ARTICLE IN PRESS

Solid-State Electronics xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Solid-State Electronics

journal homepage: www.elsevier.com/locate/sse

Investigation of ambipolar signature in SiGeOI homojunction tunnel FETs

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Tunnel FET
SiGeOI
Homojunction
Ambipolar

ABSTRACT

In this paper, we study the ambipolar tunneling signature from the output characteristics of TFETs featuring $Si_{0.8}Ge_{0.2}$ homojunctions, which we compare to those measured on conventional MOSFETs and Schottky Barrier FETs. The difference with the former is immediate since a single TFET can display a transistor effect under both pull-up (nTFET) and pull-down (pTFET) biasing conditions. This is however a property shared with SBFETs, in which injection occurs via tunneling through a single carrier Schottky Barrier instead of band-to-band tunneling. Without requiring quantitative considerations on the current levels or transfer characteristics, we find that simply performing the same dual I_D–V_{DS} electrical tests while voluntarily "swapping" the S/D terminals unequivocally characterizes TFET operation, even compared to asymmetrically doped SBFETs.

1. Introduction

A Tunnel FET (TFET) is an unconventional field-effect transistor relying on band-to-band tunneling (BTBT) injection rather than thermal emission above a diffusion barrier, thus enabling it in principle to beat the $kT/q \cdot \ln(10)$ sub-threshold swing (SS) limit [1–5]. This could open the path toward supply voltage scaling at constant I_{OFF}, hence leading to an energy-efficient alternative to traditional CMOS. Since one cannot let power dissipation gains be overshadowed by substantial losses in circuit performance, a challenging aspect of TFET optimization is to design an abruptly commuting switch with good On-State current (I_{ON}), often through the introduction of tunneling boosters. An asset of the doped homojunction approach is that the fabrication process flow remains compatible with standard CMOS, as the device merely consists of a gated p–i–n diode.

The devices under study feature compressively strained $Si_{0.8}Ge_{0.2}$ obtained by the Ge enrichment technique, epitaxially grown raised $Si_{0.7}Ge_{0.3}$ Source and Drain in order to further enhance strain, nickel germano-silicidation (NiPtSiGe) and High-κ/Metal gate (PolySi 50 nm/TiN 5 nm/HfSiON 2.3 nm/Si cap). While it is true that the Germanium mole fraction differs slightly between channel and the raised S/D region, these heterojunctions are not believed to be relevant to carrier injection given the relatively small energy bandgap variation, and granted that the electrical p^+/i and i/n^+ junctions are located within the $Si_{0.8}Ge_{0.2}$ region. The p- and n-doped regions were obtained through ionic implantation (resp. B, BF_2 and P, As) followed by a 950 °C spike anneal. A Scanning Transmission Electron Microscopy (STEM) micrograph of a TFET is shown in Fig. 1, along with the "pTFET" and "nTFET" biasing schemes applied in order to induce BTBT-mediated carrier injection on either side of the channel.

2. Ambipolar tunneling signature

When measuring the output characteristic $\log(I_D)$–V_{DS} of a conventional nFET with various V_{GS} values in standard biasing conditions ($V_{GS} > 0$ V; $V_{DS} > 0$ V), one should expect to visualize a "transistor effect" through V_{GS}-dependent, monotonously increasing plateaus corresponding to the forward-biased Source–Channel junction as in Fig. 2(b). A parasitic "tail" of current may occasionally be visible at high V_{GD} larger than the bandgap of the channel material. When biasing the same device using typical pFET polarities ($V_{GS} < 0$ V; $V_{DS} < 0$ V), all that appears is a reverse-biased diode characteristic curve shifting left with increasing $|V_G|$ as in Fig. 2(a). This sharp contrast between the "pMOSFET" and "nMOSFET" mode I_D–V_D sets of curves in Fig. 2(a) and (b) is one way to illustrate the fundamentally unipolar nature of conventional MOSFETs.

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http://dx.doi.org/10.1016/j.sse.2015.08.007
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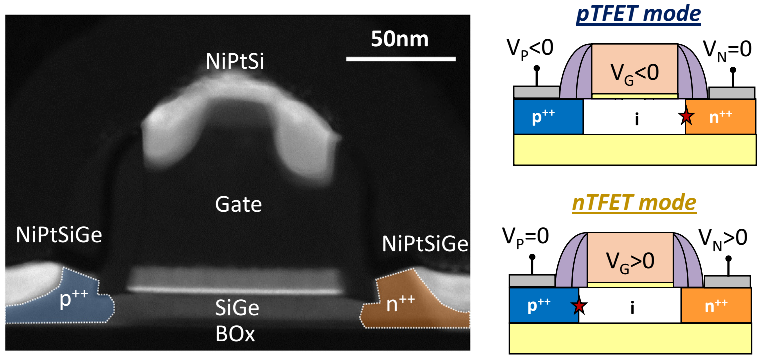

Fig. 1. STEM image of a SiGeOI tunnel FET device of gate length 100 nm, and biasing schemes corresponding to pTFET mode (tunneling occurs at the n-channel junction) and nTFET mode (tunneling occurs at the p-channel junction).

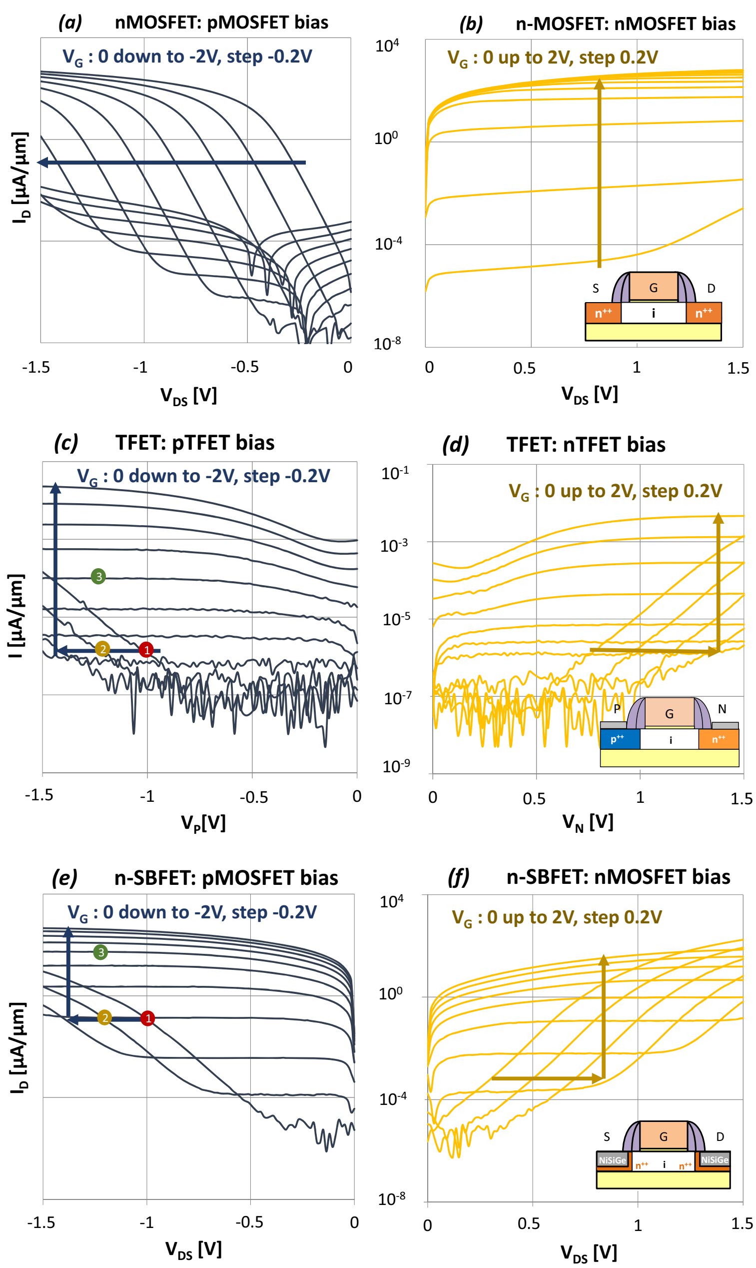

Fig. 2. (a) and (b) Measured log-scale $I_D(V_{DS})$ under pMOSFET and nMOSFET bias of a $Si_{0.8}Ge_{0.2}$ channel conventional MOSFET (L_G = 100 nm). (c) and (d) Measured log-scale $I_P(V_P)$ in pTFET mode and $I_N(V_N)$ in nTFET mode of a $Si_{0.8}Ge_{0.2}$ channel TFET (L_G = 100 nm). Colored dots correspond to Fig. 3(a) with $x = -1$ V. (e) and (f) Measured log-scale $I_D(V_{DS})$ under pMOSFET and nMOSFET bias of a $Si_{0.8}Ge_{0.2}$ channel SBFET with n-type interfacial doping (L_G = 50 nm). Colored dots correspond to Fig. 3(b) with $x = -1$ V. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)