Superlattices and Microstructures 64 (2013) 227–236

Contents lists available at ScienceDirect

Superlattices and Microstructures

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

Numerical study on the performance metrics of lightly doped drain and source graphene nanoribbon field effect transistors with double-material-gate

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A R T I C L E I N F O

Article history:
Received 22 July 2013
Received in revised form 11 September 2013
Accepted 18 September 2013
Available online 26 September 2013

Keywords:
GNRFETs
NEGF
LDD
Double-material-gate
High-frequency

A B S T R A C T

In this paper, we perform a theoretical study on the performance metrics of the lightly doped drain and source (LDD) of double-material-gate graphene nanoribbon field effect transistors (GNRFETs). A quantum model based on the non-equilibrium Green's function (NEGF) coupled with a three dimensional Poisson equation under the ballistic limits in the mode space is applied. To highlight the superior performances of LDD structure, comparisons have been made between single-material-gate GNRFETs with conventional doping (C-GNRFETs), single-material-gate GNRFETs with LDD (LDD-GNRFTEs), double-material-gate GNRFETs with conventional doping (DM-GNRFETs) and double-material-gate GNRFETs with LDD (LDD-DM-GNRFETs). The results demonstrates that LDD-DM structure has lower leakage current, better sub-threshold swing performance, larger I_{on}/I_{off} ratio, lower delay time and higher cutoff frequency, which indicates LDD-DM-GNRFETs a promising material for high-speed and lower power applications.

1. Introduction

It is predicted that CMOS technology will reach the limits of atomic engineering. Scaling down technology plays a vital role in boosting the RF performance in today's CMOS technology. To up to the Moore's law and ITRS's further requirements and overcome the scaling limitations, many efforts

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http://dx.doi.org/10.1016/j.spmi.2013.09.032

have been made. Graphene, a monolayer of sp^2-bonded carbon atoms arranged in honeycomb lattice, is a potential candidate due to its attractive nanostructures and excellent physical properties, such as its remarkably high mobility carrier velocity [1,2], high mechanical and thermal stability, making its possible usage of post-silicon electronics [3–5]. However, the lack of bandgap makes the on-current-to-off-current ratio (I_{on}/I_{off} ratio) of graphene channel field transistors very small [6], which indicates its disadvantage for transistor application. Many studies have been carried out to solve this problem, among which graphene nanoribbon (GNR) is a promising option [7–10].

It has been proved that the bandgap and electronic properties of GNR are mainly relied on the width and the shape of edges. There are mainly two types of edge shapes: zigzag- and armchair-edged GNR. Armchair GNR shares large band gap because of lack of the localized edged state [6]. Due to an exceptionally high mobility, and near ballistic transport in the channel, GNR can be used as channel material for field effect transistors (FETs). Many simulated results have shown that GNR field effect transistors (GNRFETs) can obtain high driving current, fast operation speed and a significant reduction in power consumption [11]. A recent study also proved that armchair GNRFETs has complete switch off and improved on–off current ratios, which indicates its potential in building blocks for future digital circuits [6].

In recent years, researchers have focused on the high leakage of GNRFETs, which mainly causes by the band-to-band tunneling (BTBT) [12]. The lightly doped drain and source (LDD) structure has emerged as the predominant type of device structure for contemporary MOS integrated circuit technology [13]. Based on the previous work and to further seek for the solution of this problem, in this paper, we present a theoretical study of the effect of the lightly doped drain and source (LDD) on the performances of double-material-gate GNRFETs (DM-GNRFETs). LDD employs lightly doping in the regions between the intrinsic channel and highly doped drain and source region. To investigate the transfer characteristics, output characteristics, I_{on}/I_{off} ratio and high frequency performance of GNRFETs, a quantum model based on the non-equilibrium Green's function (NEGF) coupled with a three dimensional Poisson equation under the ballistic limits in the mode space is applied. Comparison have been made between single-material-gate GNRFETs with conventional doping (C-GNRFETs), single-material-gate GNRFETs with LDD (LDD-GNRFTEs), DM-GNRFETs with conventional doping (DM-GNRFETs), and DM-GNRFETs with LDD(LDD-DM-GNRFETs). On the one hand, Our results show that double -material-gate structure shares lower leakage current and output conductance than single-material-gate structure. On the other hand, comparisons demonstrate that LDD-DM structure has lower leakage current, better sub-threshold swing performance, larger I_{on}/I_{off} ratio, lower delay time, higher cutoff frequency than conventional doping structure, which implies LDD-DM-GNRFETs a promising material for high-speed and lower power applications.

2. Model and methods

Our model is based on the self-consistent calculation of the potential and charge density of GNRFETs. The charge density can be derived by the NEGF. The retarded Green's function of the device is [14,15]:

$$G(E) = [(E + i\eta^{+})I - H_D - \Sigma_D - \Sigma_S]^{-1} \tag{1}$$

where η^{+} is a positive infinitesimal, E is energy, H_D is the Hamiltonian when electrons in GNR is under the best adjacent approximation, Σ_S and Σ_D is self-energy generated by device's source and drain electrode, which can be solved by calculating the surface Green function using iterative approach. Once we get the Green's function, the density of electron and hole in any position of the device can be given by following equations:

$$\begin{aligned} n(r) &= \int_{E_I}^{+\infty} \mathrm{d}E\left[G\Gamma_S G^{+} f(E - E_{FS}) + G\Gamma_D G^{+} f(E - E_{FD})\right] \\ p(r) &= \int_{-\infty}^{E_I} \mathrm{d}E\left\{G\Gamma_S G^{+}[1 - f(E - E_{FS})] + G\Gamma_D G^{+}[1 - f(E - E_{FD})]\right\} \end{aligned} \tag{2}$$

where E_I is partial Fermi level in GNR, $E_{FD(S)}$ is the Fermi level in drain(source), $\Gamma_{S(D)} = i\left(\sum_{D(S)} - \sum_{D(S)}^{+}\right)$ is the energy level broadening due to the source(drain) contact.