

STRUCTURING OF ELECTRODE SURFACES WITH LIGAND-FREE NANOPARTICLES VIA ELECTROPHORETIC DEPOSITION- FUNDAMENTALS AND IN VIVO APPLICATIONS

Stephan Barcikowski, University of Duisburg-Essen, Germany
Stephan.barcikowski@uni-due.de

Sven Koenen, University of Duisburg-Essen, Germany
Christoph Rehbock, University of Duisburg-Essen, Germany
Hans E. Heissler, Hannover Medical School, Germany
Svilen D. Angelov, Hannover Medical School, Germany
Kerstin Schwabe, Hannover Medical School, Germany
Joachim K. Krauss, Hannover Medical School, Germany

Key Words: pulsed laser ablation in liquids (PLAL), electrophoretic velocity, neural electrode, impedance, deep brain stimulation

Electrodes for neural stimulation and recording are highly relevant in modern medicine, e.g. for the treatment of movement disorders. As these electrodes have to be implanted directly into the patient's brain, impaired biocompatibility as well as reduced performance due to increased impedance upon tissue contact are serious problems. Strategies to improve the efficiency of electrodes entail the implementation of defined nanoscopic structures to the electrode surface, which increase the surface area and improve the current flow by possible edge effects¹. In this context electrophoretic deposition (EPD) of nanoparticles (NP) constitutes an efficient and feasible way for surface structuring as in contrast to e.g. ablative laser machining, electric field lines are naturally ordered perpendicular to the implant's surface, so that electrophoretic deposition is well compatible to shaped implants and curved surfaces.

In this work an EPD process for the structuring of Pt electrode surfaces with NP is systematically investigated. Reference NP from a modern synthesis route named pulsed laser ablation in liquids (PLAL)² are utilized as they possess a high surface charge density in order to ease their movement in an electric field. The electrophoretic velocity of these NP was examined and found to be linearly-correlated with the electric field strength, while the slope is dictated by the NP's surface charge density (zeta-potential)^{3,4}. On the other hand the PLAL-generated NP are, by design, completely free of organic ligand, which significantly affected their deposition in an EPD setup. It was found that the deposited mass linearly increased with process time, yielding a well scalable process, while on the other hand control experiments with ligands showed a saturation of the deposited mass due to electrochemical shielding of the surface by charged ligands.⁴ It was furthermore demonstrated that the EPD process with ligand-free NP could also be done in a continuous flow-through setup suitable for the parallel structuring of multiple electrodes.⁵ Interestingly, the deposition velocity was not size dependent as particle size distributions prior to and after EPD were identical.⁵ In consecutive experiments, the surface properties like coverage, oxidation, wettability⁶ and impedance of the electrode materials were evaluated and correlated with the EPD process parameters electric field strength, colloid concentration and deposition time. As a result a detailed map was obtained, which allows a defined tuning of Pt surface properties by Pt NP EPD. Finally, the impedance of electrodes coated with ligand-free Pt NP were evaluated in long term stimulation experiments with rats. The NP coating could stabilize the impedance of the electrodes *in vivo*, while it continuously increased in non-coated controls.⁷ Furthermore, the coated electrodes exhibited excellent biocompatibility similar to the controls⁷ while no significant NP desorption from the surface was found upon mechanical tear.

1. X. F. F. Wei and W. M. Grill, *J. Neural Eng.*, 2005, 2, 139-147.
2. V. Amendola and M. Meneghetti, *Phys. Chem. Chem. Phys.*, 2013, 15, 3027-3046.
3. A. Menendez-Manjon, J. Jakobi, K. Schwabe, J. K. Krauss and S. Barcikowski, *J. Laser Micro Nanoeng.*, 2009, 4, 95-99.
4. C. Streich, S. Koenen, M. Lelle, K. Peneva and S. Barcikowski, *Appl. Surf. Sci.*, 2015, 348, 92-99.
5. S. Koenen, R. Streubel, J. Jakobi, K. Schwabe, J. K. Krauss and S. Barcikowski, *J. Electrochem. Soc.*, 2015, 162, D174-D179.
6. A. Heinemann, S. Koenen, K. Schwabe, C. Rehbock and S. Barcikowski, *Key engineering materials*, 2015, 654, 218-223.
7. S. D. Angelov, S. Koenen, J. Jakobi, H. E. Heissler, M. Alam, K. Schwabe, S. Barcikowski and J. K. Krauss, *J. Nanobiotechnol.*, 2016, 14,