EIS Characterization of PEM Fuel Cell with Graphene as Electrode Support Material

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Abstract: The PEM (Polymer Electrolyte Membrane) fuel cell technology is one of the most promising energy conversion technologies under renewable energy systems because of its wide ability in most of the commercial applications like electrical vehicles, building cogeneration and standby power supply. However, direct use of PEM fuel cell in most of the commercial applications is restricted due to its slow dynamics and less peak power supplying capability. To improve slow dynamics, catalyst activity is required to be improve where as to improve peak power capability electrode surface area is required to be increase. In this paper grapheme is used as catalyst support electrode material to improve slow dynamics and peak power supplying capability of PEM fuel cell. Use of grapheme reduces internal resistance of the PEM fuel cell and hence reduces ohmic polarization drop. The use of grapheme also increases electrode surface area which in turn improves slow dynamics by increasing internal capacitance of PEM fuel cell. EIS (Electrochemical Spectroscopy) of the PEM fuel cell using grapheme as catalyst support is compared with PEM fuel having activated carbon as a catalyst support for performance validation.

Key words: EIS, Graphene, Activated carbon, PEM fuel cell, Polarization.

I. Introduction

Graphene is an atomic-scale honeycomb lattice made of carbon atoms. Graphene is undoubtedly emerging as one of the most promising nano-materials because of its unique combination of superb properties, which opens a way for its exploitation in a wide spectrum of applications ranging from electronics to optics, sensors, and energy storage. Graphene has many good properties its surface area is nearly double as compared to activated carbon (nearly $2600 \text{ cm}^2/\text{gm}$) and its mechanical and chemical properties are also very good as compared to the activated carbon. PEM fuel cell is electrochemical device which converts the chemical energy of fuel i.e. hydrogen supplied to it into electrical energy[1]. The chemical reaction rates taking place at the cathode and anode of PEM fuel cell are slow. Due to slow reaction rates the response of PEM fuel cell to the instantaneously changing load is very less [2][3]. The reaction rate can be improved by using catalyst support. Platinum is used as a catalyst for PEM fuel cell to increase rate of reaction kinetics. Platinum is a costly metal and therefore for economical point of view the amount of platinum required to be use for best performance is most important. The other factor on which the rate of chemical reaction at cathode and anode depends is the electrode surface area where reaction is taking place. In PEM fuel cell active carbon is generally used as catalyst support and electrode material which provides sufficient surface area. In present research attempt is used to use carbon derived material which provide better thermal, chemical mechanical and electrical properties at the same time provides more surface area then active carbon. In present paper graphene is used as catalyst support which provides more surface area than active carbon.

II. Polarization Characteristics of PEM Fuel Cell

The variation of cell terminal voltage with load current is characterized as polarization curve as shown in Figure 1. The electrochemical energy conversion inside the fuel cell is associated with many losses. The sources of losses are activation polarization, ohmic polarization, and concentration polarization. Due to these losses, the cell terminal voltage (*V*) is less than the ideal value ''*E*'' as follows:

$$V = E - \text{Losses in a cell.}$$

The activation polarization loss is more dominant, compared to other losses, especially at low currents, where there is a need to overcome the electronic barriers before current and ion flow [3]. The Ohmic polarization loss is almost proportional to current and thus it increases with the current or load on the fuel cell since this cell resistance is almost constant. Generally, the gas transport losses or concentration losses take place mostly at higher limiting currents because at high limiting currents there is difficulty in providing sufficient reactants flow to the anode and cathode reaction sites. If the fuel cell is operated at much below its rated current then this loss can be neglected [4]. The three types of losses are briefly described follow.
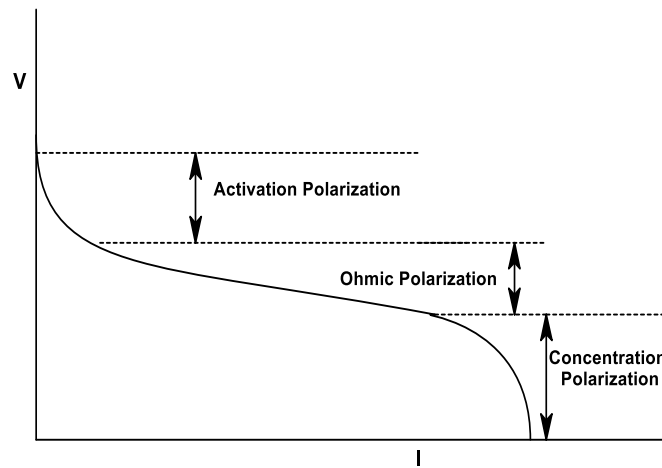
Figure 1. Polarization Characteristics of PEM fuel cell

Activation loss: The cause behind the activation loss is the slowness of the reactions at the anode and cathode surfaces. While forcing the electrons to the electrodes through the chemical reaction, parts of the potential get lost in terms of activation loss. The Tafel equation is generally used to account for this type of loss [3][4]. Using this equation, a relation between the overvoltage at the electrode surface and the natural logarithm of current density can be derived. If it is required to investigate the performance at low currents, the Bulter–Volmer equation can be used instead of the Tafel equation since it is more accurate, compared to the Tafel equation at very low currents.

Ohmic loss: The PEM fuel cell is considered to be having three types of resistances: the resistance of proton exchange membrane, the contact resistance between the membrane and electrodes, and that of electrodes. The ohmic resistance is the sum of these resistances and the total ohmic voltage drop can be expressed as follows.

$$V_{ohm} = V_{electrodes} + V_{ohm;membrane} + V_{contact} = I_{fc}\,R_{ohm}$$

Concentration loss: As a result of mass diffusions from the flow channels to the reaction sites of cathode and anode, concentration gradients are formed during the reaction process. The cause for the concentration voltage drop at high current densities is the slow transportation of reactants to the reaction sites. If the PEM fuel cell is operated much below its rated current, the effect of this loss can be neglected.

III.   EIS Characterization with Graphene.

Membrane electrode assembly (MEA) is a heart of PEM fuel cell [5]. Two MEA's, one using activated carbon as a catalyst support and second grapheme as a catalyst support, are developed. The active area for both the MEA is same i.e. 25cm^2 and platinum catalyst loading for both MEM's are same i.e. 0.5 mg/cm^2 for both cathode and anode. The EIS characterization of both the MEA's are tested on FUEL CELL TEST STATION. The EIS characteristics of both the MEA's are shown in figure 2. From figure 2 it is clear that the performance of the PEM fuel cell with grapheme as catalyst support is improved by nearly 25% as compared to PEM fuel cell using activated carbon as a catalyst support. The use of grapheme as catalyst support improves three phase boundary where reactant, catalyst and electrolyte meet for energy transformation. The improvement in three phase boundary increases catalyst activity and increases reaction rate kinetics of fuel at electrode which in turn reduces activation polarization. The decrease in activation polarization improves PEM fuel cells slow dynamics and peak power supplying capability [6].
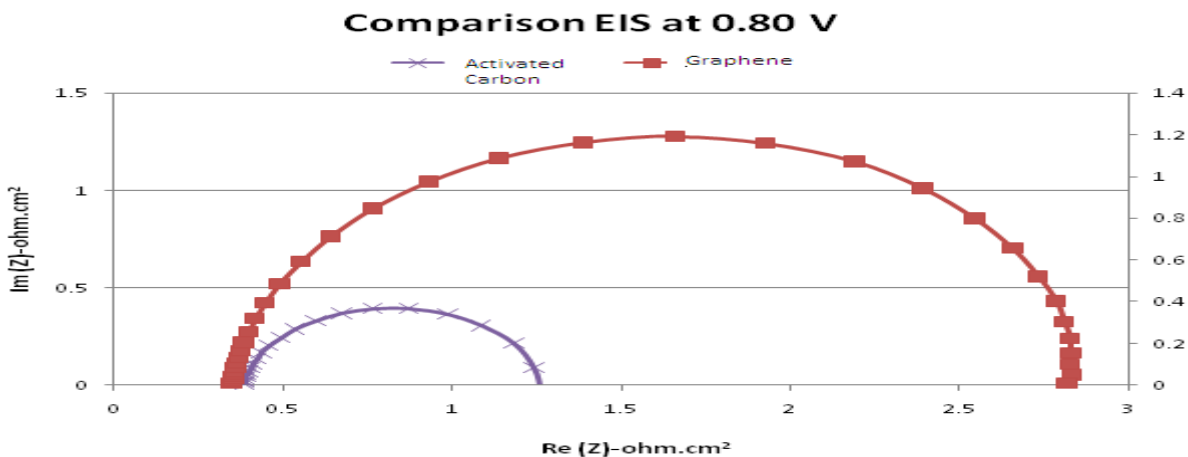

Figure 2. Comparison of polarization characteristics

IV.   Conclusion

EIS characterization of PEM fuel cell with grapheme as an electrochemical catalyst support is compared with the EIS of a PEM fuel cell using activated carbon as an electrochemical catalyst support. From EIS chatecterization, it is clear that the performance of PEM fuel cell is improved by nearly 25%. Use of grapheme as catalyst support improves three phase boundary where reactant, catalyst and electrolyte meet for energy transformation and therefore the overall performance of PEM fuel cell found to be improved.

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