Popular-science abstract of the project

Fuel cell is an electrochemical device that converts chemical energy of fuel directly into electricity. The power of fuel cell comes from direct conversion. In conventional power plant, first the chemical energy of fuel is converted into heat in the process of combustion. Heat is used to heat up water and produce steam. Next, steam uses turbine to do mechanical work on a rotating output shaft to drive an electrical generator. In fuel cell there is no middlemen and chemical energy of fuel is converted directly into the electricity. As a consequence of that has an extraordinary high-energy conversion rate not limited to a Carnot cycle. A fuel cell follows general treads in evolution of energy systems. First trend is constant and consequent decarburization of used fuel. The human race started from using wood as a primary source of energy. Wood contains mostly carbon and a ratio between hydrogen and carbon is only 0.1 (H/C=0.1). In the 18th century peoples switch to coal with H/C=0.5, 20th century was sift to oil H/C=2, 21st century is methane H/C=4. Naturally in the end of this tread, there is pure hydrogen. Second crucial trend is constant and consequent improvement of thermal efficiency. Fuel cells are the most efficient devices regardless of the size of a system. Fuel cells are able to produce energy efficiency for household application as well as large stationary power plant. In contradiction to conventional power plant a fuel cell can work dynamically. It means, that energy can be produced at the place where is needed in exact amount which is needed. It is important to keep in mind that hydrogen is not a source of energy but only an energy carrier. Hydrogen is not available in nature and must be produced using renewable, conventional or nuclear power. Some scientists call a fuel cell a missing link in renewable energy, because fuel cell might help to storage energy produced by solar or wind power plan into hydrogen. In the meanwhile the most convenient fuel for fuel cells is methane. It is widely available with developed and mature distribution infrastructure. Methane after desulfurization can be converted into hydrogen rich fuel using catalytic partial oxidation (CPOX). The gas contains also carbon monoxide, which can be converted in high working temperature fuel cells such as solid oxide fuel cells (SOFC). SOFCs are widely tested in Europe, USA and Japan.

One of the most challenging fundamental problems associated with SOFCs, is how microstructure morphology of solid oxide fuel cell evaluate during long-term operation and how it influences performance of stack. This problem is extremely complex in a case of a fuel cell fuelled with methane. In this case exothermic electrochemical reactions occurs simultaneously with endothermic chemical reactions. All those reactions happen in a very complex porous media microstructure. This creates a challenging problem on the edge of material science, chemistry, electrochemistry, thermodynamic, fluid mechanics, heat and mass transfer and mathematical modeling.

In the proposed project the local microstructure evolution of SOFC stack fuelled with hydrogen and methane will be investigated. This approach allows separating the case with electrochemical reaction from the case with simultaneous chemical reactions. The microstructure analysis will be conducted using state-of-the-art electron tomography techniques: combination of focused ion beam with scanning electron microscope (FIB-SEM). The method enables the observation of many sequential 2D images of a porous microstructure and reconstructs it into a 3D structure using advance image processing. 3D structure reconstruction was introduced to the field of SOFCs in 2006. Since then the combination of a focused ion beam and scanning electron microscope (FIB‑SEM) brought a breakthrough in the direct 3D observation of porous structure. Until today only few institutions in the word can precisely quantify all microstructures parameters. Base on the electrochemical measurements and microstructure analysis a numerical model will be developed. The model will be falsificated using a number of experimental testes. One of the most important and surprising questions is: can local microstructures change increase performance of a cell stack? Such an improvement of the stack was observed in the past by various research groups, however the mechanism behind this phenomenon reminds unclear.