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Titanium oxide films as sensitive membrane in field effect devices

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Abstract – This work presents the characterization of titanium oxide thin films as potential dielectric to be applied in ion sensitive field effect transistors. Structural characterization showed mainly the rutile crystalline phase. Electrical characterizations of Al/Si/TiOx/Al capacitors showed dielectric constants between 12 and 33, interface charge density about 10^{10}/cm^2 and leakage current density between 1 and 10^{-4} A/cm^2. Field effect transistors analyses showed early voltage value of -1629V, R_{OUT} value of 215MΩ and slope of 100mV/dec for the 20nm TiO_x film thermally treated at 960°C. C-V characteristics of Solution/TiO_x/Si/Al capacitors, with TiO_x thin film thermally treated at 600°C, showed good response to pH measurements.

In the medical area, ion sensitive field-effect transistors (ISFETs) have been explored as biosensor since they have advantages such as very small size, rapid response and low output impedance, in addition to be compatible with CMOS process and have a low cost [1,2]. The concept of ISFET device is based on the metal-oxide-semiconductor field-effect transistor operating theory, where metal gate is replaced by a reference electrode, buffer solution and an ion sensitive membrane. As an ISFET is basically a type of MOSFET without the metal gate, the study of the insulator material is an important part of the process, because it is directly exposed to the buffer solution. The films were obtained by rapid thermal oxidation and annealing (at 300, 600, 960 and 1200ºC) of thin titanium films of different thicknesses (5nm, 10nm and 20nm) deposited by e-beam evaporation on silicon wafers. According to FTIR analyses the obtained TiO_x films showed mainly the presence of rutile crystal structure, but the presence of the anatase crystal structure and SiO_2 were also identified. Raman analysis of the same samples, indicated TiO_2 Raman shifts related to rutile and anatase crystal structure, similarly to the FTIR results. XANES analyses (Figure 1) also revealed formation of TiO_2 rutile type crystal structure. The observed results indicate that even varying the process temperature it is hard to isolate a single crystal structure of TiO_2, but according to the physical characterization results, rutile is the predominant crystalline structure formed in our TiO_x films. RBS measurements and its data simulations confirm the results observed by Raman and FTIR. The optimized [O]/[Ti] ratio determined for the films annealed at 600°C was 1.9. Electrical characterizations of Al/Si/TiO_x/Al capacitors showed dielectric constants between 12 and 33, interface charge density about 10^{10}/cm^2 and leakage current density between 1 and 10^{-4} A/cm^2. Field effect transistors analyses showed early voltage value of -1629V, R_{OUT} value of 215MΩ and slope of 100mV/dec were calculated for the 20nm TiO_x film thermally treated at 960°C. C-V characteristics of Solution/TiO_x/SiO_x/Si/Al capacitors, with TiO_x thin film thermally treated at 600°C showed good response to pH measurements (Figure 2).

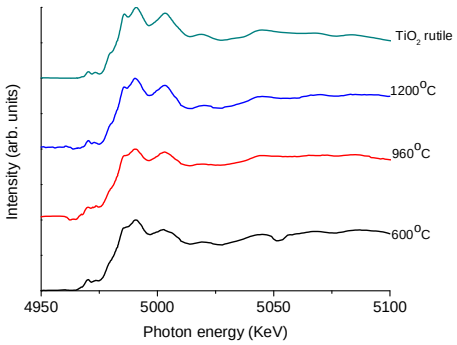

Figure 1: XANES of TiO_2 rutile crystalline phase sample, Ti_20nm titanium oxide films thermally treated at 600, 960 and 1200ºC.

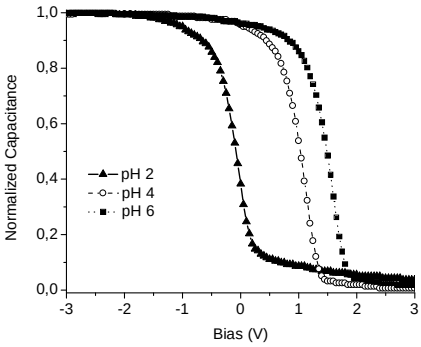

Figure 2: C-V characteristics of Solution/TiO_x/SiO_x/Si/Al capacitors, with TiO_x thin film thermally treated at 600°C.

References

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