Paper

Technology of MISFET with $SiO_2/BaTiO_3$ System as a Gate Insulator

Piotr Firek and Jan Szmidt

Abstract— The properties of barium titanate ($BaTiO_3$, BT), such as high dielectric constant and resistivity, allow it to find numerous applications in the field of microelectronics. In this work silicon metal-insulator-semiconductor field effect transistor (MISFET) structures with $BaTiO_3$ thin films (containing La_2O_3 admixture) acting as gate insulator were investigated. The films were produced by means of radio frequency plasma sputtering (RF PS) of sintered $BaTiO_3$ + La_2O_3 (2% wt.) target. In the paper transfer and output $I-V$, transconductance and output conductance characteristics of the obtained transistors are presented and discussed. Basic parameters of these devices, such as threshold voltage (V_{TH}) are determined and discussed.

Keywords— barium titanate, I–V characteristics, MISFET structures, radio frequency plasma sputtering.

1. Introduction

Barium titanate ($BaTiO_3$, BT) ceramics have been extensively used in the field of electronic applications. Multilayer ceramic capacitors (MLCCs) [1], [2], embedded capacitances in printed circuit boards [2], optical waveguides [3], electrooptic modulators [4], micromechanical [5] and humidity sensor [6] devices, positive temperature coefficient of resistivity thermistors [7], gas sensors [8] were fabricated using BT. In all those applications $BaTiO_3$ was used in the form of either bulk material or thick layer. BT shows ferroelectric and piezoelectric properties as well as a high dielectric constant that make it a promising material for potential applications in dynamic access random memories (DRAM) [9], [10] or non-volatile memories (NVM) [9], [11].

Thin barium titanate films for microelectronic applications are usually either amorphous or polycrystalline and have significantly worse electrical properties than bulk or thick-film material. It is difficult, for example, to obtain uniform composition, the piezoelectric effect is weaker, and the values of the dielectric constant are lower (typically less then 50) [12]. On the other hand, its dielectric constant is usually still much higher than that of silicon dioxide although thin BT layers are typically plagued with higher leakage current and lower dielectric strength.

2. Experimental Details

The fabrication process of metal-insulator-semiconductor field effect transistor (MISFET) structures is presented

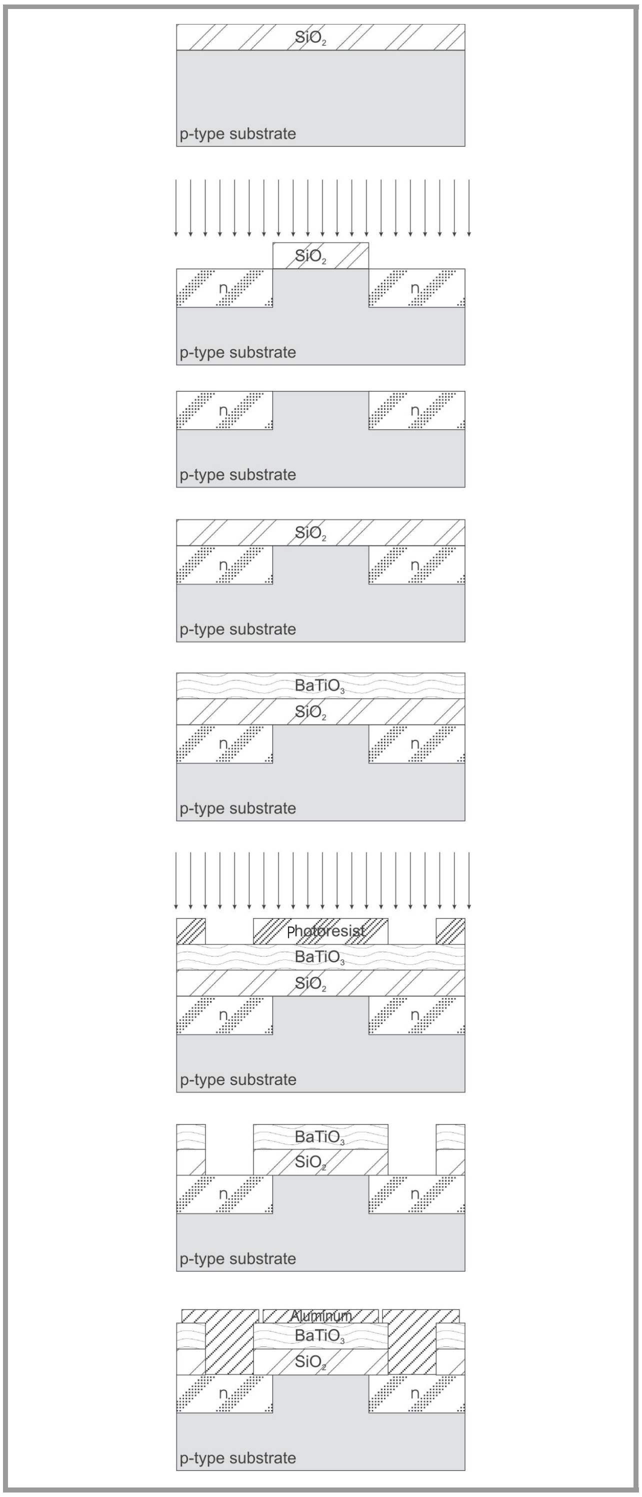

Fig. 1. MISFET fabrication process with cross-sectional view of the structures.

in Fig. 1. Its first step is thermal oxidation in order to obtain field oxide of about 440 nm. The p-type silicon $< 100 >$ oriented substrate with the resistivity of $6-8\ \Omega$cm was used. After cleaning processes 40 nm thick SiO_2 film was grown thermally and then a thin (approximately 80 nm) barium titanite film was deposited by means of radio frequency plasma sputtering (RF PS) of sintered $BaTiO_3 + La_2O_3$ (2% wt.) target.

A schematic diagram of the RF PS setup is shown in Fig. 2. The $BaTiO_3$ layer was deposited as a result of 30 min long process (280 V self-bias voltage, argon flow rate of 10 ml/min and 15 mm distance between the Si substrate and the sputtered target). Next, a photoresist mask for etching in a buffer solution of hydrofluoric acid was prepared by means of photolithography. As a last step contacts for metallization were opened and aluminum was evaporated. The described fabrication process is presented in Fig. 2. Silicon wafer and transistor topography are shown in Fig. 3.

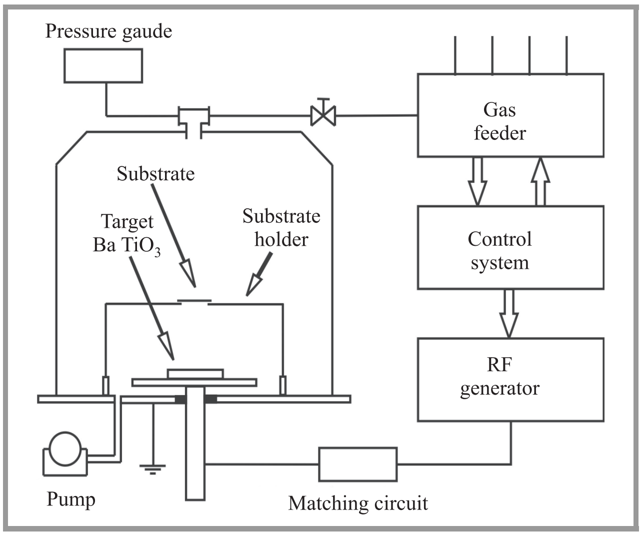

Fig. 2. Schematic diagram of the setup for radio frequency plasma sputtering deposition processes.

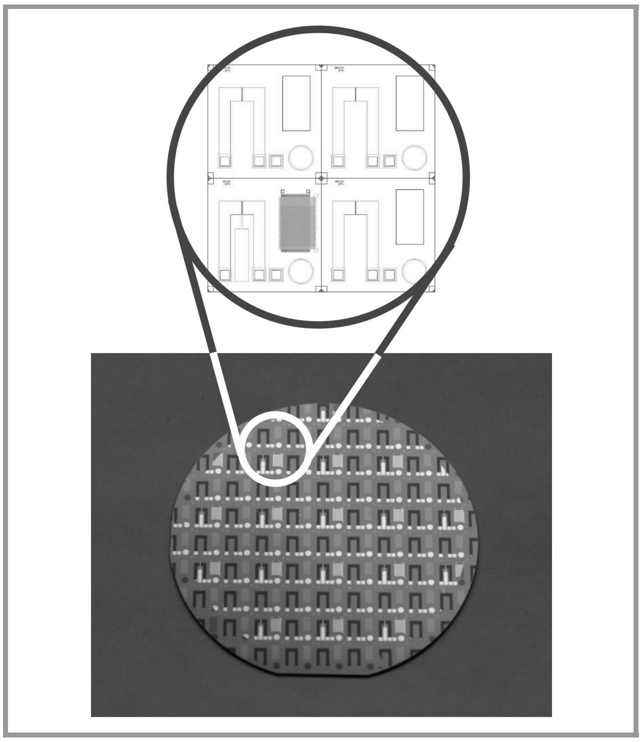

Fig. 3. Silicon wafer and MISFET topography.

3. Results and Discusions

The dielectric constant (k) of about 20 was extracted from capacitance-voltage measurements of a MIS structure

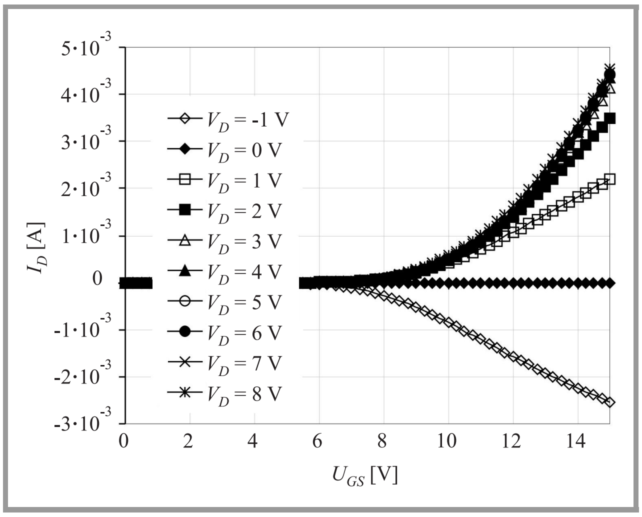

Fig. 4. Transfer current-voltage characteristics of the fabricated structures.

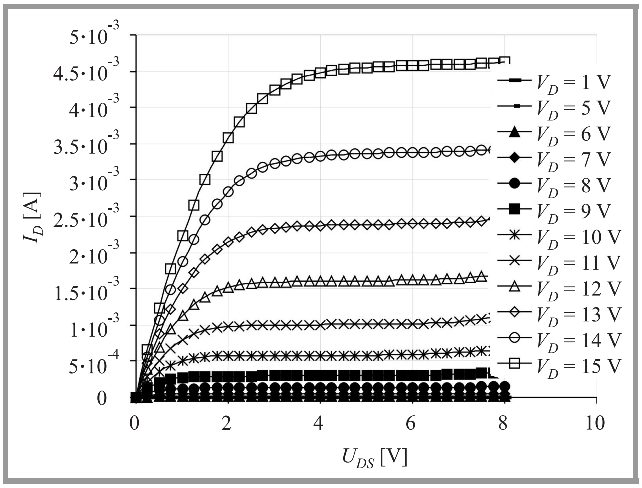

Fig. 5. Output current-voltage characteristics of the fabricated structures.

containing $BaTiO_3$ dielectric. The current-voltage ($I-V$) characteristics of MISFETs were measured with Keithley SMU 236/237/238. The obtained transfer and output characteristics are presented in Figs. 4 and 5.

Threshold voltage (U_T) is one of the most important parameters of a transistor since it represents the gate voltage at which the MISFET channel is turned on. The threshold voltage ranged from -6 V to -8 V.

The transconductance g_m and output conductance of the structures are presented in Figs. 6 and 7, respectively.

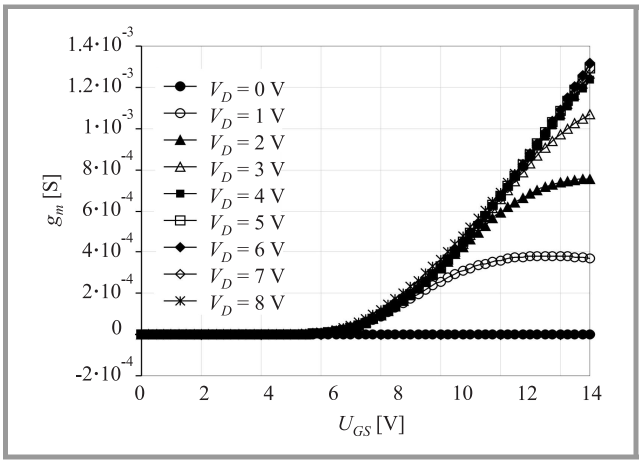

Fig. 6. Transconductance characteristics of the fabricated structures.

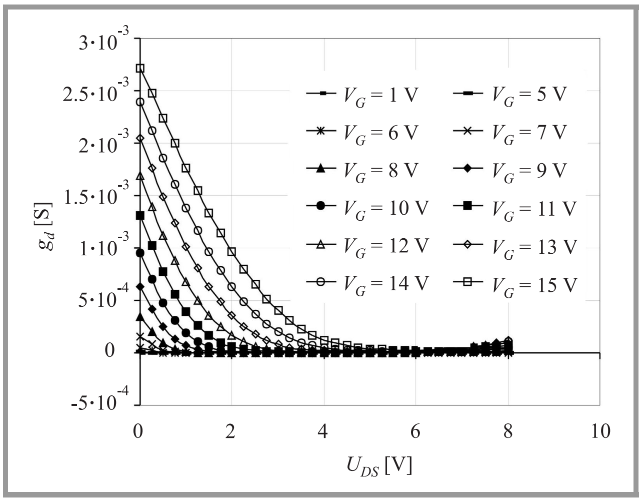

Fig. 7. Output conductance characteristics of the fabricated structures.

It can be seen that the values of transconductance are relatively low when compared to a typical silicon MOSFET. Taking into consideration that these structures contain material ($BaTiO_3$) that is relatively novel for this type of applications and demanding from the technological point of view, the obtained results in our opinion are very satisfying. Postprocessing (e.g., annealing) or better purity of the films should improve the results significantly.

The dispersion of the obtained parameters (e.g., threshold voltage, trans- and output conductance) may be caused mainly by the variations of BT thickness and its composition in the area under the gate. The structure of the layer, i.e., the grain size or the presence of amorphous phase, the quality of the interface between the BT layer and SiO_2 and the influence of plasma during fabrication may lead to different levels of the effective charge in the dielectric and at the aforementioned interface. As a consequence, the transistors show different values of flat-band voltage and threshold voltage.

4. Conclusions

The obtained BT films show good adhesion to SiO_2 layers on silicon substrate. Their relatively low dielectric constant (k) (for BT) is due to their amorphous nature. High values of the threshold voltage are a consequence of charge presence at the $SiO_2/BaTiO_3$ interface. A better control of the deposition process (e.g., purity) may significantly improve the film properties. Our investigations confirm that the RF PS method is suitable for obtaining BT layers that may exhibit several very interesting electronic properties, especially for future IS (ion sensitive) FET structures.

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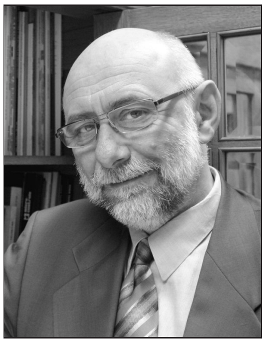

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