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Repercussions Through Inclusion of Multi Bridge Channels into Gate All Around Nano-Wire Field Effect Transistor

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A 3 channel rectangular Gate All Around Nano-Wire Multi Bridge Channel Field Effect Transistor (GAA NWMBCFET) is introduced in this work by integrating multi bridge channel into Gate All Around Nano-wire Field Effect Transistor (GAA NWFET) with increased drain current and enhanced Short Channel Effect (SCE) suppression for a gate length of 35 nm. Gate capacitance increases significantly due to vertically stacked channels enclosed by the gate. To understand the characteristics and behavior of the proposed GAA NWMBCFET, a rigorous analysis was conducted using a reliable physical model: the temperature-dependent carrier transport model (DD). Within this analysis, the Mobility Model (MM) played a crucial role in incorporating the effects of doping concentration and electric field. Additionally, the Bandgap Narrowing Model (BNM) and the Shockley-Read-Hall recombination Model (SRM) were instrumental in addressing carrier lifetime concerns. Utilizing Synopsys Sentaurus Technology Computer Aided Design (TCAD) facilitated the simulation of our proposed model, enabling a thorough examination of its characteristics. The rectangular multi bridge channel device exhibit 2.3 times better drain current than the rectangular nano-wire transistor. In addition, the Ultra Thin Body (UTB) in the device inhibits Sub threshold Swing (SS) and Drain Induced Barrier Lowering (DIBL) which contributes to minimized off current. The current drive has a 28 % increase for $L_G = 5$ nm than GAA NWFET. Furthermore, to ensure a comprehensive understanding of the device behavior, a detailed analysis of trans conductance was performed for a gate length of 35 nm. Additionally, analyses were extended to gate lengths of 5 nm, enabling a thorough evaluation of both GAA NWMBCFET and GAA NWFET.

Keywords: GAA NWFET, GAA NWMBCFET, TCAD, MBCFET, UTB

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1. INTRODUCTION

Bringing down the transistor length to nano levels with the same level of output current is a complicated process. The drain current should be maintained even when the size of the transistors is reduced because it is a key factor in defining the device's performance. By placing oxide and a gate around the channel, the fundamental MOSFET structure has been enhanced to become dual gate, trigate, and GAA. MOSFETs were later found unsuitable for short channel transistors and thus finfets were considered for that purpose [1]. The GAA structure was more appropriate for sub- 5 nm devices than FinFET structure according to the reports given in ITRS 2015 [2]. Due to the GAA's exceptional gate control over the channel [3-4], the SCE and leakage current were reduced. Single channel was generated for all the transistors, and the conduction of current took place customarily from source to drain. To enhance current drive within the existing structure, numerous channels were generated in a stacked configuration, collectively referred to as the multi-bridge channel. Ongoing research is exploring potential devices to further augment current drive. The design of Gate-All-Around (GAA) is well-suited for nanoscale devices, leading to the belief that integrating a multi-bridge channel structure into GAA could yield superior outcomes.

In 2003, an MBCFET was created with a gate length of 5 μm and a width of 1 μm, resulting in a 4.6 times larger output current compared to a planar MOSFET [6]. Subsequently, a 250 nm gate length MBCFET was fabricated, as documented in [7]. Enhancements in current drive were observed in [8] with the fabrication of a single bridge channel MBCFET featuring a 90 nm gate length. Additionally, [9] demonstrated the successful fabrication of an MBCFET with a TiN gate. Notably, the MBCFET, determined by the number of channels derived from a single channel, offers superior current drivability compared to other nano-scale devices. In this work, multi bridge channel is incorporated in the nano-wire transistor with the gate region being formed at all four sides, which produces an increase in the output current.

The rest of this paper has been divided into the following sections: Device Structure, Results and Discussions.

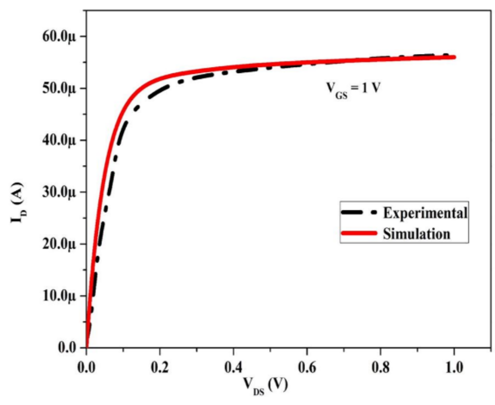

Fig. 1 – Validated output characteristics in comparison with experimental results [10]

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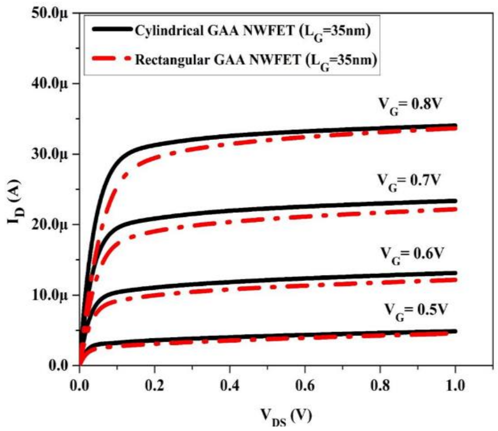

Fig. 2 – Compared output characteristics of both Cylindrical NWFET and Rectangular NWFET

2. DEVICE STRUCTURE

Fig. 1a depicts the calibration of parameters carried out by reproducing the Cylindrical NWFET device [10] as given in Table 1, which is evaluated along with the experimental data provided in [11]. This simulation is performed by placing VGS at 1 V and VDS at 1 V. Due to the geometric versatility in incorporating multi bridge channel in Nano-wires, the same volume present in the cylindrical structure is generated for the rectangular device using

Cylindrical Structure [п*(Radius)2*Height] = Rectangular Structure [Height*Width*Length]

The output characteristics have been plotted by varying VGS from 0.5 V to 0.8 V and keeping VDS constant at 1 V for both cylindrical GAA NWFET and rectangular GAA NWFET. The calibration given in Fig. 1b indicates the same current drive being produced for both cylindrical and rectangular structures since both have same volumes. In this letter three thin channels were established in a vertically stacked manner from a single channel in the above-mentioned rectangular NWFET. Fig. 2 depicts the structure of MBC where each channel will be covered by HfO_2 and a PolySilicon layer. Table 1 lists of the model parameters used for calibration. The width of the three channels was increased to equal the volume of the rectangular GAA NWFET, since the thickness of all three channels was decreased by incorporation of oxide and gate layer in between the channels.

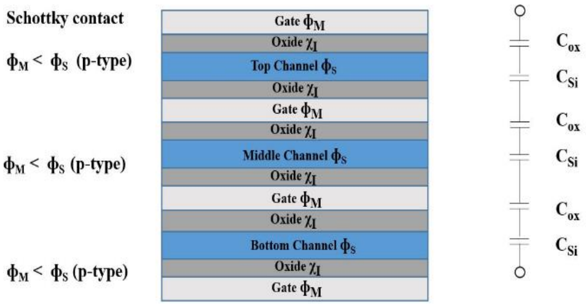

Fig. 3 – MBC Structure

Table 1 – lists of the model parameters

Parameter	Cylindrical	Rectangular	Rectangular MBCFET
Gate Length	35 nm	35 nm	35 nm
Gate Oxide	1.5 nm	1.5 nm	0.41 nm per channel
NW Diameter	21.45 nm	–	–
Channel Width	–	21.45 nm	20.52 nm
Channel Thickness	–	16.846 nm	5.87 nm per channel

Fig 2 respresents the structure of NWMBCFET when it has been vertically cut. The metal work function [ΦM] and the *p*-type semiconductor work function [ΦS] would be 4.15 eV and 5.1 eV respectively for all Cox and Csi calculations. The fabrication steps for stacked Nano sheets and for MBC structure is explained in [6-7], [12].

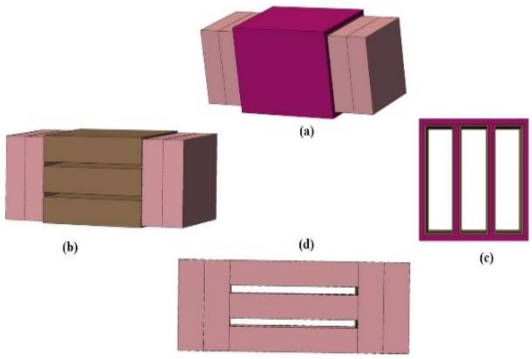

Fig. 4 – a) Rectangular structure with both oxide and poly silicon layers; b) Rectangular structure with oxide layers; c) Oxide and poly silicon layers; d) 3 channels

To check the performance of GAA MBCFET for sub 5 nm devices, the rectangular GAA NWFET gate length has been scaled down to 5 nm. The channel length was reduced to 5 nm from 35 nm, and its thickness was kept at 5 nm by using constant voltage scaling [13, 14]. The GAA NWMBCFET was formed by creating three channels over the rectangular GAA NWFET having an L_G = 5 nm, channel thickness of 4.08 nm, and a width of 6.14 nm to match with the volume of GAA NWFET. The calculated IV characteristics for a gate length of 5 nm are shown in Fig. 6. All simulations were performed on Sentaurus TCAD simulation tool. Drift-Diffusion Model and Shockley Read-Hall (SRH) recombinations are triggered and the Density Gradient Model is invoked for the study of quantum mechanical induced effects [15].

3. RESULTS AND DISCUSSION

The comparison between IV characteristics of rectangular GAA NWFET (L_G = 35 nm) and rectangular GAA NWM- BCFET (L_G = 35 nm) has been depicted in Fig. 4. The figures specify a 2.3 times increase in current drivability compared to the rectangular GAA NWFET (L_G = 35 nm) by use of multi- bridge channel concept.

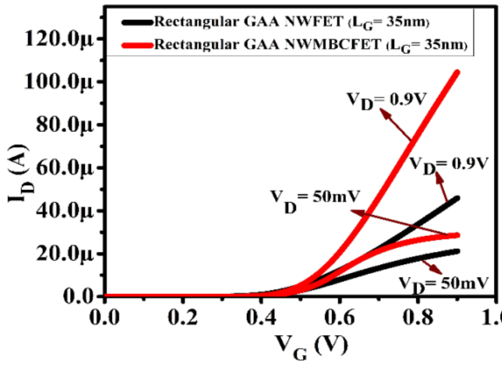

Fig. 5 – Compared Transfer Characteristics of both rectangular GAA NWMBCFET and rectangular GAA NWFET

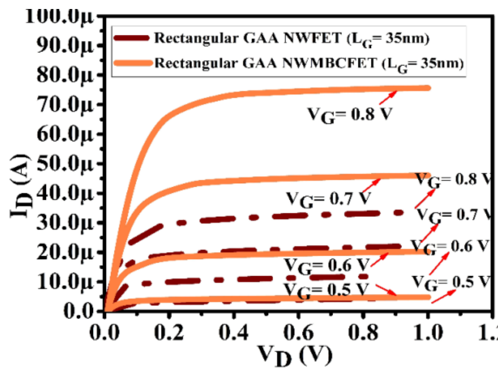

Fig. 6 – Compared Output Characteristics of both rectangular GAA NWMBCFET and rectangular GAA NWFET

The transfer characteristics show the curve been plotted where $V_G = V_D = 0.9$ V and $V_G = 0.9$ V, $V_D = 50$ mV for both rectangular GAA NWFET and rect- angular GAA NWMBCFET. The output characteristics are plotted by varying VGS from 0.5 V to 0.8 V for both devices. Upon increasing the width of the of the multi-bridge channel device, an output current 2.3 times better than the NWFET structure was produced, so the SCE could be sufficiently reduced. Even though there are multiple interfaces being made in the MBCFET structure, it is due to the reduction of oxide thickness that there occurs a decrease in the trap charges at the interfaces. As illustrated in Fig. 2, the cumulative C_{ox} achieved in the MBC structure produced an increased gate capacitance when compared with the GAA NWFET. The cumulative C_{ox} also caused an increase in transconductance of the device, which also proved that the channel has better gate control when compared to the NWFET device. This led to reduced leakage current as well as reduced tunnelling current from source to drain.

SS is also a significant short channel effect which has an ideal value of 60 mV/dec. Having a small value for SS enables the device to turn on and off quickly. MBCFET reduces the SS value which in turn increases the performance of the device as shown in Fig. 5 so the off current is reduced.

Drain-induced barrier lowering (DIBL) has been calculated by using the difference between threshold voltages at VDS = 0.05 V and VDS = 1 V. The calculated DIBL is 21 mV for MBCFET and 42 mV for NWFET for the gate length of 35 nm.

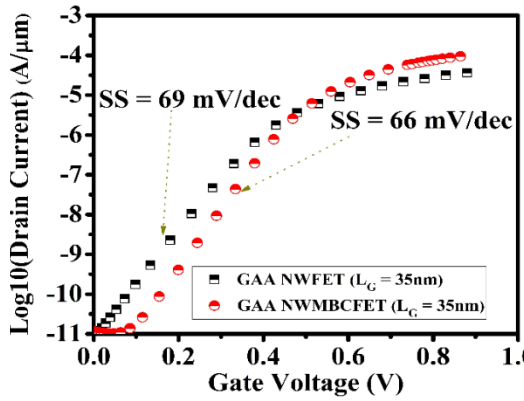

Fig. 7 – Subthreshold Swing (SS) of both GAA NWFET and GAA NWMBCFET

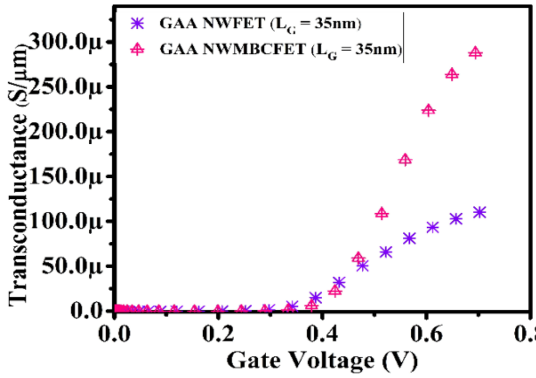

Fig. 8 – Transconductance of both GAA NWFET and GAA NWMBCFET

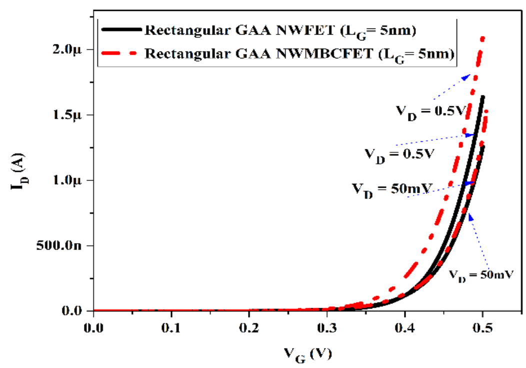

Fig. 9 – Compared Transfer Characteristics of both rectangular GAA NWM- BCFET and rectangular GAA NWFET

MBC structure reduces SS degradation and DIBL values which lead to reduced off current. The reduction in oxide layer thickness increases the oxide capacitance, and eventually the drain current.

Fig. 6 shows the transfer characteristics between rectangular NWFET and rectangular NWMBCFET for a gate length of 5 nm. The graph was plotted for $V_G = V_D = 0.5$ V and $V_G = 0.5$ V, keeping the drain voltage value at 50 mV. A 28 % improvement in drain current was exhibited when compared to NWFET. Even though the channel length is converted from 35 nm to 5 nm, the threshold voltage (V_{th}) roll-off is diminished.

4. CONCLUSION

A 35 nm Cylindrical GAA NWFET was compared with a rectangular GAA NWFET. The rectangular GAA NWM- BCFET has been formed with 3 channels and compared with the rectangular GAA NWFET for the gatelengths of 35 nm and 5 nm. The GAA NWMBCFET displayed an increase in current drive due to its Multi bridge channels compared to other typical nano-wire structures. Multi-bridge channels also reduce short channel effects like SS, DIBL as well as threshold voltage V_{th} roll-off. The Multi Bridge structure is believed to provide a more impact on short channel devices and low power applications in the future.

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Включення багатомостових каналів у затвор навколо нанодротового польового транзистора

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3-канальний прямокутний Gate All Around Nanowire Multi Bridge Channel Field Effect Transistor (GAA NWMBCFET) представлений у цій роботі шляхом інтеграції багатомостового каналу в Gate All Around Nanowire Field Effect Transistor (GAA NWFET) зі збільшеним струмом стоку та покращеним. Зменшений ефект короткого каналу (SCE) для довжини затвора 35 нм. Ємність затвора значно збільшується через вертикально розташовані канали, закриті затвором. Щоб зрозуміти характеристики та поведінку запропонованого GAA NWMBCFET, проведено ретельний аналіз з використанням надійної фізичної моделі: моделі транспортування носіїв, що залежить від температури (DD). У цьому аналізі модель мобільності (MM) зіграла вирішальну роль у врахуванні ефектів концентрації допінгу та електричного поля. Крім того, модель звуження забороненої зони (BNM) і рекомбінаційна модель Шоклі-Ріда-Холла (SRM) відіграли важливу роль у вирішенні проблем із терміном служби носія. Використання Synopsys Sentaurus Technology Computer Aided Design (TCAD) полегшило моделювання запропонованої нами моделі, дозволяючи ретельно вивчити її характеристики. Прямокутний багатоканальний мостовий пристрій демонструє в 2,3 рази кращий струм стоку, ніж прямокутний нанодротяний транзистор. Крім того, ультратонкий корпус (UTB) у пристрої блокує підпороговне коливання (SS) і зниження бар'єру, викликане стоком (DIBL), що сприяє мінімізації струму відключення. Поточний диск має збільшення на 28 % для L_G = 5 нм, ніж GAA NWFET. Крім того, для повного розуміння поведінки пристрою, був проведений детальний аналіз транс-провідності для довжини затвора 35 нм. Крім того, аналіз було розширено до довжини затвора 5 нм, що дало змогу ретельно оцінити транзистори.

Ключові слова: GAA NWFET, GAA NWMBCFET, TCAD, MBCFET, UTB