

Low-Cost FC Stack Concept with Increased Power Density and Simplified Configuration Utilizing an Advanced MEA

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ABSTRACT

In 2006, Nissan began limited leasing of the X-TRAIL FCV equipped with their in-house developed Fuel Cell (FC) stack. Since then, the FC stack has been improved in cost, size, durability and cold start-up capability with the aim of promoting full-scale commercialization of FCVs. However, reduction of cost and size has remained a significant challenge because limited mass transport through the membrane electrode assembly (MEA) has made it difficult to increase the rated current density of the FC. Furthermore, it has been difficult to reduce the variety of FC stack components due to the complex stack configuration.

In this study, improvements have been achieved mainly by adopting an advanced MEA to overcome these difficulties. First, the adoption of a new MEA and separators has improved mass transport through the MEA for increased rated current density. Second, an integrated molded frame (IMF) has been adopted as the MEA support. One advantage of the IMF is its simplified structure and production process, reducing the MEA cost. Another advantage of the IMF is that it allows the FC stack enclosure to be eliminated because the layered IMFs form insulating side walls around the FC stack. Third, the FC stack configuration has been simplified by eliminating components or using alternative ones and adopting a “single-row” stack structure.

As a result, the power density of the new FC stack has been increased to 2.5 kW/L, which is 30% higher than that of the previous 2008 model FC stack. It is estimated that the mass production cost of the new FC stack can be halved to nearly meet the target of the DOE Hydrogen Program. With further improvements such as higher current density and lower

catalyst loading, FCVs will be compact and affordable enough for ordinary consumers at the full-scale commercial stage.

INTRODUCTION

Nissan has been intensively developing zero-emission vehicles, including battery-powered electric vehicles (BEVs) such as the “Nissan Leaf” released in December 2010 and fuel cell vehicles (FCVs), under the Nissan Green Program 2010. The propulsion strategy at Nissan is to be the leader in zero-emission vehicles. These innovative vehicles will emit no exhaust gas and have no environmental impact, if the electricity or hydrogen that powers them is produced from natural energy sources. In other words, there are strong expectations for electricity and hydrogen as attractive secondary energy sources for the global environment. Since BEVs and FCVs have different characteristics in terms of vehicle size and cruising range, customers will be able to choose the optimal zero-emission vehicle that fits their needs.

Although FCV technologies are still at the research stage, the development of FCVs at Nissan has proceeded to the level of limited customer leasing. Limited leasing and intensive field tests of FCVs were started using the X-Trail FCV equipped with an in-house FC stack (2005 model FC stack).¹ By analyzing the data obtained in real-world tests, the major causes and mechanisms of performance decay were determined and that information was used to accelerate the development of FC operating modes and MEA materials.^{2, 3} The FC stack was improved further (2008 model FC stack) by doubling its power density and halving the amount of precious-metal catalysts used,⁴ thus giving the X-Trail FCV subzero startability at -20°C (Fig. 1).^{5, 6}



Figure 1. 2008 Model X-Trail FCV with Subzero Startability.

With the aim of putting FCVs on the market on a commercial basis, further FC stack improvements are under way to reduce the cost and size and improve durability and subzero start-up capability. Cost and size reductions are especially difficult to achieve because of the limited current density and complicated structure of the FC stack components, including the MEA. Therefore, this study examined the feasibility of the following development concepts, assuming the FCV commercialization stage:

1. Increase in current density for smaller reaction area and lower catalyst loading
2. MEA with an integrated molded frame for a simpler production process and functional shapes
3. Simplification of the FC stack structure using a minimal number of components

This paper presents an overview of the newly developed MEA and FC stack and describes the prospect for reducing the FC stack cost, assuming mass production.

INCREASE IN CURRENT DENSITY

At higher current densities, one of the major factors limiting the current density is limited mass transport through the MEA for water, reactant gases, heat, and electrons.^{7, 8, 9, 10, 11, 12} In this study, mass transport was improved by adopting a newly developed MEA and separators.

In order to increase water transport through the new MEA, a thinner polymer electrolyte membrane (PEM) than that of the 2008 model FC stack was adopted. The new MEA increases water flux from the cathode to the anode as shown in Fig. 2 (a), thus preventing flooding at the cathode and drying out at the anode. As a result, I-V performance is increased as shown in Fig. 2 (b). Even though the PEM is thinner, it is stabilized chemically and mechanically to ensure MEA durability. Fuel

cell efficiency is also maintained because the total quantity of gas crossover is kept almost equal by the downsized reaction area made possible by increased current density.

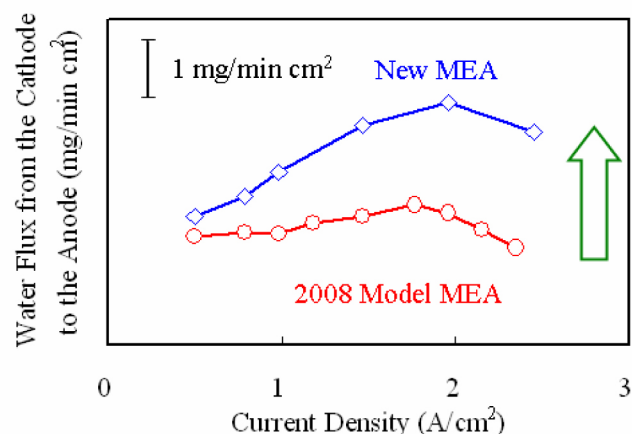


Figure 2 (a). Increased Water Flux through the New MEA.

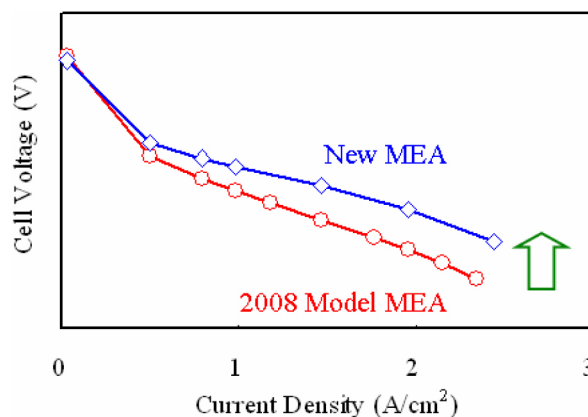


Figure 2 (b). Improved I-V Performance Using the New MEA.

New separators with narrower channels and ribs than those of the 2008 model FC stack have been developed to improve mass transport through the MEA in the plane direction. A narrower channel shortens the conduction distance of heat and electron under the channels, while a narrower rib shortens the diffusion distance of water and oxygen under the ribs. The effects obtained were predicted with a numerical model¹³ and the results are shown in Fig. 3 (a) and (b). The narrower channels and ribs improve the distribution of liquid water and oxygen concentration in the MEA in the plane direction, thereby reducing energy loss during electrochemical reactions. The I-V performance of the fuel cell with the new separators has been improved in the higher current density region as shown in Fig. 4.

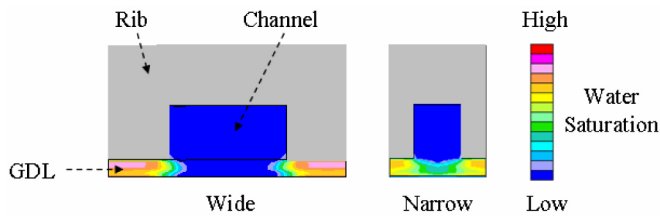


Figure 3 (a). Effect of Channel/Rib Width on Water Saturation in the Cathode.

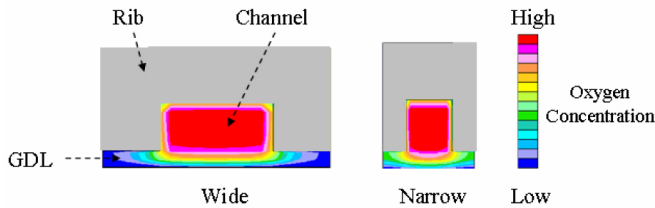


Figure 3 (b). Effect of Channel/Rib Width on Oxygen Concentration in the Cathode.

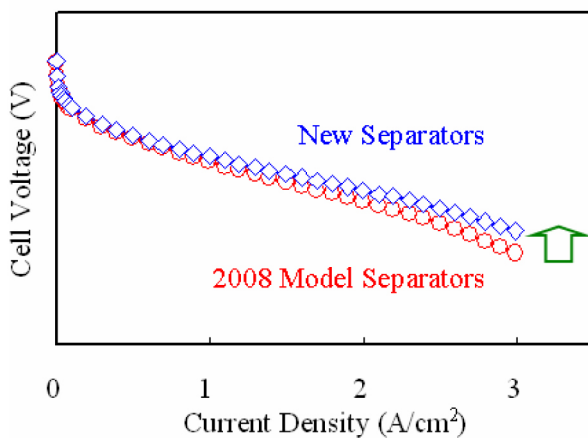


Figure 4. Improved I-V Performance Using the New Separators.

The FC stack equipped with the new MEA and the new separators provides 25% more rated current density than the 2008 model FC stack as shown [Fig. 5](#). The improved current density contributes to downsizing the reaction area, reducing the FC stack size as well as the amount of electrode catalyst loading. The amount of platinum catalyst used for the new FC stack has been halved compared with the previous stack as shown in [Fig. 6](#).

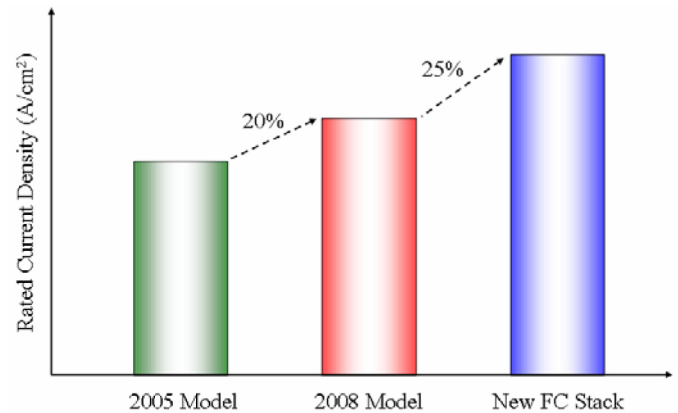


Figure 5. Improvement of the Rated Current Density of FC Stacks.

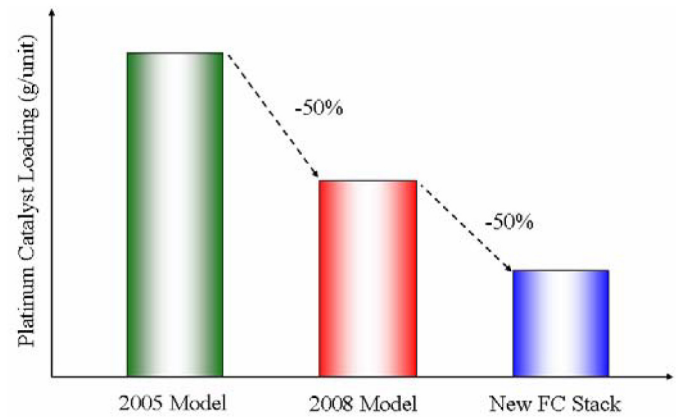


Figure 6. Reduction of Platinum Catalyst Loading in FC Stacks.

MEA WITH INTEGRATED MOLDED FRAME

Ordinary MEAs, including that of the 2008 model FC stack, are supported by a frame composed of laminated plastic sheets on both sides of the MEA rim as shown in [Fig. 7 \(a\)](#). In this study, an integrated molded frame (IMF), as shown in [Fig. 7 \(b\)](#), has been adopted not only to simplify the MEA structure and production process for cost savings, but also to form functional shapes for use in simplifying the FC stack structure.