Formation of a DC Glow Discharge at Atmospheric Pressure Using Solid Electrolyte

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Abstract It is well known that a formation of a DC glow discharge is difficult to realize because a DC glow discharge formed under low pressure can be easily transferred to an ark plasma at atmospheric pressure. Kogoma et.al have developed several methods to obtain a glow discharge at atmospheric pressure by applying high frequency AC. Recently we have observed a DC glow discharge at atmospheric in the course of an experiment of a fuel cell using a solid electrolyte. An experimental apparatus was designed to have a discharge gap through which helium was fed. The gap was consisted of a solid electrolyte(YSZ) and a platinum electrode. By applying DC voltage of 1800V/cm, the current between gap was sharply increased up to 10mA and a bright glow was clearly observed. A spectrum of a DC glow was analyzed by using a monochromator. These results implied a formation of a DC glow discharge at atmospheric pressure. Finally, we propose a following mechanism of a DC glow discharge from a solid electrolyte; an electron could be detached from an oxygen anion on a solid electrolyte due to a cathode sheath formed near the surface and be accelerated through the sheath to ionize the helium.

1. Introduction

Plasma processes are employed for many practical purposes, a thin film deposition and surface modification ,etc. Most of these processes are operated under low pressures except for the corona discharge and silent discharge. If we could substitute an atmospheric process for those low pressure processes, it would be much more advantageous from the point of running cost and a system construction.

However a discharge at atmospheric pressure tends to transfer easily to an ark plasma. It is therefore important to achieve a stable and continual glow discharge in plasma processes at atmospheric pressure. Kogoma et.al[1,3,4]and Akishev[2]have developed several methods to obtain a glow discharge at atmospheric pressure by applying high frequency AC.

Recently we have observed a DC glow discharge during the experiment of fuel cell with a solid electrolyte of Yttria Stabilized Zirconia(YSZ). An experimental set-up for a DC glow discharge is simply designed to make a discharge gap consisting of YSZ and platinum electrode. In general YSZ which is usually used for an oxygen sensor and oxygen pump can transfer an oxygen anion(O^{--}). The ion transfer is relied on a crystal lattice defect of Zirconia and that would make a DC glow discharge occur easily at atmospheric pressure.

Detail study for getting a DC glow discharge with YSZ was discussed and several requirements for a stable glow are obtained as follows.

(1) A solid electrolyte for an electrode was set to make a discharge gap(1,5mm) with platinum electrode.

(2) A DC power of 1800V/cm was supplied between a discharge gap.

(3) Helium gas was supplied between a discharge gap.

(4) The temperature of a solid electrolyte has to be kept above 470K so as to activate an ionic conductivity of YSZ.

2. Experimental apparatus and procedures

2 -1 Experimental apparatus

A configuration of an experimental apparatus is shown in Figure 1. A cylindrical impervious tube of Yttria Stabilized Zirconia(YSZ) was used for a solid electrolyte. The tube has an ID of 13mm ,an OD of 17mm and a length of 600mm. The YSZ tube was covered with a glass tube(ID 21mm,OD 23mm) so as to make a space for supplying air.

A platinum paste consisting of submicron platinum powder was applied to get an electrode of inside and outside of YSZ. Platinum electrode was prepared by heating YSZ at 850℃ for 2 hours in an atmosphere.

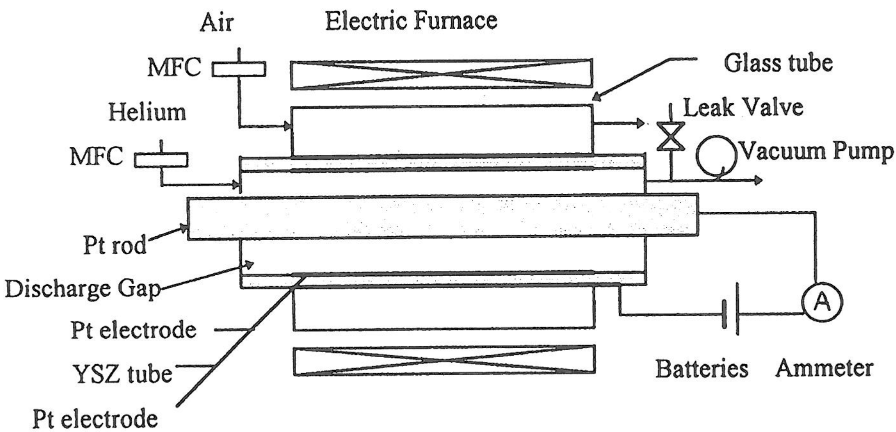
A rod covered with platinum(OD 10mm,length 700mm)was inserted into the center of YSZ tube so that a discharge gap was in a distance of 1.5mm. Each of the rod and the platinum electrode on YSZ tube was linked by platinum wire to the output terminal.

Helium gas was fed through the discharge gap inside of YSZ tube and air was fed into annular space between YSZ and glass tube. A conjunction part of a rod, YSZ tube and a glass tube was fitted with Ultra-Torr.

DC power was provided by the voltage up to 288V with a bank of batteries.

An electric furnace was used to increase temperature up to 870K. A measurement of current between a discharge gap was implemented by using a picoammeter(KEITHLEY 486).

Pressure was controlled by a vacuum pump and a leak valve under a helium or nitrogen flow condition.



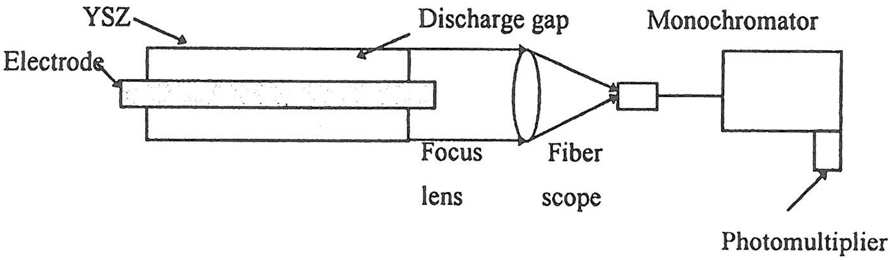
<Fig. 1 Schematic draw of experimental set-up>

2-2 Measurement of a spectrum of the DC glow discharge

A monochromator(JOBIN YVON HR320,1200 lines/mm,slit width 10 μm,blaze wave length 500nm) with quartz fiber and a photmultiplier(HAMAMATU PHOTONICS R795) was used to measure a spectrum of a DC glow discharge. A lens with focused distance 100mm was used to focus a plasma light. A fiber of monochromator was set in front of the lens.

Figure 2 shows a schematic drawing of a monochromator.

For analyzing the spectrum of discharge, the wave length from 300nm to 800nm was used.



<Fig. 2 Schematic draw of monochromator system>

3. Results and Discussions

3-1 Effect of temperature on the DC glow discharge

Effect of temperature on getting the DC glow discharge was examined. The temperature was changed over a range from 370K to 870K. Flow rate of helium gas was kept to be 100cc/min and fed through the discharge gap. Air of 100cc/min was fed through the outside of YSZ. DC voltage of 280V was supplied to the discharge gap.

Relations between temperature and current are shown in Figure 3. It is shown no current are measured at the lower temperature below 470K but that increases sharply at the temperature above 570K. As the current shows 10mA ,a bright light of plasma was observed in the discharge gap.

According to these results, it was found that the DC glow discharge occurs at atmospheric pressure by using a solid electrolyte of YSZ. The effect of temperature was also observed. This tendency of result implies that the occurrence of the DC glow discharge at atmospheric pressure relates with an ion conductivity of YSZ.

3-2 Effect of voltage on the DC glow discharge

Effect of supplying voltage on the DC glow discharge was studied. Temperature of the system was kept at 670K so as to keep a glow discharge. Helium and air at gas flow rate of 100cc/min were fed through the discharge gap and outside of YSZ,respectively. Supplying voltage was varied over a range from 85V to 288V.

Relations between current and voltage are plotted in Figure 4. Figure shows no current is measured over the range of voltage from 0V to 260V but at the voltage above 270V the current increases sharply up to the order of mA. As the current increased an emission plasma was observed between the discharge gap.

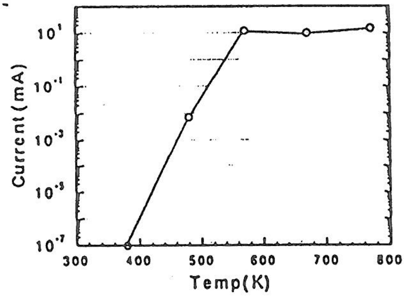


Fig. 3 Current vs Temp

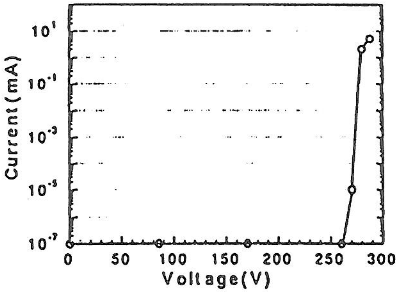


Fig. 4 Current vs Voltage

3-3 Effects of pressure on the DC glow discharge

Effects of pressure on the DC glow discharge was examined under different pressure. Pressure was varied by using a vacuum pump and a leak valve, supplying 100cc/min of helium or nitrogen . Pressure range from 760 to 1.5Torr was used. A system temperature was kept at 570K and the voltage of 280V was supplied to the discharge gap. Measurement results of current versus pressure for helium and nitrogen are shown in Fig 5.

As shown in figure 5, it is found the current between the discharge gap under helium flow condition is varied with pressure. At low pressure below 1.5 Torr the current can not be observed,but at high pressure above 10 Torr the current shows the order of milli-ampere.

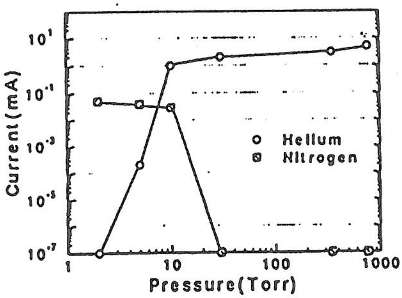


Fig.5 Current vs Pressure

Contrary to helium the effect of pressure under nitrogen condition shows that the current increases up to 50 μ A with a decrease of pressure.But at pressure above 30 Torr no current can be observed. From these results the existence of helium gas is necessary to keep a glow discharge at atmospheric pressure. According to a coefficient of ionization by collision[5] ·helium preserves much bigger coefficient than nitrogen,so that DC glow discharge occurs under helium but not under nitrogen.

3-4 Spectrum analysis of the DC glow discharge

A bright plasma at atmospheric pressure was observed under helium flow at 580K and 280V voltage supply. A spectrum analysis was implemented using monochromator. The wave length from 300 to 800nm was used. Results of assigned wave length and atoms are in Table 1.

Table 1 Assigned wave length and atoms in DC glow discharge

Wave length nm	388	394	447	510.5	550	616	631	645
Assigned atom	He	He	He	He	O	O	O	O

As shown in Table 1, an existence of an activated helium atom and oxygen atom is recognized in a plasma of the DC glow discharge. Since no oxygen was supplied at the outside of YSZ, an oxygen atom in a glow should come from a transferred oxygen ion of YSZ.

4. Conclusion

In the present work, the DC glow discharge consisting of a solid electrolyte was observed under a condition of helium flow at temperature around 570K , with supplying DC 1800V/cm. We would like to propose a following mechanism of the DC glow discharge using a solid electrolyte ;an electron could be detached from an oxygen anion on YSZ due to a cathode sheath formed near the surface of YSZ and accelerated through the sheath to ionize the helium.

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