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Characterization and optimization of a barium titanate deposition process for fabrication of capacitive microelectrodes

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This work presents high-resolution imaging and quantitative analysis of insulators with different analytical probes. Our aim is to develop a thin layer fabrication process for capacitive microelectrodes for neurotechnological applications. We use focused ion beam (FIB) milling to prepare lamellas for transmission electron microscope (TEM) imaging. The surface topography is measured with atomic force microscopy (AFM). To determine the atomic composition of the fabricated thin layers energy-dispersive and wavelength-dispersive X-ray spectroscopy (EDX and WDX) measurements are performed. Comparison of the AFM data with images acquired with helium ion microscopy (HIM) is in progress.

Due to continued miniaturization of implantable neural prosthetics the treatment of diseases where neural defects are involved is being improved. Deep brain stimulation is used to suppress Parkinson’s disease [1], cochlear implants treat deafness [2] and retina stimulators are used to restore vision in blind patients [3]. These devices are equipped with electrodes that are in contact with the adjacent tissue. By applying voltage signals to the electrodes extracellular currents are generated to stimulate neurons. The electrodes of such implants must not degenerate while they are in use in order to achieve long-term stability. Any type of electrically induced corrosion must be suppressed. This can be achieved by using capacitive microelectrodes where faradaic (i.e. direct) currents are completely blocked. In in-vitro experiments it is possible to stimulate neurons with capacitive currents with spatial resolution down to 50 µm [4].

Capacitive microelectrodes are fabricated by depositing a thin insulating layer on top of a metallic electrode. Thereby the electrode is galvanically insulated from the tissue while capacitive charge transfer is still possible. Figure 1 schematically shows an in-vitro experiment where capacitive microelectrodes are used to stimulate neurons. By increasing the specific capacitance of the electrode (i.e. capacitance per area) the electrode size can be decreased whereby the spatial resolution is increased. Because of its high permittivity we chose barium titanate ($BaTiO_3$) that is deposited in an RF sputter process. For layers thinner than 1 µm permittivities of up to 700 are reported [5].

Table 1 shows the permittivity and the capacitance of a thin layer of sputtered $BaTiO_3$ after different annealing temperatures. Because of the low permittivity of the sample annealed at 200°C it must be assumed that it is not in a ferroelectric phase. This presumption is confirmed by the fact that in the TEM image (figure 2) no grains are visible in this $BaTiO_3$ layer. The critical grain size for ferroelectric behaviour of nanocrystalline $BaTiO_3$ samples is 10 – 30 nm [6]. AFM measurements (figure 3a) show that the surface is very smooth compared to a sputtered platinum layer (figure 3b) where the grains are clearly visible.

In EDX spectra the L series of barium overlaps with the K series of titanium (figure 4). Hence we used WDX to determine the composition of the sputtered layers because of its higher energy resolution. This analysis revealed that the compounds are very close to the stoichiometric ratio. No impurities could be detected.

Currently we are investigating whether it is possible to fabricate polycrystalline layers by varying the annealing process and changing the sputtering atmosphere. We expect to increase the permittivity by increasing the grain size. TEM images of these samples will be presented.

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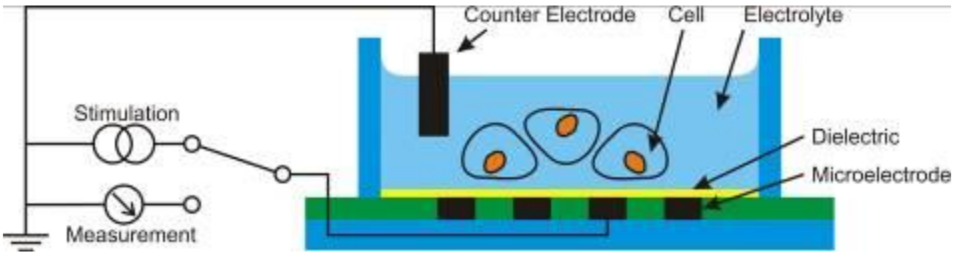

Figure 1. Schematic cross-sectional view of an in-vitro experiment in which capacitive microelectrodes are used.

Annealing temperature	200°C	400°C	600°C	800°C
Capacitance (µF/cm²)	0,167 ± 0,004	0,495 ± 0,015	1,069 ± 0,015	1,871 ± 0,047
Permittivity	15,1 ± 0,3	44,7 ± 1,3	96,6 ± 1,3	169,1 ± 4,2

Table 1. Measured capacitance and permittivity for $BaTiO_3$ thin layers (thickness: 80 nm).

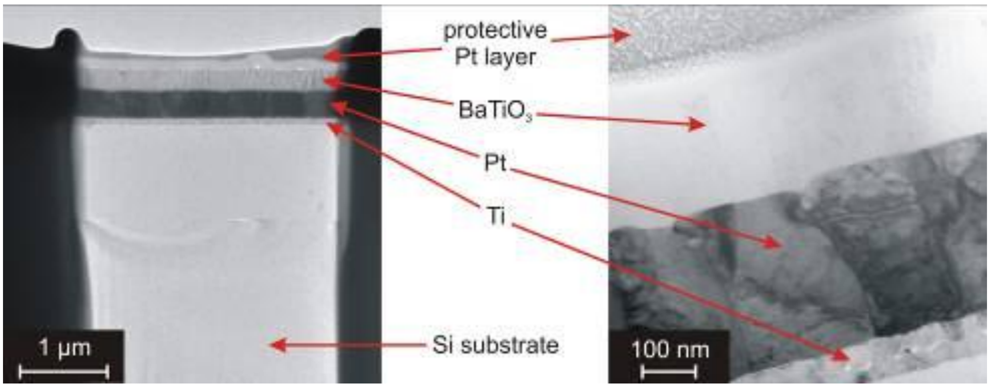

Figure 2. Brightfield TEM images of a Ti-Pt-$BaTiO_3$ layer stack annealed at 200°C after FIB sample preparation.

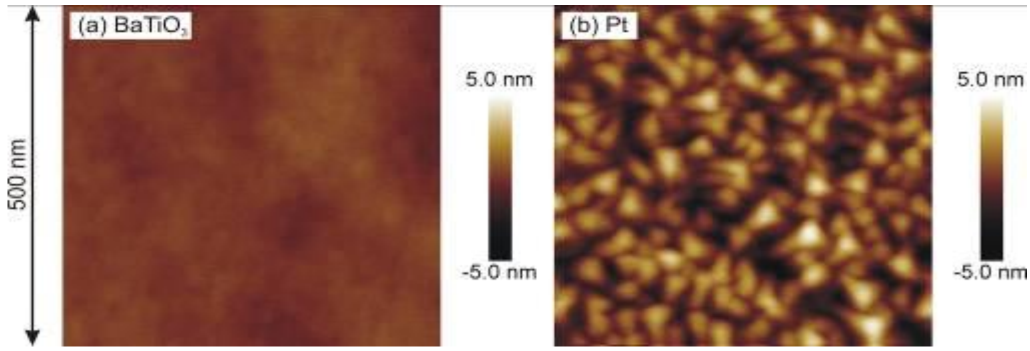

Figure 3. AFM topography measurements of $BaTiO_3$ (a) and Pt (b) for comparison.

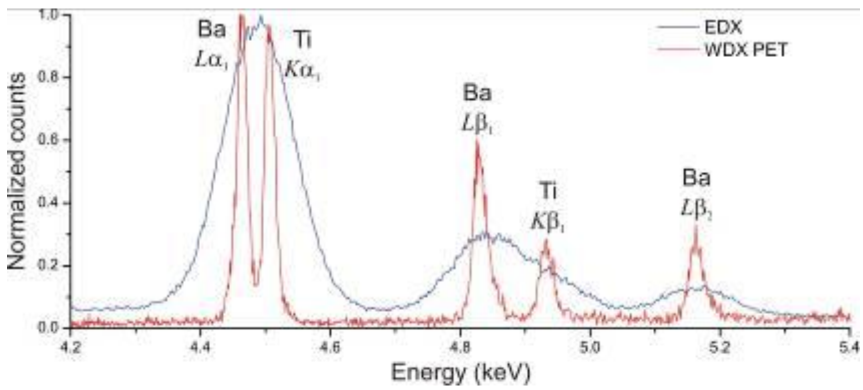

Figure 4. Comparison of EDX and WDX spectra of $BaTiO_3$