MICROSCALE HEAT TRANSFER IN ADVANCED FUEL CELLS

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The microelectronics needs for micro power supply embedded in chip or placed directly in electronic scheme, like micro scale fuel cells. The selection of initial fuel (hydrogen, methanol, or ethanol) is determined first of all by its cost, availability, ecological characteristics, reactivity and specific energy per unit mass. Successful developing the next generation of advanced microscale fuel cells (μFC), as thin film microelectronic devices will strongly depend on two key advances:
we must to develop a much more refined understanding of the thermo physical properties of MEA thin films, properties that differ dramatically from bulk materials
we must also develop sensors technology capable for on-line monitoring MEA properties. Precise control of thin film MEA properties requires the ability to measure the microstructure and morphology of the film as it is being deposited and gauge such properties as conductivity, bulk modulus, thickness, and thermal boundary resistance. So our current activities include:

- development of μFC for future electronics devices;
- study thin film MEA (Nafion 112, 115, 117) properties by atomic force microscopy (AFM) and optical (IR) properties of MEA that depends from temperature, humidity;
- numerical simulation of microscale heat transfer in MEA and μFC.

In common case the hydrogen fuel cell represents the device conversing chemical energy of a fusion reaction of hydrogen with oxygen to an electricity, Fig. 1, with by-products of response are warmly and water vapor.

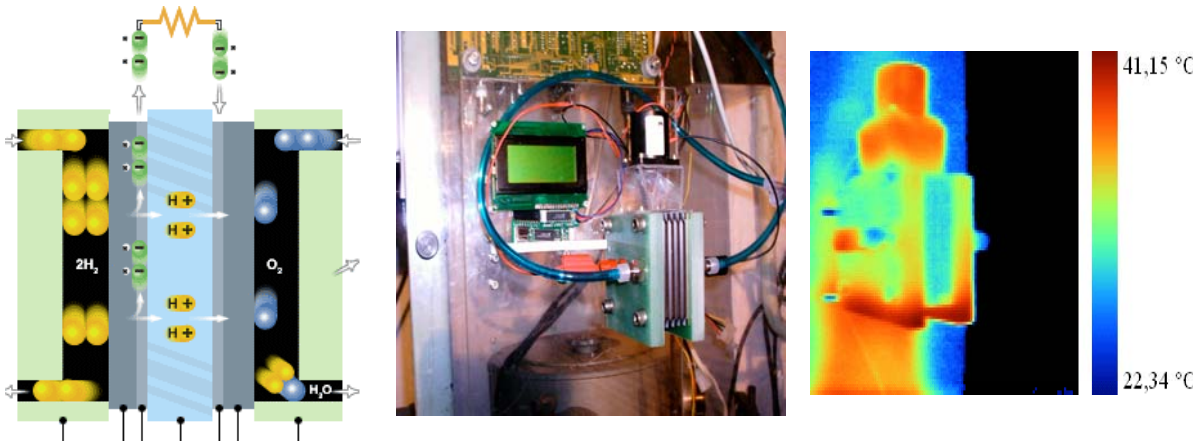

Fig. 1. Common scheme of microscale fuel cell (μFC), typical experimental setup and IR image of prototype unit during tests

At technical implementation the very relevant role is played by channels in electrodes, on which one in μFC the reactants move. Their exact selection allows to optimize a temperature operational mode of the MEA (proton exchange membrane with catalysts layers) and knowledge of these factors allows essentially to increase efficiency. It is important also, how these channels are arranged one to each other, as the exact selection of the form of channels and their positional relationship allows at the best to eliminate a gradient of MEA temperature, and can be calculated numerically by QuickField 5.0 software for different environment condition, Fig. 2–8.

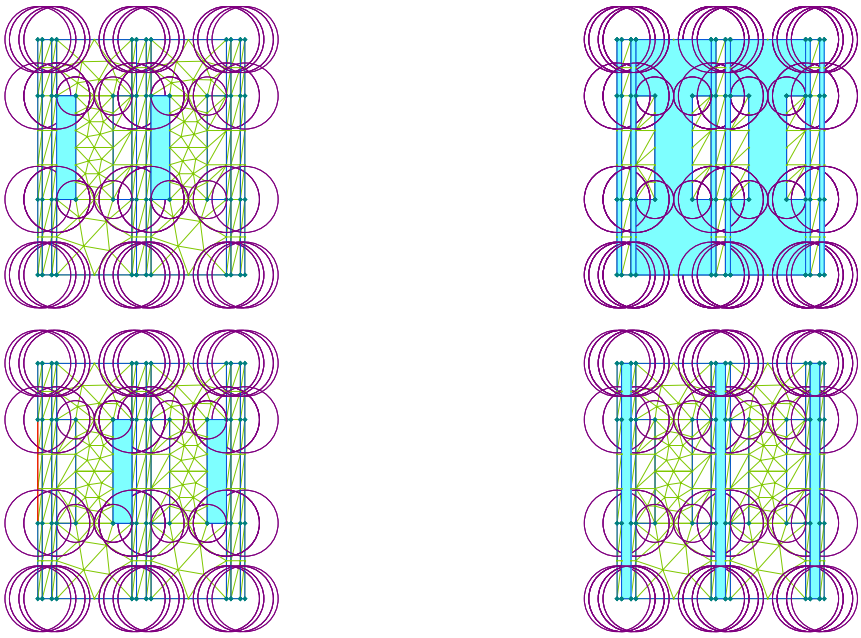

Fig. 2. Calculation grid and channels (left side top and bottom) electrode (right side top) and MEA (right side bottom) geometry for microscale advanced fuel cell (μFC) simulation

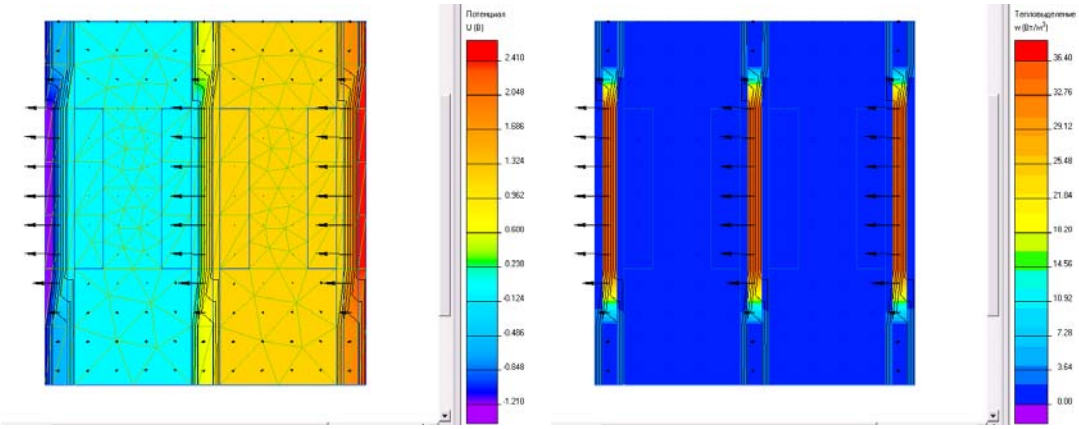

Fig 3. 2D voltage distribution and 2D heat distribution in cross section μFC simulation

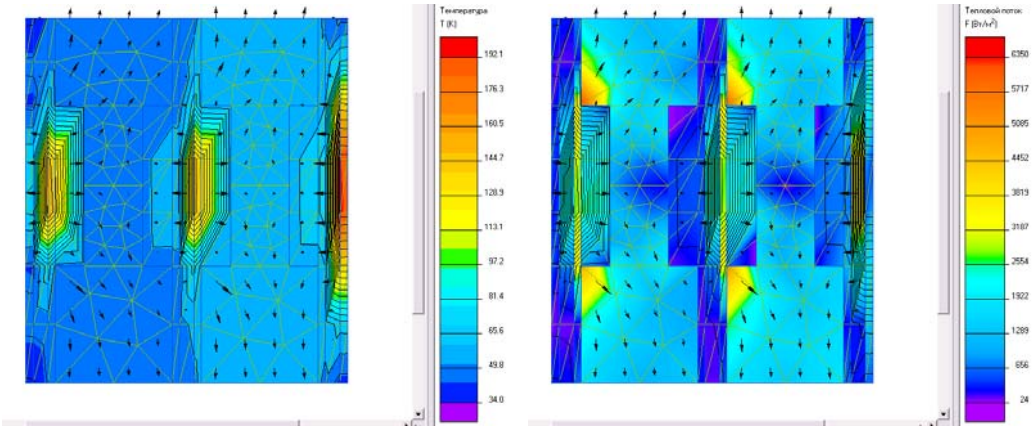

Fig. 4. 2D temperature and 2D heat flux density distribution in cross section of μFC

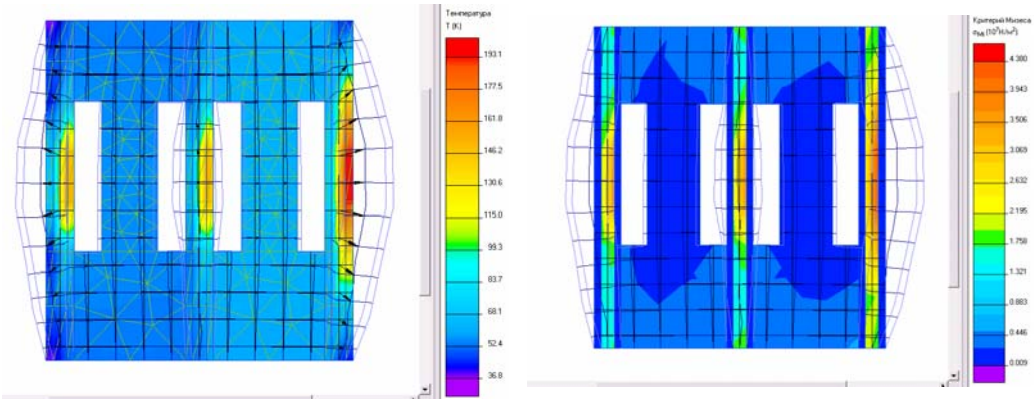

Fig. 5. 2D deformation and mechanical stress in cross section of μFC

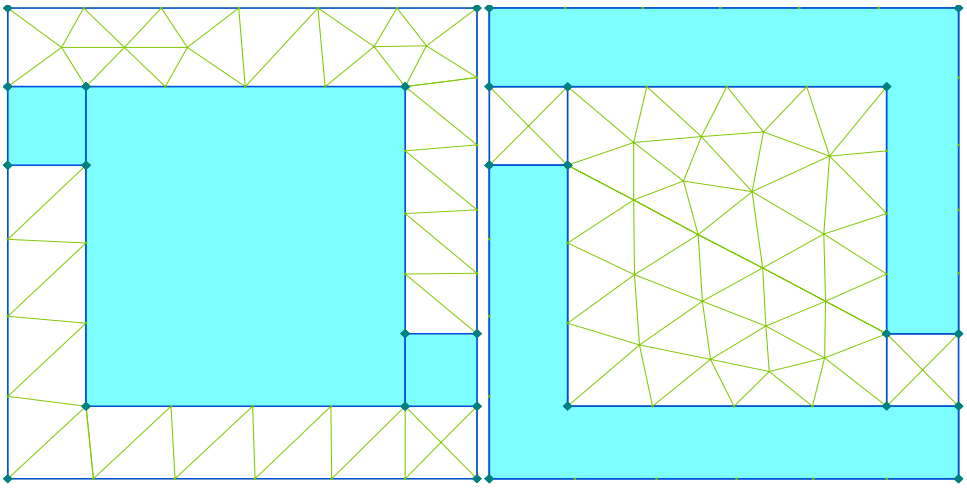

Fig. 6. Planar μFC MEA and air cooling heat exchange geometry

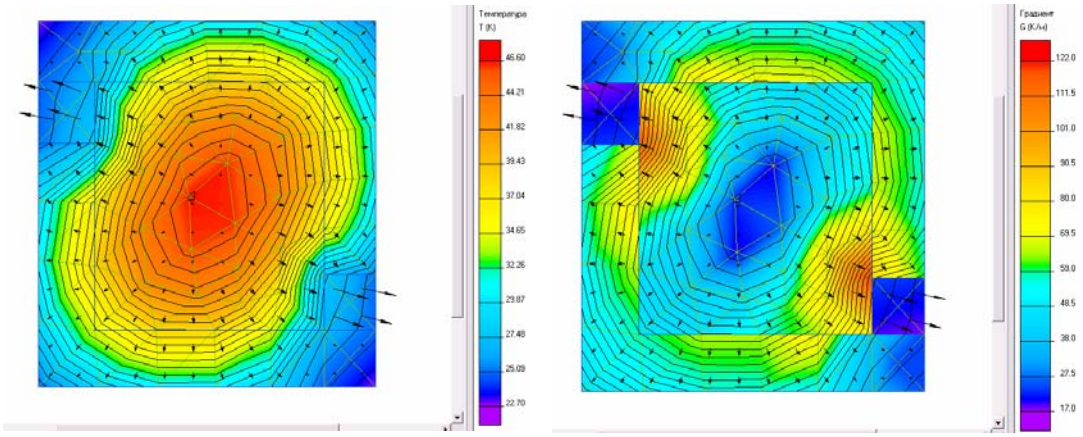

Fig. 7. 2D temperature distribution and temperature gradients fields in planar μFC

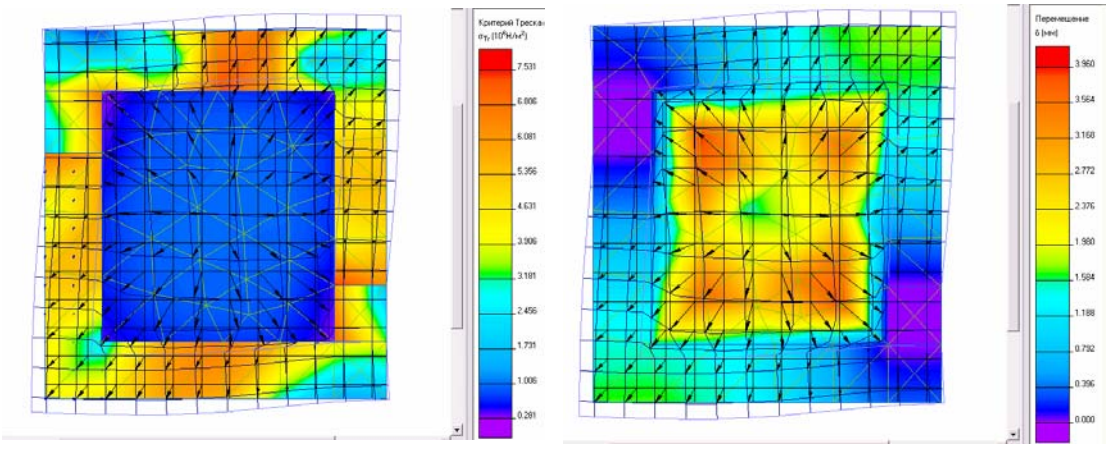

Fig. 8. 2D mechanical deformation in planar μFC correlated to quick temperature changes during start-up processes

The typical MEA consists of a solid polymer, proton exchange membrane. A layer of platinumbased catalyst and a gas-porous electrode support material are on both sides of the membrane, forming the anode and cathode of the cell. Anode in μFC is the the negative (oxidizing) fuel electrode that gives up electrons to the external circuit, oxidizing hydrogen in the process. The positive cathode – air electrode that accepts electrons from the external circuit, reducing oxygen in the process. In a fuel cell, this is where oxygen (air) reacts. Gas diffusion layer (diffuser current collector) – used to describe the conductive material in a fuel cell which collects electrons (on the anode side) or disburses electrons (on the cathode side). The current collectors are microporous, allowing fluid to flow through them, and lie between the catalyst/electrolyte surfaces and the bipolar plates. Catalyst layer increases the rate of a reaction without being consumed. After the reaction, it can potentially be recovered, chemically unchanged, from the reaction mixture. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly, or at a lower temperature.

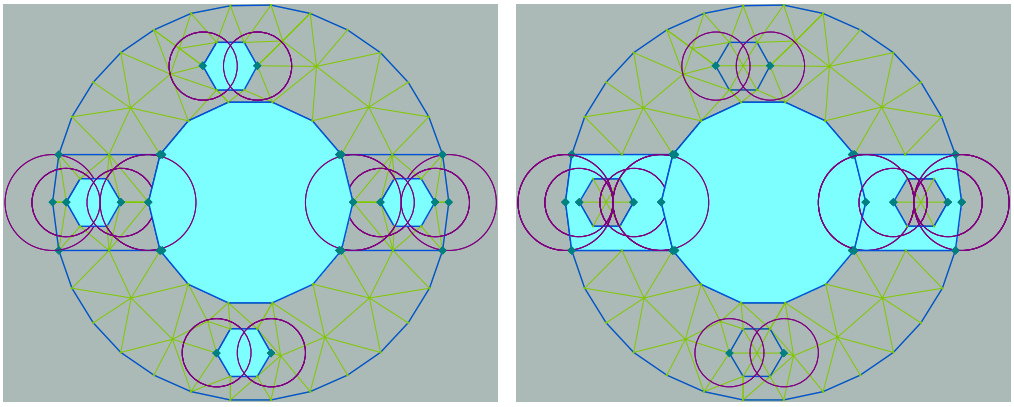

Fig. 9. Alternative μFC MEA and electrode geometry

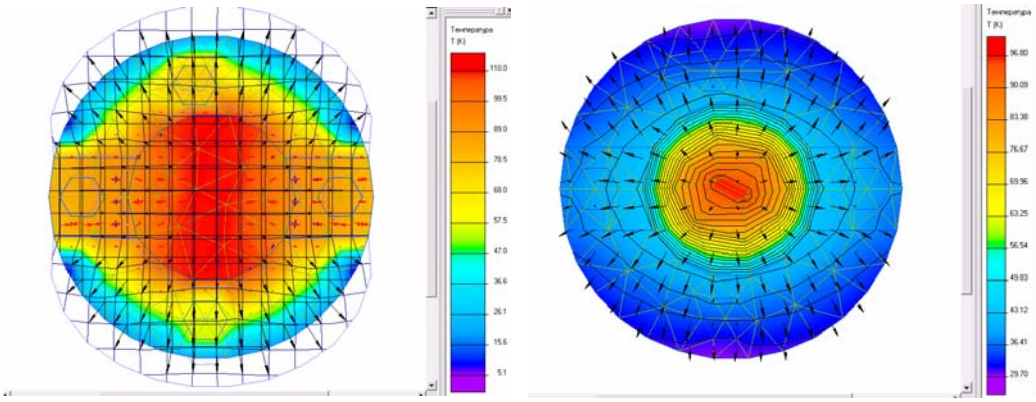

Fig. 10. 2D deformation and 2D temperature distribution in circular μFC

The form and quantity of catalyst (platinum) also plays the very relevant role, and can be measured by AFM microscope Fig. 11.

As display outcomes of experimental tests and simulations a peak efficiency is provided at completely hydrated thin film MEA and temperatures below 90 °C. It is difficult to supply a stable operation for MEA at temperature close to a boiling temperature of water at a given operating pressure - for a failure-free operation of a microscale fuel cell it is necessary to control a temperature schedule of each unit of the stack of fuel cells, that can be possible by using of fiber optic sensor in near IR band.

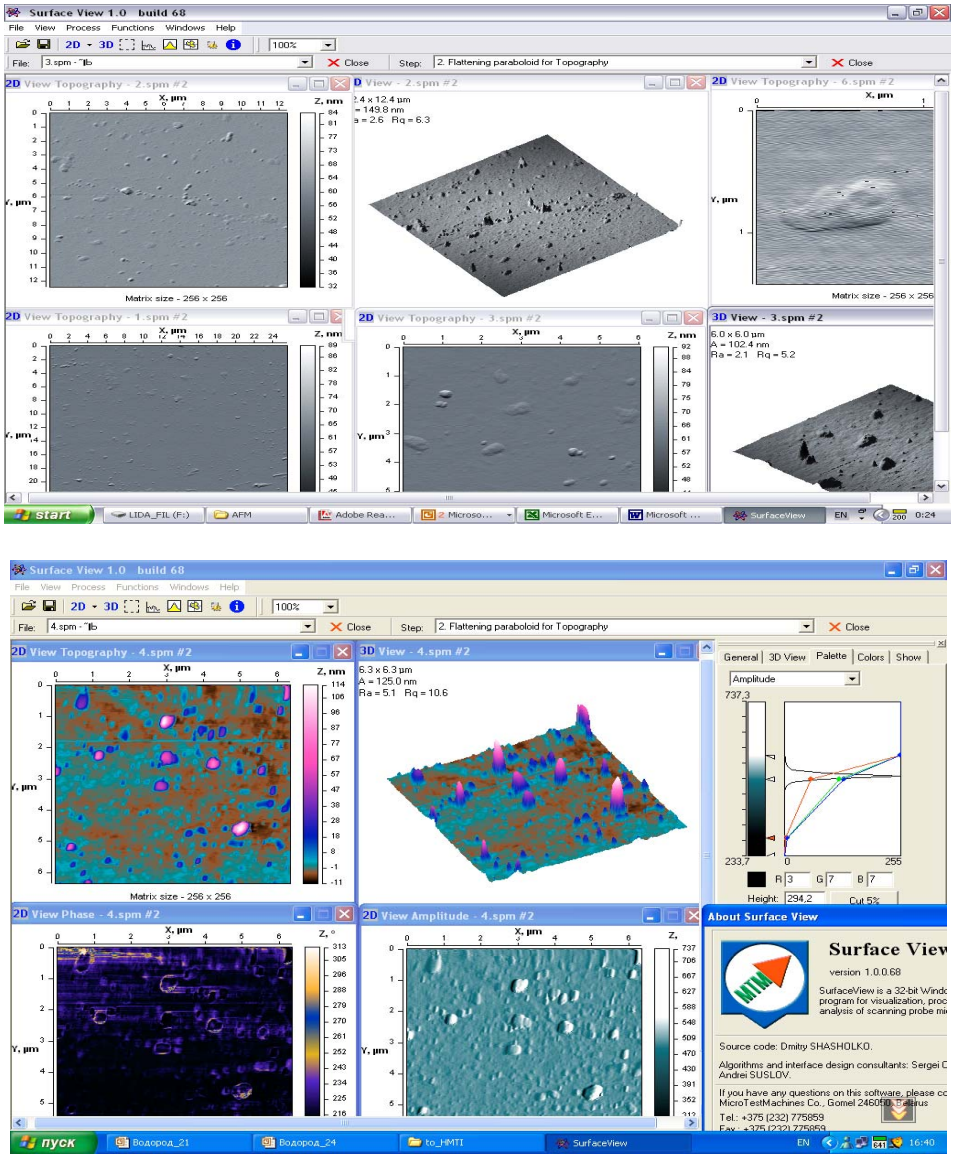

Fig. 11. Pt-Ru deposition layers on Nafion-112 MEA from 3D (top) and self made nanocatalysts coating on Nafion-112 PEM (bottom)