Breakdown Behavior of 40-nm PD-SOI NMOS Device Considering STI-Induced Mechanical Stress Effect

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Abstract—This letter reports the shallow-trench-isolation (STI)-induced mechanical-stress-related breakdown behavior of the 40-nm PD-SOI NMOS device. As verified by the experimentally measured data and the 2-D simulation results, breakdown occurs at a higher drain voltage for the device with a smaller S/D length of 0.17 μm due to the weaker function of the parasitic bipolar device, which is offset by the stronger impact ionization in the post-pinchoff region coming from the bandgap narrowing generated by the STI-induced mechanical stress.

Index Terms—CMOSFETs, silicon on insulator technology.

I. INTRODUCTION

MECHANICAL stress induced by STI may affect the performance of CMOS devices [1], [2]. Mechanical stress may change work function, effective mass, carrier mobility, and carrier lifetime [3], [4]. For nanometer PD-SOI CMOS devices, the S/D region may be very small; the influence of the STI-induced mechanical stress cannot be overlooked. Recently, STI-induced mechanical stress effects on the kink behaviors of the PD-SOI NMOS devices have been reported [5], [6]. In this letter, STI-induced mechanical-stress-related breakdown behavior of the 40-nm PD-SOE NMOS device is reported. In the following sections, the STI-induced mechanical stress is described first, followed by STI-induced breakdown, discussion, and conclusion.

The 40-nm PD-SOI NMOS test device, with its cross section being shown in Fig. 1, has a 70-nm thin film doped with a p-type density of $3 \times 10^{18} \text{ cm}^{-3}$ above a buried oxide of 145 nm, under a gate oxide of 1.5 nm. STI has been adopted. The channel width of the device is 1 μm . Two cases with S/D lengths of 1.7 and 0.17 μm , respectively, have been designed for this letter. Experimental measurements of the test device and 2-D simulation considering mechanical stress effects [7] have been used to carry out the study.

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Fig. 1. (a) TEM cross section of the 40-nm PD-SOI NMOS device under study. (b) Mechanical stress and bandgap narrowing distribution at 3 nm below the gate oxide in the lateral direction of the PD device with S/D lengths of 0.17 and 1.7 μm .

In an SOI MOS device, the internal mechanical stress is caused during the formation of the STI structure. Fig. 1(b) shows the hydrostatic pressure and the associated bandgap narrowing distribution at 3 nm below the gate oxide interface in the lateral direction of the 40-nm PD-SOI NMOS device with S/D lengths of 0.17 and 1.7 μm based on process simulation results [8]. As induced by STI, for the S/D length of 0.17 μm , the mechanical stress in terms of hydrostatic pressure is large in the S/D region near STI and decreases as the distance becomes farther away from it. The corresponding bandgap narrowing, which is correlated to the mechanical stress, has a dramatic impact on the breakdown behavior of the 40-nm PD-SOI NMOS device.

Fig. 2. I_D versus V_D of the 40-nm PD-SOI NMOS device with S/D lengths of 1.7 and 0.17 μm , based on the measured data and 2-D simulation results, with the inset figure being the measured subthreshold figure.

Fig. 3. Output conductance versus V_D of the 40-nm PD-SOI NMOS device with S/D lengths of $L = 1.7$ and 0.17 μm , biased at $V_G = 0.8$ V, based on the measured data and 2-D simulation results.

II. STI-INDUCED BREAKDOWN BEHAVIOR AND DISCUSSION

Fig. 2 shows I_D versus V_D of the 40-nm PD-SOI NMOS device with S/D lengths of 1.7 and 0.17 μm , biased with its body floating, based on the measured data and 2-D device simulation results. Also shown in the inset of the figure is the measured subthreshold figure. With the S/D length of 0.17 μm , the breakdown occurs at a larger V_D as compared to the case with the S/D length of 1.7 μm . Fig. 3 shows the related output conductance versus V_D characteristics of the PD device biased at $V_G = 0.8$ V. As confirmed by the smaller output conductance, with the shorter S/D length of 0.17 μm , breakdown occurs at a larger V_D , which is due to the higher bandgap narrowing effects from the larger mechanical stress on the parasitic bipolar device. The trends predicted by the 2-D device simulation are strongly correlated to the experimentally measured data, as shown in the figures.

Fig. 4. Body-source voltage versus V_D of the 40-nm PD-SOI NMOS device with S/D lengths of $L = 1.7$ and 0.17 μm , biased at 0.8 V, based on the 2-D simulation results.

From the current conduction mechanism inside the device [9], both the parasitic bipolar device and the post-pinchoff impact ionization determine the breakdown behavior. With a smaller S/D length of 0.17 μm , in the post-pinchoff region, the impact ionization is stronger because it is closely related to the bandgap [10]. On the other hand, the vitality of the parasitic bipolar device is also determined by the bandgap narrowing factor. Fig. 4 shows the body-source voltage, which is the base-emitter voltage (V_{BE}) of the parasitic bipolar device in the thin film, of the 40-nm PD-SOI NMOS device with S/D lengths of $L = 1.7$ and 0.17 μm , biased at $V_G = 0.8$ V, based on the 2-D simulation results. As shown in the figure, with a smaller S/D length of 0.17 μm , the body-source voltage is smaller at a larger V_D , which indicates the weaker function of the parasitic bipolar device. The less strong turn-on of the parasitic bipolar device at a high drain voltage for the 0.17- μm case could be understood from the current-gain β formula as a function of the difference in the bandgap narrowing between the base and the emitter [10]

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

where $\Delta E_{gb}/\Delta E_{ge}$ is the bandgap narrowing in the base/emitter (the source), k is the Boltzmann constant, and T is the 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 vitality of the parasitic bipolar device in the thin film of the device with a shorter S/D length of 0.17 μm becomes less strong as indicated by the smaller current gain. Because the bandgap-narrowing-related bipolar function is the dominant factor in determining the breakdown behavior compared to the bandgap-related impact ionization in the post-pinchoff region, the breakdown voltage becomes higher for the case with a smaller S/D length of 0.17 μm due to a higher STI-induced mechanical stress. Fig. 5 shows the breakdown voltage versus the gate voltage of the 40-nm PD-SOI NMOS device with S/D lengths of $L = 1.7$, 0.17, and 0.017 μm , based

Fig. 5. Breakdown voltage versus gate voltage of the 40-nm PD-SOI NMOS device with S/D lengths of $L = 1.7, 0.17$, and $0.07 \mu\text{m}$, based on the measured data and the 2-D simulation results.

on the measured data and the 2-D simulation results. From the figure, the 2-D simulation results based on the mechanical-stress bandgap narrowing are correlated to the measured data. As shown in the figure, a smaller gate voltage leads to a larger breakdown voltage due to the extra degradation of the parasitic BJT function due to the high injection effect coming from the increased impact ionization in the larger post-saturation region.

III. CONCLUSION

This letter reports the STI-induced mechanical-stress-related breakdown behavior of the 40-nm PD-SOI NMOS device. As verified by the experimentally measured data and the 2-D simulation results, breakdown occurs at a higher drain voltage

for the device with a smaller S/D length of $0.17 \mu\text{m}$ due to the weaker function of the parasitic bipolar device, which is offset by the stronger impact ionization in the post-pinchoff region coming from the bandgap narrowing generated by STI-induced mechanical stress.

REFERENCES

- [1] R. A. Bianchi, G. Bouche, and O. Roux-dit-Buisson, "Accurate modeling of trench isolation induced mechanical stress effects on MOSFET electrical performance," in *IEDM Tech. Dig.*, 2002, pp. 117–120.
- [2] C. Gallon, G. Reimbold, G. Ghibaudo, R. A. Bianchi, R. Gwoziecki, S. Orain, E. Robillart, C. Raynaud, and H. Dansas, "Electrical analysis of mechanical stress induced by STI in short MOSFETs using externally applied stress," *IEEE Trans. Electron Devices*, vol. 51, no. 8, pp. 1254–1261, Aug. 2004.
- [3] J. Pretet, D. Ioannou, N. Subba, S. Cristoloveanu, W. Maszara, and C. Raynaud, "Narrow-channel effects and their impact on the static and floating-body characteristics of STI- and LOCOS-isolated SOI MOSFETs," *Solid State Electron.*, vol. 46, no. 11, pp. 1699–1707, Nov. 2002.
- [4] J. Pretet, N. Subba, D. Ioannou, S. Cristoloveanu, W. Maszara, and C. Raynaud, "Reduced floating body effects in narrow channel SOI MOSFETs," *IEEE Electron Device Lett.*, vol. 23, no. 1, pp. 55–57, Jan. 2002.
- [5] I. Lin, V. Su, J. B. Kuo, M. Ma, C. T. Tsai, C. S. Yeh, and D. Chen, "STI mechanical-stress induced subthreshold kink effect of 40 nm PD SOI NMOS device," in *Proc. Dig. ISDRS*, Dec. 2007, pp. 1–2.
- [6] I. S. Lin, V. C. Su, J. B. Kuo, D. Chen, C. S. Yeh, C. T. Tsai, and M. Ma, "STI-induced mechanical stress-related kink effect of 40 nm PD SOI NMOS devices," in *Proc. EUROSOL Dig.*, 2008, pp. 81–82.
- [7] *Taurus Medici User Guide*, Synopsys Inc., Mountain View, CA, Oct. 2005.
- [8] *Taurus TSUPREM-4 User Guide*, Synopsys Inc., Mountain View, CA, Oct. 2005.
- [9] Y. G. Chen, S. Y. Ma, J. B. Kuo, and R. W. Dutton, "An analytical drain current model for short-channel FD ultrathin SOI NMOS devices," *Solid State Electron.*, vol. 38, no. 12, pp. 2051–2057, Dec. 1995.
- [10] S. Selberherr, *Analysis and Simulation of Semiconductor Devices*. New York: Springer-Verlag, 1984.
- [11] J. B. Kuo *et al.*, "Analytical bandgap-narrowing-related current-gain model for BJT devices operating at 77 K," *Solid State Electron.*, vol. 35, no. 6, pp. 785–790, Jun. 1992.