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RF performance enhancement in multi-fin TFETs by scaling inter fin separation

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ABSTRACT

This paper deals with the extraction of RF metrics of multi-fin Tunnel FET (TFET) with the inter fin separation (IFS) scaled up to 1 nm. The structure of multi-fin TFET is designed by varying the number of fins (N) from 1 to 5. As the number of fins increases, the drive current (I_D) gets multiplied and the maximum I_D of 76 μA can be achieved for N = 5. Higher I_D is obtained without compromising the leakage current (I_{OFF}) which is in the range of femto amperes. For the various values of IFS, RF metrics such as intrinsic gain (A_0), unity gain cut-off frequency (f_t), maximum oscillation frequency (f_{max}), and admittance (Y) parameters are extracted for multi-fin TFETs. The results show for lesser values of IFS, higher intrinsic gain is obtained and the value does not affect as N increases. The maximum value of f_t and f_{max} is obtained because of the electrostatic coupling between the two adjacent fins. The Y parameters are extracted at an operating frequency of 10 GHz. It can be seen that Y parameters offer better values as the number of fins and IFS increases. This is due to the larger value of gate to drain capacitance (C_{gd}) which occurs because of the parasitic effect for higher values of IFS.

1. Introduction

As the technology continues to shrink down to the nanometre regime, the new device structures such as multi-gate MOSFETs and multi-fin MOSFETs are coming into existence. Among the multi-gate and multi-fin devices, Tunnel FETs (TFETs) emerges to be one of the potential alternatives to CMOS technology because of its less leakage current (I_{OFF}) and less subthreshold swing (SS) [1–4]. Although TFET has low SS and low I_{OFF}, it is suffered from less tunneling probability and hence less drive current (I_D) [5].

Band gap engineering is the other factor for the increment of tunneling probability in TFETs. Many works have been carried out based on the band gap engineering with hetero structures by using group-III, IV and V materials and with their composition. Few works reported that group IV materials are performing better than III-IV materials, due to their higher density of states. Hence, a material with lower band gap and lower effective mass can also be the one of other choices for the improvement of drive current in TFETs [6–12]. Also it has been stated that by the use of multi-fin structures with an effective gate width of 2 (n × h) (where n is the number of fins and h is the height of the gate) wider transistor structures, higher ON currents can be achieved [13].

Many works have been reported on designing an accurate model for multi-fin MOSFETs to reduce the parasitic effects that influence the characteristics of the device [14–17]. Abundant literature is available for multi-fin MOSFETs for their analog/RF applications [18–21]. Studies on self-heating issues of multi-fin MOSFETs have been carried out and reported [22–24]. Recently the electrical characteristics and potential distribution of multi-fin MOSFETs were explored with respect to the corner effect [25]. Very few literature were available with multi-gate TFET which depicts only the DC characteristics of the device [26,27].

In this work, for the first time, we have extracted the RF parameters for multi-fin TFETs. RF parameters include intrinsic gain (A_0), unity gain cut-off frequency (f_t), maximum oscillation frequency (f_{max}) and admittance parameters (Y). This paper is organized as follows. Section II describes the simulation environment and the parameter space involved in this study. The results and discussion are given in Section III. Finally, Section IV summarizes the conclusion.

2. Simulation environment

2.1. TCAD simulator

All the simulations are carried out by the TCAD Simulator. The models used during the simulation are doping dependence mobility model, Shockley- Read-Hall for carrier recombination, Non-local Hurkx band to band tunneling, band gap narrowing and Fermi Dirac statistics model. The effects of high and normal electric fields models on mobility

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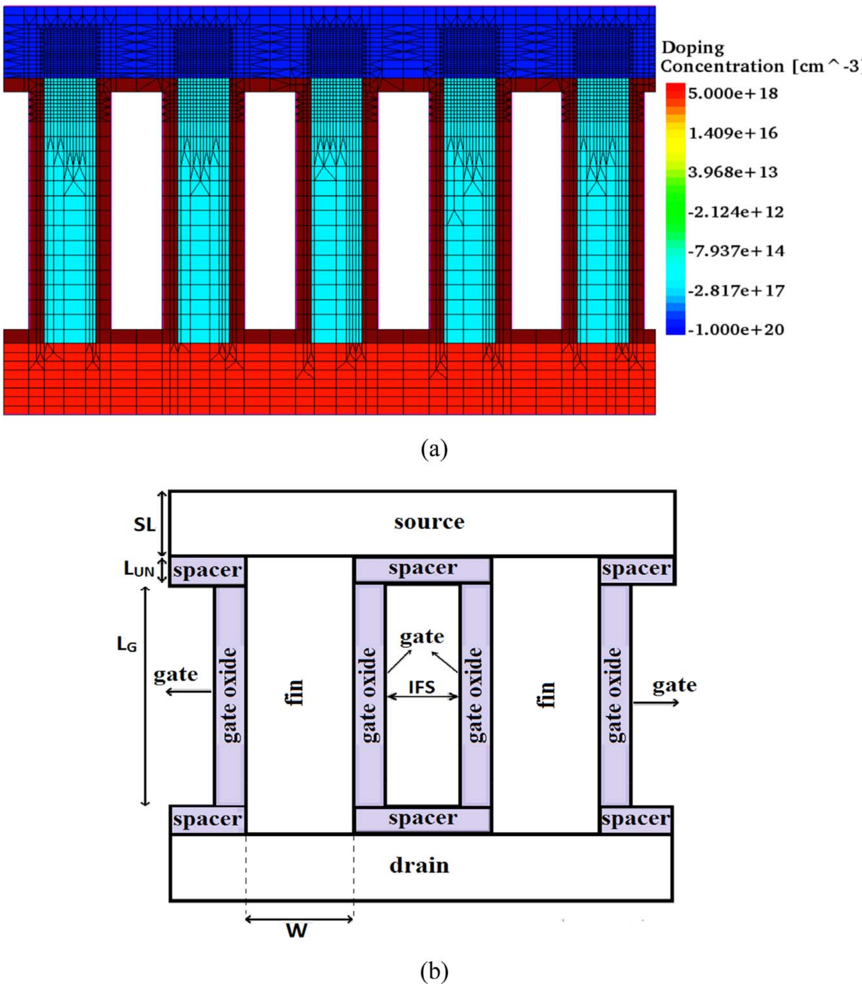

Fig. 1. a) Simulated device structure for multi-fin TFET with N = 5 (b) Schematic structure of multi-fin TFET with N = 2.

and velocity saturation are used. In our simulations, 1D Schrodinger solver Quantization model is used, which is compatible with the band to band tunneling model. To use this solver, a non-local mesh (NLM) is constructed and mesh lines with appropriate model parameters are included [28].

2.2. Device description and parameter space

Fig. 1(a) illustrates the simulated device structure of multi-fin TFET with the number of fins (N) = 5. The schematic structure of the multi-fin TFET with N = 2 is shown in Fig. 1(b). Table 1 specifies the parameter space used for the device.

The ON current of TFET is based on the transmission probability from the tunneling barrier at the source-channel junction. The tunneling probability can be analytically expressed by using Wentzel-Kramers-Brillouin (WKB) approximation [29].

$$T_{wkB} \approx \exp\left(-\frac{4\lambda\sqrt{2m^{*}}\sqrt{E_g^3}}{3q\hbar(E_g + \Delta\Phi)}\right)\Delta\Phi \tag{1}$$

where λ is the screening tunneling length at the source-channel interface, m^* is the effective mass, E_g is the energy band gap of the semiconductor material and ΔΦ is the energy range over which the tunneling take place.

The screening tunneling length can be expressed as, [30]

$$\lambda = \sqrt{\frac{\varepsilon_{si}}{\varepsilon_{ox}} t_{ox} t_{si}} \tag{2}$$

where t_{ox}, t_{si} are the thickness and ε_{ox}, ε_{si} are dielectric constants of oxide and silicon-film respectively.

The I_D-V_G characteristic of multi-fin TFET is plotted in Fig. 2. It can be seen from the plot that higher I_D is achieved for N = 5. This is due to the fact that multi-fin devices work well for the improvement of ON current as the current drive of a single fin is multiplied by the number of fins, [31]. This high drive current capability is not degraded the low OFF current phenomena of TFET.

Fig. 3(a) and (b) shows the graph of electron barrier tunneling measured along the length of the channel and electron density for multi-fin TFET respectively. It can be seen from the Fig. 3(a), that the tunneling rate is increased from N = 1 to N = 5 and this justifies the increased ON current for multi-fin TFETs. The increased number of eDensity which is depicted in Fig. 3(b) shows that, the higher order fin constitutes of overall maximum I_D current.

Table 1
Parameter space of multi-fin TFET.

Parameters	Value
Gate length (L_g)	50 nm
Gate oxide thickness (t_{ox})	3 nm
Underlap (L_{un})	3 nm
Fin width (W)	10 nm
Source Length (SL)	15 nm
Inter Fin Separation (IFS)	5 nm
Channel doping concentration (N_A)	1e17 cm − 3
Drain doping concentration (N_D)	5e18 cm − 3
Source doping concentration (N_S)	1e20 cm − 3
Gate electrode work function	4.5 eV