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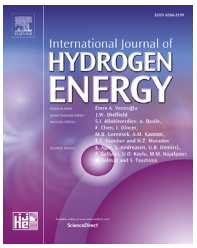

Soldering a gas diffusion layer to a stainless steel bipolar plate using metallic tin

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ABSTRACT

A novel investigation to decrease the interfacial contact resistance of stainless steel bipolar plates was performed. A thin layer of Sn was electrodeposited onto a bipolar plate and subsequently joined with a gas diffusion layer through hot-pressing at a temperature around the melting point of tin. This procedure was optimised, depositing 30 μm of Sn onto the stainless steel bipolar plate before hot-pressing at 230 °C and 0.5 bar for 20 min. A contact resistance of 5.45 mΩ cm^2 at 140 N cm^{-2} was obtained, with low values maintained after exposure to both in-situ and ex-situ conditions. The in-situ testing in a fuel cell produced excellent results, with minor increases in contact resistance from 8.8 to 9.2 mΩ cm^2 and decreases in cell voltage from 0.714 to 0.667 V after 200 h of operation. These values are comparable to gold plated stainless steel, showing that combining a gas diffusion layer with electrodeposited Sn through hot-pressing is a promising low-cost coating for bipolar plates in PEM fuel cells.

Introduction

In recent years, a greater demand for substitutes to fossil fuels has prompted the development of Proton Exchange Membrane (PEM) Fuel Cells. PEMFCs represent highly efficient energy conversion devices that are a viable alternative to combustion engines in the automobile industry [1]. Large car manufacturing companies, such as Toyota, Honda and Hyundai have set up long term plans to develop and introduce fuel cell technology for this industry [2–4]. However, a number of challenges have to be overcome before such electrochemical energy conversion devices are economically and practically feasible for mass implementation, including intrinsic limitations concerning durability, longevity and costs.

Numerous studies have looked into development of improved catalysts [5–7], ion conducting membranes [8–10] and catalytic layers [11–13] for optimised performance. Over the last few decades, more attention has been devoted to the bipolar plate (BPP) which is estimated to contribute 11–45% of the overall fuel cell cost and 45–80% of the stack weight [14–17]. BPPs must allow even distribution and separation of the anode and cathode feeds, facilitate removal of the waste products, manage heat produced during operation, and

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provide mechanical support for the stack as well as the membrane electrode assembly (MEA) [17,18]. Due to their numerous tasks within the cell, the BPP must meet a strict series of criteria. The plates must be lightweight yet mechanically supportive to minimise overall weight, have high electrical conductivity and low interfacial contact resistance to both anode and cathode to minimise ohmic losses [19]. They must also be thermally conductive to remove excess heat, have high corrosion resistance to be long lasting and avoid contamination of catalyst and electrolyte as well as being impermeable to the reactant gases to minimise fuel crossover [20].

Consequently, a vast number of different BPP materials have been investigated [21–24]. Due to the inherent limitations of graphite [25] and other carbon based BPPs [17], metal plates are now considered the most promising candidates, with stainless steel found to be more suitable than titanium [26], nickel [27] or aluminium [28] alloy plates. Stainless steels have a significantly lower manufacturing cost and a higher strength than graphite [29], as well as a high electrical conductivity and low gas permeability. The main drawback of a metallic BPP is its struggle to maintain both low contact resistance and high corrosion resistance inside the fuel cell environment. When undergoing corrosion processes, the stainless steel releases metal ions that could lead to poisoning of the membrane and catalyst [17]. Another issue is the non-conductive oxide layer (e.g. chromium oxide, Cr_2O_3) that forms on the surface of the stainless steel upon contact with air and water, increasing contact resistance [30]. In order to limit the formation of such oxides and ions, a series of protective coatings have been developed for the stainless steel BPPs. A large amount of research has been done into different coating materials, including carbon based coatings [31–33], metal nitrides [34–36], carbides [37–39] and noble metals [40,41], many of which have improved the corrosion resistance and the Interfacial Contact Resistance (ICR) of the BPP to the standards set by the US Department of Energy [42]. However, the coating methods for many of these BPPs, such as physical vapour deposition (PVD) or plasma nitriding, are costly, so a cheaper alternative must be found if stainless steel bipolar plates are to become commercially viable.

Tin is widely used as a solder in the electronics industry due to its high electrical conductivity, good wettability, low cost and reliability [43,44]. It is also easy to produce a well-defined layer of Sn by electrodeposition onto a metallic substrate, a technique that is popular due to its low cost, simplicity and good controllability of coating morphology and thickness [45,46]. As similar criteria need to be met for fuel cell applications, electrodeposition can be considered a good candidate for further research.

Tin has also been proven to improve the corrosion properties of stainless steels through the formation of a dense SnO_2 passive layer, which inhibits further corrosion [47–49]. Despite this, Sn has been thought unsuitable for PEM applications due to the potential poisoning of the membrane and catalyst by Sn ions. This has proven not to be the case by Iwai et al., who reported no decomposition of nafion membranes when exposed to Sn [50], in fact, the proton conductivity and Young's modulus of nafion membranes is improved upon small additions of Sn [51]. It has been reported that SnO_2 modified membranes have improved durability, reduced release of F^- ions and retained a higher Pt loading through the cell lifetime [52,53]. Sn based catalysts have also been used extensively for methanol oxidation with promoting effects [54–56], indicating that Sn has no negative impact on the catalyst or membrane during operation.

In this work we cover stainless steel bipolar plates with a thin and uniform layer of electroplated Sn in order to exploit the high electrical conductivity as well as the high corrosion resistance offered by metallic Sn and Sn oxide, respectively. The novel idea in this work is to join (solder) the tin-plated stainless steel bipolar plate with a pre-cut gas diffusion layer (GDL) through hot pressing at a temperature around the melting point of tin. This process softens the Sn coating, and the addition of mechanical pressure forces it into the pores of the GDL where it cools and solidifies, soldering the materials together as demonstrated in Fig. 1. This should produce improved through-plane electrical and thermal conductivity, yielding extremely low contact resistances.

The BPP will be exposed to operating PEM conditions, including a slightly acidic environment and voltages up to 1.4 V_{SHE}, that may occur during start up and shut down [57]. During exposure, the outer layer of the deposited Sn will oxidise to form a passive SnO_2 layer [58], as indicated by the Pourbaix diagram [59]. This layer remains conductive and protects the underlying Sn and stainless steel substrate from further oxidation, whilst maintaining a good conductivity and low contact resistance.

The preparation procedure and quality of the joined BPP/GDL material are studied with respect to conductivity and durability through a series of measurements, including interfacial contact resistance (ICR), ex-situ chronoamperometry and electron microscope imaging with elemental analysis. Finally, long-term in-situ testing in a simulated fuel cell environment is performed. The produced plates show good adhesion and low contact resistance, even after being exposed to a simulated fuel cell environment. Thus, the method described in this work brings a move towards simple, yet reliable, coating methods for BPPs in PEM systems.

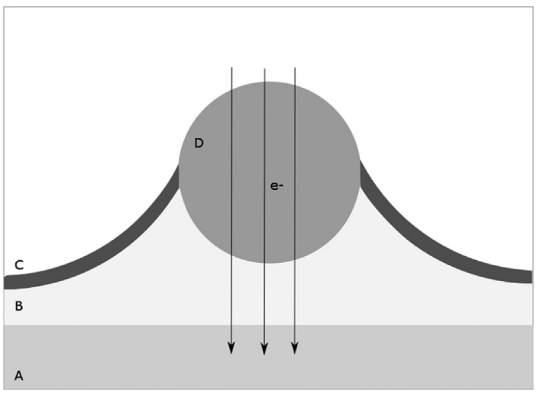

Fig. 1 – The combined Sn/GDL concept. A is the steel bipolar plate, B the deposited Sn, C the SnO_2 layer and D the carbon fibre from the GDL. Electrons can move through the system without obstruction whilst the SnO_2 prevents further oxidation of Sn.

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