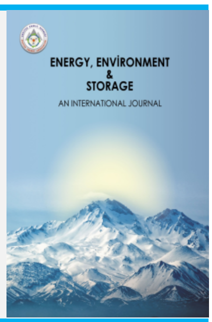
Research Article *Energy, Environment and Storage* (2023)03-03:119-125

Energy, Environment and Storage

Journal Homepage: www.enenstrg.com



Investigation of Deep Eutectic Solvent Based Super Dielectric Electrolytes for Supercapacitors

Ekrem Akif Yigit[1,3], Yahya Erkan Akansu[2,3*]

[1] *Department of Electronics and Automation, Nigde Omer Halisdemir University, Türkiye*

[2] *Department of Mechanical Engineering, Nigde Omer Halisdemir University, Türkiye*

[3] *Faradx Energy Technologies, Nigde Teknopark, Nigde, Türkiye*

ABSTRACT. This study investigates a new type of electrolyte based on deep eutectic solvents. Choline chloride based deep eutectic solvents were prepared and they were used as base ionic solvents for super dielectric theory. Deep eutectic solvent was mixed with a non-conducting material such as fumed silica, alumina. The mixture shows a super dielectric behavior which is used as electrolyte for electrochemical double layer capacitors also known as supercapacitor. The supercapacitor cells were composed of an electrode, a paper-based separator and this super dielectric electrolyte. The electrode of commercial standard supercapacitor is used first as an electrode. Second an electrode slurry was prepared in order to make custom electrode. Then the performance of both cells was investigated. The specific capacitances of cells were measured and the amount of increase at the capacitances was evaluated. The results showed that up to 14-fold increase of the specific capacitances of the commercial supercapacitor have been achieved. Also, up to 12-fold increase of the specific capacitances of our custom-made cells have been achieved. The charge discharge characteristics and ESR values of the cells confirms that the cells show outperforming properties. Deep eutectic solvents based super dielectric electrolytes are very promising electrolytes for high energy density supercapacitors.

Keywords: *Super Dielectric***,** *Supercapacitor, Equivalent Series Resistance (ESR)*

Article History: Received:18.07.2023; Accepted:28.09.2023; Available online: 30.09.2023
Doi: https://doi.org/10.52924/MSKH9311

1. INTRODUCTION

The needs of energy storage systems are increasing rapidly nowadays because of developing mobile systems, electrical vehicles and renewable energy system such as solar and wind power generation facilities. The major energy storage systems still use lead acid and lithium-ion batteries. The problem of existing battery systems such as highly cost, short life, safety and difficult production processes increase the needs of promising energy storage systems. One of the possible alternatives of current battery system is electrochemical double layer capacitors [1,2].

Electrochemical double layer capacitors (EDLCs), also known as supercapacitors or ultracapacitors are the most promising energy storage technology [3]. In EDLCs the charge is electrostatically stored at the electrode and electrolyte interface. These devices can be charged and discharged within seconds. They can give high power (up to 10 kW) and a high cycle life (>500,000). Now, the commercial EDLCs contain activated carbon as active material and electrolytes based on quaternary ammonium salt dissolved in organic solvents (acetonitrile (ACN) or propylene carbonate (PC)). The cell voltage of these EDLCs are 2.3 V and 2.7 V. In order to use EDLCs in today applications, their energy storage capacities need to be improved. The specific energy of EDLCs is defined by the equation E=1/ 2CU2, where C and U are the capacitance and operative voltage of the EDLC, respectively [4-6].

Traditional electrolytes for EDLCs can be generally divided into aqueous, organic, IL and solid- or quasi-solid types [7,8]. The working voltage of a EDLCs is determined by the decomposition of an electrolyte on the electrode surface at high potential. The working voltage of a EDLCs can be raised from 2,3 V to 2.7 V using organic electrolytes instead of aqueous electrolytes. The common working voltage of commercial EDLCs with organic electrolytes is 2.7 V. Because the energy density of a EDLCs is directly proportional to the squared working voltage, the research is focused on developing

*Corresponding author: akansu@ohu.edu.tr

electrolytes with high conductivity, good chemical and thermal stability, and wider electrochemical window. An organic electrolyte is composed of an organic solvent and a supporting electrolyte [9]. The organic solvent must have low volatility, good electrochemical stability and large dielectric constant.

In recent years, as a new type of green electrolyte, Ionic Liquids (IL) has been widely used in EDLCs. IL is featured with wide electrochemical window, relatively high conductivity and ion mobility. Deep Eutectic Solvents (DES) are also a new type of green electrolyte which has wide electrochemical windows as alternative of ILs. DES can be produced cost effectively and easily. Super dielectric materials are also newly proposed subject and getting more interest recently. Their dielectric constant can be between 106-1012 [10].

In the present study, we synthesized a novel deep eutectic solvent-based super dielectric electrolytes and used on both standard commercial and custom-made supercapacitor electrodes to demonstrate its effect. As an outstanding result, the synthesized super dielectric electrolyte exhibited the specific capacitance of up to 14-fold increase for standard commercial supercapacitor electrodes and 12-fold increase for custom made supercapacitor electrodes.

2. EXPERIMENTAL

The chemicals choline chloride (ChCl), urea, monoethylene glycol, glycerin, malonic acid, boron nitride and alumina were purchased from Sigma Aldrich, Germany. Fumed silica, xylitol and carboxymethyl cellulose (CMC) were purchased from Introgen, Türkiye and the activated carbon and Styrene-butadiene rubber (SBR) were obtained from Nanografi, Türkiye. The commercial supercapacitors were purchased from Greencap, South Korea. All chemicals were used without further purification.

2.1 Preparation of Deep Eutectic Solvents (DES)

Deep eutectic solvents (DESs) are new class of ionic liquid (IL) because they share a lot of characteristics and properties with ILs [11-15]. DESs contain large, nonsymmetrical ions. They have low lattice energy and low melting points. They are usually obtained by the complexation of a quaternary ammonium salt with a metal salt or hydrogen bond donor. Different type of DESs can be made by using suitable chemicals [16].

The following DESs were prepared by mixing at magnetic stirrer at 80 C about 1 hour. Then they were slowly cooled to room temperature. The molar ratios were used in order to make deep eutectic solvents as $\boldsymbol{ChCl + Urea}$ (1:2); $\boldsymbol{ChCl + Glycerin}$ (1:2); $\boldsymbol{Chcl + MEG}$ (1:2); $\boldsymbol{ChCl + Malonic\ acid}$ (1:2); $\boldsymbol{ChCl + Xylitol}$ (1:2). These are well known DESs and their characterization is available at scientific literature [12-14]. Our interest is to see the super dielectric properties of DESs when they mixed with non-conducting powders.

The electro chemical voltage window of these DESs is given Table 1. The supercapacitor cells are charged according to this table. This EPWs were accepted as a cell voltage but, the real stable cell voltages were below these voltages because of water content in the DESs. DESs contain water since the chemicals that we use are not anhydrous. If the chemicals are anhydrous and the electrolyte is injected in controlled atmosphere, EPWs will be at Table 1. We did not use a controlled atmosphere to see the performance of DESs at open atmosphere.

Table 1: The EAL, ECL and EPWs of ChCl Based DESs [17-19].

DESs	E_{AL} (V)	E_{CL} (V)	EPWs (V)
ChCl + glycerol	–2.21	1.38	3.59
ChCl + urea	–2.75	1.54	4.29
ChCl + MEG	–2.35	1.26	3.61
ChCl+malonic acid	–2.55	1.70	4.25
ChCl+xylitol	–2.67	1.66	4.33

2.2 Preparation of Super Dielectric Electrolyte

Super Dielectric Materials subject is a new theory that can be verified by experimental studies [20-22]. The super dielectric theory was first discovered by Prof. Jonathan Phillips and his friends.

According to theory, any porous, non-conducting material with a liquid containing a high concentration of ionic species will potentially be a Super Dielectric Material (SDM). The dielectric constant of SDM can be measured by making a parallel plate capacitor. The dielectric constant can be obtained from the time constant and this standard equation:

$$\boldsymbol{C = \varepsilon_0\ \varepsilon_R\ A/d}$$

where ε_0 is the permittivity of free space (8.85 × 10−12 F/m) and ε_R is the dielectric constant. The area of the plate surface is A and the distance between the two electrode surfaces is d. The measured dielectric constant is between $\boldsymbol{5 \times 109 - 1.2 \times 1011}$ [23].

Different type electrostatic capacitors (EC) were made by super dielectric materials that have energy density greater than 200 J. cm3 [24,25].

According to Super Dielectric Materials theory, the electrolyte is needed to mix with any non-conducting nano powder. Our deep eutectic solvents were mixed with fumed silica for one sample, mixed with boron nitride for second sample. The produced electrolyte has gel like properties. This electrolyte is our new electrolyte for EDLCs. Five different types of DESs and three different types of non-conducting powders were used in order to make 15 different types of super dielectric electrolyte. Table 2. shows these super dielectric electrolytes (Fig. 1).

Table 2. Our new super dielectric electrolytes

DESs	Non conducting powder
ChCl+glycerol	Fumed Silica
ChCl+urea	Fumed Silica
ChCl+MEG	Fumed Silica
ChCl+malonic acid	Fumed Silica
ChCl+xylitol	Fumed Silica
ChCl+glycerol	Boron Nitride
ChCl+urea	Boron Nitride
ChCl+MEG	Boron Nitride
ChCl+malonic acid	Boron Nitride
ChCl+xylitol	Boron Nitride
ChCl+glycerol	Alumina
ChCl+urea	Alumina
ChCl+MEG	Alumina
ChCl+malonic acid	Alumina
ChCl+xylitol	Alumina

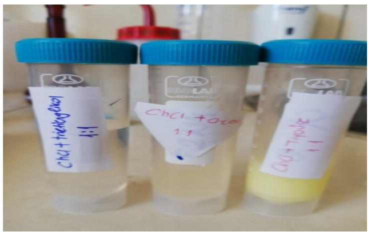


Fig. 1 - Some samples of prepared DESs

2.3. *Fabrication of EDLC cells*

EDLC cells were prepared 2 different methods. First a commercial supercapacitor cell used. Second an electrode was made by electrode slurry.

2.3.1. Using Commercial Cell Electrode

A commercial 2,7V, 500 F supercapacitor as shown in Fig. 2 was disassembled, and its electrode and paper type separator in Fig. 3 were used to fabricate of supercapacitor

Fig. 2 - Disassembled standard commercial supercapacitor

Fig. 3 - The electrode and separator taken from disassembled standard commercial supercapacitor.

First, before disassembling process, its real capacity was measured by ZTE electronic load via PC. Its real capacity was between 380-430 F. The size of the electrode of the cell were measured. It is 4.5 cm x 77 cm. Then the specific capacity was calculated, and it was found 0,32 F/cm2 as expected. In order to compare our results with the commercial cell easily, the electrode was cut 1 cm x 2 cm sizes and a new cell was constructed by using this electrode by using 1 cm x 1 cm of the electrode as shown in Fig. 4.

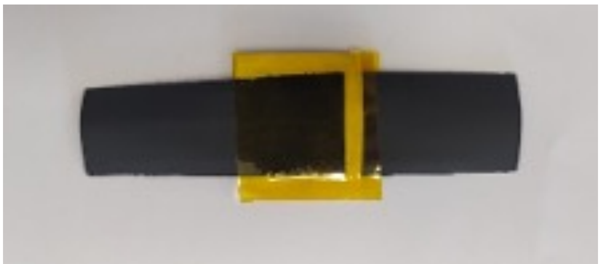


Fig.4 - The finished cell

Then, our deep eutectic solvent based super dielectric electrolyte was injected on two electrode and the paper separator were used and the cell were constructed. Then the cell insulated by Kapton tape. Fig. 5 shows our cell structure used in our measurements.

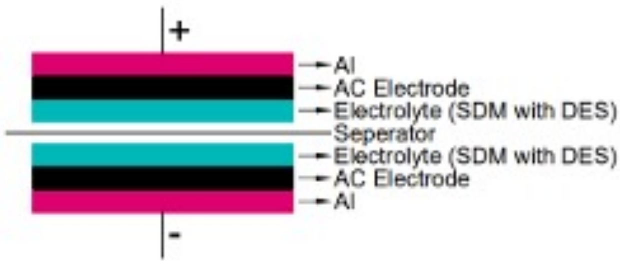


Fig. 5 - Cell structure of the supercapacitor

3. MAKING CUSTOM ELECTRODE:

3.1. Preparation Electrode Slurry

Three items are necessary for making a conductive ink. These are a solvent (water, ethanol, DMF etc.), a binder (water-based adhesive, etc.) and an active ingredient (activated carbon, graphene, a conductive material (carbon black, Super-P etc.) We used the same and common formula that is used at commercial supercapacitors. It is 80% Activated Carbon +10% Conducting Material + %10 Binder. We used activated carbon as active ingredient, graphite powders as conductive material and CMC+SBR mixture as binder. First, 0.25g of CMC added to 50 ml DI water and stirred at magnetic stirrer at 70 C about 1 hour then 0.25g of SBR added slowly into this solution and stirred about 1 hour at 70 C. 8,5g of activated carbon was mixed with 1 g of graphite powder. Then this mixture added to binder (CMC-SBR). The mixture was stirred at vacuum mixer about 4 hours. Then the electrode slurry was obtained (Fig. 6). The viscosity of the slurry was measured with a digital viscosity meter. The viscosity was adjusted between 4000-5000 cpt by adding more DI water and vacuum mixing.

Fig 6- Electrode slurry and its visual testing on paper.

3.2. Coating Slurry

Copper or aluminium strips were cut to the desired scale. The surface of strip was cleaned with ethanol. The prepared electrode slurry was coated by Dr. Blade on a special Al foil (Fig 7). The coating thickness is 100 □m. Then allowed to dry in an oven at 50 °C about 5 hours.

Fig. 7 - Film coating machine with drying oven (TOB-VFC-150) and coated electrode.

3.3. Calendaring Electrode

The coated electrode was processed at hot roll press (Fig. 8). The thickness of active material was reduced to 65 μm. After this process the surface of the electrode became smooth and perfect. Then the electrode was vacuum dried at 60 C about 2 hours in order to remove the water content. Then the electrode was cut by a mechanical blade under hydraulic press.

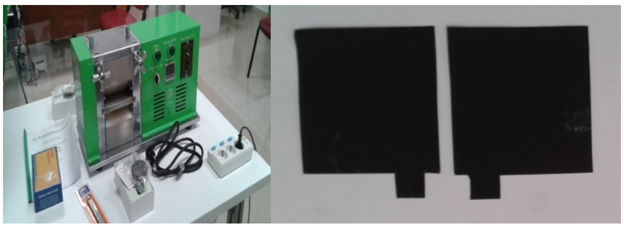


Fig. 8 - Hot roll press machine (TOB-JS100L) and prepared electrode.

3.4. Making Cells

To make a supercapacitor, the cut electrodes were stacked with a NKK 4030 type separator then our electrolyte was added. The cell was insulated by a Captone tape. One of made supercapacitors is shown in Fig. 9. In order to understand the standard cell capacity of our electrode, 3M KOH solution was used as electrolyte first. Then, its specific capacitance was measured. It is 0.4 F/cm^2

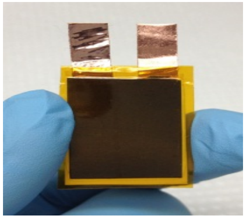


Fig. 9 - Finished Cell

3.5. Instrumentation

The ESR of the cell were measured by MESR-100 model digital ESR meter, 100 kHz in circuit test. The capacity of the cell was measured by charging and discharging the cell. The cell was charged by a DC power supply up to cell voltage of our electrolyte and the cell were discharged by ZTE electronic load via PC under constant current. According to C=Dt*I/DV equation, the cell capacity was calculated. This process was repeated several times. It showed that, the cells are EDLCs but its discharge voltage characteristic is a little bit different. According to SDM theory, the discharge voltage is effective below 1V. Fig. 10 shows a discharge graph of ChCl + MEG + Boron Nitride Sample.

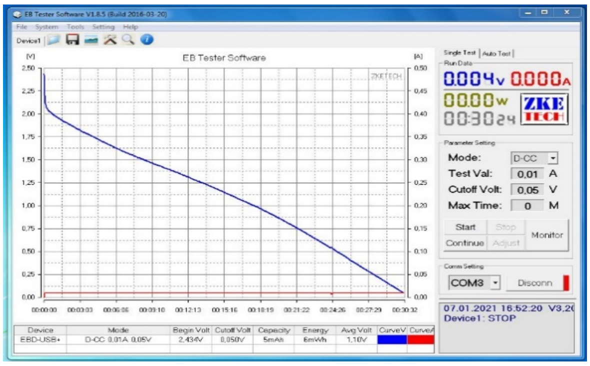


Fig. 10 - ChCl + MEG + Fumed Silica Cell.

The calculated Cell capacity is about 8,77 F for 2 cm^2 cell. The specific capacitance is 4,39 F/cm^2

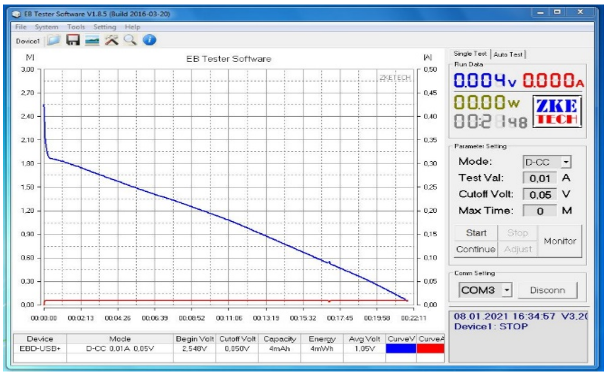


Fig. 11 - ***ChCl + MEG + Boron Nitride*** Cell.

The calculated cell capacity is 7,07 F for 2 cm2 cell. The specific capacitance is 3,54 F/cm2 for commercial supercapacitor electrode cell (Table 3). The best one is ChCl-MEG- Fumed Silica cell, it has about 14-fold increased capacity over KOH electrolyte. Table 4 shows specific capacity of custom-made supercapacitor cells. The best one is ChCl-MEG cell, it has about 12-fold increased capacity over KOH electrolyte. ChCl-MEG shows the best performance because of low viscosity and high conductivity of MEG.

Table 3. Specific capacity of commercial supercapacitor electrode made cells.

Electrolyte Type	**Specific Capacitance (F/cm2)**
ChCl+glycerol - Fumed Silica	2,90
ChCl+urea - Fumed Silica	3,11
ChCl+MEG - Fumed Silica	3,54
ChCl+malonic acid - Fumed Silica	2,59
ChCl+xylitol - Fumed Silica	2.33
ChCl+glycerol - Boron Nitride	2.03
ChCl+urea - Boron Nitride	2,09
ChCl+MEG - Boron Nitride	3,25
ChCl+malonic acid - Boron Nitride	2.17
ChCl+xylitol - Boron Nitride	1,78
ChCl+glycerol - Alumina	2.07
ChCl+urea - Alumina	1.98
ChCl+MEG - Alumina	2,60
ChCl+malonic acid - Alumina	1.55
ChCl+xylitol - Alumina	1.67

Table 4. Specific capacity of Custom-made supercapacitor cells

Electrolyte Type	**Specific Capacitance (F/cm2)**
ChCl+glycerol - Fumed Silica	3,64
ChCl+urea -Fumed Silica	3,21
ChCl+MEG- Fumed Silica	4,27
ChCl+glycerol -Boron Nitride	3.73
ChCl+urea -Boron Nitride	3,69
ChCl+MEG -Boron Nitride	4,77

4. RESULTS AND DISCUSSION

ESR values of the cell were measured with a digital ESR meter. CV measurements were taken with a cyclic voltmeter device.

4.1. Electrochemical properties of EDLCs cells

ESR Values of Some Capacitors

470 uF 16 V standard capacitor 11 mΩ

10F 2.7 V supercapacitor 30 mΩ

ESR value of commercial supercapacitor cell is 30 mΩ

Table 5. ESR values of same samples (commercial cell electrode)

DESs - Non conducting powder	**ESR(Ohm)**
ChCl+glycerol - Fumed Silica	44,6
ChCl+urea - Fumed Silica	34,2
ChCl+MEG - Fumed Silica	18,6
ChCl+malonic acid - Fumed Silica	36,4
ChCl+xylitol - Fumed Silica	46,1
ChCl+glycerol - Boron Nitride	43,2
ChCl+urea - Boron Nitride	33,7
ChCl+MEG - Boron Nitride	16,4
ChCl+malonic acid - Boron Nitride	34,5
ChCl+xylitol - Boron Nitride	48,7
ChCl+glycerol - Alumina	45,0
ChCl+urea - Alumina	37,4
ChCl+MEG - Alumina	22,2
ChCl+malonic acid - Alumina	33,9
ChCl+xylitol - Alumina	45,1

As seen Table 5, ChCl + MEG samples have lower ESR because of the viscosity. Therefore, ChCl + MEG based electrolytes were studied. In order to understand our cell shows a real EDLC characteristics, a CV measurement weas made. Fig. 12 shows that our cell shows a EDLC characteristics.

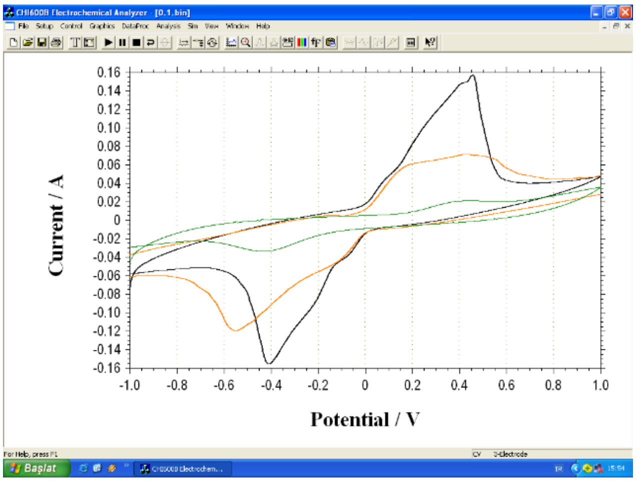


Fig. 12 - A sample from CV measurement of our cells (on commercial supercapacitor electrode) (8 Black: ChCl + MEG with Fumed Silica, Red: ChCl + glycerol with Fumed Silica, Green: ChCl + urea with Fumed Silica).

Nyquist plots of ChCl-MEG type DES electrolyte - fumed silica cell is shown in Fig.13. It shows the behaviour of an ideal capacitor at straight line parallel to the imaginary axis.

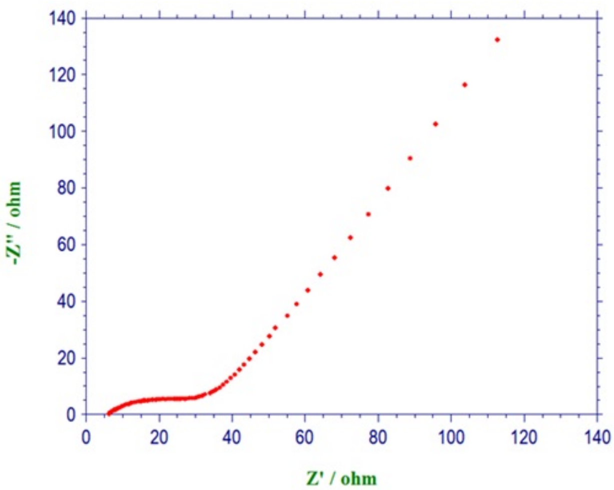


Fig. 13 - Nyquist plots of ChCl-MEG -Fumed silica electrolyte cell (on commercial supercapacitor electrode).

5. CONCLUSIONS

The commercial supercapacitor cells have 0,32 F/cm2 specific capacitance and it gives 4,7 Wh/kg energy density.

Our ***ChCl + MEG + Fumed Silica cell*** (on commercial supercapacitor electrode) showed 4,54 F/cm2 specific capacitance and it is about 14 fold increase and ChCl +MEG +Boron Nitride cell (on custom made supercapacitor electrode) showed 3,54 F/cm2 and it is about 12 fold increase. The capacity increase comes from high dielectric constant of ChCl-MEG and non-conducting powder mixture.

The energy densities will be less than 12-14-fold since the electrolyte volume is bigger than the standard electrolytes. The electrolyte contains fumed silica and boron nitride. They increase the volume of the cells.

Deep eutectic solvent based super dielectric electrolyte works both commercial supercapacitor cells electrode and custom made cells electrode. But ESR values are very big because of high viscosity and content of nonconducting powders in electrolyte.

ChCl + Glycerol and ChCl + Urea showed worse ESR because of viscosity. By adding other chemicals to DESs, ESR can be lowered.

CV plot and Nyquist plot confirm the capacitive behaviour of the cells.

Specific capacitance increases with lower viscosity. ChCl-MEG gives the highest specific capacitance because of low viscosity and high ionic conductivity.

Deep eutectic solvent based super dielectric electrolytes are very promising for making high energy density supercapacitors at their usage in hydrogen energy systems.

Acknowledgements

This study is supported by KOSGEB Research & Development and Innovation Support Program (Project No:1723948).

REFERENCES

[1] Mondal S, Rana U, Malik S. Reduced graphene oxide/Fe3O4/ polyaniline nanostructures as electrode materials for an allsolid- state hybrid supercapacitor. J. Physical Chemistry C 2017; 121:7573-7583. https://doi: 10.1021/acs.jpcc.6b10978

[2] Dalvand, S., Khoushab, Z., Mousavi-Khoshdel, S. M., Ghafuri, H., Zand, H. R. E., & Omidvar, M. (2023). Graphene oxide@ Fe3o4@ Tungstate modified ionic liquid as a novel electrode material for high-performance supercapacitor. International Journal of Hydrogen Energy, 48(27), 10098-10107. https://doi.org/10.1016/j.ijhydene.2022.12.026

[3] Libich J, Máca J, Vondrák J, Čech O, Sedlaříková M. Supercapacitors: Properties and applications. Journal of Energy Storage 2018; 17:224-227. https://doi.org/10.1016/j.carbon.2022.08.091

[4] Hashim MAB, Sa'adu L, Dasuki KA. Supercapacitors based on activated carbon and polymer electrolyte. International Journal of Sustainable Energy and Environmental Research 2012;1(1):1-6.

[5] Horn M, MacLeod J, Liu M, Webb J, Motta N. Supercapacitors: a new source of power for electric cars?. Economic Analysis and Policy 2019; 61:93-103. https://doi.org/10.1016/j.eap.2018.08.003

[6] Ye W, Wang H, Ning J, Zhong Y, Hu Y. New types of hybrid electrolytes for supercapacitors. Journal of Energy Chemistry 2021;57:219-232. https://doi.org/10.1016/j.jechem.2020.09.016

[7] Mirzaeian M, Abbas Q, Ogwu A, Hall P, Goldin M, Mirzaeian M, Jirandehi HF. Electrode and electrolyte materials for electrochemical capacitors. International Journal of Hydrogen Energy 2017;42(40):25565-25587. https://doi.org/10.1016/j.ijhydene.2017.04.241

[8] Obreja VV, Dinescu A, Obreja AC. Activated carbon based electrodes in commercial supercapacitors and their performance. Int. Rev. Electr. Eng 2010;5(1):272-281.

[9] Yanik MO, Yigit EA, Akansu YE, Sahmetlioglu E. Magnetic conductive polymer-graphene nanocomposites-based supercapacitors for energy storage. Energy, 2017;138:883-889. https://doi.org/10.1016/j.energy.2017.07.022

[10] Fromille S, Phillips J. Super dielectric materials. Materials 2014;7(12):8197-8212. https://doi.org/10.3390/ma7128197

[11] Kowsari E. High-performance supercapacitors based on ionic liquids and a graphene nanostructure. In Ionic Liquids-Current State of the Art 2015; IntechOpen. http://dx.doi.org/10.5772/59201

[12] Garcia G, Aparicio S, Ullah R, Atilhan M. Deep eutectic solvents: physicochemical properties and gas separation applications. Energy & Fuels 2015;29(4):2616-2644. https://doi.org/10.1021/ef5028873

[13] Smith EL, Abbott AP, K. Ryder S | Chem. Rev. Deep eutectic solvents (DESs) and their applications. Chemical reviews 2014;114(21):11060-11082. dx.doi.org/10.1021/cr300162p

[14] Li, G., Yang, H., Zuo, D., Xu, J., & Zhang, H. (2021). Deep eutectic solvent-based supramolecular gel polymer electrolytes for high-performance electrochemical double layer capacitors. International Journal of Hydrogen Energy, 46(24), 13044-13049. https://doi.org/10.1016/j.ijhydene.2021.01.158

[15] Puttaswamy R, Mondal C, Mondal D, Ghosh D. An account on the deep eutectic solvents-based electrolytes for rechargeable batteries and supercapacitors. Sustainable Materials and Technologies 2022;33:e00477. https://doi.org/10.1016/j.susmat.2022.e00477

[16] Gurkan B, Squire H, Pentzer E. Metal-free deep eutectic solvents: Preparation, physical properties, and significance. The Journal of Physical Chemistry Letters 2019;10(24):7956-7964. https://doi.org/10.1021/acs.jpclett.9b01980

[17] Ong SP, Andreussi O, Wu Y, Marzari N, Ceder G. Electrochemical windows of room-temperature ionic liquids from molecular dynamics and density functional theory calculations. Chemistry of Materials 2011;23(11):2979-2986. https://doi.org/10.1021/cm200679y

[18] Kadhom MA, Abdullah GH, Al-Bayati N. Studying two series of ternary deep eutectic solvents (choline chloride–urea–glycerol) and (choline chloride–malic acid–glycerol), synthesis and characterizations. Arabian Journal for Science and Engineering 2017;42(4):1579-1589. https://doi.org/10.1007/s13369-017-2431-4

[19] Li Q, Jiang J, Li G, Zhao W, Zhao X, Mu T. The electrochemical stability of ionic liquids and deep eutectic solvents. Science China Chemistry 2016; 59:571-577. https://doi.org/10.1007/s11426-016-5566-3

[20] Fromille S, Phillips J. Super dielectric materials. Materials 2014;7(12):8197-8212. https://doi.org/10.3390/ma7128197

[21] Cortes FJQ, Phillips J. Novel materials with effective super dielectric constants for energy storage. Journal of Electronic Materials, 2015;44:1367-1376. https://doi.org/10.1007/s11664-015-3641-8

[22] Zhong M, Tang QF, Zhu YW, Chen XY, Zhang ZJ. An alternative electrolyte of deep eutectic solvent by choline chloride and ethylene glycol for wide temperature range supercapacitors. Journal of Power Sources, 2020;452:227847. https://doi.org/10.1016/j.jpowsour.2020.227847

[23] Phillips J. Novel superdielectric materials: aqueous salt solution saturated fabric. Materials 2016;9(11): 918. https://doi.org/10.3390/ma9110918

[24] Cortes FJQ, Phillips J. Tube-super dielectric materials: Electrostatic capacitors with energy density greater than 200 J· cm− 3. Materials 2015;8(9):6208-6227. https://doi.org/10.3390/ma8095301

[25] Gandy J, Cortes FJQ, Phillips J. Testing the tube super-dielectric material hypothesis: Increased energy density using NaCl. Journal of Electronic Materials 2016; 45:5499-5506. https://doi.org/10.1007/s11664-016-4843-4