Niobium Application in Porous Transport Layer and Bipolar Plate in PEM Fuel Cells and Water Electrolyzers

University of Quebec at Trois Rivieres

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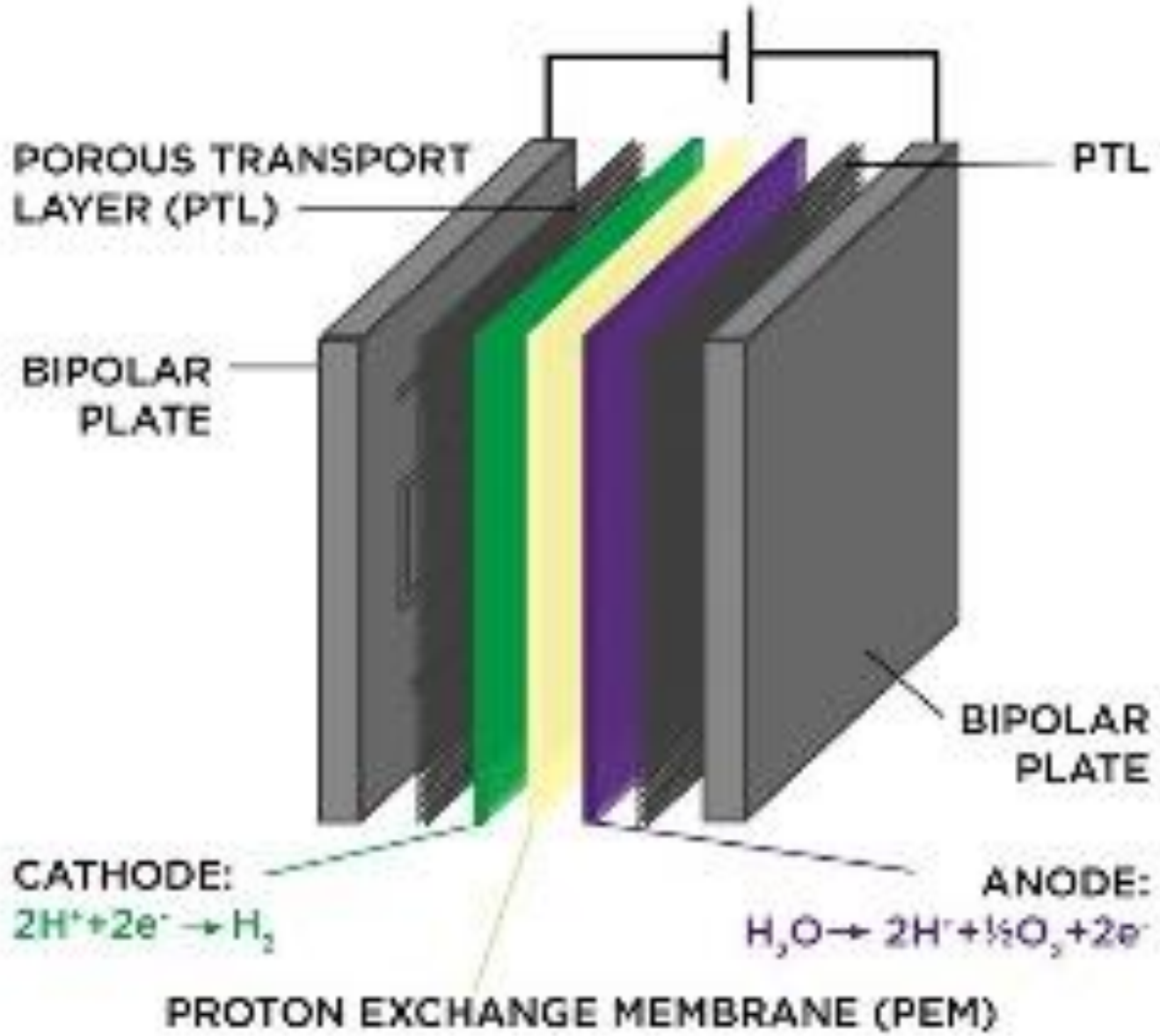
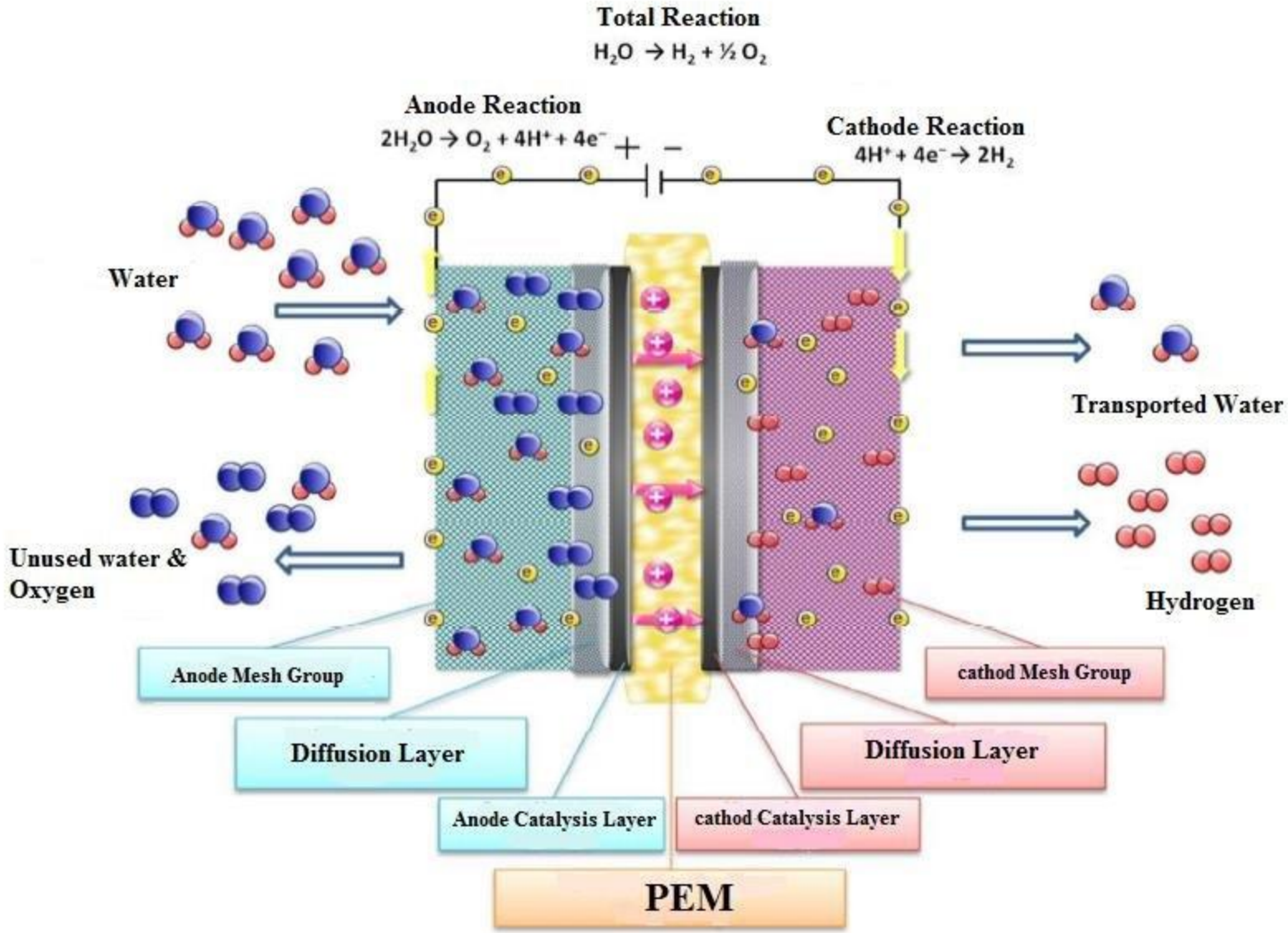
Water Electrolyzers


POROUS TRANSPORT LAYER (PTL)
PTL
BIPOLAR PLATE
BIPOLAR PLATE
CATHODE:
$2H^+ + 2e^- \rightarrow H_2$
ANODE:
$H_2O \rightarrow 2H^+ + \frac{1}{2}O_2 + 2e^-$
PROTON EXCHANGE MEMBRANE (PEM)


Total Reaction
$H_2O \rightarrow H_2 + ½ O_2$
Anode Reaction
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
Cathode Reaction
$4H^+ + 4e^- \rightarrow 2H_2$
+
−
Water
Transported Water
Unused water & Oxygen
Hydrogen
Anode Mesh Group
cathod Mesh Group
Diffusion Layer
Diffusion Layer
Anode Catalysis Layer
cathod Catalysis Layer
PEM

Porous Transport Layer

Titanium

Excellent corrosion resistance property, including low passivation current density, high passive layer stability, etc. Unfortunately, while the passive film prevents matrix from the corrosion of electrolyte, the **ICR** between bipolar plate and gas diffusion layer is significantly **increased** to make an adverse influence on the current conduction.

The surface modification technology is essential to be applied to optimize the comprehensive properties in the operating environment of PEMFC.

Porous transport layers (PTLs):
Controlling the **transport of electrons**, **water** and **gas** molecules

Characteristics

- High and interconnected porosity
- Homogeneous distribution of pores (to enable gas to be expelled and water molecules to reach the catalytic active area)
- Materials with sufficient corrosion resistance (to withstand the high electrochemical over potential, acid environment and presence of oxygen)
- High electrical conductivity
- Suitable mechanical strength (to resist differential pressures up to 50 bar in the case of operating the system in high pressure mode)

Passivated titanium has very high corrosion resistance and high mechanical strength. However, growth of passivation layer significantly **decreases electrical contact** of the PTLs, and therefore the performance

The current strategy is to cover PTLs with different coating materials including precious and non precious metals.

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Powder metallurgical production of 316L stainless steel/niobium composites for Proton Exchange membrane electrolysis cells

N. F. Daudt [a], F. J. Hackemüller [b] and M. Bram [b]

A composite made of a porous **stainless steel (SS) 316L** substrate coated with **Nb** was investigated as a novel porous transport layer (PTL) for proton exchange membrane electrolysis cells (PEMECs).

The SS316L/Nb composites was fabricated using **scalable and automatable powder metallurgical** technique.

Table 7. Sample composition measured by EDS of regions indicated on SEM image of SS316L/Nb composite produced by FAST/SPS (Figure 8).

Point	Nb (wt.%)	Fe (wt.%)	Cr (wt.%)	Ni (wt.%)	Mo (wt.%)	Mn (wt.%)
A1	97.7	0.10	0.08	0.03	1.95	0.16
A2	97.5	0.03	0.01	0.06	2.38	0.00
A3	0.34	69.4	16.2	10.4	2.53	1.11
A4	0.22	70.9	17.2	8.53	2.18	0.98
B1	96.1	1.76	0.43	0.00	1.76	0.00
B2	71.0	17.9	4.21	2.25	4.63	0.00
B3	2.81	67.0	15.8	9.98	2.78	1.62

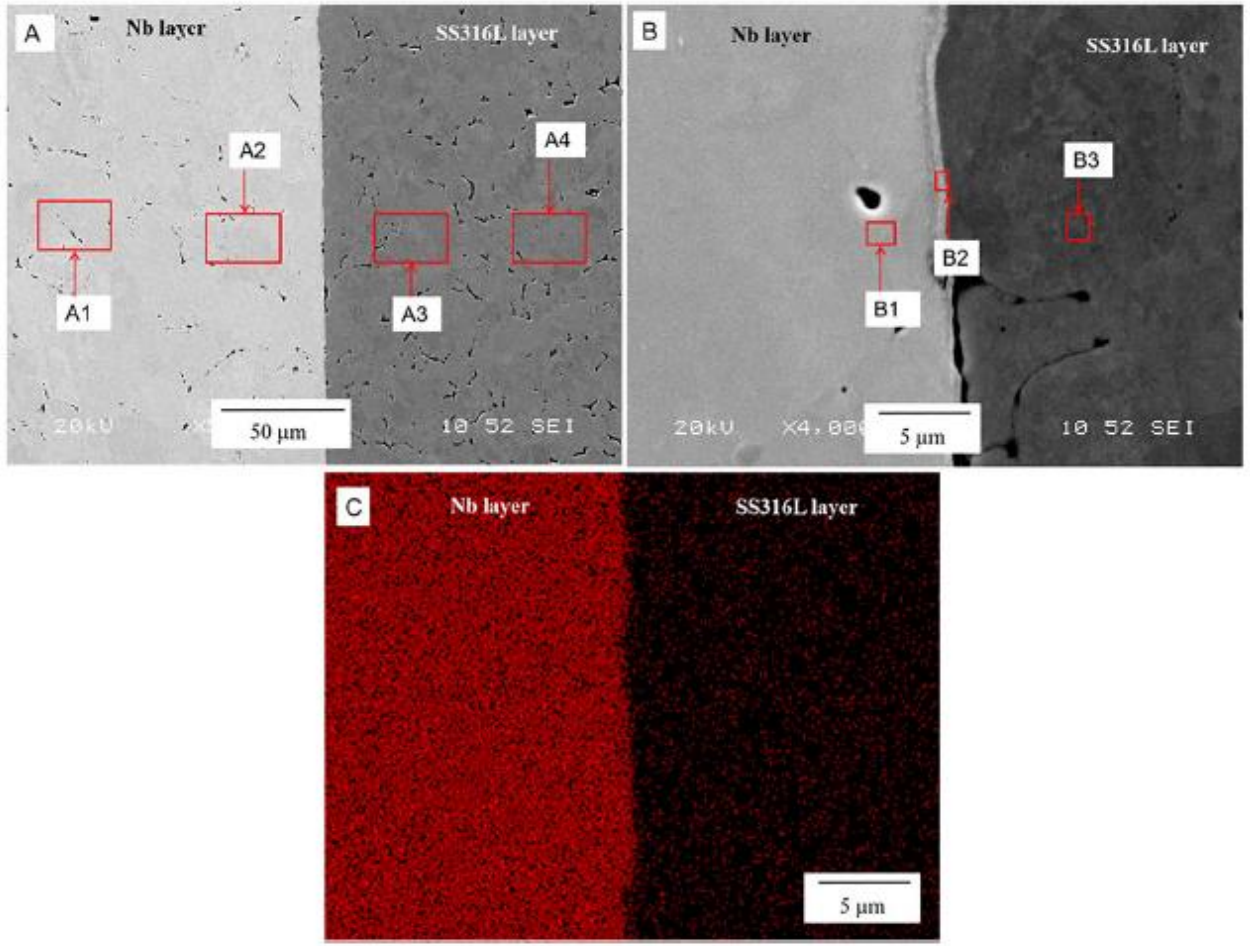

Figure 8. (a,b) SEM images of the cross-section of SS316L/Nb composite produced by FAST/SPS. Nb layer was consolidated at 1500° C and SS316L layer at 1000°C. (c) EDS mapping of Nb.

A good adhesion between both materials was achieved. A very thin diffusion layer, with a thickness of a few 100 nm was found and only few Nb atoms diffused in the SS316L layer.

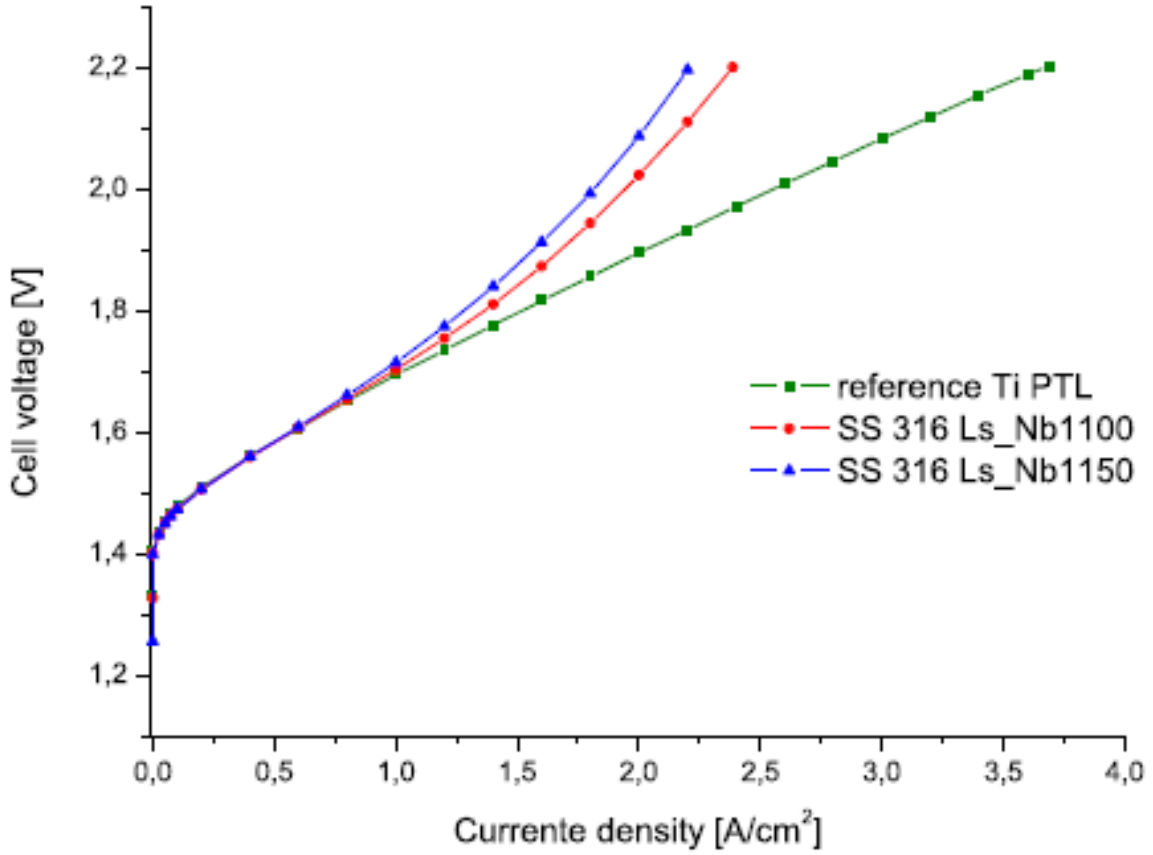

Figure 7. Polarisation curves of reference Ti PTL and SS316Ls_Nb110 and SS316Ls_Nb1150 composites.

The novel SS316L/Nb PTLs behave similar to the standard Ti PTLs up to a current density of 1 A cm^{-2}. However, at higher current densities indication of a mass transport limitation was observed.

PTLs with thickness varying between 350 and 370 μm were produced. This thickness is in the range reported in the literature as suitable for application as PTLs in PEMECs.

Screen-printing of Nb layer on both green and presintered tapes was proved to be suitable technique for manufacturing SS316L/Nb composites, which have the potential to be used as porous transport layers (PTLs) for PEMEC electrolyzers.

Preliminary experiments reveal improved sintering of Nb particles and a better control of interdiffusion at interface SS316L/Nb. However, this technique still requires efforts to adapt the processing to allow production of **thinner layers**, **porous structures** and **samples of larger size**.

Porous Transport Layers Made of Niobium/Steel Composites for Water Electrolysis

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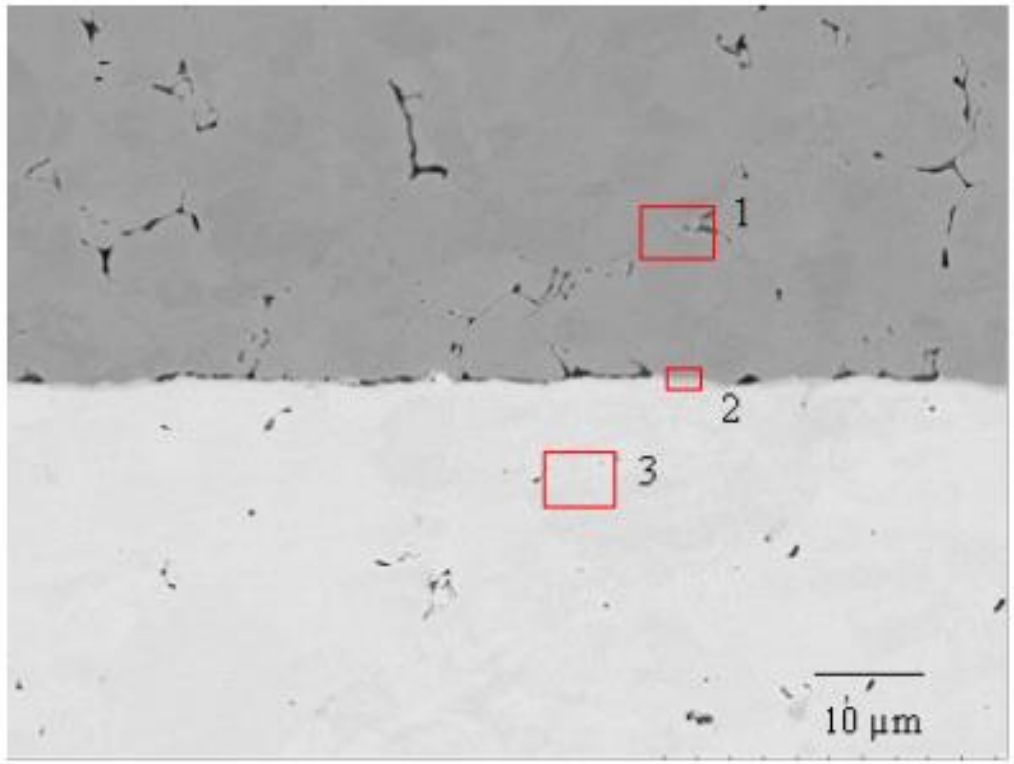
A porous transport layer for PEM electrolysis units was developed, which is based on a stainless steel substrate coated with a porous Nb layer.

Scalable powder metallurgical techniques like tape casting, screen printing and field assisted sintering/spark plasma sintering FAST/SPS were used for manufacturing this composite structure.



Point	Nb (wt.%)	Fe (wt.%)	Cr (wt.%)	Ni (wt.%)	Mo (wt.%)	Mn (wt.%)
1	97.7	0.1	0.01	0.03	1.9	0.15
2	71.0	17.9	4.2	2.2	4.6	0
3	0.2	70.9	17.2	8.5	2.2	1.0

Figure 4. SEM image and EDS composition of the cross section of SS316L/Nb composites produced by FAST/SPS. Nb Layer was consolidated at 1500ºC and SS316L layer at 1100ºC.

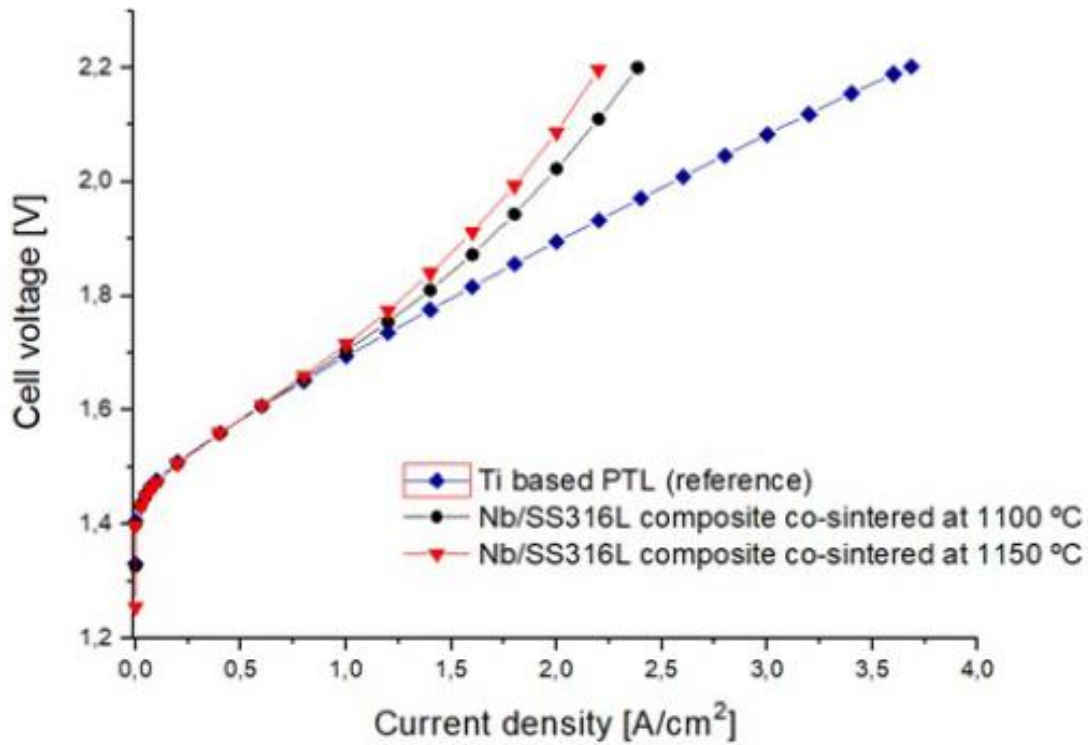


Figure 5. Polarization curves of Ti-based PTL and PTLs made of Nb/SS316L composites recorded in PEM single cell.

Other Applications

Catalyst support

Carbon is used as a catalyst support at the cathode in the present PEFCs owing to its:
High surface area
High electrical conductivity
Appropriate morphology for the transfer of reactant oxygen gas and water product

But carbon is easily oxidized in particular, the stability of carbon will become a serious problem at higher voltages and higher operating temperatures.

Titanium has been mainly investigated because of their **high stabilities under acidic conditions.** However, it has **insufficient conductivity** as a support**.**

One way is the doping of **foreign elements** into TiO2 to improve the conductivity through the formation of the doping level of electrons.

Many elements, such as **transition metals** (Cu, Co, Ni, Cr, Mn, Mo, V, Fe, Ru, Au, Ag, and Pt) and **non-metals** (N, S, C, B, P, I, and F), have been investigated. However, from the viewpoint of **stability** in an acidic environment, the doping elements are limited.

Many researchers have focused instead on **niobium** as the doping element.

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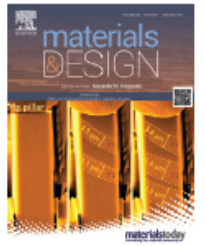

Control of surface area and conductivity of niobium-added titanium oxides as durable supports for cathode of polymer electrolyte fuel cells

Yongbing Ma [a], Takaaki Nagai [b], Yuta Inoue [a], Kaoru Ikegami [b], Yoshiyuki Kuroda [a], Koichi Matsuzawa [c], Teko W. Napporn [b,d], Yan Liu [e], Shigenori Mitsushima [a,b], Akimitsu Ishihara [b,*]

Titanium-oxide based compounds (as substitutes for carbon supports) were used as a **support for cathode catalysts** that enhance the oxygen reduction reaction (ORR) activity and durability.

They successfully proposed a procedure to prepare **highly durable** Nb-added TiO_2 supports with the **desired surface area** (10–130 $m^2\ g^{-1}$) and **conductivity** (10^{-7}–10^{-2} $S\ cm^{-1}$) were prepared by changing the amount of Nb and the heat treatment conditions.

Membranes application

Perflurosulfonic acid (PFSA) membranes such as Nafion has many advantages such as:

- High electronic insulation,
- Long-term durability
- Unique hydrophilic percolation, and
- High proton conductivity

However, there are also some drawbacks:

Water uptake and subsequently the **proton conductivity** decrease during operation at high temperature (>80°C) and low humidity (<50%).

It shows high **permeability** represented as a **high hydrogen crossover** from the anode to the cathode.

Therefore, the researchers focussed their attention by **modifying PFSA membranes.**

Niobium pentoxide is one of the most important transition metal oxide which has **rich adsorption sites** on its surface and stimulate a **strong interaction with water molecules**.

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ARTICLE

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Novel polysulfone/sulfonated polyaniline/niobium pentoxide polymer blend nanocomposite membranes for fuel cell applications

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New series of polymer nanocomposite membranes were prepared from polysulfone (PSU), sulfonated polyaniline (SPANI) and **niobium pentoxide (Nb_2O_5)** by solution casting technique.

SEM, XRD, and X-ray photoelectron spectroscopy were applied to assess the suitability of the polymer electrolytes in fuel cell applications and the successful incorporation of nanofillers into the polymer matrix

The incorporation of niobium pentoxide into pristine polymer not only improved the ionic conductivity but also enhanced the thermal and oxidative stabilities.

The physicochemical analysis proved the successful incorporation of Nb_2O_5 into the blend membranes.

The incorporation of Nb_2O_5 into the pristine polymer altered the membrane morphology and thereby imparted **hydrophilic characteristics**.

The proton conductivity was improved (0.0674 S cm^{-1} compared to 0.0110 S cm^{-1} for pristine membrane).

Finally it was reported that membranes loaded with Nb_2O_5 are promising material for PEMFC applications.

Thank you