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Theme: A State of the Art : Heat Transfer within a MOSFET System

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Abstract

The FET (field effect transistor) is the backbone of today's semiconductor electronics. The Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is the most popular type of isolated gate FET used in a variety of electronic circuits. In recent years, the MOSFET miniaturization has gained considerable interest. As the size of the device decreases (nano-scale) , the heat generated influences the efficiency of the device. There have been many thermal studies to improve the operation of the device. This paper gives an idea on the MOSFET and heat transfer phenomena within it.

Keywords: Heat conduction ; MOSFET; Nano-scale .

1. Introduction

Although one could say that the electronics age started with Braun's cathode ray tube (1897) and Fleming's vacuum tube rectifier (1904), the real electronics era began with Lee de Forest's triode, where they transformed Fleming's rectifier as an amplifier. The use of triode (amplifier) in the field of communications led to amazing success and communication became a reality, but a problem emerged in this device is the consumption of a lot of energy. In the mid-1920s, Julius Lilienfeld began his work on finding a solid-state replacement for the triode [1]. In 1930 and 1933, Julius Lilienfeld obtained patents for devices resembling today's MESFET and MOSFET, respectively. In 1934 Oskar Heil made a theoretical work on capacitive control for field-effect transistors (FETs) [2]. When manufacturing a MOSFET, we must give importance to the effect of heat transport due to low channel region and reduction size of device especially since it has become on nano-scale [3, 4]. The heat conduction is generally modeled by Fourier's law which gives the phenomenological relation between the heat flux and the temperature gradient. This equation becomes limited use when studying the thermal transfer in electronic device his size reach the free path of the particles because the speed of thermal diffusion depends on the phonons [5]. So Fourier 's law became invalid in the thermal study of nanoscale devices. the researchers have developed new theoretical models to study heat transfer within MOSFET instead of Fourier's law.

2.Conventional MOSFET

Source current is transmitted by electrons (NMOS), holes (PMOS) or complementary MOSFET (CMOS), electrons and holes in two devices[6]. Figure.1 shows a schematic of an NMOS device. This device consists of a channel connecting the source to the drain, a gate located on top of the channel, a gate oxide (insulator) between the gate and the channel, which blocks the current flow from the gate to the channel [7].

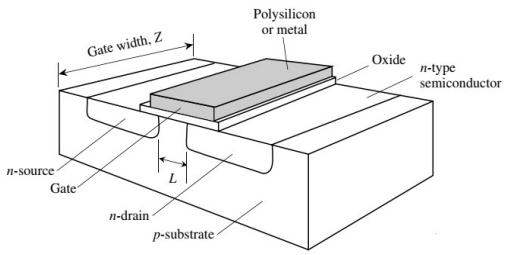

Figure.1: schematic of an NMOS device [6]

3.Structure of MOSFET

The design of the MOSFET is based on finding a structure that helps us to improve the work of electronic devices; therefore, there are a variable of MOSFET structures.

3.1. Silicon on Insulator (SOI) MOSFET

It is like a MOSFET conventional but a layer of insulator (SiO_2) is added to reduces current leakage from the drain/source junction to substrate (figure.2) [8] .

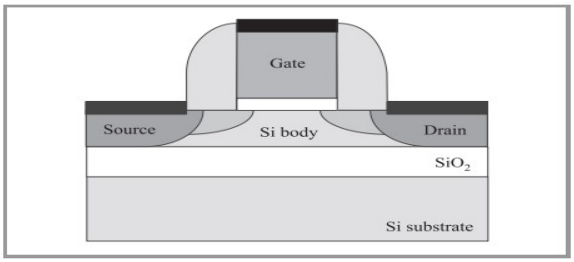

Figure.2: Cross-section of a SOI MOSFET [9]

3.2. Double gate

This device has two gates connecting between them as shown in the figure.3. Both gates are present to control (simultaneously) the current flow. The two gates are present at the front and the back end. [10] .

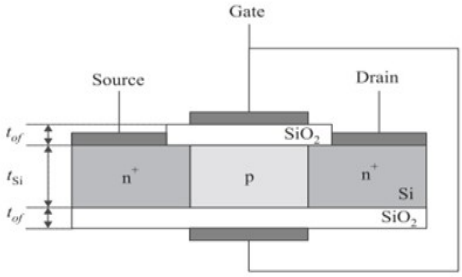

Figure.3:Cross-section of a double gate[9]

4.The reduction of feature size

The miniaturization of electronics has reached the nano-scale and you can imagine this ,with hundreds of millions of semiconductors assembled on a chip area no larger than a few square centimeters and the smallest lateral device feature sizes approach 10 nm[11] .

Although nowadays more than 90 % of integrated circuits are manufactured in complementary MOSFET (CMOS) technology, Moore's Law is still true in many aspects of the development trends of semiconductor microelectronics . The MOSFET has been improved countless times and it has been miniaturized beyond imagination[1]The reduction in feature size, as it depicted in Figure.5

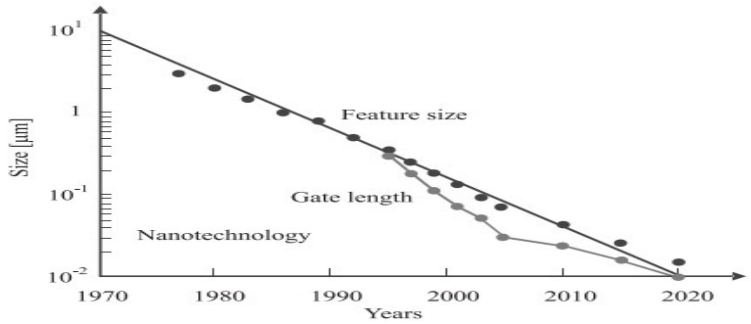

Figure.5 : Feature size as a function of time [12]

5.Literature review of heat transfer in a nano-MOSFETs

Thermal transfer within MOSFETs has known important attention due to its effect on these devices. Several theoretical methods have developed to study this phenomenon. Table.1 shows the most common methodologies for investigating the heat conduction within a nanostructures in recent years.

Table.1: The different heat transfer equations

Equation	Formula	reference
Boltzmann transport equation	$\frac{\partial I}{\partial t} + v.\nabla I = - \frac{I - I^0}{\tau_r} + S$	[13]
Ballistic-Diffusive Equation	$\tau_r \frac{\partial^2 T_m}{\partial t^2} + \frac{\partial T_m}{\partial t} = \frac{k}{C} \nabla \nabla T_m - \frac{\nabla q_b}{C} + \frac{q_v}{C} + \frac{\tau_r}{C} \frac{\partial q_v}{\partial t}$	[14]
Single phase lag (SPL)	$\tau_r \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \frac{k}{C} \Delta T + \frac{q_v}{C} + \frac{\tau_r}{C} \frac{\partial q_v}{\partial t}$	[15, 16]
Dual phase lag (DPL)	$\tau_r \frac{\partial^2 T}{\partial t^2} + \frac{\partial T}{\partial t} = \frac{k}{C} \Delta T + \frac{q_v}{C} + \frac{\tau_r}{C} \frac{\partial q_v}{\partial t} + \tau_t \frac{k}{C} \frac{\partial}{\partial t} \Delta T$	[17, 18]
Poisson equation	$\rho c_p \frac{\partial T}{\partial t} = \nabla.(k \nabla T) + q_v$	[19]

Yang et al [20] used ballistic-diffusive heat conduction equations (BDE) and phonon Boltzmann transport equation (BTE) to study the 2D thermal phenomena in a nMOSFET. Where their relative errors of results are 25 percent and 85percent for the BDE and the Fourier law respectively, compared to the phonon BTE.

J. Ghazanfarian and Z. Shomali [21] developed the DPL model with the temperature-jump boundary condition to investigate the heat flux and temperature distribution within nano-scale metal oxide semiconductor field effect transistor at Kn = 10. They show that the results of their model with mixed-type temperature boundary condition is comparable with the results of BTE .

Moghaddam et al published a paper on analysis of nano-scale heat thermal in nMOSFETs by dual-phase-lag (DPL) drift-diffusion (DD), where heat source depends electrical properties. This article shown that the device appropriate when the gate length is 100-nm and Kn = 3. they found that replacing the gate dielectric with an appropriate high-k material can improve the thermal and the electrical performance [5].

Nano investigation of the thermal properties and thermal stability of Black phosphorus (BP) transistors at the nanoscale is extremely challenging. F. Nasri et al studied 2D heat transport in BP MOSFET using the DPL model with the finite element method, all thermal properties were considered dependent to temperature. the results showed that the channel of PB MOSFET is more thermal stable than The channel of classical MOSFET [22].

Recently, REZGUI et al studied 2D heat transfer process and phonon transport in graphene nanoribbon field effect transistor (GNRFET) using the BDE model with the effective thermal conductivity depends to the Knudsen number and secularity parameter. The results given by the used model are close to those obtained by Boltzmann transport equation. Furthermore, the finding of this paper proved that the characteristic length (Lc) of the graphene nanoribbon has no important role in temperature increasing, in which the temperature distribution and heat flux profile in length of 50 nm and 100 nm are have the same maximum value [23]. In another paper, REZGUI et al proposed a ballistic-diffusive model (BDE) to investigate heat transport in MOSFET. This study showed that the effective thermal conductivity reduces when the Knudsen number increases. Also, the effective thermal conductivity increases when the Silicon thin film increase [24].

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