Interface Phonon Modes of Dual-Gate MOSFET System

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INTRODUCTION

As we all know, silicon dioxide is a popular material for gate dielectrics. However, the thickness of silicon dioxide cannot be decreased below the 1.5-1.0 nm range as required by device scaling because leakage current increases. This leads us to search for new materials to replace silicon oxide. Indeed, high-k dielectrics are introduced into use since they have even larger dielectric constants, k, than silicon oxide, leading to an increase in the overall capacitance. However, a high-k dielectric is a material with a high dielectric constant κ. The dielectric constant of a solid results from both the ionic and the electronic polarization. A higher dielectric constant can come from a large ionic polarization for high-k material. The large ionic response dominates at low frequency which causes a large scattering strength and as a result leads to a reduction of the effective electron mobility in the inversion layer of a MOS system. [1] The mechanism of this effect is the starting point of the idea to use dual-gate MOSFET system to avoid the scattering yielded by the phonon modes in the system.

THEORY

As shown in Fig 1, the dielectric function of the semiconductor in the structure under study is ε and the thickness is 2t (from -t to t). The metal in this treatment is not an ideal metal with zero Thomas-Fermi screening length. Herein, we consider the Thomas-Fermi screening length, δ, of the non-ideal metal. Let the phonon potentials, Φ, for the given structure be defined as follow [2]:

$$\begin{cases} \Phi = Ae^{\frac{-(z-d)}{\delta}} & \text{when } z>d \\ \Phi = Be^{q(z-t)} + Ce^{-q(z-t)} & \text{when } t\le z<d \\ \Phi = De^{qz} + Ee^{-qz} & \text{when } -t\le z<t \\ \Phi = Fe^{q(z+t)} + Ge^{-q(z+t)} & \text{when } -d\le z<-t \\ \Phi = Ae^{\frac{(z+d)}{\delta}} & \text{when } -z<-d \end{cases} \quad (1)$$

From this equations we can get the following results:

$$\begin{cases} \Phi' = -\frac{A}{\delta}e^{\frac{-(z-d)}{\delta}} & \text{when } z>d \\ \Phi' = Bqe^{q(z-t)} - Cqe^{-q(z-t)} & \text{when } t\le z<d \\ \Phi' = Dqe^{qz} - Eqe^{-qz} & \text{when } -t\le z<t \\ \Phi' = Fqe^{q(z+t)} - Gqe^{-q(z+t)} & \text{when } -d\le z<-t \\ \Phi' = \frac{A}{\delta}e^{\frac{(z+d)}{\delta}} & \text{when } -z<-d \end{cases} \quad (2)$$

At the heterointerface of region 1 and region 2, the following two conditions have to be satisfied [3]:

$$\Phi_1(Z) = \Phi_2(Z) \quad (3)$$

$$\varepsilon_1 \frac{\partial \varepsilon_1}{\partial z} = \varepsilon_2 \frac{\partial \varepsilon_2}{\partial z} \quad (4)$$

Substituting equation (3) into equation (1) one finds:

$$\begin{cases} A = Be^{q(d-t)} + Ce^{-q(d-t)} & \text{at } z=d \\ B + C = De^{qt} + Ee^{-qt} & \text{at } z=t \\ De^{-qt} + Ee^{qt}) = F + G & \text{at } z=-t \\ Fqe^{q(-d+t)} + Gqe^{-q(-d+t)} = A & \text{at } z=-d \end{cases} \quad (5)$$

Substituting equation (4) into equation (2) leads to:

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$$\begin{cases} \varepsilon_m(-\frac{A}{\delta}) = \varepsilon_{ox}(Bqe^{q(d-t)} - Cqe^{-q(d-t)}) & \text{at } z=d \\ \varepsilon_{ox}(Bq - Cq) = \varepsilon(Dqe^{qt} - Eqe^{-qt}) & \text{at } z=t \\ \varepsilon(Dqe^{-qt} - Eqe^{qt}) = \varepsilon_{ox}(Fq - Gq) & \text{at } z=-t \\ \varepsilon_{ox}(Fqe^{q(-d+t)} - Gqe^{-q(-d+t)}) = \varepsilon_m \frac{A}{\delta} & \text{at } z=-d \end{cases} \quad (6)$$

where ε_m is the dielectric function of metal, ε_{ox} is the dielectric function of the insulator, and ε is the dielectric function of semiconductor.

Solving these equation sets one obtains the following secular equation for the system:

$$(1-\frac{\varepsilon_m}{\varepsilon_{ox}}\frac{1}{\delta q})(1+e^{-2qt}+2e^{2q(2t-d)}-e^{2q(2t+d)} + \frac{\varepsilon}{\varepsilon_{ox}}(e^{-2qd}-2e^{2q(2t-d)}+1)) + (1+\frac{\varepsilon_m}{\varepsilon_{ox}}\frac{1}{\delta q}) (e^{2q(d-t)}+e^{-2qd}-e^{2qt}+2e^{-4qt}+\frac{\varepsilon}{\varepsilon_{ox}}(e^{-2qd}+ 2e^{2qd}-3e^{2q(d-2t)}-e^{-4qt}+e^{2qt})) \quad (7)$$

In the secular equation:

$$\varepsilon_m = 1 - \frac{\omega_{p,m}^2 \tau^2}{1-\omega^2\tau^2} \quad (8)$$

where $\omega_{p,m}$ and τ are the plasma frequency and the dielectric relaxation time for the metal. [3] Moreover,

$$\varepsilon = \varepsilon^{\infty}(1-\frac{\omega_{p,s}^2}{1-\omega^2}) \quad (9)$$

where $\omega_{p,s}$ is the plasma frequency of the 2DEG, and ε^{∞} is the optical permittivity of the semiconductor. In addition,

$$\varepsilon_{ox} = \varepsilon_{ox}^{\infty}\frac{(\omega_{LO2}^2-\omega^2)(\omega_{LO1}^2-\omega^2)}{(\omega_{TO2}^2-\omega^2)(\omega_{TO1}^2-\omega^2)} \quad (10)$$

where $\varepsilon_{ox}^{\infty}$ is the optical permittivity of the insulator; ω_{LO1} and ω_{LO2} are the longitudinal-optical phonon modes while ω_{TO1} and ω_{TO2} are the angular frequencies of the phonon modes in the insulator [1].

RESULTS AND DISCUSSION

Herein, the secular equation is solved by substituting the dielectric functions to obtain the interface phonon modes for dual-gate MOSFET system. Herein, the metal is considered to be a non-ideal metal with a non-zero screening length, δ. In the interesting limit of an ideal metal, we can set the screening length is the secular equation to zero. In this case, it is demonstrated that in the symmetrical dual-gate MOSFET structure, that no interface optical phonon modes survive as a result of the boundary conditions. Similar symmetry-related phonon mode suppression of phonon modes and the related suppression of carrier-phonon scattering processes have been discussed previously. [4] Thus, through the introduction of a symmetrical dual-gate MOSFET structure, unwanted interface-phonon-related scattering effects associated with high-k dielectrics may be eliminated.

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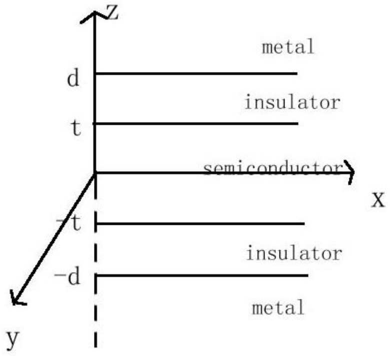

Fig. 1. Structure of Dual-gate MOSFET system