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Commercial power transistor p-type semiconductor segment as an efficient photocathode for oxygen reduction reaction (ORR) in a microbial fuel cell (MFC)

Vahid Mohammadzadeh, Research Laboratory for Electrochemical Instrumentation and Energy Systems, Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran
V.mohammadzadeh2014@gmail.com
Iraj Ahadzadeh, Research Laboratory for Electrochemical Instrumentation and Energy Systems, Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran
Irajahadzadeh@gmail.com
Mir Ghasem Hosseini, Research Laboratory for Electrochemical Instrumentation and Energy Systems, Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran
Mirghasem.h@gmail.com
**Hamed Nosrati, Research Laboratory for Electrochemical Instrumentation and Energy Systems,
Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran**
Hamed.nosraty@gmail.com
**Nazila Farsad Layegh, Research Laboratory for Electrochemical Instrumentation and Energy Systems,
Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran**
Farsad.nazilla@yahoo.com
**Shaghayegh Bordbar Ghazijahani, Research Laboratory for Electrochemical Instrumentation and Energy
Systems, Department of Physical Chemistry, Faculty of Chemistry , University of Tabriz, Tabriz, Iran**
Sh.bordbari@yahoo.com

Abstract

Oxygen (O_2) is the most abundant element in the Earth's crust. The oxygen reduction reaction (ORR) is also the most important reaction processes such as biological respiration, and in energy converting systems such as fuel cells. the ORR, which is one of the most important reactions in energy conversion systems such as fuel cells, including its reaction kinetics, is presented. Recent developments in electrocatalysts for ORR in fuel cells, including low and non-Pt electrocatalysts, metal oxides, transition metal macrocycles and chalgogenides, are discussed. Because of the expensive electrochemical catalysts; In recent decades, many efforts have been made to reduce the cost of these reactions. In this research, using the commercial 2N3055 and MJ2955 power transistors for oxygen reduction reaction, open circuit potential (OCP) and chronoamperometry (CHA) electrochemical methods were studied. The results showed that p-type surface of transistors can be used to reduce oxygen, which can be a simple and inexpensive method can be used as a photocathode electrode in microbial fuel cells (MFC).

Keywords: Oxygen Reduction Reaction, BJT transistor, p-type semiconductor, photocathode

Introduction

The oxygen reduction reaction (ORR) and conversion of O_2 to OH^- in electrochemistry is importance both from a theoretical and industrial point of view [1,2]. For example, in microbial fuel cells (MFC), air O_2 is used as an oxidant in the cathode chamber, in which O_2 is reduced on a substrate of a suitable catalyst such as powder or nanoparticles Pt, Pd, etc [3,4]. In microbial fuel cells, one of the most common cathode reactions to generate power is the reduction reaction of water dissolved oxygen in aerated cathode medium [5]. Due to the low concentration of dissolved oxygen in water at environmental temperature to create the desired power level of these energy systems, the development of a suitable catalyst to reduce O_2 is very important as quickly and efficiently as possible. One of the main problems in this case is the three-phase O_2 gas system of the catholyte solution cathode electrode. In this system,O_2 gas must be first dissolved in water (catholyte solution) and then transferred to the cathode solid electrode surface to be reduced (penetration mass transfer) and there to be revived to OH^-. The development of suitable catalytic systems for the construction of the electrode / electrolyte interface plays a key role in this regard which should reduce the activation energy of the ORR reaction by adding less electrochemical cathode potentials and save energy to reduce a certain amount of O_2 from dissolved [6]. One of the common solutions to this problem is the use of light energy, which raises the issue of photocathodes. In fact photocathodes are semiconductor components, mainly p-type, which in the face of light due to the bending of the edge of the conduction band (C_B) and their capacitance band (V_B) down to a level of cathodic potential, less action than the dark state, regenerate species in solution with Adjust the energy level [7]. Figure 1 shows the general concept of photocathodes and photovoltaics based on P and N type semiconductors [8].

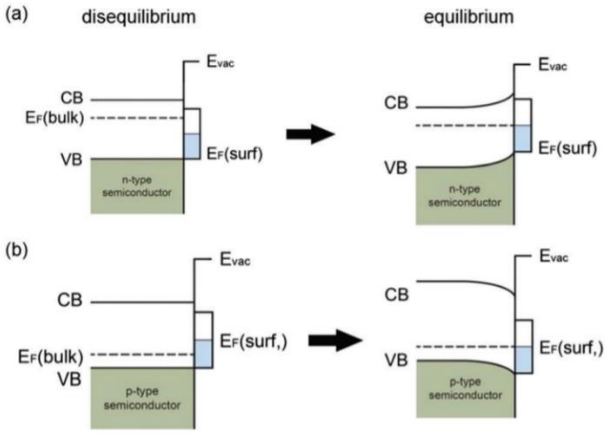

Figure (1) Schematic illustration of surface-state induced band bending: (a) disequilibrium and equilibrium between the bulk and the surface for an n-type semiconductor; (b) disequilibrium and equilibrium between the bulk and the surface for a p-type semiconductor [8].

Different p-type semiconductors have been studied as photocathodes for different reduction reactions. New nanomaterials and nanocomposites are also being developed and studied. In fact, the beating heart of the electronics industry and the manufacture of electronic devices such as diodes, integrated circuits, etc…[9,10]. Based on the use of p and n type semiconductors, the PN junction is based. One of the most basic devices is bijuction transistors or BJTs, which are made and used in both PNP and NPN types. To get acquainted with the construction and operation of BJT transistors, reader can refer to any general reference [11-14]. An overview of BJT transistors studied in this work is given in Figure (2).

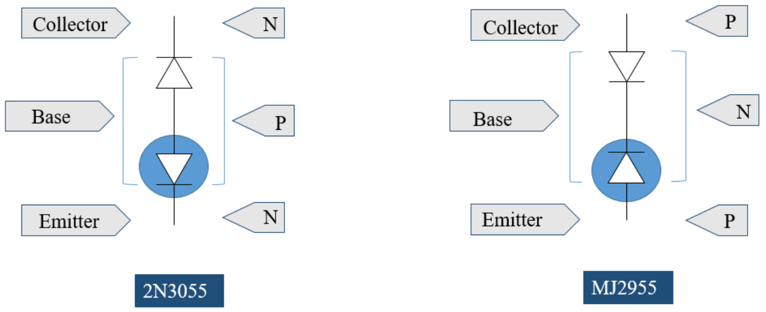

Figure (2) General schematic of the BJT (2N3055 and MJ2955) transistors.

The aim of this study is to investigate the possibility of using p-type segments in PN junction of BJT power transistors as photocathodes to reduce oxygen in a neutral media. The philosophy behind this research is the availability, cheap price and readiness of these semiconductor components without the need for any previous or subsequent treatment. In the future, these components will be used as photocathodes to increase the power of microbial fuel cells (MFCs).

Experimental

The BTJ, 2N3055, and MJ2955 transistors were stripped off their caps as shown in Figure (3) to expose the semiconductor die, and the 2N3055 base and MJ2955 emitter were placed as P-type semiconductors for oxygen reduction reaction (ORR).

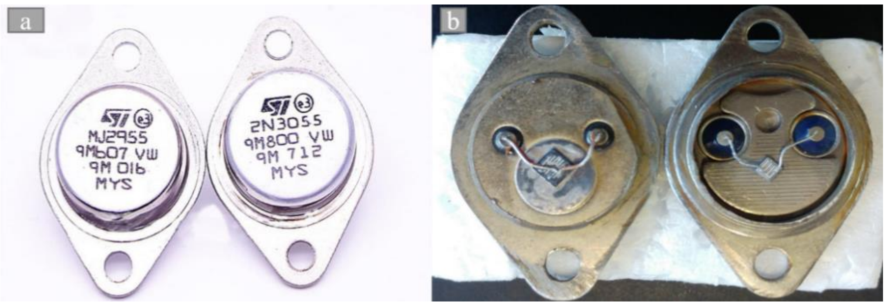

Figure (3) BJT power transistors, (a) before and (b) after decapping

Schematic illustration and actual phpto of the setup used with p-type semiconductors developed in laboratory, which are shown in Figures (4) and (5), respectively.

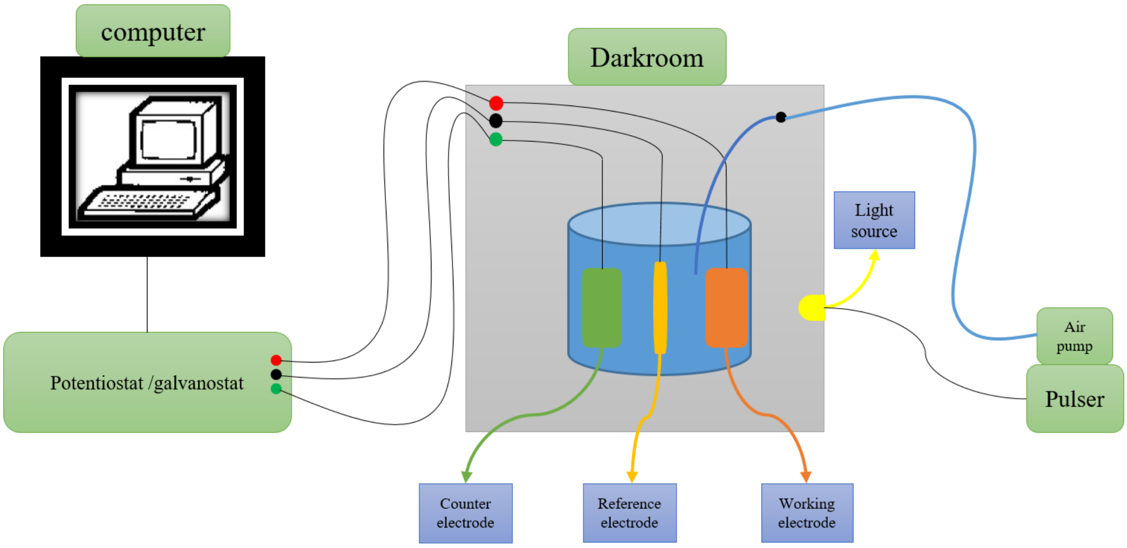

Figure (4) Schematics of a test set-up for semiconductor photocatalytic investigations.


Figure (5) Real photo of the test set-up .

A solution of 1M Na_2SO_4 was used to prepare the neutral electrolyte; stainless steel was used as the counter electrode and Ag / AgCl electrode as the reference electrode.

According to Figure (4), a dark chamber was used in this part, in which a lamp with specifications of 1.5 A, 32V 50W was installed in the chamber to lighten the pulsed light on the BJT semiconductor surface, and also in this chamber, an air pump was employed to aerate at a rate of 2 L/min the catholyte to ensure an O_2 saturation in that area. A Sama500 potentiostat connected to a PC was used for open circuit potential (OCP) and chronoamperometry (CHA) measurments.

Resultsb and Discussion

The OCP test was performed for 100 s in the presence of light and aerated conditions on the p surface of the NPN and PNP transistors and it was observed that in the NPN transistor the voltage increased by about 250mV when the light was pulsed and about 300mV when the pulsed light was irradiated simultaneously with the aeration. The relevant diagrams are given in Figure (6).

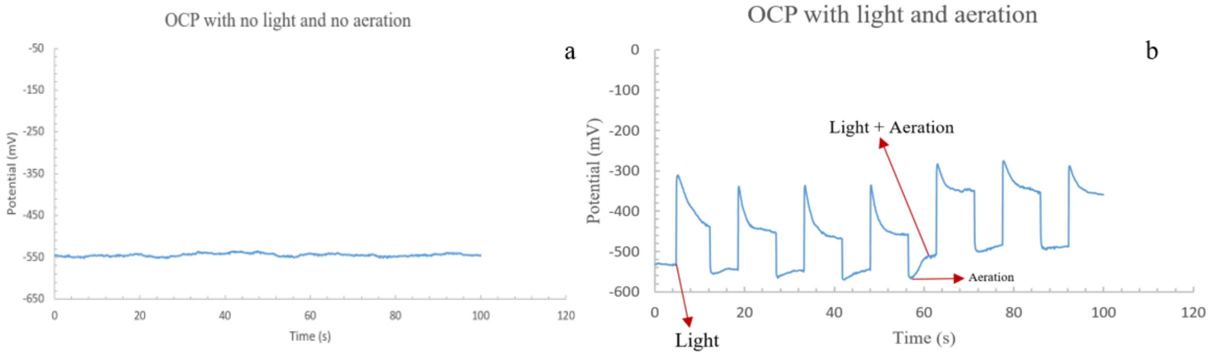

Figure (6) OCP diagram of NPN transistor (2N3055) before (a) and after light exposure and aeration (b).

In the OCP test of the PNP transistor, the voltage increased by about 30mv during irradiation and by about 100mv during aeration at the same time as the pulsed light irradiation, the corresponding diagrams of which are shown in Figure (7). According to the results, it was observed that the effect of light and aeration on the P level of the NPN transistor is much greater than the P surface of the PNP transistor.

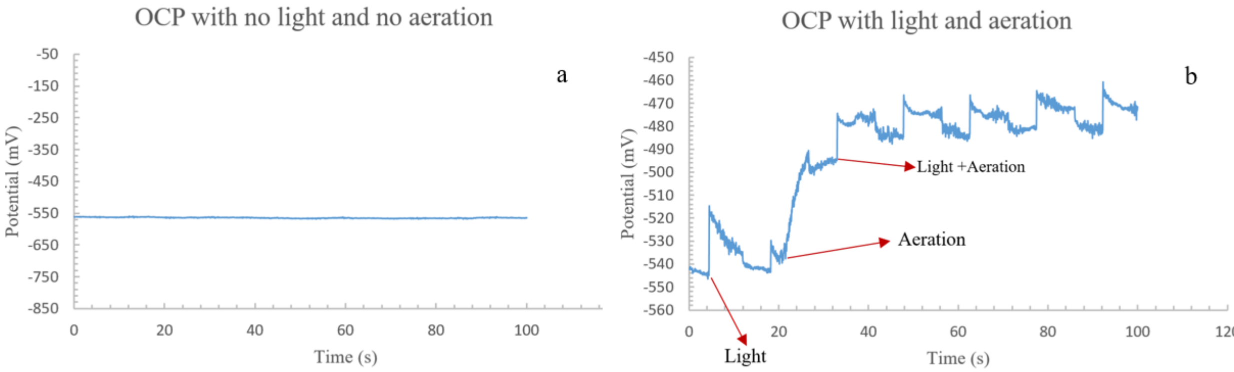

Figure (7) OCP diagram of PNP transistor (MJ2955) before (a) and after light exposure and aeration (b).

The CHA test was performed at an applied potential of -0.54 vs. Ag/AgCl along with exposing both transistors p-type segment to light and at the same time aeration of the solution. During illumination of the p segment of NPN transistor, a current of 600µA was observed which increased to about 800µA after illumination and aeration. These observations were summarized in figure (8).

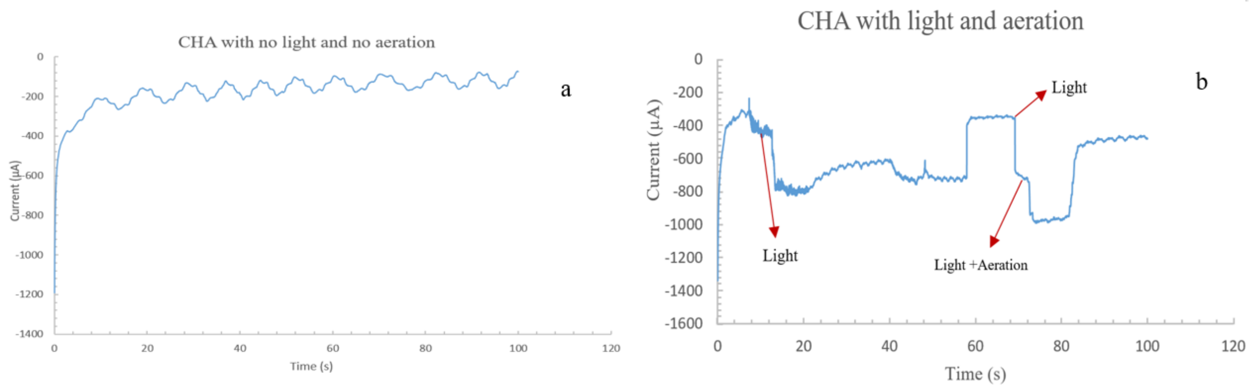

Figure (8) CHA diagram of NPN transistor (2N3055) before (a) and after light exposure and aeration (b).

The CHA test increased on the level of P transistor PNP when the pulsed light of the current of about 610µA and the shining light with aeration of 1200µA current increased; That the corresponding diagrams are brought in Figure (9); According to the results, the effect of light and aeration on increasing PNP transistor flow is higher than NPN.

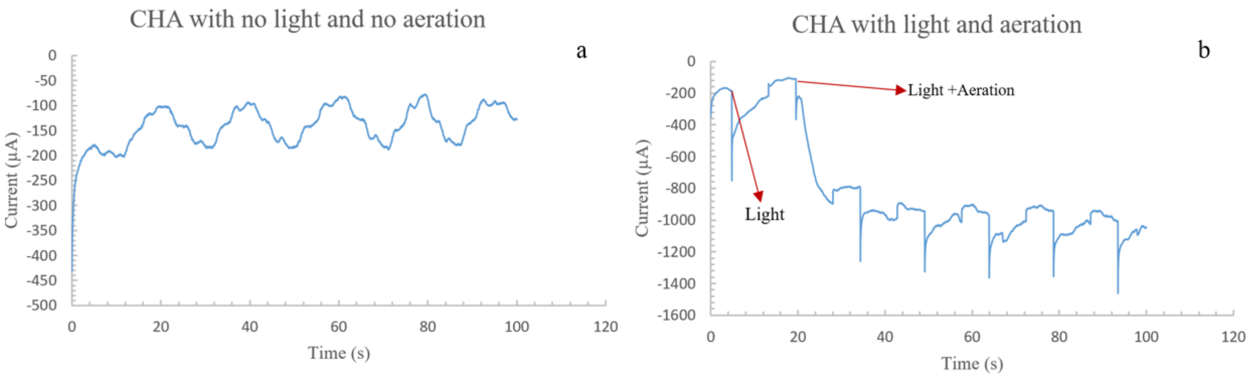

Figure (9) CHA diagram of PNP transistor (MJ2955) before (a) and after light exposure and aeration (b).

Conclusions

In this study, the value of voltage and current generated by oxygen reduction reaction by 2N3055 and MJ2955 transistors was studied by electrochemical methods of OCP and CHA. These transistors can be used as commercially available and inexpensive photocatalytic electrodes in microbial fuel cells, which this experiment is continuing to be designed and implemented.

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