Study of Piezoresistivity Effect in FET

M. Auf der Maur,* M. Povolotskyi, F. Sacconi, and A. Di Carlo
MINAS Lab, University of Rome "Tor Vergata", Italy
*Department of electronic engineering, Via del Politecnico 1, 00133 Rome, Italy
e-mail: auf.der.maur@ing.uniroma2.it

INTRODUCTION

Piezoelectric effect is very important for the functionality of FET based on GaN/AlGaN heterostructures. Such systems were realized and characterized experimentally. The measurements of piezoresistivity of nitride-based heterostructures were also reported [1]. In this study we model the effect of an external mechanical force applied to a transistor. We describe a theoretical model, numerical methods and application for different structures such as GaN/AlGaN HFETs and GaAs/InGaAs HEMTs grown on (N11)-oriented substrates [2]. These systems are chosen because they exhibit a strong piezoelectric effect and therefore change their electrical characteristics due to applied stress.

THEORETICAL MODEL

Mechanical deformation of transistors are studied in the framework of continuous media theory. Strain is a result of both lattice mismatch between the constituent materials of the structure and external mechanical forces applied at the surface of the device. We assume perfect crystallographic interfaces between materials and a linear relationship between stress and deformation. Computed strain enables us to calculate piezo- and pyroelectric polarization ($\mathbf{P}^{pz}$ and $\mathbf{P}^{py}$) and the deformation potentials of conduction and valence bands. The built-in potential φ is calculated by solving the nonlinear Poisson equation

$$\nabla(\varepsilon\nabla\varphi + \mathbf{P}^{py} + \mathbf{P}^{pz}) = \quad \rho(\varphi), \tag{1}$$

assuming Fermi-Dirac distribution of the free charge density $\rho(\varphi)$. The electrical characteristics are simulated by means of a drift-diffusion approximation considering both constant and field-dependent mobilities.

The numerical model for the above equations is based on the finite element method. We performed 2D simulations on a mesh that is automatically refined in the regions of interest such as regions near interfaces and stressed surfaces. Poisson and current equations are solved as a coupled nonlinear system, while the mechanical strain equation is solved separately. A Gummel iteration scheme is used for coupling strain and current equations in order to study the converse piezoelectric effect.

APPLICATION EXAMPLE

We show an InAs/GaAs HEMT (see Fig. 1) grown on a (411) InAs substrate. The y-component of the piezopolarization induced by an external mechanical force is shown in Fig. 3. The applied pressure is equal to 0.5 GPa over a band with width of 0.5 m. In Fig. 2 we show the equilibrium band diagrams calculated for the device with and without pressure applied. One can see that pressure results in additional bending of the bands. This is similar to applying a negative voltage to the gate as demonstrated in the output characteristic (Fig. 5). Fig. 4 shows the electron density in the channel with and without external pressure. One can observe a partial depletion of the channel caused by piezoelectric effect.

ACKNOWLEDGMENT

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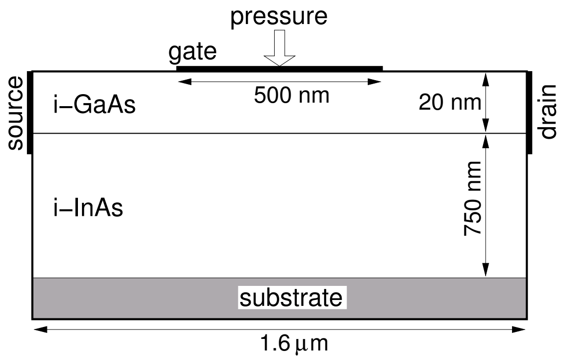
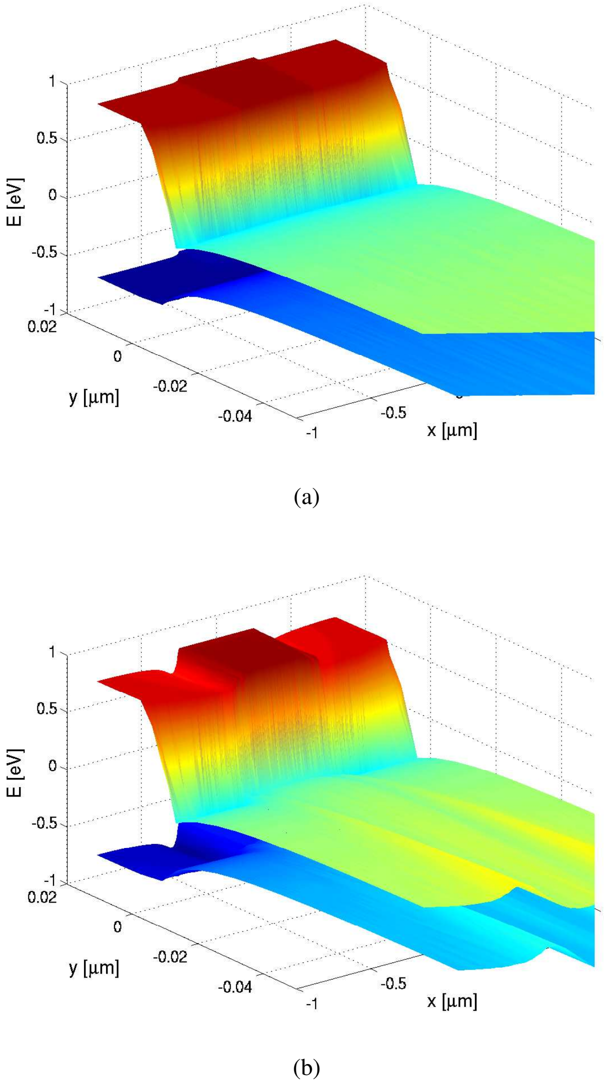


Fig. 1. Sketch of the considered HEMT structure



(a)

(b)

Fig. 2. Lowest conduction and highest valence band without (a) and with (b) applied pressure

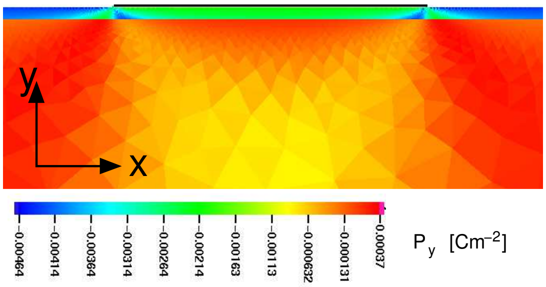


Fig. 3. y-component of the piezopolarization with applied pressure on top of the gate

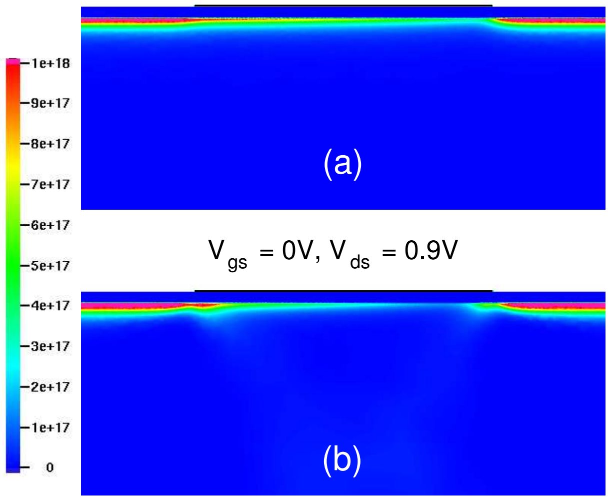


Fig. 4. Electron density without (a) and with (b) pressure

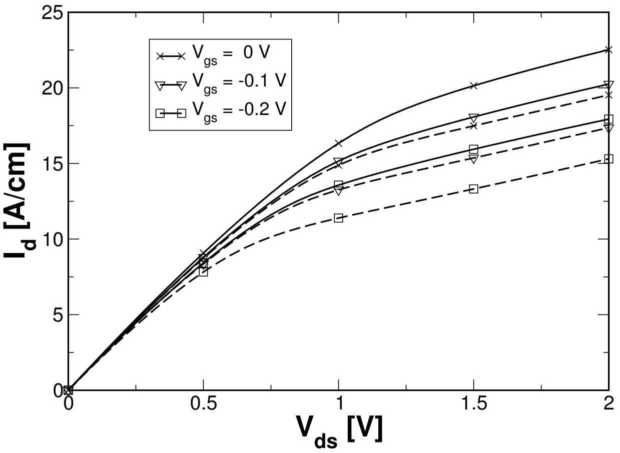


Fig. 5. Output characteristic with (dashed lines) and without (solid lines) pressure