Corrigendum: Efficiency of supercapacitor with CaTiO$_3$-filled polysulfone separators (2021 J. Phys.: Conf. Ser. 2145 012041)

S Suwanwong*, C Yuenyao and A Hutem
Physics Division, Faculty of Science and Technology, Phetchabun Rajabhat University, Phetchabun 67000, Thailand

Page 3:
In the Results and discussion section, the following text appears:
"The efficiency of supercapacitor using CaTiO$_3$-filled PSF separators in the weight percentage of 0.5, 1.0 and 2.0 wt% to analyze specific energy (as shown in figure 5) and specific capacitance (as shown in figure 6) using Battery Testers system,"

This should read:
"The efficiency of supercapacitor using CaTiO$_3$-filled PSF separators in the weight percentage of 0.5, 1.0 and 2.0 wt% to analyze specific energy and specific capacitance (as shown in figure 6) using Battery Testers system,"

Page 3:
In the Results and discussion section, the following Figure appears:

Figure 4. FT-IR spectra of CaTiO$_3$-filled PSF separators.

Figure 6. Specific capacitance of supercapacitors with CaTiO$_3$-filled polysulfone separators.
This should **Figure**:

![FT-IR spectra of CaTiO₃-filled PSF separators.](image1)

**Figure 4.** FT-IR spectra of CaTiO₃-filled PSF separators.

![Specific capacitance of supercapacitors with CaTiO₃-filled polysulfone separators.](image2)

**Figure 6.** Specific capacitance of supercapacitors with CaTiO₃-filled polysulfone separators.
Efficiency of supercapacitor with CaTiO$_3$-filled polysulfone separators

S Suwanwong*, C Yuenyao and A Hutem

Physics Division, Faculty of Science and Technology, Phetchabun Rajabhat University, Phetchabun 67000, Thailand

*Corresponding author E-mail: sanit.suw@pcru.ac.th

Abstract. Supercapacitors are one of the energy storages designed to serve the increasing demand for electricity nowadays. They are durable and can charge electricity faster and keep electric charge longer. In this study, electrodes for supercapacitors were made from aluminum foils coated with carbon nanotube film and separated by electrolyte solution and a separator. A separator could prevent short circuit but allow ions to pass through, and consequently increased storage layers of electric charge. The separators used in this study were made from polysulfone containing CaTiO$_3$ 0.5, 1.0 and 2.0 wt% with perovskite properties, high dielectric constant, electrical resistivity and energy density. After that, they were built in coin-cell form. It was found from the study that the addition of 2.0 wt% CaTiO$_3$, the largest proportion of all samples, provided a maximum specific energy at 4.03 mWh/g and a maximum specific capacitance at 4.64 F/g, accounting for 2.17-time higher than that of polysulfone without CaTiO$_3$. The functional group analysis of PSF and CaTiO$_3$ separators showed that the increasing of CaTiO$_3$ in the PSF separators, the 2958 cm$^{-1}$ in C-H stretch peaks reduced, and consequently specific energy and specific capacitance were higher. Thus, supercapacitors with CaTiO$_3$-filled polysulfone separators are suitable for improving efficiency of supercapacitors in energy storage from electrical supply.

1. Introduction

The constantly increasing demand for electric energy in the present world results in the need for energy storage such as batteries, capacitors and supercapacitors. The problems are that batteries require long charging time while providing short cycle time and capacitors, though can be fast charged, have low storage capacity and discharge quickly. Thus, supercapacitors with durability, faster electric charge and longer electric storage are developed. Since electrodes for supercapacitors were made from aluminum foils coated with carbon film [1,2], and separated by an electrolyte solution and a separator to prevent short circuit but allow ions to pass through, storage layers of electric charge increase when dielectric material is added to separator sheets. The added material possesses perovskite properties including catalyst, sensor and high dielectric constant. Calcium titanate (CaTiO$_3$) is a high-dielectric-constant substance with high electrical resistivity and high energy density [3]. Because of its wide space between the particles, CaTiO$_3$ allows greater amount of energy to be stored, which is called internal-barrier-layer-capacitor model. It is suitable for inventing ceramic capacitors and polymer capacitors [4] by using polysulfone-based polymers as a polymer sheet [5,6] which has low dielectric constant and porosity [7].

In this study, the researcher was interested in developing supercapacitors using CaTiO$_3$-filled polysulfone separators by analyzing functional groups in the separators using FT-IR techniques and
oxidation numbers of Ca, Ti and O ion using XPS technique in order to increase the efficiency of supercapacitors in energy storage from electricity sources such as wind turbines and solar cells.

2. Materials and methods
In this section, the preparation of electrodes, electrolyte solution, CaTiO$_3$ and separators is elaborated. To prepare nano-carbon electrodes, LA 133 (Linyi Gelon LIB Co., Ltd.) was dissolved in DI water and mixed well. Then, nano-carbon was added to the LA 133 adhesive solution and stirred at 60°C for 3 hours. After that, it was poured into a 5 x 10 cm aluminum foil sheets, scraped longitudinally and at 120°C for 30 minutes to obtain films on an aluminum sheets used as electrodes. Electrolyte solution was made of the mixture of Tetraethylammonium tetrafluoroborate with solution density at 1 M and Acetonitrile. CaTiO$_3$ was prepared by ball milling 1 mol calcium oxide powder with 1 mol titanate dioxide powder for 6 hours and sintering at 1,000°C for 8 hours. CaTiO$_3$ crystal structure, then, was investigated using X-ray diffraction (XRD) (Bruker, model D2 PHASER) in the range of 10 - 80°. For separators, 15 wt% Polysulfone (PSF) was dissolved in Dimethylacetamide (DMAc) and stirred well at 60°C for 4 hours. Then, the solution was poured onto glass, scraped using doctor blade and immersed in DI water to allow the PSF separators to have phrase transformation before they took out from the glass. The separators with 15 wt% PSF solution were filled with CaTiO$_3$ at 0.5, 1.0 and 2.0 wt%, respectively. Through the steps above, 4 separators were obtained. The surfaces of the separators were examined through scanned images of electrodes using Field Emission Scanning Electron Microscope (FE-SEM) (Carl Zeiss, model AURIGA), and functional group analysis was used to analyze the CaTiO$_3$ - filled separators using FT-IR spectrometer (PerkinElmer, model Spectrum Two). After that the oxidation state of Ca, Ti and O ion of CaTiO$_3$-filled separators was investigated using X-rays Photoelectron spectroscopy (XPS) technique from BL3.2a beamline at the Synchrotron Light Research Institute (SLRI), Thailand. To assemble supercapacitor, nano-carbon electrodes on aluminum foil and the separators were cut into circles with 1.6 cm and 1.8 cm diameters, respectively (see figure 1), then coin-cell were made with a hydraulic press. Their efficiency was measured with the Battery Testers System (NEWARE, model BTS 3000) by charging and discharging 10 mA current under electric potential difference (V) of 2.5 V in order to analyze specific energy (W) and calculate specific capacitance (C) as shown in equation (1).

\[ W = \frac{1}{2} CV^2 \]  

3. Results and discussion
Calcium oxide and titanium dioxide in a 1:1 mole ratio was mixed and sintered at 1,000°C for 8 hours to generate CaTiO$_3$, then its crystal structure was examined using XRD technique as shown in figure 2. After measuring the diffraction angle 2-theta range of 10-80°, it was found that the crystal structure corresponds to CaTiO$_3$ (ICSD code: 031864) with planes 001, 110, 220, 112, 131 and 222. The examination of polysulfone (PSF) surface in DMAc solution as shown in figure 3(a) and polysulfone...
containing CaTiO$_3$ 0.5, 1.0 and 2.0 wt% as shown in figure 3(b)–(d) revealed that the increasing amount of CaTiO$_3$ in PSF separators results in the replacement of CaTiO$_3$ particles in the porosity.

The functional group analysis of PSF and CaTiO$_3$ separators using FT-IR spectrometer as shown in figure 4 was conducted. The results revealed no interesting peak in the PSF separators. However, for CaTiO$_3$-filled PSF separators, the peak at 2958 cm$^{-1}$ in C-H stretch, at 1589 and 1487 cm$^{-1}$ in C-C stretch, at 1240, 1150, 1105 and 1015 cm$^{-1}$ in C-N stretch and at 835 cm$^{-1}$ in C-H stretch were observed. Additionally, the greater amount of CaTiO$_3$ made all of the aforementioned peaks weaker. The analysis of XPS spectra of 2wt% CaTiO$_3$-filled separators as in figure 5 showed that the oxidation numbers of Ca ions were Ca$^{2+}$, Ca$^{3+}$, Ca$^{2+}$ and Ca$^{3+}$ and those of Ti ions were Ti$^{2+}$ and Ti$^{3+}$ and those of O ions were O1s and O2s.

The efficiency of supercapacitor using CaTiO$_3$-filled PSF separators in the weight percentage of 0.5, 1.0 and 2.0 wt% to analyze specific energy (as shown in figure 5) and specific capacitance (as shown in figure 6) using Battery Testers system, brand NEWARE model BTS 3000 (as shown in table 1) was examined. The results showed that supercapacitors with PSF separators held specific energy at 1.85 mWh/g and specific capacitance at 2.13 F/g. Supercapacitors with CaTiO$_3$-filled separators in the weight percentage of 2.0% (PSF_CaTiO3_2.0%) generated specific energy and specific capacitance at 4.03 mWh/g and 4.64 F/g, respectively. Supercapacitors with CaTiO$_3$-filled separators in the weight percentage of 1.0% (PSF_CaTiO3_1.0%) generated 2.96 mWh/g of specific energy and 3.41 F/g of specific capacitance, respectively. The specific energy and specific capacitance produced by CaTiO$_3$-filled separators in the weight percentage of 0.5% (PSF_CaTiO3_0.5%) were the least as they were marked at 0.70 mWh/g and 0.81 F/g, respectively.
Table 1. Maximum specific energy and specific capacitance of supercapacitors with CaTiO$_3$-filled polysulfone separators.

| Sample                  | Specific energy (mWh/g) | Specific capacitance (F/g) |
|-------------------------|-------------------------|---------------------------|
| PSF                     | 1.85                    | 2.13                      |
| PSF_CaTiO$_3$_0.5%      | 0.70                    | 0.81                      |
| PSF_CaTiO$_3$_1.0%      | 2.96                    | 3.41                      |
| PSF_CaTiO$_3$_2.0%      | 4.03                    | 4.64                      |

It was found from the study that the mixture of CaO and TiO$_2$ in a 1:1 mole ratio with sintering at 1,000°C for 8 hours to generate CaTiO$_3$ caused phase transformation of crystal structure. This corresponds to the crystal structure of CaTiO$_3$. The analysis of FE-SEM images of PSF separators from XRD technique revealed that the greater amount of CaTiO$_3$ replaced porosity in separators which lowered porosity and consequently increased storage layers of electric charge.

The functional group analysis of PSF and CaTiO$_3$ separators showed that the increasing of CaTiO$_3$ in the PSF separators, the 2958 cm$^{-1}$ in C-H stretch peaks reduced, and consequently specific energy and specific capacitance were higher. The analysis of XPS spectra of CaTiO$_3$-filled separators revealed the presence of Ca, Ti and O ion. It can be seen when the amount of CaTiO$_3$ in PSF separators increases, the amount of Ca, Ti and O increases accordingly, and this is in line with the decrease of C-H stretch peaks (2958 cm$^{-1}$) making energy storage more effective. Thus, supercapacitors with 2.0 wt% CaTiO$_3$ provided a maximum specific energy at 4.03 mWh/g and a maximum specific capacitance at 4.64 F/g accounting for 2.17-time higher than that of PSF separators without CaTiO$_3$, and followed by the addition of 1.0% CaTiO$_3$ while the addition of 0.5% CaTiO$_3$ could produce the least.

4. Conclusion

The addition of CaTiO$_3$ in PSF separators can increase storage layers of electric charge. Supercapacitors filled with 2.0% CaTiO$_3$ provided 2.17-time higher than the polysulfone without CaTiO$_3$. Thus, supercapacitors with CaTiO$_3$-filled polysulfone separators are suitable for improving efficiency of supercapacitors in energy storage from electrical supply and electronic devices.

Acknowledgements

This study was supported by Physics Division, Science Center, Faculty of Science and Technology, and Research and Development Institute, Phetchabun Rajabhat University which received funding from Thailand Science Research and Innovation (TSRI) under Thailand research strategy and innovation plan in the fiscal year 2020.

References

[1] Deng M, Yang B and Hu Y 2005 J. Mater. Sci. 40 5021–23
[2] Xiong W et al 2011 J. Power Sources 196 10461–64
[3] Zhou H Y, Liu X Q, Zhu X L and Chen X M 2017 J. Am. Ceram. Soc. 101(5) 1999–2008
[4] Hu Y, Zhang Y, Liu H and Zhou D 2011 Ceram. Int. 37(5) 1609–13
[5] Chitrtrakarn T, Tirawanichakul Y, Sirijarukul S and Yuenyao C 2016 Surf. Coat. Tech. 296 157–63
[6] Ruangdit S, Chitrtrakarn T, Anuchit S, Tirawanichakul Y and Yuenyao C 2017 Malaysian J. Anal. Sci. 21(2) 372–80
[7] Zheng X, Pu Z, Hu L, Tian Y, Xia J, Cheng J and Zhong J 2019 J. Mater. Sci. Mater. Electron. 30, 18168–76