 6), agreeing with our experimental observations. Similarly, our Medici simulations also confirm that both

RSCE and NSCE are enhanced after irradiation (Figs. 7 and 8).

The effects of substrate bias are also measured (Figs 9-12), confirming with previous reports that RSCE. is reduced with substrate bias [10]. The DIBL effects are also measured. for nMOSFET's, the N_2O-devices depict worse DIBL. DIBL also worsens for the irradiated devices (Fig. 13). For pMOSFETs, similar trends are observed (Fig. 14). The drive currents are plotted in Figs 15-16.

四、結論:

In conclusion, we report, for the first time, that RSCE in MOSFETs can also be effectively suppressed by employing an N_2O-treated sacrificial oxide [11]. More importantly, we also report, for the first time, the intriguing observations that for devices that depict NSCE, the NSCE is enhanced after irradiation. While for devices that depict RSCE, the RSCE is also enhanced after irradiation [12]. Our Medici simulations employing a uniform layer of trapped holes indeed agree with our experimental observations. Our findings suggest that short channel effects, be it NSCE or RSCE, are mostly likely to get worse after irradiation. The conventional thinking of designing devices with a slight RSCE before irradiation in hope that RSCE will be reduced and an ideal that V_{th}-vs-L curve would be achieved after irradiation is therefore impractical, if not impossible.

Some works have been published [11-12]. A full paper of the account is current under preparation.

五、致謝:

The authors greatly acknowledge the support of National Science Council, and National Nano Device Labs for technical assistance during this study.

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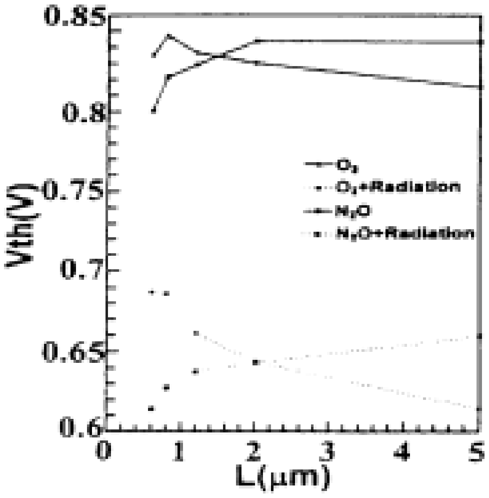

Fig. 1:Vth vs. Channel length for nMOSFET's. Nitridation of sacrificial oxide is as effective in suppressing RSCE. The RSCE is enhanced after irradiation on

SiO2-devices which depict minor RSCE prior to irradiation. While the NSCE is also enhanced after irradiation on N2O-devices which depict minor NSCE prior to irradiation.

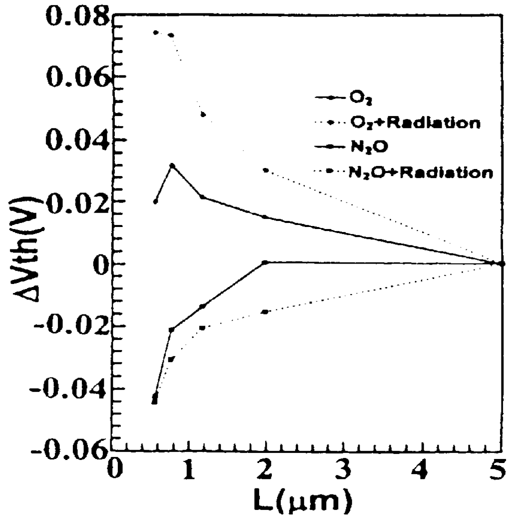

Fig. 2: Delta Vth (which respect to long L) vs. Channel length for nMOSFET's.

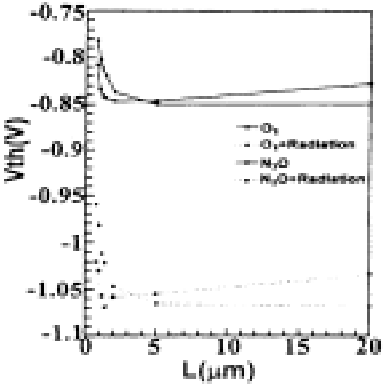

Fig. 3: Vth vs. Channel length for pMOSFET's. The NSCE is enhanced after irradiation on SiO$_2$-devices which depict minor NSCE prior to irradiation. While the RSCE is also enhanced after irradiation on N2O-devices which depict minor RSCW prior to irradiation.

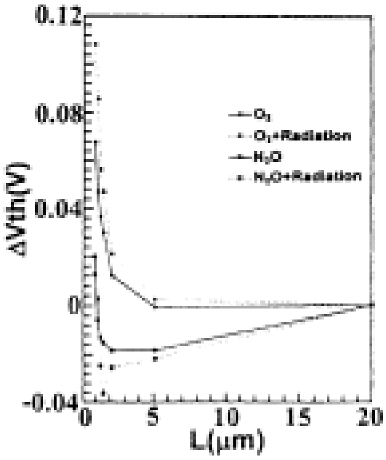

Fig. 4: Delta Vth (which respect to long L) vs. Channel length for pMOSFET's.

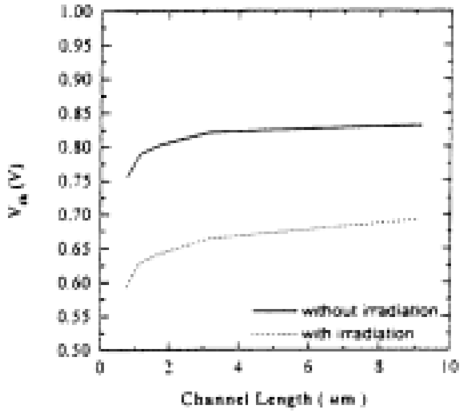

Fig. 5: Simulated Vth vs. Channel length for nMOSFET's with uniform lateral channel doping profile. The devices depict NSCE prior to irradiation, and the NSCE is further enhanced after irradiation, agreeing with experimental observation on N$_2$O-nMOSFET's.

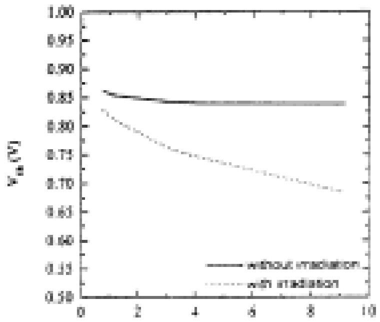

Fig. 6: Simulated Vth vs. Channel length for nMOSFET's with non-uniform lateral channel doping profile. The devices depict RSCE prior to irradiation, and the RSCE is futher enhanced after irradiation, agreeing with experimental observation on

SiO_2-nMOSFET's.

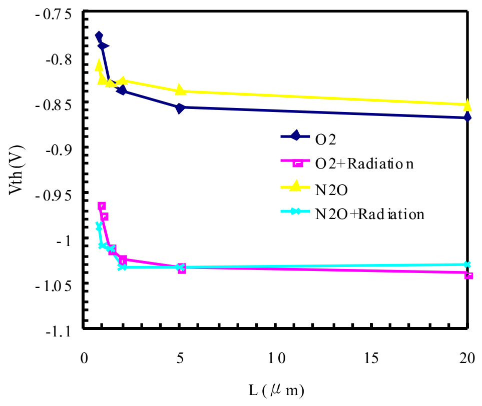

Fig. 7: Simulated Vth vs. Channel length for pMOSFET's.

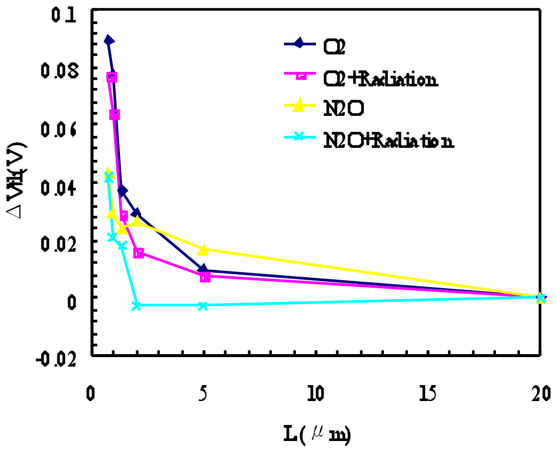

Fig. 8: Simulated delta Vth (which respect to long L) vs. Channel length for pMOSFET's.

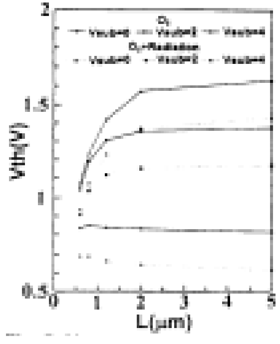

Fig. 9: Vth vs. Channel length with substrate bias as parameter for SiO_2-nMOSFET's.

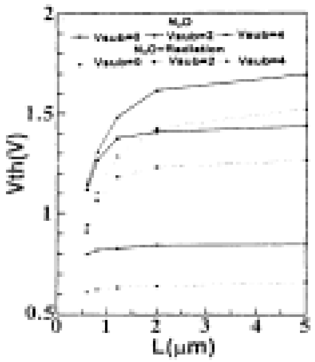

Fig. 10: Vth vs. Channel length with substrate bias as parameter for N_2O-nMOSFET's.

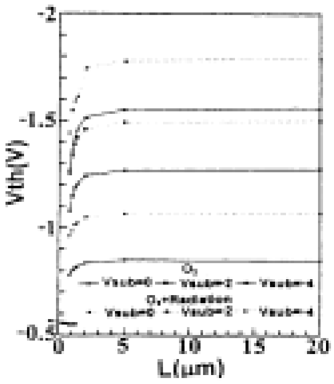

Fig. 11: Vth vs. Channel length with substrate bias as parameter for SiO_2-pMOSFET's.

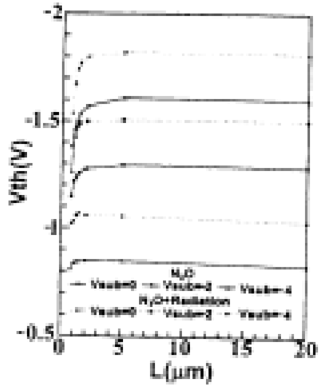

Fig. 12: Vth vs. Channel length with substrate bias as parameter for N_2O-pMOSFET's.

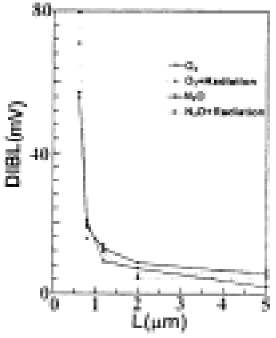

Fig. 13: DIBL effects for nMOSFET's.

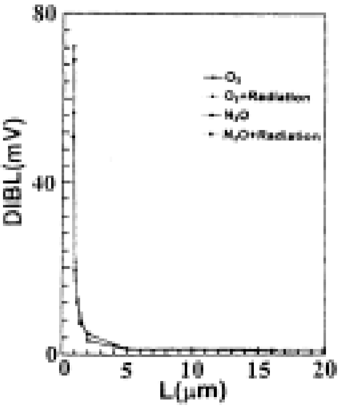

Fig. 14: DIBL effects for pMOSFET's.

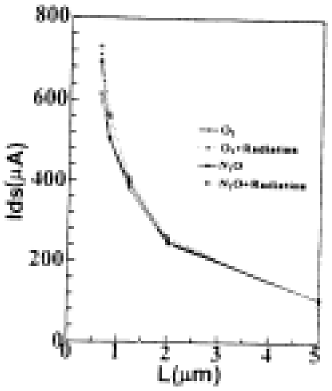

Fig. 15: Drive current for nMOSFET's.

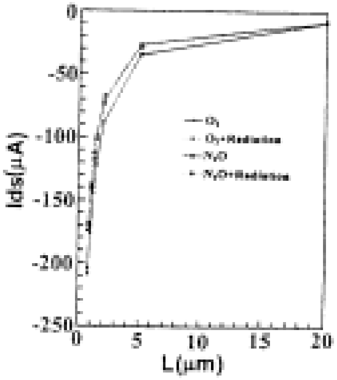

Fig. 16: Drive current for pMOSFET's.