The modeling of a SOI microelectromechanical sensor

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Abstract

The goal of this paper is to model a SOI pressure sensor based on piezoelectric effect. A PZT film deposited onto a SOI wafer acts like the transistor's gate. The transducer element is an SOI-MOSFET. The electrical simulation made with ATLAS presents the static characteristics of the device. An analytical model for sensitivities was presented to offer a designing rule. Mechanical simulations with ANSYS establish some mechanical characteristics.

1 Introduction

The classical pressure sensors, even SOI sensors, work on other principles (piezoresistive effect, capacitive effect) [1]. Piezoelectric layers represent an alternative to piezoresistors.

The combination between SOI technology and PZT layers brings some advantages: (1) electrical isolation of the device; (2) higher temperature of operation (from 120^0C in conventional technologies where reverse current become significant, up to 300^0C because SOI structure avoids reverse biased junctions for isolation); (3) the Curie temperature of PZT is suitable for this range ($T_C > 300^0C$); (4) possible miniaturization of the sensor because PZT layer represents the SOI-MOSFET's gate; (5) the buried insulator is an excellent etch stop layer. Selecting a piezoelectric layer with better parameters (e.g. PXE5 instead of PZT) yields a better sensitivity.

In this paper is proposed an analytical model for a pressure sensor with PZT as the gate of a SOI-MOSFET. The model allows a study of this kind of pressure sensor, establishing a bi-univocal correspondence between the mechanical pressure and an equivalent gate voltage (V_G). This formal parameter, V_G, has not any practical sense, but is helpful to design the sensor, because some device simulations with ATLAS can be done and some analytical models are available [2]. The mechanical simulations with ANSYS verify the mechanical resistance of the structure.

2 The analytical model for the sensor sensitivity

In figure 1 is presented the proposed sensor architecture.

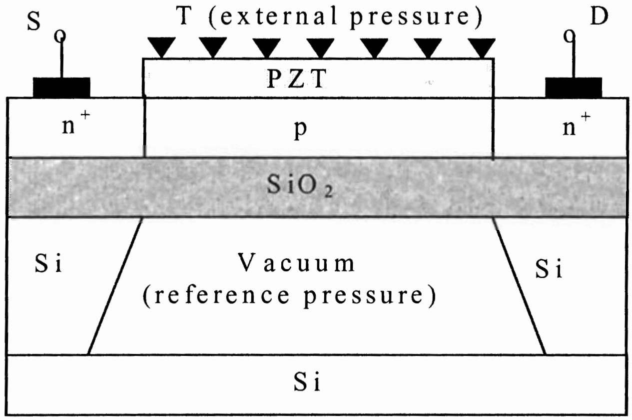

Fig.1. The sensor architecture.

Because the pressure exerts on vertical direction, the incoming pressure, T, induces a polarization state in PZT and depletes the film. An equivalent situation occurs, when the same amount of electric charge is obtained in the absence of any pressure, but with an equivalent positive gate voltage, V_G. Starting from the Poisson's equation integration, in non-depletion approximation, the following global charge enclosed in the transistor body, Q_S, versus the surface potential, ϕ_S results:

$$Q_S(\phi_S) = \sqrt{\frac{2\varepsilon_{Si} q N_A}{\beta}} \left[\exp\beta(\phi_S - 2\phi_F) - 1 + \beta\phi_S\right]^{1/2} \tag{1}$$

On vertical direction and Gauss's law, results:

$$D = d_{PZT}T = \varepsilon_{PZT}E = Q_S \tag{2}$$

where $C_{PZT} = \varepsilon_{PZT}/x_{PZT}$ – the specific capacitance of PZT; ϕ_F – the Fermi potential of Si-film; N_A - the doping film; ε_{Si} – the dielectric permittivity of silicon; x_{PZT} – the PZT thickness; ε_{PZT} – the dielectric permittivity of PZT on vertical axis; d_{PZT} – the component of piezoelectric coefficient on vertical axis, T – the pressure, E – the intensity of the electric field, β=q/kT (is a notation). In strong inversion the lasts terms in eq. (1) are negligible in respect with the exponential function. So, combining (1) and (2) results:

$$V_G = \frac{d_{PZT}T}{C_{PZT}} + \frac{2}{\beta}\ln\frac{d_{PZT}T}{\sqrt{2\varepsilon_{Si}qN_A/\beta}} + 2\phi_F \tag{3}$$

The function (3) establishes a bijection between V_G and T (because their first order derivatives preserve constant sign). Consequently, this expression can be used in the sensor sensitivity computing. The current through the inversion channel, in quasi-linear regime, depends on the gate voltage:

$$I_{D2} = \frac{f_g C_{PZT} \mu_{0n}}{1+\theta_0 (V_G - V_T)} \cdot \left[(V_G - V_T) \cdot V_D - \frac{V_D^2}{2} \right] \tag{4}$$

where f_g is a geometrical parameter, θ_0 is the mobility attenuation factor, μ_{n0} is the "pure" electron mobility. So, the sensitivity in current for the pressure sensor, S_i, is:

$$S_i = \left| \frac{dI_D}{I_D} \frac{T}{dT} \right| = \frac{\frac{d_{PZT} T}{C_{PZT}} + \frac{2}{\beta}}{[1+\theta_0 (V_G - V_T)](V_G - V_T)} \tag{5}$$

3 Electrical simulation with ATLAS

The electrical simulations with ATLAS use the equivalent gate voltage (eq 3).

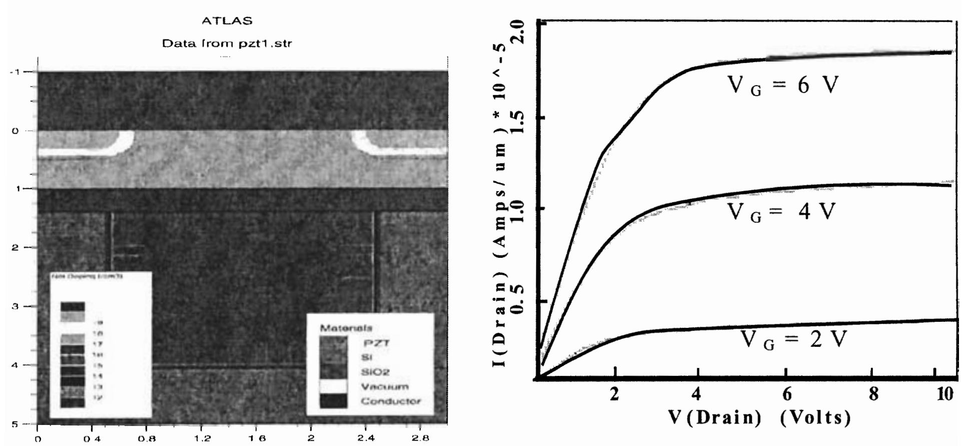

Fig. 2. The simulated structure and the current dependence on equivalent gate voltage, performed by ATLAS.

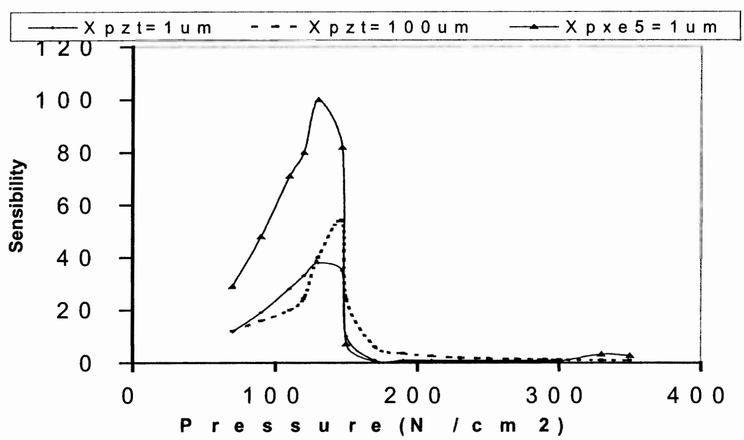

Fig. 3. The dependence of the sensitivities versus pressure in different cases.

The transistor had: $N_A=2\times10^{17}cm^{-3}$ (film), $N_D=10^{20}cm^{-3}$ (n+ source/drain), $N_A=10^{15}cm^{-3}$ (substrate), $Q_{SS1}=3\times10^{10}cm^{-2}$, $Q_{SS2}=10^{11}cm^{-2}$, $V_S=0V$, $V_D=V(3) \in (0,10V)$. From figure 2 a $V_D=1V$ is suitable for the sensor working in quasi-linear regime. The variation of V_G corresponds to a variation of pressure, T, from 0 to 350 N/cm^2. ATLAS has an especial command EXTRACT to extract the model parameters: $\theta_0=0.093V^{-1}$, $V_T= 1.08V$. With these parameters and PZT data from [3], accordingly with eq (5), an analysis was performed (see fig.3).

4 Mechanical simulations with ANSYS

From ANSYS simulations, the pressure that break the sensor was evaluated: $T_{lim} > 350N/cm^2$. In figure 4 is presented the simulations results regarding the distributions of the mechanical tensile into the structure when $T=100N/cm^2$, that correspond to the maximum sensitivity.

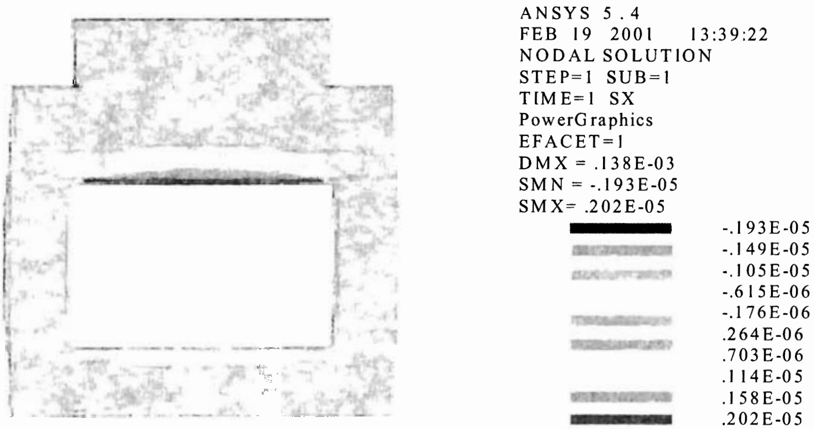

Fig. 4. The ANSYS structure at $T=100N/cm^2$.

5 Conclusions

The ANSYS analysis has a great impact since to consolidate the sensor shape by technological methods. The analytical model can be used for electrical simulations. The designing rule presented here represents a starting point in developing of this kind of devices.

References

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[3] *** Philips Data Handbook, 1970, pp G9.