STATUS OF SOFC DEVELOPMENT IN JAPAN

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ABSTRACT

In Japan various R&D activities on SOFC have been conducted. MITI-AIST/NEDO is promoting R&D on fuel cell technology by New Sunshine Project. MITI-ANRE/PEC is also supporting research activity on fuel cells at oil companies. Many cooperating programs are now in progress between utility companies and future SOFC manufacturers. And basic researches on component materials and mechanism on the electrodes, etc. has been performed at a lot of universities, national and private laboratories and companies.

INTRODUCTION

Fuel cells are expected to be commercialized early because of their high power generation efficiency with low pollutant emission. Among them, Solid Oxide Fuel Cell (SOFC) is considered to have several distinguishing features as follows;

(1) high power generation efficiency of more than 50% by itself and 65% by combined system
(2) high temperature exhaust recovery heat
(3) utilization of various fuels such as natural gas, petroleum, methanol and coal gas, etc.
(4) capability of compact system design due to high power density and internal reforming, etc.

In Japan, a lot of sectors have carried out research and development on SOFC(1-3). This paper describes the general introduction of national project and R&D activities by companies, universities and laboratories.
NEW SUNSHINE PROJECT

Japanese national SOFC program has been carried out in the following projects by Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI).

1) Sunshine Project (1974-1993)
2) Moon Light Project (1979-1993)
3) New Sunshine Project (1993-)

In the New Sunshine Project, national laboratories of AIST have been conducting basic research. In parallel with R&D by the national laboratories, New Energy and Industrial Technology Development Organization (NEDO) has carried out the SOFC R&D project since 1989.

1. National laboratories

Under the Sunshine Project, basic research on SOFC was started out by Electrotechnical Laboratory (ETL) in 1974. ETL focused their effort on the supported series-connect multi-cell configuration tubular SOFC using the plasma spray as the production process. They are now developing metallic substrate type tubular SOFC.

National Institute of Material and Chemical Research (NIMC) started R&D of planar type SOFC in 1986. They have conducted fundamental studies on cell component materials including new ones for lower temperature operation.

National Institute for Resources and Environment (NIRE) has performed research on the heat recovery system for SOFC and studied the evaluation method for high temperature heatpipes, heatpipe type heat exchangers and liquid layer type heat exchangers.

2. NEDO

NEDO has conducted a three-year R&D project since 1989 to develop basic SOFC fabrication technology under Moon Light Project. During this period, several SOFC stacks in hundred of W were built and successfully tested. Based upon the results, NEDO launched a six-year program in 1992 aiming at the development of stacks in tens of kW which can be utilized as a basic units for a large-scale power generating plant. However, there are a lot of problems to be solved in developing planar type SOFCs. In 1995 the program was extended for two years by 1999.

This year the intermediate evaluation will be conducted on each of the three elemental technology research items listed below.

I) Research and development of modules

Study on basic module structure has been studied for extension of cell area
and lamination.

[Intermediate target]
To develop several kW modules using steam-reformed natural gas
Target specification
- current density 0.18W/cm²
- fuel utilization ratio 70%

[Final target]
To develop several 10kW modules using steam-reformed natural gas
Target specification
- current density 0.20W/cm²
- fuel utilization ratio 75%
- degradation ratio less than 1%/1000h

Fuji Electric Corporate R & D Ltd.
Large-area cell type planar SOFC using metallic substrates and metallic separators has been developed. In 1996 a 5-cell stack with 528cm² cell was operated. The maximum output was 505W at 0.35A/cm².

Sanyo Electric Co.
A 2kW class combined cell stacked type module (182cm² X 4 X 17) has been developed. An output power of 2.47kW and output power density of 0.20W/cm² were obtained at current density of 0.3A/cm².

II) Research and development of material and fundamental technologies
Study on electrode structures, cell materials and manufacturing methods has been conducted.

Japan Fine Ceramics Center (JFCC)
R&D on microstructure of the electrode has been carried out. Synthesis of powders for high performance and deterioration of the electrodes has been developed.

Fujikura Ltd.
Electrode structure by spray coating, etc. has been studied in order to develop a cell with high performance and long life.

Mitsubishi Heavy Industries Co. (MHI)
R&D on multi-function fuel electrodes for internal reforming has been conducted.

Murata Manufacturing Co.
The fabrication process with cofiring technology has been developed. Using 5

Electrochemical Proceedings Volume 97-18
X 4 multiple cell stack fabricated by cofiring method, the maximum power output of 601W was achieved.

**Mitsui Engineering & Shipbuilding Co.**
R&D on current collecting technology has been conducted. Structure and manufacturing technology of gas separator have been developed.

**III) Research and development of power generation system**
Study on the SOFC power generation system and BOP has been conducted.

**Central Research Institute of Electric Power Industry (CRIEPI)**
Conceptual design of SOFC power generation system has been developed.

**Electric Power Development Co. (EPDC) and MHI**
Study on design of cell surrounding system and operating condition of SOFC generation system has been performed.

**Japan Research and Development Center for Materials (JRCM)**
Development of 1000 °C class elemental technologies for peripheral equipments, such as heat exchanger, high temperature valve and high temperature blower for SOFC power generation system has been conducted.

**PETROLEUM ENERGY CENTER**

Petroleum Energy Center (PEC) has conducted SOFC R&D program subsidized by Agency of Natural Resource and Energy (ANRE).

A planar SOFC has been researched in order to decrease the deterioration rate and improve the electrical performance. The following results were obtained by Tonen Corp.; (1) The improved sintering technology made the interface between electrolyte and anode stable and a 5cm X 5cm cell test recorded the rate of 1.4%/1000h. (2) Screening tool of mechanical strength was applied to 20cm X 20cm zirconia electrolyte and screened electrolyte shows a sharp parameter of 15 under the weibul statistics. (3) Gas flow rate distribution in cells stack was simulated and the variation of 10% was found in electrolyte plane. (4) A 3 cell stack with 20cm square cells was able to be operated with 85% of fuel utilization and over 45% of electric efficiency using improved glass sealant.
R&D ACTIVITIES ON SOLID OXIDE FUEL CELLS

In Japan, there are many companies in different industries which are interested in R&D on SOFC. Some of their activities are introduced as follows.

**EPDC and MHI-Nagasaki**
MHI has been developing tubular type SOFC since 1984. 10kW module has been successfully developed in 1995. It has been operated for 5,000 hours continuously at EPDC. This module does not need heating support to maintain the operation temperature, and the module efficiency was 34% (HHV). In 1996 pressurized 1kW module has been tested at MHI Nagasaki Works.

**Chubu Electric Power Co. (CEPCO) and MHI-Kobe**
They have jointly developed and evaluated a planar-type SOFC of mono block layer built, so-called MOLB since 1990. In 1996, 5kW class stack by 2 stacks of 200 X 200 mm 40-cells has been tested at CEPCO. They have also carried out the research for raising the performance of the electrolyte and electrodes, etc. with/in their Takasago Laboratory.

**Kyushu Electric Power Co. and TOTO Ltd.**
They have been developing tubular type SOFC with an air electrode support by a wet processing technique. To enhance the power output of the module, the Integrated Tubular-Type (ITT) cell has been developed. In 1996 1kW class bundle with 9 series-connected ITT cells (the active area of each ITT cell was 840cm²) was tested.

**Kansai Electric Power Co. (KEPCO), CEPCO, NGK Insulator, Ltd.**
A new SOFC design has been developed for high power density generation. The single cell has a long monolithic planar structure. The monolithic self-sealed structure enables easy gas-sealing and easy cell stacking. A power density of 0.48 W/cm² has been obtained in a small single cell test with wet hydrogen and oxygen at 1000°C.

**KEPCO**
After the completion of 25kW SOFC generation system verification test, KEPCO has been evaluating new type tubular SOFC cells which are called AES-cell (Air Electrode Supported cell) as manufactured by Westinghouse Electric Corp. (WELCO). The first test article (Article-#1) which contained four 50cm active length AES cells was tested for about 3,700 hours without cell voltage degradation. Article-#2 with the same specifications as the Article-#1 has been
operated for 8,414 hours and has experienced 83 thermal cycles and cell degradation seems to be very small.

Tokyo Gas Co. and Osaka Gas Co.
They have been conducting a joint development program of a 25kW class SOFC system called as JGU system with WELCO to verify a co-generation system. The JGU's second system (JGU-2) which was modified from JGU-1 by replacing one module consisting of new designed AES cells has been successfully operated more than 11,000 hours with 8 thermal cycles as of December 1996. Its degradation ratio is less than 0.1%/1000h.

Tokyo Gas Co.
Planar-type SOFC has been developed with the aims of expanding the uses and highly-efficient utilization of natural gas. And basic researches on component materials and stack manufacturing technology have been carried out. With single cells, they have increased a power density up to 0.93W/cm² by the unique process for manufacturing the electrode. To develop a kW class stack which can be directly fueled by natural gas in near future.

Osaka Gas Co.
Tubular-type SOFC with the same design concept as Westinghouse Electric Corp. has been developed. Fundamental studies on component materials and fabrication technologies such as EVD method and laser ablation, etc. have been carried out.

Osaka Gas Co. and Murata Manufacturing Co
They have been developing a planar type SOFC (OG type SOFC) which has a suitable for stacking. 5 single cell are mounted on the cell holder, connected with Ni felts electrically. Their 10-cell stack appeared its good thermal cycle performance, and there is little decrease of the power density after thermal cycles.

Toho Gas Co.
A planar type SOFC with scandia-stabilized zirconia electrolyte has been developed. The maximum power density of 1.25W/cm² was obtained in a 8cm X 8cm cell (active electrode area is 25cm²) test.

Saibu Gas Co. and Totsu Co.
Tubular SOFC has been developed using wet process, such as slip casting and slurry coating methods.
BASIC RESEARCH

Basic research on SOFC-related subjects in the field of solid state ionics and ceramics have been carried out in a lot of universities, national and private research organizations.

Muroran Institute of Technology
- Reaction mechanism on noble metal/YSZ electrodes

Akita University
- Kinetics and mechanism in the reactions between component materials

Tohoku University
- Reaction kinetics and mechanism on electrodes, characterization of component materials

Gunma University
- Study on electrode reaction mechanism, fuel electrode performance of internal reforming, fabrication technique of a thin electrolyte thin film

University of Tokyo
- R&D of electrode materials, fuel electrode for internal reforming
- Establishment of plasma-spraying technology for fabricating a single cell

Tokyo Institute of Technology
- Design of high electrically-conducting and thermal resisting alloys for separator use, stress analysis of planer stack
- R&D of alloy interconnectors, thermodynamics and electrochemical property of component materials

Yokohama National University
- Reaction kinetics and mechanism on electrodes, thermodynamics and physicochemical properties of component materials

Yamanashi University
- Development of high performance electrodes for SOFC operating at medium temperatures

Nagoya University
- Protonic conducting electrolytes and its application to SOFC

Mie University
- R&D of component materials for low temperature operation, fundamental studies on materials

Kyoto University
- Vapor phase electrolytic deposition of component materials, simulation of cell properties

Kyushu University
- Ceria-based electrolyte and its application to SOFC, and reaction kinetics and
mechanism on electrodes
Oita University
- Fabrication of perovskite-type oxides materials for low temperature SOFC

ETL
- R&D of metallic substrate type tubular SOFC, estimation and measurement of stress in SOFC, study on electrode phenomena using spattered electrode

NIMC
- R&D of wet cofire process, investigation on component materials for temperatures lower than 1273K, fundamental studies on materials

Government Industrial Research Institute, Osaka
- R&D of ceria-based electrolytes, electrode materials, perovskite type electrolytes

CRIEPI
- R&D of component materials, gas seal materials, connecting technology of cell components

FUTURE PROSPECT

R&D on SOFC in Japan is approaching an important stage. In 1997, AIST/NEDO will conduct the intermediate evaluation in New Sunshine project. Next R&D schedule on SOFC will be decided after the evaluation.

There are a lot of things to do in SOFC development including fundamental studies. It is important to cooperate between academic sectors and manufacturers, and to pursue international cooperation.

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