International Journal of Engineering and Applied Physics (IJEAP)
Vol.2, No.3, September2022, pp. 544~548
ISSN: 2737-8071

Electrochemical Performance of Laser Modified Zinc Electrode

Reham Seddig Mohammed Ahmed[1], Yousef A. Alsabah[2], Ali A. S. Marouf[3]
[1]Dept. of Physics at College of Science, Sudan University of Science and Technology, Khartoum, Sudan.
[2]Dept. of Physics at College of Education and Applied Science, Hajjah University, Hajjah, Yemen.
[3]Institute of Laser, Sudan University of Science and Technology, Khartoum, Sudan

Article Info

Article history:

Received Jun 15, 2022
Revised Jul 25, 2022
Accepted Sep 02, 2022

Keywords:

Energy storage system
Electrochemical cell
Electron-transfer reactions
Laser-matter interaction
Surface texturing

ABSTRACT

In this work CO_2 laser has been utilized to produce textured surface in zinc foil to use in electrochemical cells as a cathode, the modified surface was obtained by making two parallel lines in 1mm, using CO_2 laser with (λ=10600nm) and power of 90 watts and 10mm/s speed. The experimental evidence of the effect of surface texturing on the performance of the electrochemical cell was demonstrated and investigated. The results show considerable increase in cell voltage with the textured cathode comported to the planar one, also the performance of cell with the textured cathode is more stable.

Corresponding Author:

Ali A. S. Marouf,
Institute of Laser,
Sudan University of Science and Technology,
Khartoum, Sudan.
Email: marouf.44@gmail.com

1. INTRODUCTION

The electron-transfer reactions that occur at the surface of a metal immersed in a solution take place near the surface of the electrode, so there is no way that the electrons passing between the solution and the electrode can be channelled through an instrument to measure their voltage or to control the rate of the reaction. If we have two such metal-solution interfaces, we can easily measure a potential difference between them, such an arrangement is called a galvanic cell, a typical cell might consist of two pieces of metal, one zinc and the other copper [1]. Laser texturing process increases the active surface area. In this work the effect of laser texturing on electrode in the electrochemical cell performance is investigated.

Different types of laser processing were established for increasing the active surface area ‘laser-assisted self-organizing structuring' and ‘direct structuring' of electrodes. The first of these processes can be applied to thin films and thick film electrodes that have small electrode footprint areas (coin cells). The second process is suitable for small and large electrode footprint areas (pouch cells). In 2016 Wilhelm Pfleging et al., used excimer laser ablation at a wavelength of 248nm to produce self-organized surface structures on lithium cobalt oxide and lithium nickel manganese cobalt oxide (NMC) thick- and thin-film electrodes. They found that the active surface area could be increased by a factor of 10. They also used direct laser structuring either with a 200ns fiber laser or an ultrafast fiber laser (380fs)—to form 3D microstructures It improved cycle lifetimes and increased capacity retention [2]. Alexer et al, described the preparation and analysis of laser micro-structured nickel metal electrodes for application as a cathode material in micro-batteries based on the nickel oxyhydroxide chemistry. Using ultra-short pulse length lasers (picoseconds to femtoseconds); surface microstructures in the form of ripples were rapidly generated at the surface of nickel metal cathodes. These ripple micro-structures, with a periodic spacing approximately equal to the wavelength of laser radiation used, are more commonly referred to as laser-induced periodic plasmonic structures (LIPPS). The electrochemical activity of the LIPPS nickel metal cathodes is investigated in aqueous KOH using cyclic voltammetry. Cyclic voltammetry was used to demonstrate that the formation of yields increased electrochemical. The observed improvement is attributed to both the increase in surface area and the thickening of the NiOx overlayer on nickel by localised surface heating during the laser process, as evidenced by Raman spectroscopy and XPS data [3]. Ulrich Muecke, deposited Nickel oxide x (NiO/CGO) films by spray pyrolysis and pulsed laser deposition on polished CGO electrolyte pellets. The thicknesses of the as-deposited films were 500–800 nm. The sprayed films showed a homogeneously distributed nano-grain sized microstructure after annealing in the air whereas the PLD films exhibited a texture with elongated columnar grains oriented perpendicular to the substrate surface. The electrochemical performance of the Ni/CGO cermet thin film anodes was measured in a symmetrical anode/electrolyte/anode configuration in a single gas atmosphere set up by impedance spectroscopy. The electrochemical performance was similar to the state-of-the-art thick film anodes and the Ni/CGO thin film cermets are promising candidates as electrodes in micro solid oxide fuel cells [4].

Several studies were done in deferent applications of the laser matter interactions such as laser-heating in combustion of agricultural wastes [5] [6] [7]. Other researchers used it in enhancing of the ceramic mechanical properties [8] [9]. Numerous studies were done using laser in food irradiations such as milk pasteurization [10] [11], production of yogurt [12], oil irradiation [13][14] and irradiation of bee honey [14]. In this paper we investigate the effect of laser texturing of cathod in electrochemical cell by CO_2 laser and its effect on the electrochemical cell performance.

2. MATERIALS AND METHOD

2.1. Materials

2.1.1. Zinc Electrode

High-purity zinc (99%) foils with a thickness of 500 µm were used in the preparation of the zinc electrodes, with area of 12.25 cm2. The laser spot was scanned across the planar zinc surface in two parallel lines in1mm. The ability of a zinc-based energy storage device to store and deliver power relies on the amount of the electrochemically active material that can accumulate at the electrode/electrolyte interface.

2.1.2. Copper Electrode

High-purity Copper (99.5%) foils with a thickness of 200µm were used in the preparation of the Copper electrodes with an area of 12.25 cm2. It represents a positive electrode in an electrochemical cell.

2.1.3. Zinc Sulfate

Zinc sulfate is the inorganic compound with the formula $ZnSO_4$ with a molarity of 1M and weight 50g.

2.1.4. Copper (II) Sulfate

Copper (II) sulfate, also known as cupric sulfate, or copper sulphate, is the inorganic compound with the chemical formula $CuSO_4$ concentration= 1M.

2.2. Method

2.2.1. Laser-induced periodic structures

Carbon dioxide lasers are the highest-power continuous wave. D1310 CO_2 laser cutting machine was used here. The CO_2 laser produces a beam of infrared light with the principal wavelength bands centring on 9.4 and 10.6 micrometres (10600nm). These are one of the most common types of lasers, are used for many different applications, and maximum output power 90watt. The laser spot was scanned across the planar zinc foil surface in parallel lines at a predefined scan rate 10mm-1 so as to induced periodic structures.

2.2.2. Electrochemical performance

A salt bridge, in electrochemistry, is a laboratory device used to connect the oxidation and reduction half-cells of the galvanic cell (voltaic cell). It maintains electrical neutrality within the internal circuit, preventing the cell from rapidly running its reaction to equilibrium. If no salt bridge were present, the solution in a one-half cell would accumulate negative charge and the solution in the other half cell would accumulate positive charge as the reaction proceeded, quickly preventing a further reaction, and hence production of electricity and the type of the salt inside the bridge K_2SO_4.

Electrochemical measurements were obtained using two-electrode cell equipped with the zinc working electrode, a copper electrode, K_2SO_4 used as the electrolyte in a salt bridge. The voltage of the Electrochemical Cells was measured every one-minute using planar zinc electrode and then using textured zinc electrode with different electrolyte figure 1.

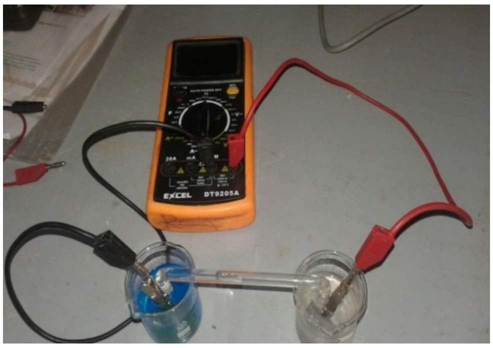

Figure 1. Electrochemical Cell

3. RESULTS AND DISCUSSIONS

The laser-processed area of the zinc strip was observed to reflect infrared light differently compared to the planar unprocessed area, making it apparent which section of the metal had been laser treated. Figure2 represents the periodic-ripple-cathode in the electrochemical cell.

Figure 2: Periodic Ripple Zink foil

The results in table 1 showed the voltage and time of electrochemical cell consisting of Zn/$ZnSO_4$ II $CuSO_4$/Cu for the planer zinc cathode. The results in table 2 showed the voltage and time of electrochemical cell consisting of Zn/$ZnSO_4$ II $CuSO_4$/Cu. After texturing cathode (Zn) with a wavelength10600 nm from IR range and energy 90watt and speed 10mm/s.

Table1: Results of the voltage of the Electrochemical Cell Before Texturing Cathode (Zn)(With Planar Cathode).

Voltage (mv)	Time(Minutes)
0.955	0
0.908	1
0.873	2
0.872	3
0.870	4
0.869	5
0.866	6
0.863	7
0.860	8
0.857	9

Table2: The Results of the Voltage of the Electrochemical Cell after Texturing Cathode (Zn).

Voltage(mv)	Time(Minutes)
1.085	0
1.074	1
1.068	2
1.063	3
1.050	4
1.042	5
1.031	6
1.019	7
1.011	8
1.007	9

The results show a considerable increase in voltage of the electrochemical cell (more surface area) after texturing cathode (Zn) by the CO_2 laser beam. The results of the electrochemical cell obtained in the time (in minute 0) using texturing cathode (Zn) showed a high value of voltage but using planer cathode (Zn) showed ordinary values of voltage, also in last time (in minute 9) using texturing cathode (Zn) the voltage highest than the first result before texturing. It would be expected that maximizing the accessible surface area of zinc cathode would create a larger area for active material accumulation, leading to improved energy storage performance. It produce thickening layer of ZnOx over zinc [1].

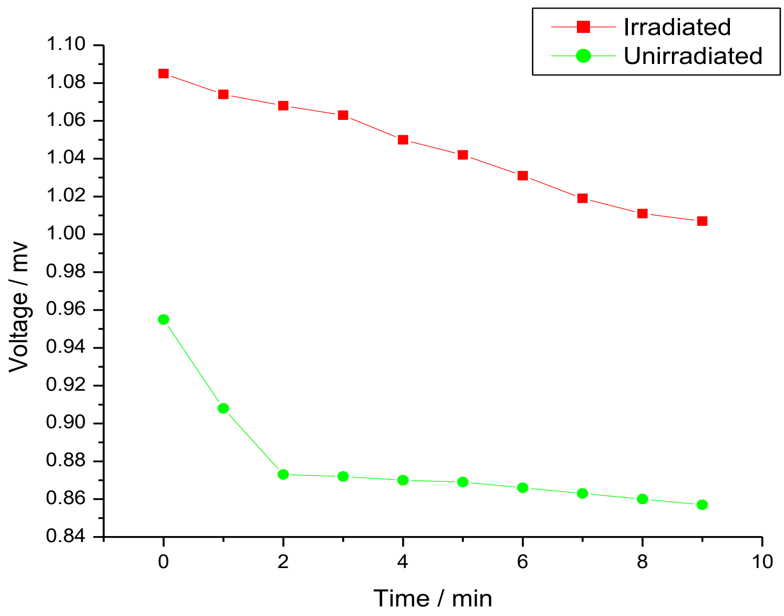

Figure 3: voltage-time curve of the electrochemical cell
(red with textured cathode-green with planar cathode)

Figure 3 shows variation in voltage with an increase of time, the area under the curved for the irradiated cathode (red curve) is 0.99101 and the area under the curved for unirradiated (green curve) is 0.97052.The area under the voltage curves indicating the total voltage of the two cells, the area of the total quantum yield before and after texturing increase by a factor 2.1% over the whole time operation. From this figure, it can be seen that in the case of the electrochemical cell with irradiated cathode the slope is equal to 0.0087 which is mean that the performance is relatively stable from the begin time to the end. The case of the non-irradiated cell the curve is divided into two slopes from the first time to the third the slope is 0.041 and from the fourth time to the end the curve slope is equal 0.00178, it is observed that the second region is more stable than the first region or Irradiated cell.

4. CONCLUSION

In conclusion, the effect of the laser on improving the electrochemical cell performance was obtained; it was found that irradiation of the cathode of the cell by carbon dioxide laser beam increase the cell surface area and leads to increased voltage. It has been reached to increase the cell performance by a factor about 2.1%. It was observed that laser carbon dioxide does not affect the positive electrode of the cell (Cu) because of reflectivity of copper is 90% in IR. In the future works, one can study the effect of laser texturing in the anode, studing the relation of current and time and determine the efficiency of Irradiated cell.

ACKNOWLEDGEMENTS

Authors would like to thank the Institute of Laser at Sudan University of Science and Technology (SUST) for providing equipment used in this work.

REFERENCES

[1] Alexer, Neale, Yang Jin, Jinglei Ouyang, Stephen Hughes, David Hesp, Vinod Dhanak, Geoff Dearden, Stuart Edwardson, Laurence. Hardwick (2014) "Electrochemical performance of laser micro-structured nickel oxyhydroxide cathode" Journal of Power Sources.

[2] Lower, S., 1999. Chem1 virtual textbook.

[3] Ulrich, (2007). Tokyo Institute of Technology, S8-11, 2-12-1, O-Okayama, Meguro-ku, Tokyo, 152-8552, Japan.

[4] Pfleging, W., Mangang, M., Zheng, Y., Smyrek, P. and Pröll, J., (2016). Production of Lithium-Ion Batteries."laser effect for improved electrochemical cell performance". Newsroom 10.1117/2.1201602.006342.

[5] Awad, A.A.G., Gawbah, M.A.P., Orsod, M.U., Alsabah, Y.A. and Marouf, A.A., 2020. Investigation of the Effects of Laser-Based Combustion on Sorghum Bran. Albaydha University Journal, 2(2), pp.52-59.

[6] Gawbah, M.A.P., Elbadawi, A.A., Alsabah, Y.A., Orsod, M.U. and Marouf, A.A., 2018. Characterization of the Crystal Structure of Sesame Seed Cake Burned by Nd: YAG Laser. Journal of Materials Science and Chemical Engineering, 6(04), p.121. https://doi.org/10.4236/msce.2018.64013

[7] Gawbah, M.A.P., Marouf, A.A., Alsabah, Y.A., Orsod, M.U. and Elbadawi, A.A., 2017. Synthesis of Silica, Silicon Carbide and Carbon from Wheat Bran and Converting its Crystal Structure Using Nd: YAG Laser. International Journal of Advanced Research in Physical Science, 4(11), 31-37.

[8] Awadala, A.S., Elfaky, A.E. and Marouf, A.A., 2020. Influence of high power Nd: YAG laser on hardness and surface properties of zirconium silicate. Int. J. Mat. Math. Sci, 2(3), pp.39-44. https://doi.org/10.34104/ijmms.020.039044

[9] Awadala, A. S., Elfaky, A. E., and Marouf, A. A. S., 2020. INVESTIGATION OF THE EFFECTS OF HIGH-POWER Nd: YAG LASER ON ZIRCONIUM SILICATE SURFACEROPERTIES. International Journal of Latest Research in Science and Technology, 9(4), pp. 6-10. https://dx.doi.org/10.29111/ijlrst-2018-10959

[10] Marouf, A. and Sara, I.E., 2017. Monitoring pH During Pasteurization of Raw Cow's Milk using Nd: YAG Laser. International Journal of Advanced Research in Physical Science (IJARPS), 4(12), pp.1-4.

[11] Amna O.B Malik and Marouf, A.A., 2018. Comparison of the Effects of Laser Pasteurization and Heat Pasteurization on The Cow's Milk, Haya: The Saudi Journal of Life Sciences,3 (1), 46-50.

[12] Marouf, A. A. S. & Esra O. H. Siddiq, 2018. "Evaluation of Laser Pasteurization on Production of Yogurt", International Journal of Advanced Research in Physical Science (IJARPS), 5(4), pp. 15-23.

[13] Mudawi, A.A. and Marouf, A.A., 2022. Impact of Single Wavelength (532 nm) Irradiation on the Physicochemical Properties of Sesame Oil. Journal of Materials Science and Chemical Engineering, 10(4), pp.1-15. https://dx.doi.org/10.4236/msce.2022.104001

[14] Mudawi, A.A. and Marouf, A.A.S. (2022) Evaluation of Laser-Heating and Laser-Reheating of Sunflower (Helianthus annuus) Seed Oil Quality. Open Access Library Journal, 9: e8883. https://doi.org/10.4236/oalib.1108883

[15] Ahmmed, A. E. G., A. and Marouf, A.S., 2017. Effect of Pulsed He-Ne Laser Irradiation on Bee Honey Physicochemical Properties. Res Rev Insights, 1(4), 6-7. doi:10.15761/RRI.1000122.