ABSTRACT

Institute for Physics and Power Engineering (IPPE) has been developing planar SOFCs and power systems based on them since 1996. The R&D work includes SOFC materials investigations, single cell and stack design, manufacturing and testing, small-scale power plant design development, and creation of the base for power plant long-term tests. Currently our efforts are concentrated mainly on development and optimization of electrolyte-supported and anode-supported planar SOFC technologies. More than two hundred single SOFCs have been tested. Maximum power density of 700 mW/cm² at 950°C has been achieved. Recently several three- and five-cell planar SOFC stacks have been tested. The status of R&D work on planar SOFC at IPPE and some results are discussed in this paper.

INTRODUCTION

Two types of SOFC design differing in shape (round and rectangular) have been developed at IPPE (1). The more advanced round planar SOFC is shown in Figure 1. The SOFC consists of planar solid oxide electrolyte (YSZ) and two porous electrodes: cathode and anode. The SOFC is sealed into the ceramic (or metal) outer housing using special glass. There are several gas ducts (for air, fuel and exhaust gases) in the housing.

Figure 1. Components of the round planar SOFC (IPPE design).
Since 1996, practically all basic technologies, associated with SOFC and stack manufacturing, have been developed at IPPE:

- Electrolyte and electrodes material synthesis
- Three-layered SOFC structure (electrolyte, anode, cathode) manufacturing
- Formation of cermetal catalytic electrode interlayers
- Multi-component glasses for stepped sealing of SOFCs and stacks
- Spinel SOFC outer casing manufacturing
- Development of high-temperature materials for gas ducts
- Metal-ceramic unit manufacturing

Recently, an original electrostatic spray technique for electrolyte and protective thin-film deposition has been developed.

All planar SOFC technologies (to a greater or lesser extent) are being developed at IPPE: electrolyte-supported (ES), anode-supported with thin-film electrolyte (AS) and cathode-supported (CA) ones. To date the most progress has been achieved in the first two technologies. Some characteristics of these technologies are summarized in Table 1.

Table 1. Planar SOFC technologies’ characteristics.

| Characteristics            | ES SOFC     | AS SOFC     |
|----------------------------|-------------|-------------|
| SOFC diameter, mm          | 60 - 100    | 60 - 100    |
| Electrolyte (ZrO2)0.92(Y2O3)0.08 [YSZ] | thickness, μm | 250 - 500 | 5 - 50 |
| Anode NiO + YSZ            | thickness, μm | 20 - 50   | 500 - 1000 |
| Cathode (two layers):      | total       |             |
| I - LSM + YSZ              | thickness, μm | 50 - 100   | 50 - 100   |
| II - LSM [La0.85Sr0.15MnO3] |             |             |

SINGLE PLANAR SOFC TESTS

In order to optimize SOFC design and technology, more than two hundred single SOFCs have been tested at IPPE to date. Most of these were ES SOFCs, but in the recent two years, two tens of AS SOFCs were also tested. Usually (50% H2 + 50% Ar) gas mixture is used as the fuel for the SOFCs. Experimental J - V characteristics of the typical ES SOFC with electrolyte thickness of 370 μm in the temperature range of 700 - 950°C are shown in Figure 2. Maximum power density was found to be above 700 mW/cm2 at 950°C. This corresponds to a SOFC area-specific resistance of about 0.32 Ω·cm².
Figure 2. J - V characteristics of the electrolyte-supported SOFC (lab # 295).

A comparison of power curves (as a function of temperature) for some experimental ES SOFCs (lab # 250, 252, 295) differing in electrolyte thickness and electrodes technology is shown in Figure 3. These SOFCs were manufactured and tested at IPPE over the last two years.

Figure 3. Power density vs temperature for some ES SOFCs tested at IPPE.
Currently our efforts are aimed at the further ES SOFC technology improvement in order to reduce internal cell polarization and ohmic losses. Particularly the cermet catalytic electrode interlayers are used for this purpose (2). We expect it will enable us to increase the ES SOFC electrical power density up to ~1000 mW/cm².

As mentioned above, the technology of anode-supported SOFCs with thin-film electrolyte was intensively developed at IPPE in recent years. This technology enables to lower SOFC operating temperatures to at least up to 800 - 850°C keeping sufficiently high output performance (IT SOFC). Lowering the cell operating temperature is beneficial, as it potentially lowers SOFC stack production cost, because less expensive materials can be used.

Figure 4 shows the power density as a function of current density at various operating temperatures for the experimental anode-supported SOFCs with thin electrolyte (~ 5 μm). The anode thickness was ~ 690 μm. The cell power density was 150 - 275 mW/cm² in the temperature range of 800 - 850°C. Maximum power density (~ 450 mW/cm²) was reached at 950°C.

![Figure 4. Power density as a function of current density for the anode supported SOFCs with a thin-film electrolyte at various operating temperatures.](image)

Apparently, we have not yet reached the best AS SOFC performance attained by more advanced developers (3). We realize that our current AS SOFC technology is not adequately optimized now. Nevertheless we are planning its further optimization because this technology seems to be very promising (cost reduction, resistance to cracking, etc.).
SOFC STACK DEVELOPMENT AND TESTS

In 2001-02, several 3-cell and 5-cell stacks based on planar ES SOFCs were developed and tested at IPPE. The ready-assembled 5-cell SOFC stack (together with heat exchangers) before testing is shown in Figure 5. The SOFC diameter is ~ 60 mm.

![Photo of ready-assembled 5-cell SOFC stack (together with heat exchangers) before testing.]

Maximum electrical power of the stack and stack-average power density at 900 and 950°C are given in Table 2. There was no significant performance degradation during the short-term endurance test (~ 200 hrs).

Table 2. Stack power and power density.

|                  | 900°C   | 950°C   |
|------------------|---------|---------|
| 5-cell stack maximum electrical power, W | 23 (2.7 V; 8.6 A) | 30 (3 V; 10 A) |
| (cell diameter 60 mm) |         |         |
| Stack - average power density, mW/cm² | 200 | 260 |

It can be seen from Table 2 that the stack-average power density is about 1.5-2.0 times lower than that for single SOFCs (see Figure 3). It is considered to be caused by...
sufficiently high electrical losses in the cathode and anode current collectors of cells. Note that anode and cathode current collectors were respectively the nickel mesh and the deformable contact layer made of a granulated material. The stack interconnects were made of stainless steel coated with lanthanum-strontium chromite (LSC) protective layer. Of course, such high electrical losses in the cell current collectors are unacceptable, and now our efforts are aimed at the solution of this problem by means of technological and design measures. Recently we have obtained promising results which indicate a considerable (several times) reduction of the losses. Currently, a stack with greater number of cells is being manufactured and prepared for test.

PLANAR SOFC POWER PLANT DEVELOPMENT

The IPPE's SOFC R&D program is aimed at the development of competitive 2.5 – 5.0 kW power plant for remote power generation. The marketing research indicates that in Russia alone companies such as GAZPROM and RAO "ES Russia" need hundreds of power plants per year in this power range. The stage-by-stage realization of the aim is possible over the next few years.

At the first stage we are going to manufacture and test the basic 40-cell stack with anode-supported SOFCs and metallic interconnects operated at 800 – 850°C. Calculated electrical power of the stack with 10 cm diameter cells are 700-800 W at a voltage of 24 V. Note that the 40-cell stack performances are based on the experimental data obtained during the 5-cell stack test (see Table 2).

The other key problems (planar SOFCs manufacturing in large series according to IPPE's technology, system integrated fuel processor, power condition system, automatic control system, heat exchangers, etc.) can be solved in cooperation with other Russian companies and institutes.

In the course of the project the base for a long-term test of power plants (up to 10 kW) is being created at IPPE now.

CONCLUSIONS

1. IPPE has been developing the planar SOFCs and power plants based on it, since 1996. The R&D work includes SOFC material investigations, SOFC design and technology, single cells and stacks manufacturing and testing, stack and power plant design development, and creation of the base for power plant long-term test.

2. Now our efforts are concentrated mainly on the development of two planar SOFC technologies (electrolyte-supported and anode-supported). More than a hundred single SOFCs have been tested. Maximum power density of 700 mW/cm² at 950°C has been achieved.

3. The technology of anode-supported SOFC with thin electrolyte for temperature range of 800-850°C was intensively developed at IPPE in recent years. Now the technology is in the process of optimization. We have not yet reached the best AS SOFC
performance obtained by advanced developers. Nevertheless we are planning its further optimization because this technology seems to be very promising (cost reduction, resistance to cracking, etc.).

4. Over the recent two years based on the planar electrolyte-supported SOFCs the 3-cell and 5-cell stacks were manufactured and tested at IPPE. Maximum electrical power of the 5-cell stack (60 mm cell diameter) was ~ 30 W at 950°C. The stack-average power density (~ 260 mW/cm²) was about 1.5 – 2.0 times lower than that for single SOFCs. The reason is a large voltage loss in cathode and anode cell current collectors. That is why now our efforts aim at the loss reduction. Recent promising results allow us to expect considerable reduction of the loss.

5. Our SOFC R&D program is aimed at the development of the competitive 2.5-5.0 kW power plant for remote power generation. The stage-by-stage realization of the program is planned over the next few years. Currently within the framework of the program, the base for power plant long-term tests is being created at IPPE.

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