Shallow-Trench-Isolation (STI)-Induced Mechanical-Stress-Related Kink-Effect Behaviors of 40-nm PD SOI NMOS Device

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Abstract—This brief reports the shallow-trench-isolation (STI)-induced mechanical-stress-related kink-effect behaviors of the 40-nm PD silicon on insulator (SOI) NMOS device. As verified by the experimentally measured data and the 2-D simulation results, the kink-effect behaviors occur at a higher V_D in the saturation region and show a less steep subthreshold slope for the 40-nm PD device with a smaller S/D length of $0.17\ \mu\text{m}$ due to the weaker function of the parasitic bipolar device as a result of the larger body-source bandgap-narrowing effect coming from the higher STI-induced mechanical stress.

Index Terms—CMOSFET, silicon on insulator (SOI) technology.

I. INTRODUCTION

MECHANICAL stress induced by shallow trench isolation (STI) may affect the performance of CMOS devices [1], [2]. Mechanical stress may change work function, effective mass, carrier mobility, and junction leakage [3]. Silicon on insulator (SOI) has been becoming another mainstream technology for CMOS VLSI in the nanometer regime [4]. For nanometer PD SOI CMOS devices, the S/D region may be very small; the STI-induced mechanical stress is not negligible. The effects of mechanical stress on the performance of the SOI MOS devices with STI have been studied [2]. Until now, no papers about the STI-induced effects on the performance of the PD SOI CMOS devices could be found. In this brief, STI-induced mechanical-stress-related kink-effect behaviors of the 40-nm PD SOI NMOS device are reported. In the following sections, the STI-induced mechanical stress is described first, followed by STI-induced kink effects, discussion, and conclusion.

II. STI-INDUCED MECHANICAL STRESS

The 40-nm PD SOI NMOS test device fabricated in the industry with its cross section, as shown in Fig. 1(a) and (b), has a 70-nm thin film doped with a p-type doping density of

Fig. 1. (a) TEM cross section of the 40-nm PD SOI NMOS device under study. (b) Cross section of the PD SOI NMOS device used in the Medici simulation.

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$3 \times 10^{18}\ \text{cm}^{-3}$ above a buried oxide of 145 nm, under a gate oxide of 1.5 nm. A 65-nm lightly doped drain region doped with an n-type density of $10^{19}\ \text{cm}^{-3}$ under a sidewall spacer has been adopted. In addition, a nickel polycide is formed on the top of the gate, and a SiN capping layer is deposited over the device. STI structure has been adopted in forming this PD SOI NMOS device. Two cases with the S/D length of 1.7 and $0.17\ \mu\text{m}$ have been designed for this brief. Experimental measurement of the

Fig. 2. Mechanical stress and bandgap-narrowing distribution in the lateral direction of the PD device with the S/D length of 0.17 μm .

test device and 2-D simulation considering mechanical-stress effects and energy-balance equation [5] have been used to carry out this brief. There are 8871 grids in the test device for the 2-D simulation.

Due to the trench isolation, the difference in the thermal-expansion coefficient between silicon and silicon dioxide, and the visco-elastic effects during the thermal anneals, a mechanical stress develops [2]. Using the result from a process simulator considering the hydrostatic pressure with the 2-D device simulator, Fig. 2 shows the hydrostatic pressure and the associated bandgap-narrowing distribution in the lateral direction of the 40-nm PD SOI NMOS device with S/D length of 0.17 μm based on process-simulation results [6]. As induced by STI, the mechanical stress in terms of hydrostatic pressure is large in the S/D region near STI and decreases away from it. The corresponding bandgap narrowing, which is correlated to the mechanical stress, has a dramatic impact on the kink effect of the 40-nm PD NMOS device.

III. STI-INDUCED KINK BEHAVIORS

Fig. 3 shows I_D versus V_D of the 40-nm PD NMOS device with the S/D length of 1.7 and 0.17 μm , biased with its body floating, and based on the measured data and 2-D device simulation results using Medici. As shown in the figure, with a smaller S/D length of 0.17 μm , the kink-effect behavior occurs at a larger V_D as compared to the case with the S/D length of 1.7 μm . Fig. 4 shows the related output conductance versus V_D characteristics of the PD device biased at $V_G = 0.8$ V. With the shorter S/D length of 0.17 μm , the kink-effect behavior occurs at a larger V_D due to the higher bandgap-narrowing effect from the larger mechanical stress.

Fig. 5(a) and (b) shows the subthreshold characteristics of the 40-nm PD SOI NMOS device with the S/D length of 1.7 and 0.17 μm , biased at $V_D = 0.05$ V and 0.8 V and body floating. At $V_D = 0.05$ V, the subthreshold curves are less steep than those at $V_D = 0.8$ V, since the parasitic bipolar device is not activated yet. At $V_D = 0.8$ V, the subthreshold slopes become steeper due to the turn-on of the bipolar device (the subthreshold-kink

Fig. 3. I_D versus V_D of the 40-nm PD SOI NMOS device with the S/D length of 1.7 and 0.17 μm .

effect). With a smaller S/D length of 0.17 μm , the subthreshold slope becomes less steep as compared to the case with the S/D length of 1.7 μm , which implies a weaker action of the parasitic bipolar device due to the effect of more body-source bandgap narrowing from the STI-induced mechanical stress. The trends predicted by the 2-D device simulation are strongly correlated to the experimentally measured data, as shown in the figures.

IV. DISCUSSION

The higher V_D at the onset of the kink-effect behavior in the saturation region and the less steepness of the subthreshold-kink behavior of the 40-nm PD SOI NMOS device with the smaller S/D length of 0.17 μm could be reasoned by considering the function of the parasitic bipolar device in the thin film. Fig. 6 shows the body-source voltage, which is the base-emitter voltage (V_{BE}) of the parasitic bipolar device in the thin film, versus V_D of the 40-nm PD NMOS device with the S/D length of $L = 1.7$ and 0.17 μm , biased at $V_G = 0.4$ V and 0.8 V, based on the Medici simulation results. As shown in the figure, with

Fig. 4. Output conductance versus V_D of the 40-nm PD NMOS device with the S/D length of $L = 1.7$ and $0.17 \mu\text{m}$, biased at $V_G = 0.8 \text{ V}$.

Fig. 5. (a) Subthreshold characteristics of the 40-nm PD NMOS device biased at $V_G = 0.8$ and 0.05 V . (b) Subthreshold S factor of the 40-nm PD NMOS device with the S/D length of $L = 1.7$ and $0.17 \mu\text{m}$, biased at $V_G = 0.8$ and 0.05 V .

a smaller S/D length of $0.17 \mu\text{m}$, the body-source voltage rises at a larger V_D , which indicates the later turn-on the parasitic bipolar device. At the onset of the kink-effect behavior, the parasitic bipolar device is triggered to turn on with its current

Fig. 6. Body-source voltage versus V_D of the 40-nm PD NMOS device with the S/D length of $L = 1.7$ and $0.17 \mu\text{m}$, biased at $V_G = 0.4$ and 0.8 V , based on the Medici simulation results.

gain β as a function of the difference in the bandgap narrowing between the base and the emitter [7]

$$\beta \propto \exp((\Delta E_{gb} - \Delta E_{ge})/kT) \quad (1)$$

where $\Delta E_{gb}/\Delta E_{ge}$ is the bandgap narrowing in the base/the emitter (the source), k is Boltzmann constant, and T is temperature in kelvin. Due to the higher mechanical stress from STI, the bandgap narrowing in the emitter (source)— ΔE_{ge} —is larger than that in the base (the channel) region ΔE_{gb} . Therefore, the function of the parasitic bipolar device in the thin film of the device with the shorter S/D length of $0.17 \mu\text{m}$ becomes weaker as indicated by the smaller current gain. As a result, the onset of the kink-effect behavior occurs at a higher V_D , and its subthreshold slope is less steep [8].

More implications could be obtained from studying the mechanical-stress effects on the device performance. Fig. 7(a) shows the drain voltage at the onset of the kink effect— V_{kink} —versus the S/D length of the PD SOI NMOS device biased at $V_G = 0.6$ and 0.8 V , and Fig. 7(b) shows the S factor versus the S/D length of the PD SOI NMOS device biased at $V_D = 0.05$ and 0.8 V , based on the 2-D simulation results. As shown in Fig. 7(a), until the S/D length is shrunk below $1.5 \mu\text{m}$, the drain voltage V_{kink} is insensitive to the S/D length. When the S/D length is smaller than $1.5 \mu\text{m}$, V_{kink} is sensitive to the S/D length. A smaller S/D length leads to a larger V_{kink} , which implies that the increased bandgap-narrowing effect slows down the turn-on of the parasitic bipolar device. As shown in Fig. 7(b), a similar trend could be seen on the S-factor plot. As the S/D length is smaller than $1.5 \mu\text{m}$, the subthreshold slope of the device is sensitive to the S/D length. A smaller S/D length worsens the subthreshold slope due to the increased bandgap-narrowing effect, which weakens the function of the bipolar device. Therefore, the STI-induced mechanical-stress effect is important for the PD SOI NMOS devices with an S/D length smaller than $1.5 \mu\text{m}$. The STI-induced mechanical-stress effects could be a key factor in determining the short-channel-effect behavior of the PD SOI CMOS device in the nanometer regime.

S/D L \ V _{DS}	V _{DS}	
	0.05V	0.8V
1.7μm	79.9mV/dec	76.2mV/dec
0.17μm	82.6mV/dec	81.4mV/dec

Fig. 7. (a) Drain voltage at the onset of the kink effect— V_{kink} —versus the S/D length of the PD SOI NMOS device biased at $V_G = 0.6$ and 0.8 V, and (b) S factor versus the S/D length of the PD SOI NMOS device biased at $V_D = 0.05$ and 0.8 V, based on 2-D simulation results.

V. CONCLUSION

This brief reports the STI-induced mechanical-stress-related kink-effect behaviors of the 40-nm PD SOI NMOS device. As verified by the experimentally measured data and the 2-D simulation results, the kink-effect behaviors occur at a higher V_D in the saturation region and show a less steep subthreshold slope for the 40-nm PD device with a smaller S/D length of $0.17\ \mu\text{m}$ due to the higher body-source bandgap narrowing coming from the higher STI-induced mechanical stress.

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