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GIDL analysis of the process variation effect in gate-all-around nanowire FET

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ABSTRACT

In this paper, the gate-induced drain leakage (GIDL) is analyzed on gate-all-around (GAA) Nanowire FET (NW FET) with ellipse-shaped channel induced by process variation effect (PVE). The fabrication process of nanowire can lead to change the shape of channel cross section from circle to ellipse. The effect of distorted channel shape is investigated and verified by technology computer-aided design (TCAD) simulation in terms of the GIDL current. The simulation results demonstrate that the components of GIDL current are two mechanisms of longitudinal band-to-band tunneling (L-BTBT) at body/drain junction and transverse band-to-band tunneling (T-BTBT) at gate/drain junction. These two mechanisms are investigated on channel radius (r_{nw}) and aspect ratio of ellipse-shape respectively and together.

1. Introduction

Gate-All-Around (GAA) nanowire FET (NWFET) is the promising candidate for sub-5 nm technology to suppress detrimental effect like short channel effects (SCEs) and improve current characteristic [1–4]. GAA structure cuts a conspicuous figure in excellent electrostatic controllability over the channel and high performance of circuits based on GAA structure because of the fully gate coverage. The round-shaped channel cross-section of nanowire has advantage than the other shaped (double-, tri-, etc.) devices in terms of the aforementioned electrical characteristics [5,6]. Hence, GAA NWFET is the suitable structure for extremely scaling-down in next-generation technology. However, the limitation of fabrication process is an obstacle in applying for GAA NWFET with ideal round-shaped cross-section. The fabricated nanowire may have unintended cross-section that consists of different major and minor axes [7–9]. This cross-section distorted from ideal shape is detrimental at the circuit performance and device reliability. This phenomenon is defined as process variation effect (PVE), which is considered to a factor influencing the reliability, such as work-function fluctuation (WKF) and random dopant fluctuation (RDF) [10]. The GAA NWFET with ellipse-shaped cross-section by PVE is researched at many previous works [11–14]. But, the analysis of the ellipse-shaped cross-section in gate induced drain leakage (GIDL) is insufficient than other electrical characteristics of GAA NW FET. GIDL as one of the primary leakage components is serious problem within the framework of static power. In previous works, GAA structure is predicted to successfully suppresses GIDL issue using highly scaled GAA structure [15–18]. However, one of the new problems, which arise as the result of changing to 3D structure like GAA, is the longitudinal band-to-band tunneling (L-BTBT) occurring from the entire channel to drain junction [19]. For 2D planer metal-oxide-FET (MOSFET), the mechanism of GIDL is the transverse band-to-band tunneling (T-BTBT) in the gate/drain overlap region [20–23]. In case of GAA NWFET, this strong gate controllability will enhance the other GIDL mechanism, L-BTBT at the body/drain junction instead of suppressing T-BTBT. Because L-BTBT occur at the body/drain junction at GAA NWFET, the larger or smaller channel radius (r_{nw}) than ideal shape induced by PVE effect on degraded GIDL based on the recent research.

In this paper, the effect of the channel area increased or decreased by PVE in GAA NWFET will be investigate in terms of GIDL mechanism. According to previous work, which GIDL originated from the L-BTBT is dominant at small r_{nw} and low $|V_{gs}|$ condition, the gate length (L_g) in this paper is shorter than primary research and $|V_{gs}|$ condition is similar with $|V_{ds}|$. At first, the GIDL mechanism induced by L-BTBT is analyzed in the extremely scaled various value of r_{nw} for sub-5 nm technology. The location occurring L-BTBT and T-BTBT is investigated along the total channel length in GAA NWFET. Furthermore, correlation of r_{nw} with aspect ratio (AR) by PVE in GAA NWFET will be investigated focusing on the impact on the GIDL by Sentaurus technology computer aided-design (TCAD) simulation [24].

2. The device structure and simulation methodology

Fig. 1(a) presents the device structure for sub-5 nm technology. The

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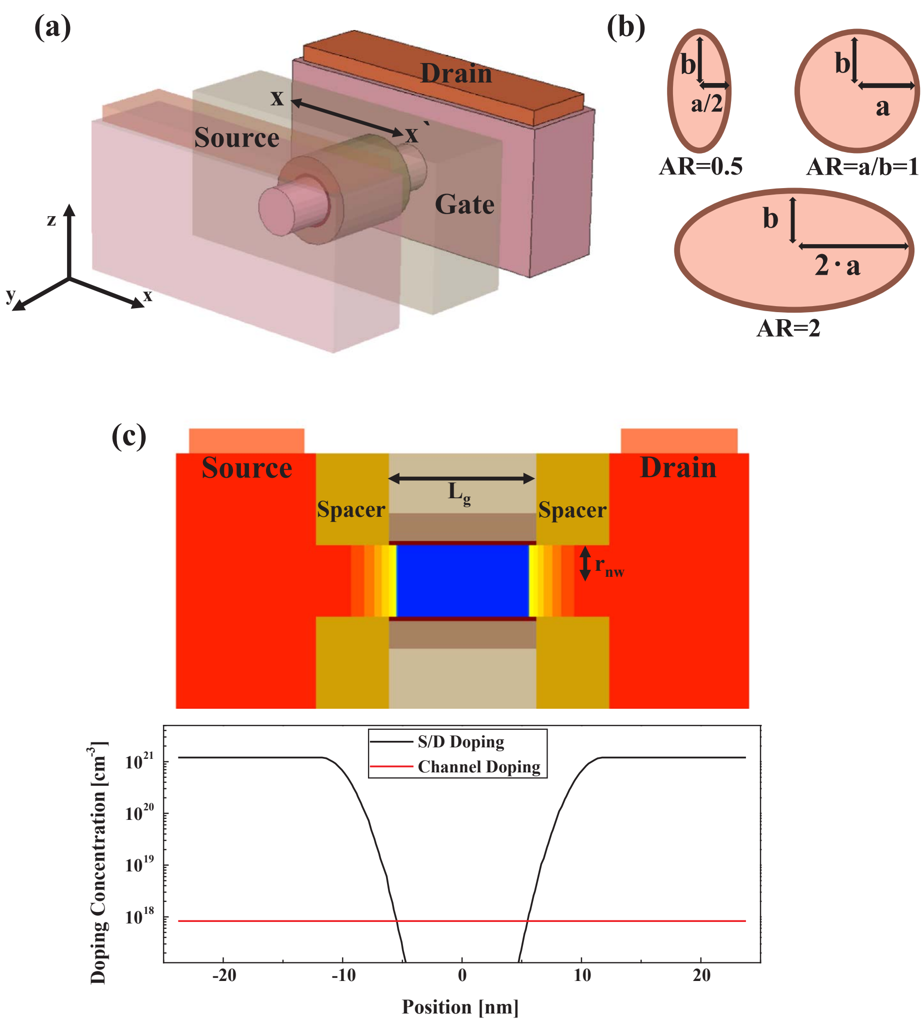

Fig. 1. (a) The structure of GAA NWFET for sub-5nm technology (b) Cross-sectional view of ellipse-shaped channel from AR = 0.5 to AR = 2. The vertical axis is fixed to b and horizontal axis varies from 0.5 a to 2 a (c) 2D cross section of GAA NWFET and doping profile along the channel direction.

Table 1
The detail device parameter of used GAA NWFET structure targeting sub 5-nm technology in this simulation.

Device parameter	Value
Gate length	12.2 nm
Channel radius	3–7 nm
Spacer length	6 nm
Channel doping	8.3×10^{17} cm^{-3}
S/D doping	1.2×10^{21} cm^{-3}
EOT	0.75 nm
Supply voltage (V_{dd})	0.75 V

simulated device structure has ellipse-shaped channel cross-section with asymmetric longitudinal (a) and horizontal (b) axes: the aspect ratio is defined as the ratio of the longitudinal axis to the horizontal axis (a/b). The aspect ratio (AR) has a range of 0.5–2. Fig. 1(b) shows the ellipse-shaped channel at each case of AR. Table. 1 figures out the detail of this simulated structure. The vertical axis of the channel cross-section is fixed and the horizontal axis varies from 0.5 a to 2 a. The electrical oxide thickness (EOT) is uniform at channel/oxide interface regardless of the ellipse-shaped channel cross-section. In this simulation, r_{nw} has a range of 3–7 nm and AR varies at each case. In this simulation, poisson equation was computed to consider drift-diffusion. Density-gradient quantization model was also used to analyze 3D structure. Shockley-Read-Hall recombination and Lombardi high-k mobility was adopted. Hurkx BTBT model with fitting parameter previously extracted in our group is considered to analyze GIDL mechanism in GAA structure.

3. Simulation results

Fig. 2(a) shows the channel of GAA NWFET in condition of $|V_{gs}| = V_{ds} = 0.75$ V portraying the band-to-band generation ratio (BTBT gen.). Fig. 2(b) and (c) shows the specific position of L-BTBT and T-BTBT on cross-section of x-x′ and y-y′ respectively. In the body/drain junction, it is possible to confirm that the L-BTBT occurred under the drain-side spacer region. According to Fig. 2(b) and (c), we confirm the contribution of these two GIDL mechanism. Based on this simulation results, L-BTBT on body/drain junction is the main component of GIDL behavior in GAA NWFET. T-BTBT still contributed to GIDL current but the generation volume of T-BTBT is negligible comparing with L-BTBT. The cross section 1 is shown for comparison with cross section 2 because the L-BTBT and T-BTBT are superposed in the drain overlap region.

Simulated $I_d - V_g$ curves in GAA NWFETs with various r_{nw} are plotted in Fig. 3(a). The simulation of $I_d - V_g$ curves is performed from 0 V to $|V_{gs}| = V_{ds} = 0.75$ V at V_{ds} of 0.75 V and the GIDL current is extracted from V_{gs} of -0.75 V. In this low $|V_{gs}|$ case, L-BTBT is more dominant than T-BTBT at the GIDL behavior based on previous work [19]. The extracted on-current at V_{gs} of 0.75 V in Fig. 3(b) is decreasing with r_{nw} from 3 to 7 nm, which means that quantum confinement effect is alleviated by increased channel area. On the other hand, the GIDL current increases as r_{nw} increases, which can be proved by the effect of larger channel area in Fig. 4. The impact of increased channel area in GIDL current is explained by Fig. 4. L-BTBT is more dependent with channel area because it occurs at general body/drain junction area. As