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トンネル FET に対する放射線影響および Si 系ヘテロ接合による ON 電流向上効果

Irradiation Effect of Tunnel FET and Impact of Si base Hetero-Junction Improve ON Current

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Abstract: In this paper, two approaches for tunneling field effect transistor (TFET) has been investigated. Soft error performance for Si Conventional FET and TFETs have been evaluated by device simulation. The bipolar gain effect has relax at TFET, due to which forming one direction potential slope and non-space to store charge in the channel. Secondly, for improving drivability and performance of the TFETs, used by semiconducting silicide-Silicon hetero junction. Mg_2Si has lower bandgap and large conduction/valence band-offset to Si. The hetero-junction formed Source-Channel improve the tunnel resistivity for TFET, and that lead to larger drain current and smaller Subthreshold Slope than Si homo-junction TFETs.

1. Introduction

One of the most detrimental problem on semiconductor device in radiation environments are single event phenomena (SEP). A high energy cosmic ray irradiates to the device, electron-hole pairs are generated along the ion-track induce sufficient transient current to cause an incorrect device response such as a single-event upset. Silicon-on-insulator (SOI) technology had been developed for separate the individual transistors from the substrate, and that prevents latchup and decrease the transient current by limiting the charge collect. However, the reliability issue is more sensitivity of the higher performance CMOS device that due to the small device size, thin active region and lower applying voltage [1]. In conventional n-type FET, the irradiation induced electrons in channel are collected at the drain due to source-drain bias. The hole is stored in the channel body due to the source/drain-channel barrier, and that degrade the source-channel potential barrier. Therefore, the hole charge created within the channel body acts as base injection for the amplified parasitic lateral bipolar transistor (bipolar gain effect). On the other hand, the TFET is essentially a reverse biased p-i-n diode with asymmetric source/drain doping that lead deposited hole can be collected by the source node. Thus, reduction of the minority carrier storage in the channel may reduce the bipolar gain effect and total collected charge of TFETs. Secondly, the TFET has possible to suppress the off-state leakage current between source and drain (I_{off}), because the gate voltage controls the channel potential in order to modulate the tunneling current through the source/channel junction in TFET, instead of modulating the drift-diffusion current in the channel as in the conventional FETs. However, owing to the tunneling resistivity through the semiconductor junctions with a certain bandgap is relatively high, TFETs suffer from the small I_{on} [2], in general. Improvement of the drivability of TFETs has been pursued by using hetero-junctions, in which the tunneling probability is conduction or valence band discontinuities. The hetero-junction has been realized by III-V compound semiconductor. However, high-k gate stack and large contact resistivity are unavoidable issues in ULSI process [3]. On the other hand, hetero-junctions among semiconductors of group IV have also been proposed for their application to the TFETs using Ge-Si and SiGe-Si structures. Semiconducting silicide (Fig.1 (b)) such as $FeSi_2$, $BaSi_2$ and Mg_2Si as hetero-junction materials with Si can be applied. The semiconducting silicide as Mg_2Si source region was modeled according to Figure 1 (c), where shows bandgap, conduction band offset and valence band offsets are 0.77eV and 0.42eV, respectively.

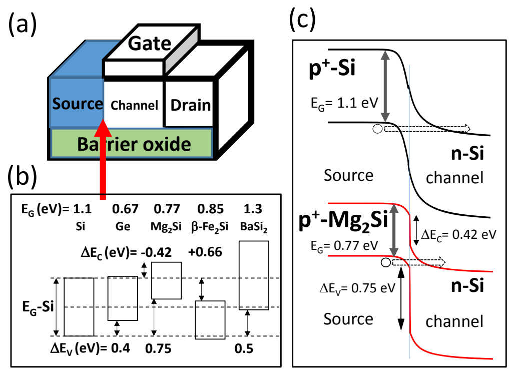

Figure 1. TFET device structure (a), Band alignment of Si, Ge and several semiconducting silicides (b) and Band diagram of P^+-Si/n-Si homo-junction and P^+-Mg2Si/n-Si hetero-junction (c)

In this study, (1) we simulated the irradiation induced transient current on conventional FET and TFET and

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observed the bipolar gain effect of each. (2) hetero-junction TFETs with low SS and high drivability could be realized by simulation. The schematic illustration of the device is shown in Figure 1 (a).

2. Irradiation effect on Emerging devices

We adopted the TCAD Sentaurus to perform the radiation-induced transient current evaluation. Linear energy transfer (LET) describes, the charge deposition per length along the ion track is modeled as a fixed value along the track for structure. The ion strike center in the channel at normal incidence. The generated transient current and charge were observed at the device off-state (V_G= 0 V, V_D= V_{dd}). Irradiation induced effect of conventional FET and TFET are shown in figure 2. Significant reduction in bipolar gain is observed in TFET compared to conventional FET. In conventional type, the generated holes are stored in the body due to the source and drain barrier, which degraded the source-channel potential barrier. Additional electrons were injected from the source into the channel and further increase the drain charge collection (bipolar gain). Owing to the asymmetric S/D doping in TFET, both electrons and holes can be collected through the ambipolar transport, that greatly reduces the body charge storage induced bipolar gain and further reduces the collected charge and the transient time.

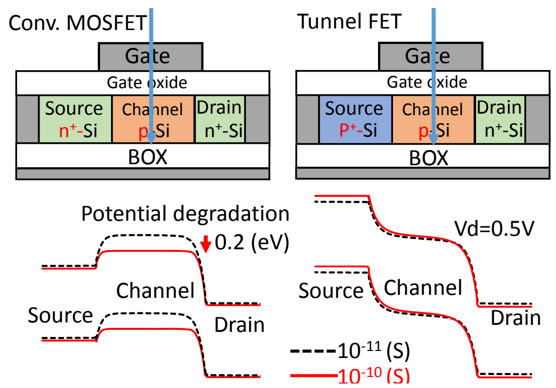

Figure 2. Time evolution of bipolar gain effect radiation indued Conventional FET and Tunnel FET band diagram, dotted line at ion strike, solid line at 10^{-10} (s) after the strike.

3. TFET performance improvement with Herero-junction

A n-type silicon MOS structure in an SOI structure with a thickness of 10 nm was used in the present simulation. Doping concentration of channel (Si) N_d was seted 1×10^{17} cm^{-3}. Doping concentration of source N_a (Mg_2Si, Si) was set to be $1x10^{20}cm^{-3}$. Figure 3 (a) shows I_d – V_G characteristics of the TFET with p-Mg_2Si source hetero-junction. The gate length L_g and the channel doping concentration N_d are 100nm and $1x10^{17}cm^{-3}$, respectively. The drain voltage was set to be 1.0V. Also shown are the characteristics of Si homo-junction tunneling FET. The drain current of Mg_2Si hetero-junction TEFT was larger than that of Si case by more than two orders of magnitude. This figure also shows the steeper subthreshold characteristic for the Mg_2Si hetero-junction TFET. Figure 2 (b) shows the subthreshold swing SS dependence on the gate voltage. The smallest SS less than 10mV/dec. is observed for Mg_2Si source hetero-junction TFET at the region where the drain current starts to rise from the off state. As the drive current increases, the SS gradually increases, however, it keeps small value below 60mV/dec. for the gate voltage range of about 0.2 V.

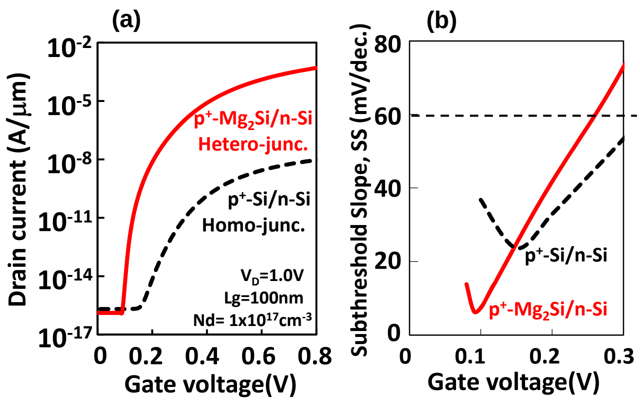

Figure 3. I_D –V_G characteristics of the TFET with p-Mg_2Si source hetero-junction and Si homo-junction tunneling FET (a), The subthreshold swing SS dependence of the gate voltage for both (b).

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Reference

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