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PEM Fuel Cell Separator with Thermally Nitrided Low Carbon Steel

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Abstract. The separator is one of the most important parts in PEM fuel cells. Stainless steels are widely used as separator for its good mechanical properties and mass production. However, for a good chemical compatibility, stainless steels need to have high chromium content or surface treatment, which makes separator high cost. Low cost of separator is important for commercial use. In this study, conventional low carbon steel is used as base metal of separator. Low carbon steel is low at cost, but has poor chemical properties for separator. For a good corrosion resistance, low carbon steel needs to be surface treated. To make a uniform surface treated layer on low carbon steel, chromium is conventionally electroplated on the steel and thermally nitrided. Surface treated low carbon steel is investigated using microstructure and element analysis tools. Interfacial contact resistance and polarization test is applied for the properties of fuel cell separator. The results show that chromium nitrided layer uniformly formed on low carbon steel. And the surface treated steel showed a good corrosion resistance as a separator.

Introduction

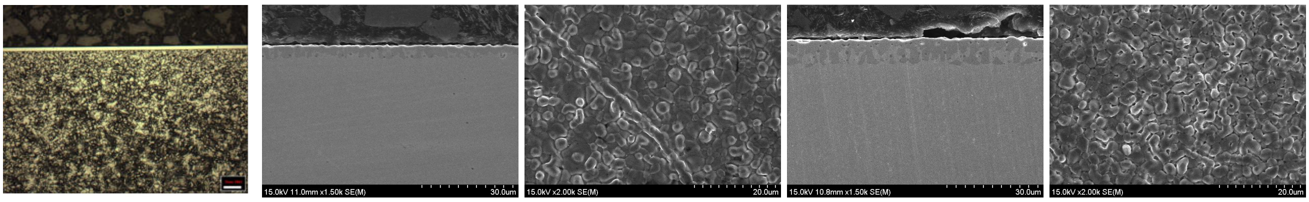
The fuel cell is a device that coverts the chemical energy into electricity [1]. The Polymer Electrolyte Membrane Fuel Cell (PEMFC) uses polymer films as an electrolyte. Its distinguishing features include high-power density and relatively low operating temperature. It can be used in a variety of areas as environmental-friendly energy. Nevertheless, its high cost hinders its commercial application. The separator is one of the most important parts in PEMFC stack and accounts for much of the high cots and weight of the stack. It needs to be reduced the cost and weight of separator in the stack.

Experimental Procedures

Carbon steel (A283-C) sheet with a thickness of 2mm was used as the substrate. Chromium electroplating was performed a thickness of 10㎛ on the substrate and nitriding was applied for 1-2 hour at 1373K in a furnace with 50torr nitrogen gas pressure. The planar and cross-sectional microstructures of the chromium electroplated and thermally nitrided layers on carbon steels were observed by means of optical microscope (OM) and scanning electron microscope (SEM). The crystal structures of the surface treated layers were investigated by means of x-ray diffraction (XRD). Interfacial contact resistance (ICR) and corrosion test was considered to simulate the internal operating conditions of PEMFC stack. The compaction force of ICR test was varied up to $150 Ncm^{-2}$ and measured room temperature by Davies method [2]. The corrosion test was performed 0.1N H_2SO_4 + 2ppm F^- solution at 80℃ and measured at anode potential (-0.1V) and cathode potential (0.6V).

Results and Discussion

The chromium electroplated and thermally nitrided layer was observed in Fig. 1. The chromium electroplated layer was uniformly formed on the substrate (Fig. 1a). Also, the nitride layer was seen on the surface, which has a good and uniform surface layer and can not be observed any defect like cracks (Fig. 1b, e). The trace of a filled crack, the crack being formed during the prior chromium electroplating, can be seen on the surface of nitrided layer (Fig. 1c). The 1hour sample has lower surface roughness and thinner Cr_2N nitride layer than the 2hour sample.



(a) (b) (c) (d) (e)

Fig. 1. Micrographs of the cross-section in chromium electroplated sample (a) and the cross-section and the surface of thermally nitrided carbon steel in 1hour (b, c), and in 2hour (d, e)

The XRD pattern of the chromium nitrided layer for 2hour at 1100℃ in pressure 50torr shows higher Cr_2N diffraction peaks than the chromium nitrided layer for 1hour at 1100℃ in pressure 50torr. Fig. 2 shows that more Cr_2N nitrides were made during longer nitriding holding time.

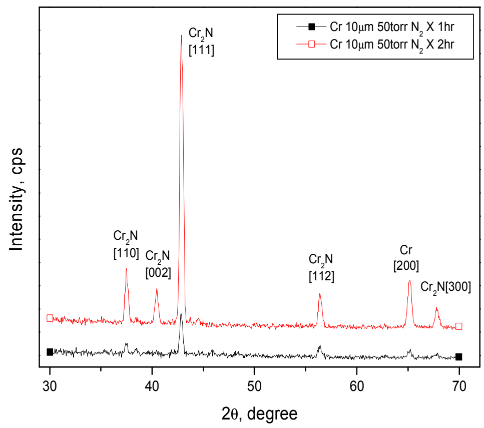


Fig. 2. XRD patterns of chromium nitrided layer.

The ICR is evaluated to the compaction force of $150N\cdot cm^{-2}$. The nitride samples at the nitriding holding time, 1hour and 2hour, are shown in Fig. 3. The ICR value of a nitride coated sample for the 1hour ($15m\Omega\cdot cm^2$ at $150N\cdot cm^{-2}$) is lower than that of a nitride coated sample for the 2hour ($45m\Omega\cdot cm^2$ at $150N\cdot cm^{-2}$). Chromium has lower electric resistivity ($12.7\times10^{-8}\Omega\cdot cm$) than Cr_2N ($79\text{-}89\times10^{-6}\Omega\cdot cm$) [3]. And the surface microstructure of the 2hour sample (Fig. 2e) is coarser than the surface microstructure of the 1hour sample (Fig. 2c). It is thought that the 1hour sample has lower ICR value than the 2hour sample, because the 1hour sample has lower surface roughness and thinner Cr_2N nitride layer which has higher electric resistivity than chromium.

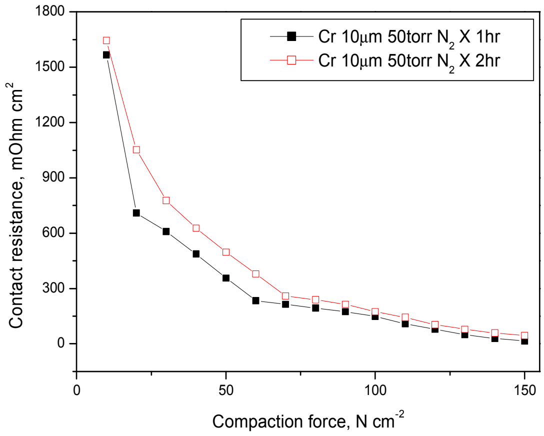


Fig. 3. Interfacial contact resistance of chromium nitrided carbon steels as a function of compaction force.

Chromium nitride coated carbon steel was tested by potentiodynamic polarization in 0.1N H_2SO_4 + 2ppm F^- solution at 80℃. The results of the corrosion tests for the chromium nitride coated carbon steel are shown in Fig. 4. The current density of the 1 hour sample is 1.35×10^{-6}A·cm^{-2} and 6.87×10^{-7}A·cm^{-2} at the anode (-0.1V) and the cathode (0.6V), and the current density of the 2hour sample is 2.82×10^{-6}A·cm^{-2} and 8.31×10^{-7}A·cm^{-2}, respectively. The nitride layer of the 2hour sample is thicker than that of the 1hour sample. Because Cr_2N has high corrosion resistance, it is assumed that the 2hour sample which has thick nitride layer showed high corrosion resistance.

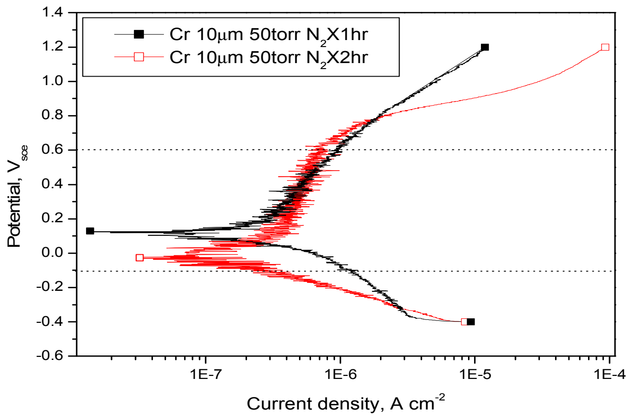


Fig. 4. Potentiodynamic curves of chromium nitrided carbon steels in 0.1N H_2SO_4 + 2ppm F^- at 80℃

Summary

Chromium electroplated carbon steel was nitrided for 1-2hour at 1373K in a furnace with 50torr nitrogen gas pressure. The chromium electroplated layer and the Cr_2N nitride layer was uniformly formed on the substrate. The 1hour nitriding sample has lower ICR and corrosion resistance than the 2hour sample in the simulated internal operating conditions of PEMFC stack. The 1hour sample has lower surface roughness but thinner nitride layer than the 2hour sample.

References

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