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1D structural CNH dependency in needle type Solid-state CMOS compatible glucose Fuel Cell for open-circuit voltage and their biomedical application

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Abstract

The solid-state CMOS-compatible glucose fuel cell was fabricated on anode area by 1D structural CNH (Carbon Nano Horn), which express an OCV (open-circuit voltage) of 375 mV and the power density of 53.95 μW/mm^2 at 30 mM glucose solution. The developed fuel cell can be manufactured using a semiconductor (CMOS) fabrication process from biocompatible materials for the human body. CNH improved enhancement of the fuel cell due to their high electrocatalytic ability. For the challenge, we have introduced CNH material to fabricate the CMOS compatible glucose fuel cell for the first time.

This work presents a (1 cm 75 mm × 0.7 mm) solid-state CMOS compatible glucose fuel cell that 375 mV of OCV. It is the highest value for a glucose fuel cell when the anode area is (16.2 mm × 0.3 mm). The highest power is 0.42 μW. The power generation is the main challenges in the glucose fuel cell for the biomedical Internet of Things (IoT) applications.

1. Introduction

To developing IoT-based healthcare systems, CMOS-compatible offer high-performance of low-power computing, sensing, and communications. To satisfy these demands, CMOS biosensor LSIs are intensely developed.［1–8］CMOS technology improves the energy efficiency of an IoT-based healthcare system. However, energy-autonomous operation using energy harvesting techniques has been difficult. To address this issue, a CMOS-compatible glucose sensor was proposed and developed in 2010. [9] The developed needle type CMOS-compatible glucose sensor can be fully fabricated with a CMOS-compatible process, which enables integration with CMOS LSIs. The open-circuit voltage (OCV) of the conventional CMOS-compatible glucose fuel cell is only 192 mV. This voltage cannot satisfy the requirement for reliable operation of CMOS LSIs.

The main components in the design of glucose fuel cells are the carbon materials (CNH) as a catalyst the electrode reactions of glucose and oxygen. When CNH catalyst offer less specificity and exhibit lower reaction rates but their stability preferred a long-term application.

Thus, further improvement of OCV is essential for practical application.

In this work, we propose and present a new structure for improving the OCV. We enhanced the performance of a fuel cell by improving the electrocatalytic ability of the anode. The prototype successfully achieved an OCV of 375 mV, which is the highest ever reported. This achievement will contribute to the developments of next-generation's healthcare IoT technology.

2. Experimental methods

The systemic of CMOS-compatible glucose fuel cell shown in Fig.1. The glucose fuel cell gains energy from completely oxidation of glucose. The chemical reaction is as follows:

Anode: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$,
Cathode: $6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$,
Whole: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

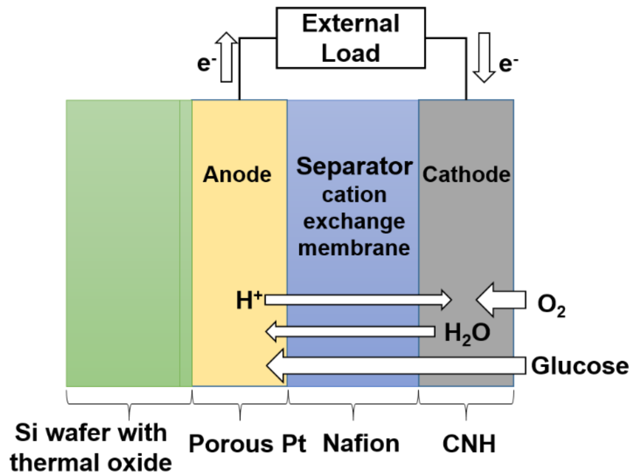

Fig. 1 CMOS-compatible fuel cell

However, Raney platinum cannot mediate complete oxidization of glucose but mainly mediates the oxidation of glucose to gluconic acid. The main chemical reaction mediated by Raney platinum is as follows:

Anode: $C_6H_{12}O_6 + H_2O \rightarrow C_6H_{12}O_7 + 2H+ + 2e-$,

Cathode: $1\ 2O_2 + 2H+ + 2e- \rightarrow H_2O$,

Whole: $C_6H_{12}O_6 + 1\ 2O_2 \rightarrow C_6H_{12}O_7$.

As shown above, oxidation of glucose and reduction of oxygen occur at the anode and cathode, respectively. The theoretical electromotive force generated due to the partial reaction is 1.30 V. The fabrication process is for the wafer-scale CMOS-compatible glucose fuel cell is depicted.

Measurement results Table 1 show the measured output voltage and power as a function of the output current of the prototype using porous-Pt and CNH, respectively. The voltage and current dependence on the power of the CNH (1, 3, 5 and 7 % respectively) OCV in one of the measured at 30 mM glucose solution. The CNH at 3% obtained highest OCV is 375 mV and the peak power density is 55.26 μW/mm^2 when the current density is 184.68 μA/mm^2.

In this work, 1D structural CNH dependency CMOS compatible fuel cell to develop the OCV for the biomedical application. This fuel cell was diffused on the anode surface. Because an anode reaction rate depends on the fuel concentration on its surface, a current density is affected by the CNH %wt ratio due to their less specificity and lower reaction rates. For the results, the glucose fuel cell was performed for the long-term application. On the other hand, the voltage is not significantly affected by fuel diffusion except in the high current range, called diffusion control, but determined by the chemical reaction and losses such as internal resistance. When increased the CNH % weight, the voltage and current were decreased. Each point of view, the CNH resistances were lower, when the amount of CNH increased due to the 1D (one dimensional) structural carbon properties. We need further investigation for this work.

Table 1 Experimental results

CNH (%)	After dropped Glucose solution on CNH				
	Voltage (mV)	Current (μA)	Resistance (kΩ)	Power μW	Power density (μW/mm^2)
1	343.0	1.20	285.8	0.41	53.95
3	375.0	1.13	331.9	0.42	55.26
5	310.0	1.30	238.5	0.40	52.63
7	291.0	1.0	291.0	0.29	38.16

3. Conclusions

CMOS-compatible glucose fuel cells are attractive energy sources of next-generation healthcare sensors. However, the OCV of the existing CMOS-compatible glucose fuel cell is 375 mV. In this work, CNH anode structure for improving the OCV of CMOS-compatible glucose fuel cells is proposed.

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References

[1] K. Niitsu, S. Ota, K. Gamo, H. Kondo, M. Hori, and K. Nakazato, IEEE Trans. Biomed. Circuits Syst. 9, 607 (2015).

[2] K. Niitsu, T. Kuno, M. Takihi, and K. Nakazato, IEICE Trans. Electron. E99-C, 663 (2016).

[3] K. Niitsu, K. Yoshida, and K. Nakazato, Jpn. J. Appl. Phys. 55, 03DF13 (2016).

[4] S. Tanaka, K. Niitsu, and K. Nakazato, Jpn. J. Appl. Phys. 55, 03DF10 (2016).

[5] Y. Yamaji, K. Niitsu, and K. Nakazato, Jpn. J. Appl. Phys. 55, 03DF07 (2016).

[6] H. Ishihara, K. Niitsu, and K. Nakazato, Jpn. J. Appl. Phys. 54, 04DL05 (2015).

[7] T. Kuno, K. Niitsu, and K. Nakazato, Jpn. J. Appl. Phys. 53, 04EL01(2014).

[8] K. Niitsu, A. Kobayashi, Y. Ogawa, M. Nishizawa, and K. Nakazato, Proc. IEEE Biomedical Circuits and Systems Conf., 2015, p. 595.

[9] B. I. Rapoport, J. T. Kedzierski, and R. Sarpeshkar, PLOS ONE 7, e38436 (2012).