行政院國家科學委員會補助專題研究計畫成果報告

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※奈米金氧半場效電晶體之新閘結構及閘材料金氧半場效電晶體　※

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計畫主持人：金雅琴

本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份

□赴大陸地區出差或研習心得報告一份

■出席國際學術會議心得報告及發表之論文各一份

□國際合作研究計畫國外研究報告書一份

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中　華　民　國　91 年　　10 月　2　日

行政院國家科學委員會專題研究計畫成果報告

奈米金氧半場效電晶體之新閘結構及閘材料金氧半場效電晶體之設計與最佳化

Design and Optimization of New Gate Structure and Material for Sub-100nm MOS Transistors

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執行期限：90 年 8 月 1 日至 91 年 7 月 31 日

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中文摘要

現今成熟的互補式金氧半技術是超大型積體電路的基礎，此互補式金氧半技術快速的進步和金氧半元件在過去三十年來不斷的縮小，成就高效能的超大型積體電路的發展。當金氧半元件的閘極長度小於一百奈米以下，這類奈米電晶體的發展不僅挑戰半導體製成技術的極限，奈米電晶體的元件特性也因電晶體縮小於一百奈米而需要結構上的改變。最近有許多國內外的研究，已發表許多五十奈米以下閘極長度的金氧半元件成功製作的案例，然而，這些元件仍然有一些小結構導致的元件特性限制需要突破。這些小結構導致的元件特性限制包括有:因為降低短通道效應的超薄源極/汲極所導致的源極/汲極電阻上升，以及採用高介電長數閘極層所導致的邊緣電場導致能障下降效應最為嚴重。我們提出利用跨立閘結構以及堆疊高低介電長數閘極層等結構變化，來解決上述奈米電晶體元件特性的問題。

本計畫將使用元件模擬軟體以及自行開發的元件模型，針對跨立閘結構應用在奈米電晶體上進行最佳化的設計，以期取代傳統的超薄源極/汲極結構。同時並針對高介電長數閘極層所導致的邊緣電場導致能障下降效應開發效應模型，進行堆疊高低介電長數閘極層結構對奈米電晶體元件特性的影響及設計。本計畫期望經由奈米電晶體閘極結構和堆疊氏閘極層的分析及設計，對於奈米金氧半電晶體技術的繼續研發和推展有基礎性的助益。

關鍵詞：奈米電晶體，金氧半元件，跨立閘結構，短通道效應

Abstract

A comprehensive investigation of the transistor characteristics of Straddle-gate and unetched-gate structure is presented in this work. Using the careful analysis of these characteristics, sub-100nm length straddle-gate transistors can be optimized with various structure variables, such as spacer width and side dielectric thickness. The straddle-gate transistor is shown to exert much better control on gate than the control device with the same effective channel length, which leads to a significant improvement in I_{on}/I_{off} ratio.

Keywords: Straddle-gate transistor, Short channel effect

INTRODUCTION

In the scaling of MOSFETS, some of the well-recognized constraints for sub-100 nm designs must be overcome. One of the constraints in sub-100nm transistor design is the severe threshold voltage roll-off as the channel length scaled. Straddle-gate transistors which provide non-uniformed threshold voltages across the channel were proposed to resolve this issue [2]. Straddle-gate transistors have a low threshold-voltage at side-walls which turns on before the main transistor, therefore they provide as high the conductive current as that of the main transistor. Since the transistor has effectively a longer channel length when it is off and a shorter channel length when it is on, a lower off-state current and a higher I_{on}/I_{off} ratio can be obtained. A comprehensive study via device simulation on the effect of side-spacer design on the device is performed, which allows a better understanding and optimization of the straddle-gate transistors.

DEVICE SIMULATION

As shown in Fig.1, the structures simulated in this study are (i) NMOS transistors with lightly doped source/drain extension region as control devices, (ii) transistors with the straddle gate regions formed by two side-wall gates with thinner oxides and (iii) unetched-gate transistors with the straddle gate regions formed by side-wall gates with lightly doped p- regions. In our study, two dimensional device simulations were performed on control devices, straddle-gate transistors and unetched-gate transistors by using TMA SUPREM4 for structural simulation and TMA MEDICI for electrical

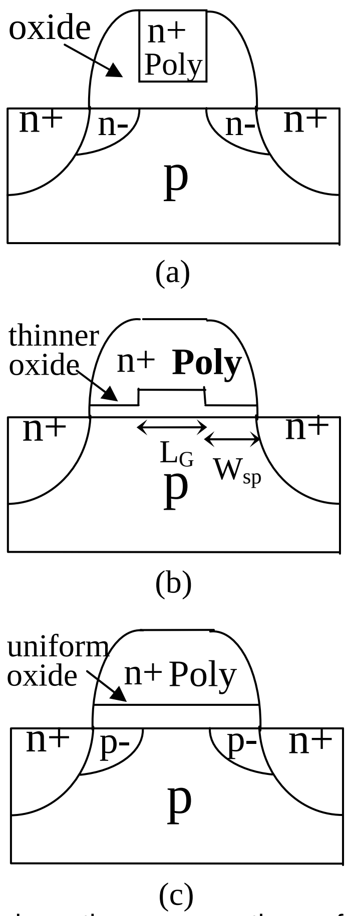

Fig.1 Schematic cross-section of (a)control device, (b)straddle-gate transistors and (c)unetched-gate transistors.

simulation.

RESULTS AND DISCUSSION

The main objective of the straddle-gate device is to reduce the short channel effect, especially V_T-roll-off in deep-sub-micron device. The threshold voltage roll-off characteristics vs. scaling channel length of straddle-gate transistors, unetched-gate transistors and control-gate transistors are compared in Fig.2. Both the straddle-gate and unetched-gate transistors exhibit less V_T-roll-off than the control device. It is because straddle-gate and unetched-gate transistors have an effective longer physical channel length when the device is off, which is a very advantageous feature in device scaling.

The relationships of off-state and on-state current of a transistor significantly affect the design of the transistors' threshold voltages that directly affect the scaling in V_{dd} and power consumption in circuit. The off-state current is here determined at $V_d=V_{dd}$, $V_g=0V$ whereas the on-state current is determined at $V_d=V_g=V_{dd}$. Fig.3, 4, 5 compare I_{on}, I_{off} and I_{on}/I_{off} ratio of the three structures investigated vs. various channel length. As shown in Fig.3, the off-state current of control-gate transistor is much bigger than that of the others while no significant difference is observed between their on-state current shown in Fig.4. Hence, the I_{on}/I_{off} ratios of straddle-gate transistors are found to be much larger than of the control (see Fig.5). It is because the straddle-gate transistors have effectively a longer channel length, $L+2W_{sp}$, when it is off and channel length of L when it is on.

For device with various oxide thickness under the straddle-gates, the threshold voltages, I_{on}, I_{off} and I_{on}/I_{off} ratio are monitored. The threshold voltages of straddle-gate transistors decrease slowly when straddle oxide thickness decrease, as shown in Fig.6. By the way, similar behavior is found in the threshold voltages of unetched-gate transistors with decreasing doping concentrations in the p- region beside of interest. The insensitivity in V_{th} on these structure variables allows us the change T_s and p- concentration drastically without

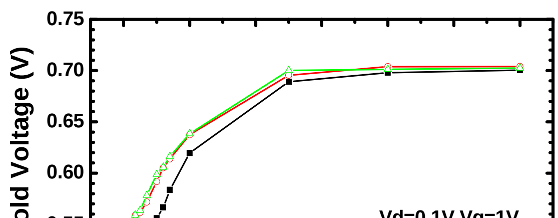

Fig.2 Threshold voltages of transistors with and without straddles vs. L_G.

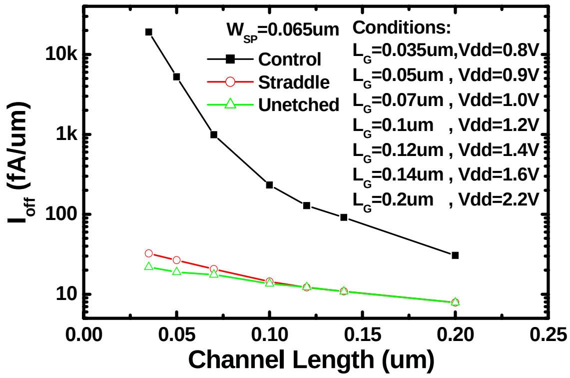

Fig.3 The off-state current of control device is 1~3 order higher than the others.

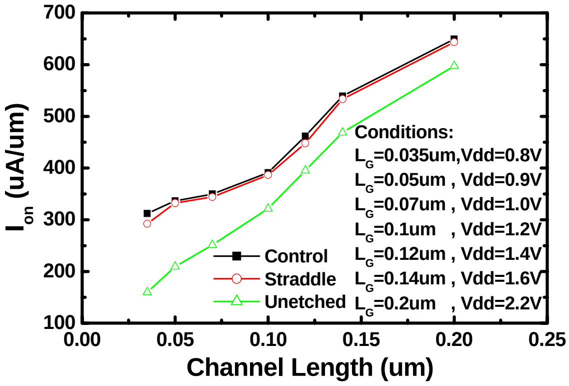

Fig.4 No significant difference is observed between control device and straddle device.

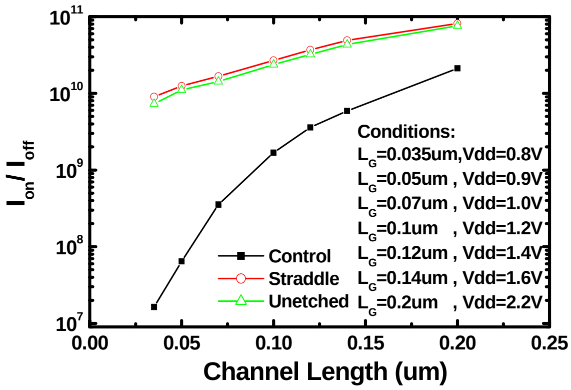

Fig.5 Straddle-gate transistors have higher I_{on}/I_{off} ratios as device scales down.

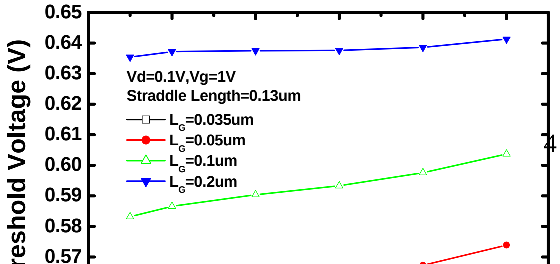

Fig.6 Vth of straddle-gate transistors with different straddle oxide T_s/T_m ratios while T_m (main gate oxide thickness) is fixed.

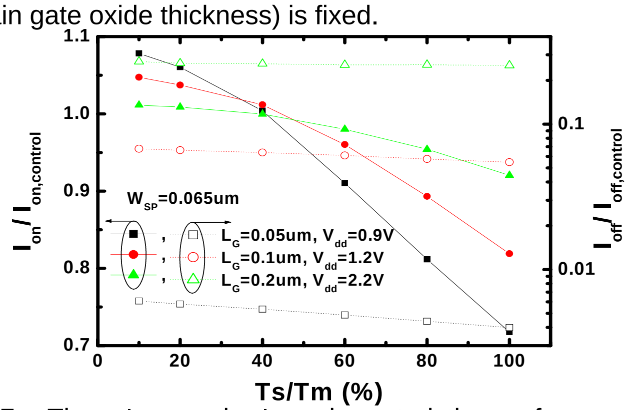

Fig.7 The I_{on} and I_{off} characteristics of straddle-gate transistors vs. T_s/T_m(%).

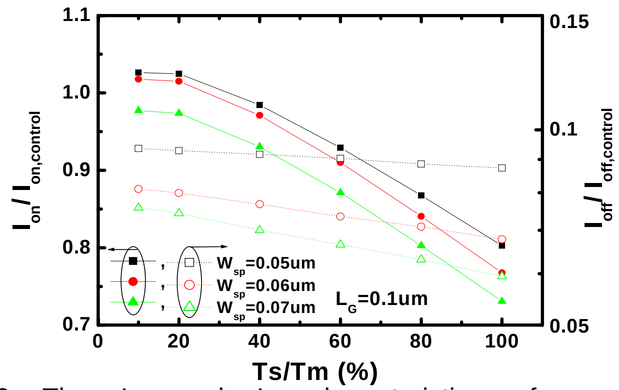

Fig.8 The I_{on} and I_{off} characteristics of straddle-gate transistors with different spacer width vs. T_s/T_m(%).

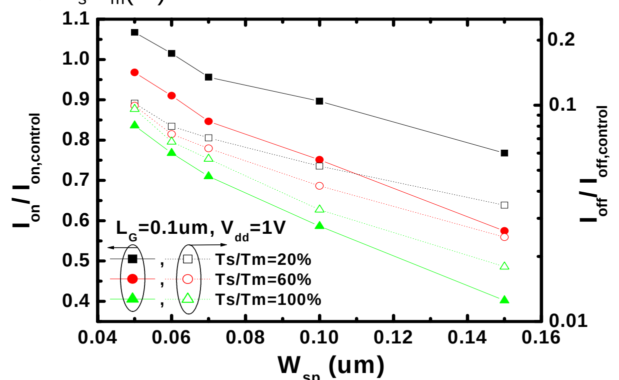

Fig.9 The I_{on} and I_{off} characteristics of straddle-gate transistors with T_s/T_m(%) vs. Wsp.

source/drain. However, the effect of both straddle oxide thickness and p- doping level on V_{th} is found to be insignificant in device affecting the target V_{th} significantly. Varying the straddle oxide thickness of straddle-gate transistors, the corresponding on-state current and off-state current are shown in Fig.7. It is found that both I_{off} and I_{on} increase when thickness of straddle oxide or the doping concentration decreases. The off-state currents of straddle-gate transistors are much lower than that of control device and their on-state currents do not have a significant difference. In Fig.8, varying the oxide thickness of straddle-gate transistors with different spacer width, similar I_{off} and I_{on} characteristics can also be found. Fig. 9 shows the corresponding I_{on} and I_{off} characteristics of straddle-gate transistors with varying spacer widths. The on-state current and off-state current increase when spacer width decreases. They are both mainly due to lower on-resistance resulting from a thinner straddle oxide or a lower doped inversion region.

As shown in Fig. 10, varying straddle oxide thickness, the sub-threshold slopes of straddle-gate transistors are monitored. The sub-threshold slope is lower when straddle oxide thickness is thinner. It is a very good advantage for us to scale down the straddle oxide.

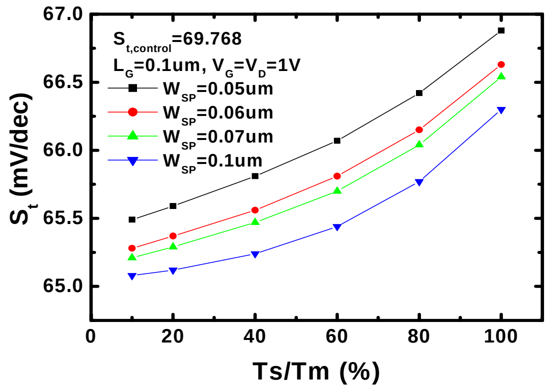

Fig. 10 The thinner the straddle oxide thickness, the lower the sub-threshold slope is.

In Fig. 11 and Fig. 12, the I_{on} and I_{off} of one-sided straddle-gate transistors are discussed. Both the on-state current and off-state current of source-side straddle transistors are higher than that of drain side-side straddle transistors. And the effect

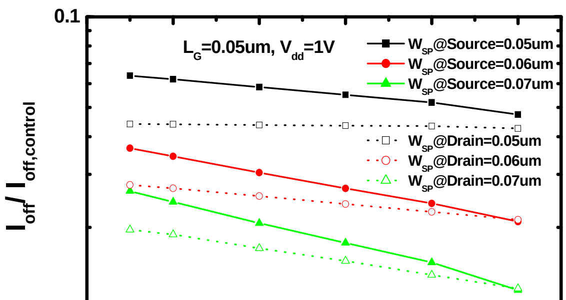

Fig.11 The off-state currents of one-sided straddle-gate transistors.

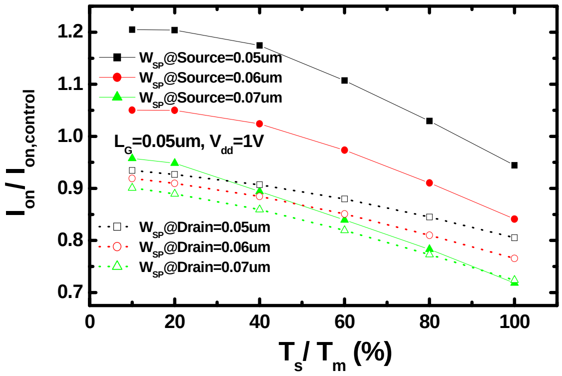

Fig.12 The on-state currents of one-sided straddle-gate transistors.

is more significant when straddle oxide thickness is thinner. When the one-sided straddle transistors turn on, the channel resistance (Rch) of source-side straddle transistor is lower than that of drain-side straddle transistor.

計畫成果自評

Compared with control transistors, straddle-gate transistors have a lower off-state current and a higher I_{on}/I_{off} ratio. The sub-threshold slope of straddle-gate transistor decreases when straddle oxide thickness decreases. By adjusting the oxide thickness or the spacer width of the straddle gate, we can also optimize I_{on} and I_{off}. These are advantages for integrated circuit to scale down.

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