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Oxides with a high dielectric constant obtained by the atomic layer deposition (ALD) method for electronic application

The „transparent electronics" is a novel area of technology which was developed for the production of transparent integrated circuits and devices such as an electronic paper (e-paper). The idea of transparent, flexible and mechanically robust electronics is based on thin-film materials with a wide energy gap. This type of semiconductor and insulating materials are prepared on transparent and thermally sensitive substrates. These substrates require the low-temperature processes for the preparation of electronic components, below 200°C.

My investigations concentrate on the optimization of physical characteristics and growth processes for the dielectric thin films, in this case, the oxides with a high dielectric constant (called high-*k* materials). I focus on the optimization of technological growth parameters for thin dielectric films: HfO_2, Al_2O_3, ZrO_2, TiO_2 and their composite layers. Modification of the composition of oxide layers allows the deposition with their required insulating properties in electronic structures, "transparent electronic" structures mostly. In my paper I demonstrated structural, electrical and optical properties of dielectric layers. Electrical properties were performed by measuring and analyzing parameters of test electronic structures such as thin-film capacitors and transistors based on insulators - high-*k* oxides and semiconductors - Si, GaAs, ZnO, graphene, SiC, GaN and GaN/AlGaN. These electronic structures are described by optical, electrical and structural properties of dielectric materials in the interaction with the substrates, in particular transparent substrates based on ZnO layers. Furthermore, due to a wide range of desirable properties, various dielectric oxides can also be applied as gate insulators in transparent devices with low power consumption, resistance switching materials for semiconductor memories, optical coatings in lasers and microscopes or charge-coupled devices, and barriers and/or active layers in photovoltaic structures.

All of oxide layers were prepared using the ALD method at low temperature (60 - 350°C) using the different growth parameters (growth temperature, precursor pulses, number of cycles, precursor temperature). This technique enables excellent thickness control of thin films at the nanometer scale and growth at low temperature, assures a high reproducibility of deposition and of uniformity over large substrates. These properties made ALD an ideal candidate for a low-cost deposition of various transparent insulating and semiconducting layers for electronic applications.

My dielectric films are characterized by a high dielectric constant (HfO_2 - 21±3, ZrO_2 - 23±3, Al_2O_3 - 10±3, TiO_2 - 40±3 and composite layers - 19±3), very smooth surface, wide energy gap (above 3 eV), low leakage current (In the range of 10^{-8} A/cm^2 at 1 V), high dielectric strength (even 6 MV/cm), high refractive indexes (above 1.5 in the visible spectral range), low fabrication temperature and high transparency over a wide spectra range. My analysis have shown that the most efficient insulator is the composite layers which consist of least two materials such as HfO_2 and Al_2O_3. These features enable applications of my dielectrics in the transparent and flexible structures. My insulating layers are used in the thin-film electronic structures based on the ZnO layers. In my approach the ALD system was implemented not only to deposit the transparent insulating oxide, but also semiconducting oxide layers. The objective was to produce the first reported thin-film transistor structure in which all key elements, i.e. the dielectric composite layers and the ZnO channel and gate, were deposited by the same method at low temperature (no more than 150°C) on a transparent substrate. The resulting test devices exhibit reproducible electrical characteristics. The simple construction and low costs of these structures make them attractive for applications in the „transparent electronics".