Introduction
NGK Spark Plug Co., LTD. has developed SOFC systems for micro CHP application as a commercial entry of our planar SOFC stacks. (1) Our R&D focus is how to achieve the highest power efficiency exceeding 60% LHV, using natural gas fuel. Based on our simulation studies, we knew there are three major technical hurdles which we must clear. The first is the compactness of the stack, so we firstly worked on improving power density to exceed 0.8W/cm$^2$ (700C at 0.7V) at the size of 100cm$^2$, which enables 1kW output only with 15 cells (Conventional planar type stack needs to have about 30-40 cells to get 1kW power), which was presented in the last FC seminar in Texas. (2) The second hurdle is the high fuel utilization, like 80 to 90 %, which requires perfect fuel distribution to all cells and all active triple points of anode. The last hurdle is how we can minimize heat loss from the thermally insulated vessel, where power stack and several heat exchangers inside, to maintain thermally self-sustained operation even at maximum high fuel utilization. In this seminar, we would present our recent progresses and findings for these challenges.

Design and Fabrication
1. Ceramic Cell
We have developed the anode-supported cell design for 700C low temperature operation. Reflecting detailed cell impedance studies, we accepted conventional thin YSZ electrolyte with our standard tape casting process. Major efforts have been paid to optimization of pore distribution and size of Ni+YSZ anode and LSCF cathode, which really key elements in terms of efficient gas diffusion to triple points of both electrodes.

2. 1kW-class Integrated 16 Cells Stack and the Thermally Insulated Vessel
Our latest 1kW class stack is consisted of 16 cells with a 100cm$^2$ active area per cell. If just considering DC power output, even 13 cells will be possible solution for 1kW. However, conversion loss from DC to AC can not be ignored at low DC output voltage, so we made a compromise at a 16 cells/stack, which has only 80mm thickness (Figure 1). At the low end of stack, there are integrated combustion layer and steam reforming layer to get heat balance from top to end.
3. 1kW-class SOFC CHP system
We successfully packed the thermally insulated vessel, ECU, power conditioner, heat exchanger and BOPs in a compact system unit which size is 530mm width, 330mm depth and 950mm height. We believe that is the one of the most compact 1kW CHP unit in the world (Figure 2).

Results and Discussion
1. Output dependency on hydrogen fuel and air utilization of 16 cells and a 1kW stack
For the maximum power efficiency, firstly we must eliminate out leak and cross leak of fuel. However, it had been very difficult for us to secure gas tight structure under heat cycles. We tasted various methods, such as seal materials, fastening bolts and torque, and preheat treatment of the stack. Based on all the design optimization from those findings, we have got an acceptable solution. Also, we carefully designed gas flow channels, chambers and current collectors for effective gas distribution to active electrodes. Then, by harmonizing all the design elements, we got flat and stable output curves over 90% utilization for fuel and air (Figure 3).
2. Power Efficiency by CH4 fuel in Electric Furnace
As a result of very stable outputs at high fuel utilization, we have got over 60% power efficiency as a 1kW stack (Figure 4).

Figure 4. 16 cells stack voltage with using CH4 fuel at 700C (Current density: 0.75A/cm²)

3. Power Efficiency as a complete SOFC CHP system
As a system, additional considerations are necessary to have 60% efficiency.
Minimum heat loss from the thermally insulated vessel, precise control of A/F ratio and S/C ratio, minimum power consumption from BOPs and minimum conversion loss from power conditioner, are the major four design elements for this subject.
The latest system configuration and obtained data will be presented at the conference.
References
