Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 172-173

A-5-1

Successful CMOS Operation of Dopant-Segregation Schottky Barrier Transistors (DS-SBTs)

A. Kinoshita, Y. Tsuchiya, A. Yagishita*, K. Uchida and J. Koga

Advanced LSI Technology Laboratory, Corporate R&D Center, Toshiba Corporation
*Process and Manufacturing Engineering Center, Semiconductor Company, Toshiba Corporation
8, Shinsugita-cho, Isogo-ku, Yokohama 235-8522, Japan (atsuhiro.kinoshita@toshiba.co.jp)

Abstract

CMOS operation is successfully demonstrated in a novel Schottky-source/drain MOSFET, which has dopant segregation (DS) Schottky junctions. Arsenic and boron are used as dopants to form complementary DS-Schottky junctions. The behavior of dopant segregation is characteristic of each dopant. The obtained lowering of Schottky barrier height exceeds 0.4 eV for arsenic doped DS-Schottky junction and 0.3 eV for boron doped junction, which results in high drive currents for CMOS operation.

Introduction

Schottky source/drain MOSFETs (SBTs) have attracted much attention as a candidate for high-performance devices in deep sub-50-nm gate regime [1-6]. However, it has been pointed out that large barrier height, ϕ_b, at the source Schottky junction significantly lowers drive current of SBTs. Therefore, several researches have been carried out in order to lower ϕ_b and achieve high-performance SBTs [7-9].

Recently, we proposed a novel approach for ϕ_b engineering using the dopant-segregation (DS) technique, and demonstrated competitive drive current and better short-channel effect immunity in As doped n-type DS-SBTs, compared to the conventional MOSFETs [9]. In this paper, we investigate the formation mechanism of As/B doped DS-Schottky junctions, and demonstrate complementary operation in DS-SBT.

Experiments and Discussions

A. Device structure and S/D fabrication

Fig.1 shows a schematic of our complementary DS-SBT. As/B doped DS-Schottky junctions were used as the source/drain electrodes, in order to reduce the Schottky barrier height. The mechanism of ϕ_b modulation varies by the type of dopant. In the case of As doped DS-Schottky junction, As^+ ion induced image force and tunneling current *equivalently* reduces the barrier height. Here, the thickness of As doped layer is adjusted to be fully depleted, in order to achieve the ϕ_b modulation without losing Schottky-like characteristics [9]. On the other hand, the metal work function can be modulated *directly* at the B doped interface in the B doped DS-Schottky junction. This difference in the ϕ_b modulation mechanism is based on different dopant profiles, which will be mentioned below.

The formation process of DS-Schottky junction is schematically shown in Fig.2. Before the silicidation, dopant is implanted and activated to form a shallow doping region. Next, the doping region is silicided to be consumed. The dopant is piled-up at the $CoSi_2$/Si interface during the silicidation process by the snowplow effect [10]. The piled-up dopant atoms remained to be activated, which will be apparent in the ϕ_b modulation results (Fig.5). It should be noted that this *super-shallow* doping layer is achieved owing to the physical mechanism inherent to the impurity segregation.

B. Characteristics of DS-Schottky Junctions

Fig.3 shows As and B profiles in the DS-Schottky junction taken by backside SIMS. Abrupt junctions are achieved. It should be emphasized that the actual impurity profiles are steeper than the apparent SIMS profiles, taking into account the deviation of $CoSi_2$/Si interface. Different behavior of dopant segregation are obtained for As and B; almost all dopant atoms are included in the silicide region in the case of B.

These behavior for As and B can be explained qualitatively by the difference of their solubility in Si and silicide (Table I a). In the case of As, the solubility in Si is larger than that in $CoSi_2$. Therefore, excessive As atoms in $CoSi_2$ region are plowed out to the Si region during silicidation. Since the silicidation temperature is low enough, dopant self-diffusion is negligible in the Si region (Table I b). The solubility and diffusion coefficient for B can cause the reverse change. However, further examinations are necessary for complete understanding on the segregation process, especially for B.

Fig.4 shows junction depth, x_j, and peak As concentration as a function of Co sputter thickness, estimated from SIMS profiles. The junction depth can be controlled by the Co sputter thickness without much decrease in the peak concentration. This x_j dependence on Co sputter thickness suggests that there exists additional diffusion mechanism based on Co and As interaction, compared to B.

Fig.5 shows ϕ_b modulation in the DS-Schottky junctions extracted from *I-V* characteristics. It is clearly observed that the effective ϕ_b is significantly modulated by the implantation dose. The amount of ϕ_b modulation, $\Delta\phi_b$, exceeds -0.4 eV and -0.3 eV for As and B, respectively. In the case of B, $\Delta\phi_b$ shows saturation, which is similar to the gate work-function modulation due to the impurity segregation reported by Kedziersky et al. [11].

C. Transistor characteristics and CMOS operation

Fig.6 shows a cross-sectional TEM image of DS-SBT. Flatness of silicon surface was improved compared to the previous work [9]. Typical I_d-V_d characteristics of DS-SBTs are shown in Fig.7. Normal CMOS characteristics are observed. Fig.8 shows typical I_d-V_g characteristics of DS-SBTs. Interestingly, the junction leakage current is smaller for the B doped DS-SBT, even though the impurity profile is much shallower for B (Fig. 3). This result indicates that the leakage current of DS-Schottky junction is not always determined by the junction thickness, which is contrary to PN junction.

Finally, CMOS inverter operation of DS-SBTs with L_g of 460 nm was successfully achieved as shown in Fig.9. To our knowledge, this is the first successful CMOS operation in *conventional* SBTs fabricated with single-metal process.

Conclusion

Successful CMOS operation has been demonstrated in As/B doped DS-SBTs. It is considered that the origin of ϕ_b modulation for As is the image force and tunneling current, whereas that for B is the direct modulation of metal work function. This difference is related to the different behaviors in the dopant segregation process. Lowering of Schottky barrier height exceeds 0.4 eV for As doped DS-Schottky junction and 0.3 eV for B doped junction. In conclusion, DS-SBT is a promising device as advanced CMOS.

References
[1] J. R. Tucker et al., *APL*, **65**, 618 (1994).
[2] J. P. Snyder et al., *APL*, **67**, 1420, (1995).
[3] M. Nishisaka et al., *JJAP*, **37**, 1295 (1998).
[4] C. Wang et al., *APL*, **74**, 1174 (1999).
[5] K. Uchida et al., *APL*, **76**, 3994 (2000).
[6] J. Kedzierski et al., *IEDM* (2000), 57.
[7] K. Ikeda et al., *EDL*, **23**, 670 (2002).
[8] A. Yagishita et al., *SSDM* (2003), 708.
[9] A. Kinoshita et al., *VLSI Symp.* (2004), 16-5.
[10] J. P. Gambino et al., *Mat. Chem. Phys.*, **52**, 99 (1997).
[11] J. Kedzierski et al., *IEDM* (2003), 315.

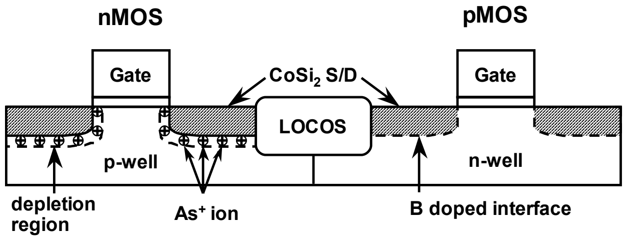

Fig.1 Schematic of our complementary DS-SBT. As/B-doped DS-Schottky junctions were used as the source/drain electrodes, in order to reduce the Schottky barrier height.

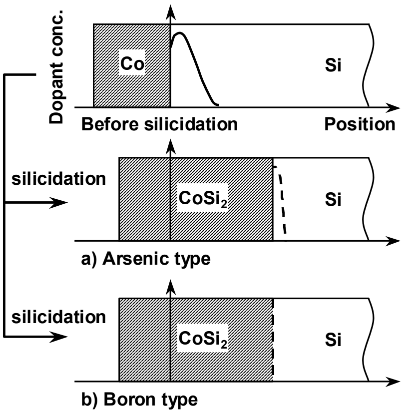

Fig.2 Schematic formation process of the DS-Schottky junction. A part of As ions diffuse into the Si substrate, whereas almost all B atoms remains inside the $CoSi_2$.

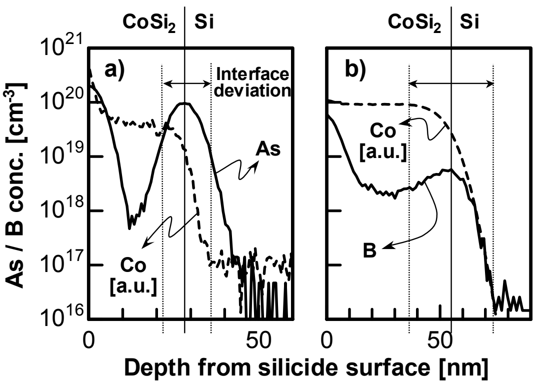

Fig.3 Backside SIMS profiles of a) As and b) B doped DS-Schottky junction. Implanted dose is 1×10^{15} cm^{-2}. Co sputter thickness is a) 120 Å and b) 200 Å.

a) Solubility [cm^{-3}]

	Si	$CoSi_2$
As	2×10^{20}	$< 1\times10^{17}$
B	7×10^{19}	2×10^{20} *

at 900°C, * at 1050°C

b) Diffusion length [cm]

	Si	$CoSi_2$
As	< 1 Å	1.6×10^{-7}
B	< 1 Å	8×10^{-6}

under silicidation condition

Table I a) Solubility and b) estimated diffusion length for As and B in Si and $CoSi_2$, modified from [10].

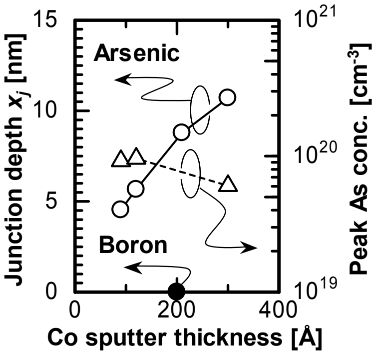

Fig.4 Junction depth and peak As concentration as a function of Co sputter thickness. The interface deviation is taken into account.

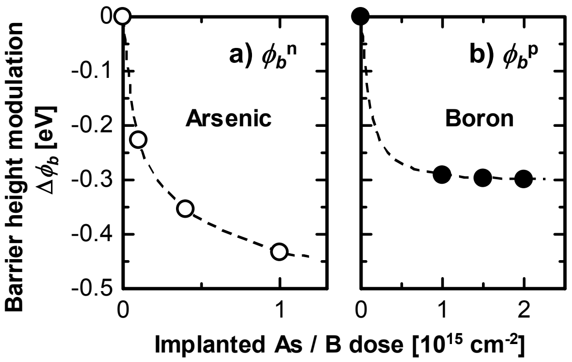

Fig.5 Schottky barrier height modulation in DS-Schottky junctions as a function of implanted dose of a) As and b) B, extracted from *I-V* characteristics.

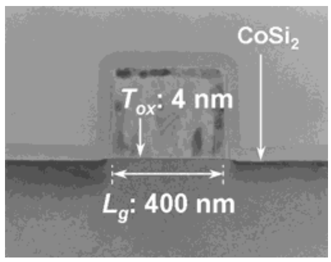

Fig.6 Cross-sectional TEM image of DS-SBT. As and B were implanted with the dose of 1×10^{15} cm^{-2} at 1 keV and 1×10^{16} cm^{-2} at 0.2 keV, respectively.

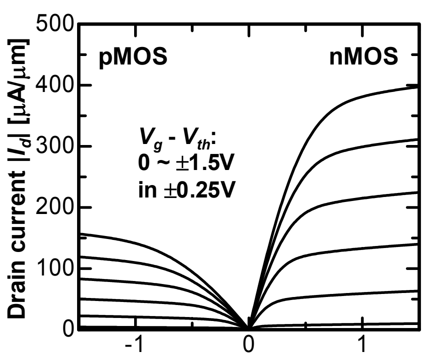

Fig.7 Typical I_d-V_d characteristics of DS-SBT with L_g of 400 nm.

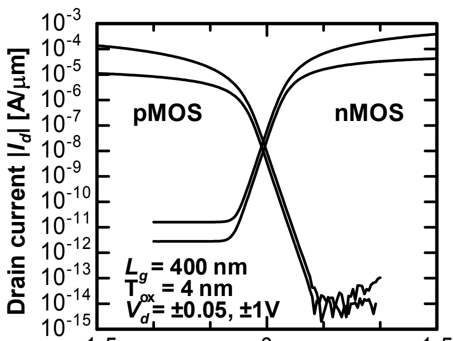

Fig.8 Typical I_d-V_g characteristics of DS-SBT with L_g of 400 nm.

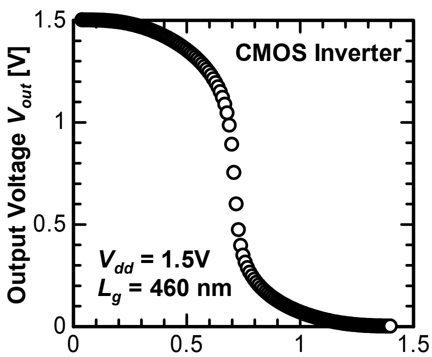

Fig.9 Typical inverter characteristics of complementary DS-SBTs with L_g of 460 nm.