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(71) Applicant(s):
Johnson Matthey Fuel Cells Limited
5th Floor, 25 Farringdon Street, LONDON, EC4A 4AB, United Kingdom

(72) Inventor(s):
Jonathan David Brereton Sharman
Brian Ronald Theobald

(74) Agent and/or Address for Service:
Johnson Matthey Public Limited Company
Gate 20, Orchard Road, Royston, Hertfordshire,
SG8 5HE, United Kingdom

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WO 2011/021034 A1 **WO 2003/032418 A3**
WO 2001/015247 A3 **CN 101773826 A**
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(54) Title of the Invention: **Catalyst**
Abstract Title: **Catalyst for fuel cells**

(57) A catalyst comprising: (i) a first catalytic material, wherein the first catalytic material facilitates an oxygen reduction reaction or a hydrogen oxidation reaction; and (ii) a second catalytic material, wherein the second catalytic material facilitates an oxygen evolution reaction, wherein the second catalytic material comprises iridium or iridium oxide and one or more metals M or an oxide thereof, wherein M is selected from the group consisting of transition metals and Sn; characterised in that first catalytic material is supported on second catalytic material. A catalyst layer comprising the catalyst is disclosed.

CATALYST

The present invention relates to a novel catalyst and catalyst layer, particularly for use in a fuel cell that experiences high electrochemical potentials.

A fuel cell is an electrochemical cell comprising two electrodes separated by an electrolyte. A fuel, such as hydrogen or an alcohol such as methanol or ethanol, is supplied to the anode and an oxidant, such as oxygen or air, is supplied to the cathode. Electrochemical reactions occur at the electrodes, and the chemical energy of the fuel and the oxidant is converted to electrical energy and heat. Electrocatalysts are used to promote the electrochemical oxidation of the fuel at the anode and the electrochemical reduction of oxygen at the cathode.

In proton exchange membrane (PEM) fuel cells, the electrolyte is a solid polymeric membrane. The membrane is electronically insulating but proton conducting, and protons, produced at the anode, are transported across the membrane to the cathode, where they combine with oxygen to form water.

The principle component of a PEM fuel cell is known as a membrane electrode assembly (MEA) and is essentially composed of five layers. The central layer is the polymer ion-conducting membrane. On either side of the ion-conducting membrane there is an electrocatalyst layer, containing an electrocatalyst designed for the specific electrochemical reaction. Finally, adjacent to each electrocatalyst layer there is a gas diffusion layer. The gas diffusion layer must allow the reactants to reach the electrocatalyst layer and must conduct the electric current that is generated by the electrochemical reactions. Therefore the gas diffusion layer must be porous and electrically conducting.

Electrocatalysts for fuel oxidation and oxygen reduction are typically based on platinum or platinum alloyed with one or more other metals. The platinum or platinum alloy catalyst can be in the form of unsupported nanometre sized particles (such as metal blacks or other unsupported particulate metal powders) or can be deposited as even higher surface area particles onto a conductive carbon substrate, or other conductive material (a supported catalyst).

The MEA can be constructed by several methods. The electrocatalyst layer may be applied to the gas diffusion layer to form a gas diffusion electrode. Two gas diffusion electrodes can be placed either side of an ion-conducting membrane and laminated together to form the five-layer MEA. Alternatively, the electrocatalyst layer may be applied to both faces of the ion-conducting membrane to form a catalyst coated ion-conducting membrane. Subsequently, gas diffusion layers are applied to both faces of the catalyst coated ion-conducting membrane. Finally, an MEA can be formed from an ion-conducting membrane coated on one side with an electrocatalyst layer, a gas diffusion layer adjacent to that electrocatalyst layer, and a gas diffusion electrode on the other side of the ion-conducting membrane.

Typically tens or hundreds of MEAs are required to provide enough power for most applications, so multiple MEAs are assembled to make up a fuel cell stack. Field flow plates are used to separate the MEAs. The plates perform several functions: supplying the reactants to the MEAs, removing products, providing electrical connections and providing physical support.

High electrochemical potentials can occur in a number of real-life operational situations and in certain circumstances can cause damage to the catalyst layer/electrode structure. Further description of a number of situations where high electrochemical potentials are seen are described below:

(a) Cell Reversal

Electrochemical cells occasionally are subjected to a voltage reversal condition, which is a situation where the cell is forced to the opposite polarity. Fuel cells in series are potentially subject to these unwanted voltage reversals, such as when one of the cells is forced to the opposite polarity by the other cells in the series. In fuel cell stacks, this can occur when a cell is unable to produce, from the fuel cell reactions, the current being forced through it by the rest of the cells. Group of cells within a stack can also undergo voltage reversal and even entire stacks can be driven into voltage reversal by other stacks in an array. Aside from the loss of power associated with one or more cells going into voltage reversal, this situation poses reliability concerns. Undesirable electrochemical reactions may occur, which may detrimentally affect fuel cell components. Component degradation reduces the reliability and performance of the fuel cell, and in turn, its associated stack and array.

A number of approaches have been utilised to address the problem of voltage reversal, for example employing diodes capable of carrying the current across each individual fuel cell or monitoring the voltage of each individual cell and shutting down an affected cell if a low voltage is detected. However, given that stacks typically employ numerous fuel cells, such approaches can be quite complex and expensive to implement.

Alternatively, other conditions associated with voltage reversal may be monitored instead, and appropriate corrective action can be taken if reversal conditions are detected. For instance, a specially constructed sensor cell may be employed that is more sensitive than other fuel cells in the stack to certain conditions leading to voltage reversal (for example, fuel starvation of the stack). Thus, instead of monitoring every cell in a stack, only the sensor cell need be monitored and used to prevent widespread cell voltage reversal under such conditions. However, other conditions leading to voltage reversal may exist that a sensor cell cannot detect (for example, a defective individual cell in the stack). Another approach is to employ exhaust gas monitors that detect voltage reversal by detecting the presence of or abnormal amounts of species in an exhaust gas of a fuel cell stack that originate from reactions that occur during reversal. While exhaust gas monitors can detect a reversal condition occurring within any cell in a stack and they may suggest the cause of reversal, such monitors do not identify specific problem cells and they do not generally provide any warning of an impending voltage reversal.

Instead of, or in combination with the preceding, a passive approach may be preferred such that, in the event that reversal does occur, the fuel cells are either more tolerant to the reversal or are controlled in such a way that degradation of any critical cell components is reduced. A passive approach may be particularly preferred if the conditions leading to reversal are temporary. If the cells can be made more tolerant to voltage reversal, it may not be necessary to detect for reversal and/or shut down the fuel cell system during a temporary reversal period. Thus, one method that has been identified for increasing tolerance to cell reversal is to employ a catalyst that is more resistant to oxidative corrosion than conventional catalysts (see WO01/059859).

A second method that has been identified for increasing tolerance to cell reversal is to incorporate an additional or second catalyst composition at the anode for purposes of electrolysing water (see WO01/15247). During voltage reversal, electrochemical reactions may occur that result in the degradation of certain components in the affected fuel cell. Depending on the reason for the voltage reversal, there can be a significant rise in the absolute potential of the fuel cell anode to a higher potential than that of the cathode. This occurs, for instance, when there is an inadequate supply of fuel (i.e. fuel starvation) to the anode. In this situation the cathode reaction and thus the cathode potential remains unchanged as the oxygen reduction reaction (ORR):

$$\tfrac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$$

whereas the normal fuel cell reaction at the anode – the hydrogen oxidation reaction (HOR):

$$H_2 \rightarrow 2H^+ + 2e^-$$

can no longer be sustained and other electrochemical reactions then take place at the anode to maintain the current. These reactions can typically be either water electrolysis – the oxygen evolution reaction (OER):

$$H_2O \rightarrow \tfrac{1}{2}\,O_2 + 2H^+ + 2e^-$$

or carbon electrochemical oxidation:

$$\tfrac{1}{2}C + H_2O \rightarrow \tfrac{1}{2}CO_2 + 2H^+ + 2e^-$$

Both these reactions occur at a higher absolute potential than the oxygen reduction reaction at the cathode (hence the cell voltage reverses).

During such a reversal in a PEM fuel cell, water present at the anode enables the electrolysis reaction to proceed and the carbon support materials used to support the anode catalyst and other cell components enables the carbon oxidation reaction also to proceed. It is much more preferable to have water electrolysis occur rather than the carbon oxidation reaction. When water electrolysis reactions at the anode cannot consume the current forced through the cell, the rate of oxidation of the carbonaceous anode components increases, thereby tending to irreversibly degrade certain anode components at a greater rate. Thus, by incorporating a catalyst composition that promotes the electrolysis of water, more of the current forced through the cell may be consumed in the electrolysis of water than in the oxidation of anode components.

A reversal condition can also be experienced due to oxidant starvation on the cathode. However, this is much less detrimental to the cell, because the reaction likely to occur instead of the reduction of the oxidant is that the protons produced at the anode cross the electrolyte and combine with electrons directly at the cathode to produce hydrogen via the hydrogen evolution reaction (HER):

$$2H^+ \rightarrow 2e^- + H_2$$

In this reversal situation the anode reaction and thus the anode potential remain unchanged, but the absolute potential of the cathode drops to below that of the anode (hence the cell voltage reverses). These reactions do not involve potentials and reactions at which significant component degradation is caused.

(b) Start-up Shut-down

For many fuel cells it is also not practical or economic to provide purging of hydrogen from the anode gas space with an inert gas such as nitrogen during shut down. This means that there may arise a mixed composition of hydrogen and air on the anode whilst air is present on the cathode. Similarly, when a cell is re-started after being idle for some time, air may have displaced hydrogen from the anode and as hydrogen is re-introduced to the anode, again a mixed air/hydrogen composition will exist whilst air is present at the cathode. Under these circumstances an internal cell can exist, as described by Tang et al (Journal of Power Sources 158 (2006) 1306-1312), which leads to high potentials on the cathode. The high potentials can cause carbon to oxidise according to the electrochemical carbon oxidation reaction indicated previously:

$$\tfrac{1}{2}C + H_2O \rightarrow \tfrac{1}{2}CO_2 + 2H^+ + 2e^-$$

and this is highly damaging to the structure of the catalyst layer where the catalyst layer contains carbon. If the cathode layer is able to support oxygen evolution by the water electrolysis reaction (OER) however, the high potentials can be used to drive water electrolysis rather than carbon corrosion.

(c) Regenerative Fuel Cells

In regenerative fuel cells the electrodes are bi-functional and both anode and cathode must support two electrochemical reaction types at different times. When operating as a fuel cell the cathode must reduce oxygen (ORR) and the anode oxidise hydrogen (HOR); when operating as an electrolyser the cathode must evolve hydrogen (HER) and the anode evolve oxygen (OER). The catalyst layer of the present invention is well suited to be used as an anode in a regenerative fuel cell because it can carry out both the hydrogen and oxygen reactions effectively.

Electrocatalysts for the water electrolysis reaction are generally based on ruthenium oxide or ruthenium oxide mixed with at least one other metal oxide. However, despite their good activity for the oxygen evolution reaction (OER), the stability of such catalysts is poor under certain practical operational modes of the fuel cell, particularly those where highly oxidative potentials are applied. A particular problem with Ru-containing anode catalyst layers in an MEA, is that under start-stop operational modes of the fuel cell, high potentials can occur at the anode, resulting in Ru dissolution and movement to the cathode, where Ru is a poison for the ORR and reduces the effectiveness of Pt for this reaction.

It is therefore an object of the present invention to provide a catalyst and catalyst layer comprising alternative catalysts comprising an electrocatalyst which facilitates the ORR and HOR reactions and a water electrolysis catalyst which facilitations the OER reaction, which have comparable activity to state of the art catalysts, but which demonstrate good performance and durability when incorporated in a MEA and operated under practical real-life fuel cell operating conditions.

Accordingly, the present invention provides a catalyst comprising:

(i) a first catalytic material, wherein the first catalytic material facilitates an oxygen reduction reaction or a hydrogen oxidation reaction; and

(ii) a second catalytic material, wherein the second catalytic material facilitates an oxygen evolution reaction, and wherein the second catalytic material comprises iridium or iridium oxide and one or more metals M or an oxide thereof, wherein M is selected from the group consisting of transition metals and Sn,

characterised in that the first catalytic material is supported on the second catalytic material.

In one embodiment, all the first catalytic material is supported on the second catalytic material. In a second embodiment, some of the first catalytic material (for example up to 90%, suitably up to 70%, more suitably up to 50%, preferably up to 25% and more preferably up to 5%) is not supported on the second catalytic material and exists as discrete unsupported particles.

Suitably, M is selected from the group consisting of group IVB, VB and VIB metals and Sn; more suitably selected from the group consisting of Ti, Zr, Hf, Nb, Ta and Sn; preferably selected from the group consisting of Ti, Ta and Sn. In a preferred embodiment, M is not Ru.

The iridium or oxide thereof and the one or more metals (M) or oxide thereof may either exist as mixed metals or oxides or as partly or wholly alloyed materials or as a combination of the two or more. The extent of any alloying can be shown by x-ray diffraction (XRD).

The atomic ratio of iridium to (total) metal M in the second catalytic material is from 20:80 to 99:1, suitably 30:70 to 99:1 and preferably 60:40 to 99:1.

Suitably, the second catalytic material has a surface area of at least 10 m^2/g, more suitably at least 15 m^2/g, and preferably at least 30 m^2/g.

The first catalytic material comprises a metal (the primary metal), which is suitably selected from

(i) the platinum group metals (platinum, palladium, rhodium, ruthenium, iridium and osmium), or

(ii) gold or silver, or

(iii) a base metal

or an oxide thereof.

The primary metal may be alloyed or mixed with one or more other precious metals, or base metals or an oxide of a precious metal or base metal. Suitably, the weight ratio of the primary metal of the first catalytic material to the second catalytic material is 1: 99 to 70:30, preferably 5:95 to 40:60.

The catalyst of the invention may be prepared by adding the second catalytic material (suitably in solid form) to an acidic solution of a precursor of the first catalytic material, with rapid stirring. Stirring is continued for several days, after which the resulting slurry was collected by filtration, washed and air-dried at elevated temperature.

The catalyst of the invention has utility in a number of applications, but particularly at the anode and/or cathode of a fuel cell. Accordingly, a further aspect of the invention provides a catalyst layer comprising the catalyst of the invention. The catalyst layer may be the anode catalyst layer or the cathode catalyst layer.

In one embodiment of the invention, the catalyst layer comprises a third catalytic material wherein the third catalytic material may be the same or different to the first catalytic material and comprises a metal (primary metal) as defined hereinbefore for the first catalytic material. Suitably, the third catalytic material is unsupported. Suitably, the third catalytic material is the same as the first catalytic material. The third catalytic material may account for 0-50% of the total of the first catalytic material and the third catalytic material.

Suitably, the total loading of the primary metal of the first (and if present third) catalytic material in the catalyst layer is less than 0.5 mg/cm^2, and is preferably from 0.01mg/cm^2 to 0.4 mg/cm^2, most preferably 0.02mg/cm^2 to 0.2mg/cm^2. The loading will depend on whether the catalyst layer is for use at the anode or cathode and suitable loadings will be known to those skilled in the art.

The catalyst layer may comprise additional components, such as an ionomer, suitably a proton conducting ionomer. Examples of suitable proton conducting ionomers will be known to those skilled in the art, but include perfluorosulphonic acid ionomers, such as Nafion® and ionomers made from hydrocarbon polymers.

The catalyst layer of the invention has utility in PEM fuel cells. Accordingly, a further aspect of the invention provides an electrode comprising a gas diffusion layer (GDL) and a catalyst layer according to the invention. In one embodiment, the electrode is an anode; in a further embodiment, the electrode is a cathode.

The catalyst layer can be deposited onto a GDL using well known techniques, such as those disclosed in EP 0 731 520. The catalyst layer components may be formulated into an ink, comprising an aqueous and/or organic solvent, optional polymeric binders and optional proton-conducting polymer. The ink may be deposited onto an electronically conducting GDL using techniques such as spraying, printing and doctor blade methods. Typical GDLs are fabricated from substrates based on carbon paper (e.g. Toray® paper available from Toray Industries, Japan or U105 or U107 paper available from Mitsubishi Rayon, Japan), woven carbon cloths (e.g. the MK series of carbon cloths available from Mitsubishi Chemicals, Japan) or non-woven carbon fibre webs (e.g. AvCarb series available from Ballard Power Systems Inc, Canada; H2315 series available from Freudenberg FCCT KG, Germany; or Sigracet® series available from SGL Technologies GmbH, Germany). The carbon paper, cloth or web is typically modified with a particulate material either embedded within the layer or coated onto the planar faces, or a combination of both to produce the final GDL. The particulate material is typically a mixture of carbon black and a polymer such as polytetrafluoroethylene (PTFE). Suitably the GDLs are between 100 and 400μm thick. Preferably there is a layer of particulate material such as carbon black and PTFE on the face of the GDL that contacts the catalyst layer.

In PEM fuel cells, the electrolyte is a proton conducting membrane. The catalyst layer of the invention may be deposited onto one or both faces of the proton conducting membrane to form a catalysed membrane. In a further aspect the present invention provides a catalysed membrane comprising a proton conducting membrane and a catalyst layer of the invention. The catalyst layer can be deposited onto the membrane using well-known techniques. The catalyst layer components may be formulated into an ink and deposited onto the membrane either directly or indirectly via a transfer substrate.

The membrane may be any membrane suitable for use in a PEM fuel cell, for example the membrane may be based on a perfluorinated sulphonic acid material such as Nafion® (DuPont), Flemion® (Asahi Glass) and Aciplex® (Asahi Kasei); these membranes may be used unmodified, or may be modified to improve the high temperature performance, for example by incorporating an additive. Alternatively, the membrane may be based on a sulphonated hydrocarbon membrane such as those available from Polyfuel, JSR Corporation, FuMA-Tech GmbH and others. The membrane may be a composite membrane, containing the proton-conducting material and other materials that confer properties such as mechanical strength, such as expanded PTFE or a non-woven PTFE fibre network. Alternatively, the membrane may be based on polybenzimidazole doped with phosphoric acid and include membranes from developers such as BASF Fuel Cell GmbH, for example the Celtec®-P membrane which will operate in the range 120°C to 180°C and other newer developmental membrane such as the Celtec®-V membrane.

In a further embodiment of the invention, the substrate onto which the catalyst of the invention is applied is a transfer substrate. Accordingly, a further aspect of the present invention provides a catalysed transfer substrate comprising a catalyst layer of the invention. The transfer substrate may be any suitable transfer substrate known to those skilled in the art but is preferably a polymeric material such as polytetrafluoroethylene (PTFE), polyimide, polyvinylidene difluoride (PVDF), or polypropylene (especially biaxially-oriented polypropylene, BOPP) or a polymer-coated paper such as polyurethane coated paper. The transfer substrate could also be a silicone release paper or a metal foil such as aluminium foil. The catalyst layer of the invention may then be transferred to a GDL or membrane by techniques known to those skilled in the art.

A yet further aspect of the invention provides a membrane electrode assembly comprising a catalyst layer, electrode or catalysed membrane according to the invention. The MEA may be made up in a number of ways including, but not limited to:

(i) a proton conducting membrane may be sandwiched between two electrodes (one anode and one cathode), at least one of which is an electrode according to the present invention;

(ii) a catalysed membrane coated on one side only by a catalyst layer may be sandwiched between (i) a gas diffusion layer and an electrode, the gas diffusion layer contacting the side of the membrane coated with the catalyst layer, or (ii) two electrodes, and wherein at least one of the catalyst layer and the electrode(s) is according to the present invention;

(iii) a catalysed membrane coated on both sides with a catalyst layer may be sandwiched between (i) two gas diffusion layers, (ii) a gas diffusion layer and an electrode or (iii) two electrodes, and wherein at least one of the catalyst layer and the electrode(s) is according to the present invention.

The MEA may further comprise components that seal and/or reinforce the edge regions of the MEA for example as described in WO2005/020356. The MEA is assembled by conventional methods known to those skilled in the art.

Electrochemical devices in which the catalyst layer, electrode, catalysed membrane and MEA of the invention may be used include fuel cells, in particular proton exchange membrane (PEM) fuel cells. The PEM fuel cell could be operating on hydrogen or a hydrogen-rich fuel at the anode or could be fuelled with a hydrocarbon fuel such as methanol. The catalyst layer, electrode, catalysed membrane and MEA of the invention may also be used in fuel cells in which the membranes use charge carriers other than protons, for example OH^- conducting membranes such as those available from Solvay Solexis S.p.A., FuMA-Tech GmbH. The catalyst layer and electrode of the invention may also be used in other low temperature fuel cells that employ liquid ion conducting electrolytes, such as aqueous acids and alkaline solutions or concentrated phosphoric acid. Other electrochemical devices in which the catalyst layer, electrode, catalysed membrane and MEA of the invention may be used are as the anode electrode of regenerative fuel cells where the hydrogen oxidation and oxygen evolution reactions are both performed, and as the anode of an electrolyser where oxygen evolution is performed by the second catalytic material and contaminant hydrogen is recombined with oxygen by the first (and if present third) catalytic material.

Accordingly, a further aspect of the invention provides a fuel cell, preferably a proton exchange membrane fuel cell, comprising a catalyst layer, an electrode, a catalysed membrane or an MEA of the invention.

The invention will now be further described by way of example only.

Preparation of IrTa mixed oxide catalyst

$IrCl_3$ (76.28g, 0.21 mol Ir) was suspended in water (500ml) and stirred overnight. $TaCl_5$ (32.24g, 0.090 mol Ta) was added to concentrated hydrochloric acid (200ml) with stirring to give a slightly milky solution. The Ta solution was stirred into the $IrCl_3$ solution and kept until ready to use. The solution was spray dried and calcined in air to yield a 70at%Ir 30at%Ta mixed oxide catalyst.

Preparation of Pt/IrTa oxide catalyst

Hexachloroplatinic acid (H_2PtCl_6) solution containing 2.0 g of Pt was diluted to 500ml with water. Formic acid (60ml) was added to the Pt solution and stirred. To the resulting solution, IrTa Oxide (18.0g) was added with rapid stirring. Stirring was continued for 6 days. The slurry was collected by filtration, washed copiously with water and dried in air at 105°C. The product was ground in a mortar and pestle.

Yield: 19.4 g

Metal assay (wt%): Pt = 9.21%, Ir = 46.3%, Ta = 18.5%

CO metal area = $13.6m^2/g$-Pt

XRD characterised as indicating a Pt and IrTa oxide phase; Pt crystallite size ~ 5.4nm, IrTa oxide phase crystallite size ~ 7.0 nm, lattice parameters a = 4.584 Å, c = 3.175 Å.

Claims

1. A catalyst comprising:
    - (i) a first catalytic material, wherein the first catalytic material facilitates an oxygen reduction reaction or a hydrogen oxidation reaction; and
    - (ii) a second catalytic material, wherein the second catalytic material facilitates an oxygen evolution reaction, wherein the second catalytic material comprises iridium or iridium oxide and one or more metals M or an oxide thereof, wherein M is selected from the group consisting of transition metals and Sn,

characterised in that the first catalytic material is supported on the second catalytic material.

2. A catalyst according to claim 1, wherein all the first catalytic material is supported on second catalytic material.

3. A catalyst according to claim 1 or claim 2, wherein M is selected from the group consisting of Group IVB, VB and VIB metals and Sn.

4. A catalyst according to claim 3, wherein M is selected from the group consisting of Ti, Zr, Hf, Nb, Ta and Sn.

5. A catalyst according to any preceding claim, wherein the first catalytic material comprises a metal (the primary metal) which is suitably selected from
    - (i) the platinum group metals (platinum, palladium, rhodium, ruthenium, iridium and osmium), or
    - (ii) gold or silver, or
    - (iii) a base metal

or an oxide thereof.

6. A catalyst layer comprising a catalyst as claimed in any one of claims 1 to 5.

7. An electrode comprising a gas diffusion layer and a catalyst layer as claimed in claim 6.

8. A catalysed membrane comprising a solid polymeric membrane and a catalyst layer as claimed in claim 6.

9. A catalysed transfer substrate comprising a transfer substrate and a catalyst layer as claimed in claim 6.

10. A membrane electrode assembly comprising a catalyst layer as claimed in claim 6, an electrode as claimed in claim 7 or a catalysed membrane as claimed in claim 8.

11. A fuel cell comprising a catalyst layer as claimed in claim 6, an electrode as claimed in claim 7 or a catalysed membrane as claimed in claim 8.

Application No:	GB1102138.3	**Examiner:**	Mr Martin Price
Claims searched:	1-11	**Date of search:**	7 June 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 at least	CN 101773826 A Dalian Chem Phys Inst - see WPI abstract number 2010-M35613
X	1 at least	CN 101773825 A Dalian Chem Phys Inst - see WPI abstract number 2010-K78905
X	1 at least	WO 01/15247 A3 Ballard - see e.g. claims 1, 8, 24-32 and page 23 line 27 to page 24 line 5
A,E	-	WO 2011/021034 A1 Johnson Matthey - see e.g. the claims
A	-	WO 2003/032418 A3 Lynntech - see e.g. the claims

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

B01J; C25B; H01M

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
B01J	0035/00	01/01/2006
B01J	0023/46	01/01/2006
C25B	0011/04	01/01/2006
H01M	0004/86	01/01/2006
H01M	0004/90	01/01/2006