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# Solid Oxide Fuel Cell Development at NIMTE

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The largest SOFC R&D activity in China is conducted at NIMTE where 45 full time staff is vertically integrated. We manufacture and sell planar anode supported cells for international market with the highest performance/price ratio. We offer various nano-powders including LSM, LSCF, LSC, CGO, YSZ and SSZ. Long term tests on performance degradation, in particular at low temperature and high current density, are intensively carried out in our cell testing group. We demonstrated low cost stack by combining internal manifolding design and low cost components selection. A five cell short stack has run for more than 3000 hours and the voltage is monitored for individual cells. Stacks of 500 W to kW power range are built and tested. We successfully manufactured 30×30cm$^2$ cells for multi-kilowatt single stack. 2 kW power and heat co-generation system are under development and 20 kW electrical generation system is planned this year in collaboration with a large Chinese electricity generation company.

## Introduction

The largest SOFC R&D activity in China is conducted at Ningbo Institute of Material Technology and Engineering (NIMTE). 45 full time staff is vertically integrated, and they come from various areas including Chemical Engineering, Applied Physics, Material Science and Engineering, Mechanical Engineering, Power Engineering, Electrical and Electronic Engineering, Control Engineering, System Science, as well as Computer Science. They are working on nano-powder preparation, single cell manufacture, cell testing, stack components and stack manufacture, fuel processing and thermal management, as well as system integration. Currently we manufacture and sell planar anode supported cells for international market with highest performance/price ratio and have many customers. Cells with performance of 0.4-0.6 W/cm$^2$ at 750$^o$C are routinely produced. We offer various nano-powders including LSM, LSCF, LSC, CGO, YSZ and SSZ. Our cell testing group offers long term testing services in various fuel gases. Long term tests on performance degradation, in particular at low temperature and high current density, are intensively carried out. Stack components development and stack building are the most important activities in the mean time. We and our strategic partner have produced high performance special stainless steels manufactured in a cost economical way which meets our interconnect requirement. We demonstrated low cost stack by combining internal manifolding design and low cost components selection. Stacks of 100 W to kW power range are built and tested. We successfully manufactured 30×30cm$^2$ cells and the multi-kilowatt single stack is under development. Fuel treatments with different processes are under investigation for various applications including steam reforming, auto-thermal reforming and CPOX. 2 kW power and heat co-generation system are under development and 20 kW electrical generation system is planned this year in collaboration with a large Chinese electricity generation company. Our goal is to commercialize solid oxide fuel cell technology through collaborations with any potential partner including research, industry and investment vehicles. Our current activities are focused on low cost raw materials and components, manufacturing and offering low cost single cells for international market, low cost stack technology with high stability and life time, as well as system demonstration.

## Nano-powder and Single Cell Fabrication

Nano-powder fabrication for SOFC application is conducted by our Powder and Cell Group where various cathode powders, CGO, YSZ, SSZ, NiO are routinely produced (1-4). Configurations of single cells are 1$^{st}$ generation cell (NiO+YSZ)/YSZ/(LSM+YSZ), 2$^{nd}$ generation (NiO+YSZ)/YSZ/CGO/(LSCF/LSC+CGO), and 3$^{rd}$ generation (NiO+YSZ)/SSZ/CGO/(LSCF/LSC+CGO). Currently we supply LSM, LSCF, LSC nano-powders for international market. The processing and performance details are presented in this symposium (5). Figure 1 shows the I-V curves measured from the cell with configuration of (Ni+YSZ)/YSZ/CGO/(LSCF+CGO). The maximum power density of 0.4 W/cm$^2$ can be reached at 650$^o$C ($H_2$, Air). The cell is tested for more than 3500 hours shown in Figure 2. The degradation rate is 5.45%/kh for the first 1761 hours. Because of the testing equipment accident, the cell underwent through a thermal cycle to 200$^o$C. There was a small drop in voltage of the cell after the testing furnace temperature was re-ramped to 650$^o$C. From 1761 hour to 3463 hour, the degradation rate is 0.53%/kh. We demonstrated that the cells with LSCF+CGO cathode can be run at the low temperature of 650$^o$C and reasonable current density of 0.5A/cm$^2$. The testing is still continuing.

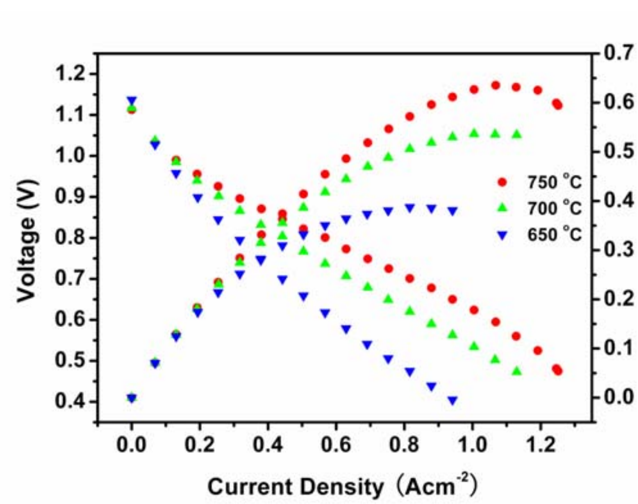


Figure 3. I-V curves of the cell with LSCF + CGO cathode.

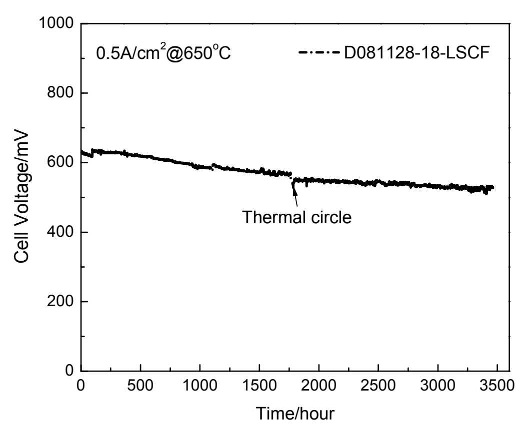


Figure 4. Long term test of the cell at 650$^o$C and 0.5 A/cm$^2$.

This potential was also confirmed on the cells with LSC cathode as shown in Figures 3 and 4. Our Single Cell Testing Group puts more effort on testing cells at low temperatures and high current density. The degradation behavior of the cells shows potential for application of cells at 600-650$^{o}$C. It is contrary to some reports which claim that the degradation will be much more severe under conditions of lower temperature and higher current density.

The effects of syngas on cell performance are studied and are reported in this symposium (6). The syngas mainly comes from methane after partial pre-reforming natural gas. For the coal-gas application, the effects of $H_2S$ and $Cl_2$ on the cell performance are also investigated. It will be reported in the future.

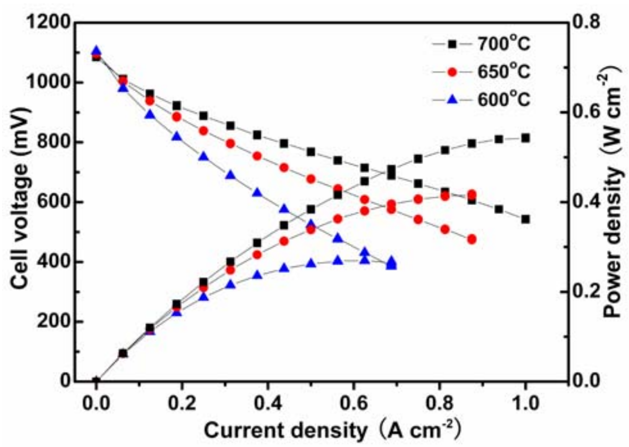


Figure 3. I-V curves of the Cell with LSC as the cathode.

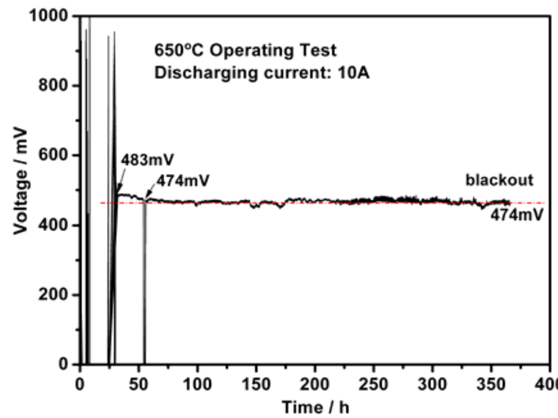


Figure 4. Long term test of the cell at 650$^{o}$C and 0.625 A/cm$^2$.

## Single Cell Pilot Production

Our Single Cell Production Group routinely produces single cells with a conventional configuration of (NiO+YSZ)/YSZ/(LSM+YSZ). The power densities of 0.4-0.6 W/cm$^2$ are reached for the cells which are supplied for our own stack development activities and sold for international market with the highest performance/price ratio. The appearance and performance of the cells are shown in Figures 5 and 6. The cell is around 0.5 mm in thickness and greater than 250 MPa in flexural strength.

Figure 5. Appearance of our single cells made by our Single Cell Production Group.

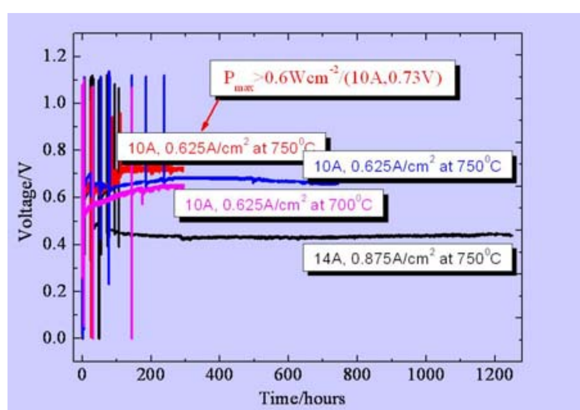


Figure 6. Performance of our single cells measured at various conditions.

## Stack Development

At current stage, stack design and development are the most important tasks in our research activities. From a former report (7), our stack design offers excellent thermal cycling property from our short stack experiment. More experiment results are presented in this symposium (8).

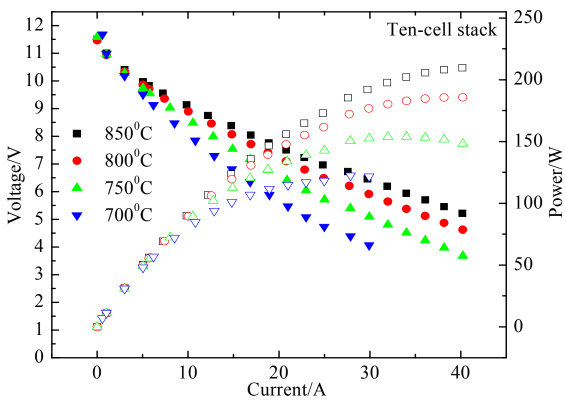


Figure 7. I-V curves and powers of the 10-cell stack at various temperatures.

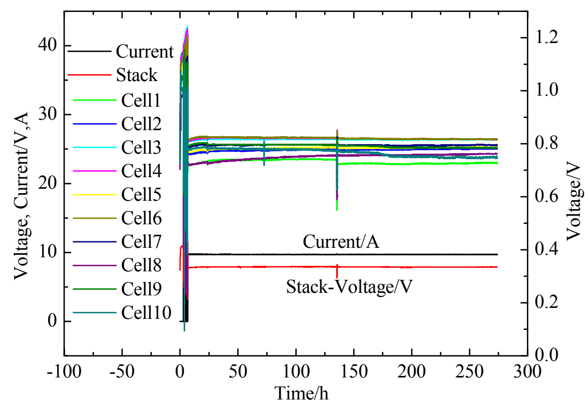


Figure 8. Degradation behaviors of our 10-cell stack and individual cells.

The stack development efforts are made for two targets, one is towards high power, and another towards high stability. Recently we put more efforts on the stability issues. Figure 7 shows that for our 10-cell stack, the power of 100 W-200 W can be reached from 700°C to 850°C under $H_2$ and air. The degradation behavior of the 10-cell stack has been examined by testing the stack under 700°C and 0.1 A/cm$^2$ with 70% fuel utilization ($H_2$, air) as shown in Figure 8. The voltage under current of 10 A and voltage degradation rate of the individual cell show that the individual cells have similar performance. With our internal manifold design and stack components selection, we are confident that the stack cost can be controlled well below 100 Euro/kW in the mass production stage.

## Large cells and stack

For the MW electricity generation, high power and large cells are needed. We have successfully made large cells with 30×30cm$^2$ in area as shown in Figure 9.

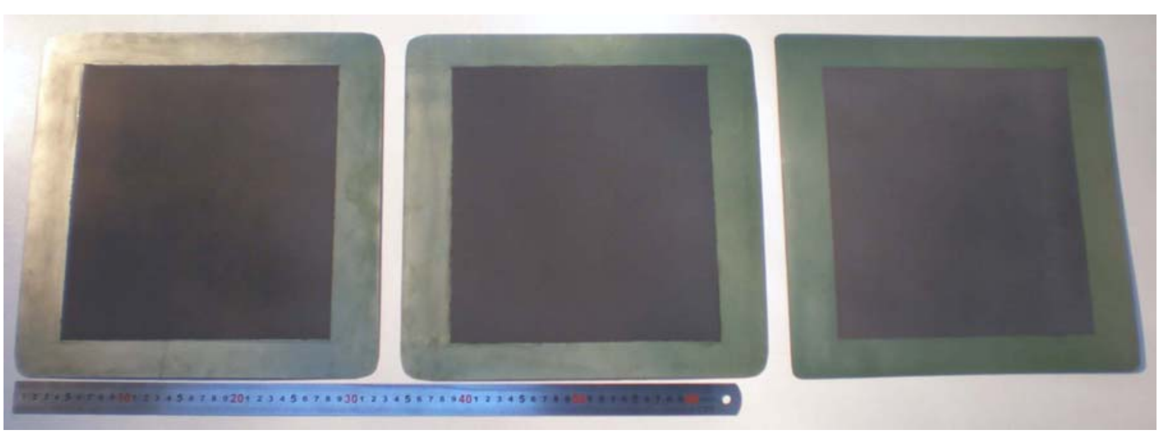

Figure 9. Large cells with 30×30cm$^2$ in area (active area of 25×25cm$^2$ ).

We have made two-cell stack by using 30×30cm$^2$ cells. Figure 10 shows the I-V curves and power density of the stack. The power of more than 40 W can be reached for the individual cells at 750$^o$C. It shows much lower power density in comparison to 13×13cm$^2$ cells. We cut cells of 5×6 cm$^2$ and 4×4 cm$^2$ in active area from large cells and measured their performance. It showed similar performances between the pieces cut from large cells and our normal production cells. We assume that the low performance in our two-cell stack is mainly due to the testing method rather than the intrinsic property of the large cells. The estimation of the resistance indicates that the internal resistance of the large cell is too small in comparison to the external resistance from current leads and current collection. We expect that similar performance of the large cells to normal size cells can be reached when a large stack is built with more single cells in series. Figure 11 shows the degradation behavior of the two-cell stack. There is no degradation under 10 A and 30 A in running current.

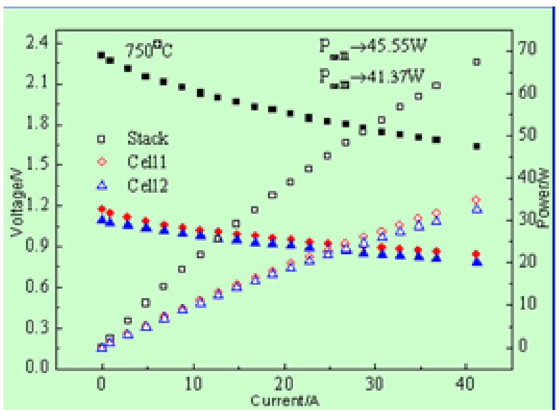


Figure 10. I-V curves and powers of the two-cell stack with large cells.

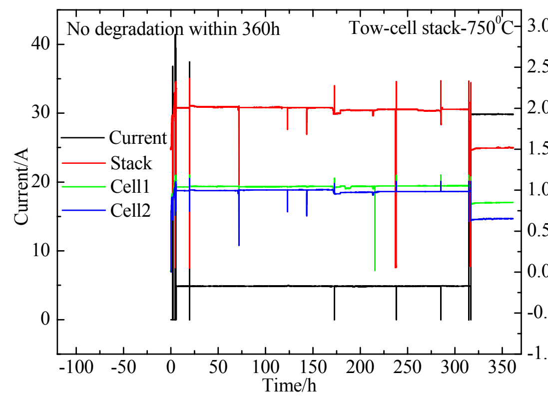


Figure 11. Degradation behaviors of 2-cell stack with large cells.

## System Development

Our system integration work is divided into two groups, i.e. Fuel Treatment and Thermal Management Group and System Integration and Control Group. Currently, the Fuel Treatment and Thermal Management Group focuses on the design of methane catalytic steam-reforming reactor, developing methane steam-reforming catalysts for providing the SOFC stack with desulfurized synthetic gas. Another project is to investigate the formation mechanism of coke from fuels heated at high temperatures. The group is also working on developing catalysts for propane reforming process, building the model of heat transfer, reaction kinetics. In the near future, methane carbon dioxide reforming catalysts will be the research focus so that the SOFC stack can use synthetic gas obtained from the reaction between methane and carbon dioxide. The System Integration and Control Group mainly focuses on the following work: 1) Mechanical design of SOFC co-generation system and system integration; 2) Development of real-time software and hardware environment for rapid control prototyping and hardware-in-the-loop (HIL) simulation for SOFC system; and 3) Planning of demonstration and experimental study of SOFC system for the future commercialization of SOFC systems.

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