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Metal-Based Oxides/Hydroxides and Conducting Polymers as Materials for Ultracapacitors – A Simple Communication

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ABSTRACT

Ultracapacitors has now become an integral part of the contemporary energy storage systems. Their uniqueness in optimal power delivery, charge storage capabilities and long cyclic stability ($>10^5$) are what make them attractive to the energy storage industries. Basically, Ultracapacitor consists of two separated electrodes impregnated with an electrolyte. Its performance is largely a function of the chosen electrode-electrolyte materials. The choice of the materials depends on the prevailing conditions at hand and is always at a tradeoff between certain merits and demerits. In this communication, we reviewed two contemporary materials namely; Transition Metal Oxides and Conducting Polymers with emphasis on the challenges associated with each. This will create an avenue in determining the direction and future perspective of Ultracapacitors materials.

Keywords: Ultracapacitors, Transition Metal Oxides, Conducting Polymer, Electrodes, Electrolytes.

1.0 INTRODUCTION

Of all the important components of the energy storage device, electrodes hold crucial position not only in Ultracapacitors, but even in the batteries. The two major groups of the Ultracapacitors are pseudocapacitors and Electrodouble Layer Capacitor (EDLCs). In pseudo-capacitors the storage mechanism occurs via fast Faradaic reactions that occur between the electrode and the electrolyte. Whereas In EDLCs, the mechanism of energy storage is based on the physical ions' absorption at the electrode's surface. In this case, the active materials for the electrodes are activated carbon, carbon nanotubes and different synthesis of graphene (Soltani & Beheshti, 2021). Although most of the carbon-based materials are characterized with high surface area and porous for ions' easy penetration, their weakness in both energy density production and specific capacitance output limit their widespread applications in real devices (Chodankar et al., 2020)

Typical and most explored electrode materials for the pseudocapacitors fabrication are metal oxides (such as RuO_2 or MnO_2) and Conductive Polymers (Yoo et al., 2014;) (Chodankar et al., 2020). These

types pseudocapacitors exhibit much higher specific capacitances than EDLCs, only that, their inadequate electrical conductivity hampered the realisation of commercial redox capacitors. Another challenging issue are their poor electron transport and severe damage to the electrode materials during redox reaction. (Yadav & Devi, 2020).

2.0 METAL-BASED OXIDES/HYDROXIDES

Transition Metal Oxides as described by B.E Conway include but not limited to; RuO_2 , IrO_2 , Fe_3O_4 , MnO_2 , NiO , Co_3O_4 are the commonly considered redox-active materials, utilized as electrode materials for mostly hybrid supercapacitors, that exists in oxides and hydroxide structures. These are suitable materials for SCs' electrode due to their variable valence and good chemical stability. They also possess longer operating cycles and high pseudocapacitance (Poonam et al., 2019 ; Patel et al., 2021). They also deliver more energy density than EDLC (Kamila et al., 2021).

Taking these Transition Metals after the other, one of the most promising among them is the NiO based

electrode because of its characteristics of high electrical conductivity of the oxide, the metal must exhibit in more than one oxidation state that co-exist over a potential window and must exhibit good surface area. Its theoretical capacitance can be as high as 2584 F g^{-1} (Verma et al., 2021).

Another interesting and popular metal oxide found in the literature is the MnO_2 . Its advantages include environmental friendliness and lower cost. This oxide can achieve a theoretical capacitance limit of up to $\sim 1370 \text{ F g}^{-1}$, but its major setback is the power conductivity. This is in contrast to the Ruthenium Oxide which exhibits high conductivity but is very costly in the market (Hillier et al., 2020).

3.0 CONDUCTING POLYMERS

Conductive polymers which are commonly found in composite materials have over the past few decades gained considerable attention that combine the advantages of organic and traditional polymeric materials have received significant attention in the electrochemical Ultracapacitors fabrication. Their high conductivity, flexibility, excellent processability, low cost (W. Liu et al., 2022), high volumetric capacitance values and richness of the constituent materials (Bamgbopa et al., 2021) make them attractive compared to most especially plain carbon based electrodes. The mechanism for the charging in conductive polymers takes place all over the bulk of the material in the form of redox process as against that of carbon based electrodes, which only involve their surface (Miller et al., 2018).

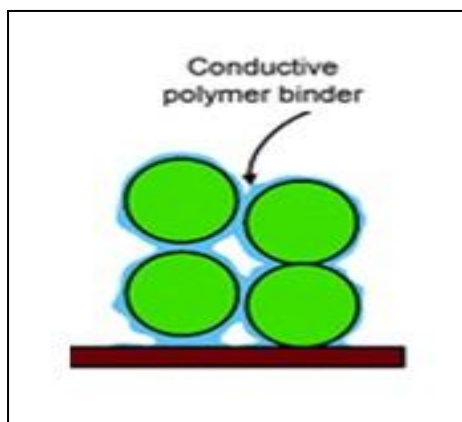


Fig. 1 Effect of binder on conductive polymer-based Ultracapacitor electrode

Few among the numerous nanostructured conductive polymers are; polyaniline (PANI), conductive polymer gels (CPGs), ethylenedioxythiophene:poly(styrene sulfonate) (PEDOT:PSS) and so on. PANI is of interest due to its high conductivity, ease of synthesis and low cost and when combined with carbon nanotubes can achieve a higher capacitance as 1035 F g^{-1} (Miller et al., 2018). CPGs are also commonly used. CPGs have been used to develop mixed materials with multiple functionalities, such as self-healing. (Cheng et al., 2020).

4.0 CONCLUSION

For an Ultracapacitor to perform effectively, proper choice of material is eminent. Here, we reviewed the different types of Ultracapacitors electrode mainly of Oxides and Composite forms (Conducting Polymers) with emphasis on their corresponding drawbacks. It is pertinent to note that, till date no single electrode material; whether conducting polymer based, or metal oxide based matches all the desired electrode characteristics, because each of these materials has its own setback. So, scientific community is struggling to enhance both the power and energy densities of Ultracapacitors by developing new electrode and electrolyte materials. This report will therefore create more room in determining the direction and future perspective of Ultracapacitor materials.

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REFERENCES

Bamgbopa, M. O., Belaine, D., Mengistie, D. A., Edberg, J., Engquist, I., Berggren, M., & Tybrandt, K. (2021). Modelling of heterogeneous ion transport in conducting polymer supercapacitors. *Journal of Materials*

- Chemistry* A, 9(4), 2184–2194.
<https://doi.org/10.1039/d0ta09429c>
- Cheng, Y., Xiao, X., Pan, K., & Pang, H. (2020). Development and application of self-healing materials in smart batteries and supercapacitors. In *Chemical Engineering Journal* (Vol. 380). Elsevier B.V.
<https://doi.org/10.1016/j.cej.2019.122565>
- Chodankar, N. R., Pham, H. D., Nanjundan, A. K., Fernando, J. F. S., Jayaramulu, K., Golberg, D., Han, Y. K., & Dubal, D. P. (2020). True Meaning of Pseudocapacitors and Their Performance Metrics: Asymmetric versus Hybrid Supercapacitors. In *Small* (Vol. 16, Issue 37). Wiley-VCH Verlag.
<https://doi.org/10.1002/sml.202002806>
- Hillier, N., Yong, S., & Beeby, S. (2020). The good, the bad and the porous: A review of carbonaceous materials for flexible supercapacitor applications. *Energy Reports*, 6, 148–156.
<https://doi.org/10.1016/j.egyr.2020.03.019>
- Kamila, S., Kumar Jena, B., & Basu, S. (2021). 4 *Advances in Electrochemical Energy Storage Device: Supercapacitor*.
- Liu, W., Li, X., Li, W., Ye, Y., Wang, H., Su, P., Yang, W., & Yang, Y. (2022). High-performance supercapacitors based on free-standing SiC@PEDOT nanowires with robust cycling stability. *Journal of Energy Chemistry*, 66, 30–37.
<https://doi.org/10.1016/j.jechem.2021.07.007>
- Miller, E. E., Hua, Y., & Tezel, F. H. (2018). Materials for energy storage: Review of electrode materials and methods of increasing capacitance for supercapacitors. In *Journal of Energy Storage* (Vol. 20, pp. 30–40). Elsevier Ltd. <https://doi.org/10.1016/j.est.2018.08.009>
- Poonam, Sharma, K., Arora, A., & Tripathi, S. K. (2019). Review of supercapacitors: Materials and devices. In *Journal of Energy Storage* (Vol. 21, pp. 801–825). Elsevier Ltd. <https://doi.org/10.1016/j.est.2019.01.010>
- Soltani, M., & Beheshti, S. H. (2021). A comprehensive review of lithium ion capacitor: development, modelling, thermal management and applications. In *Journal of Energy Storage* (Vol. 34). Elsevier Ltd. <https://doi.org/10.1016/j.est.2020.102019>
- Verma, S., Arya, S., Gupta, V., Mahajan, S., Furukawa, H., & Khosla, A. (2021). Performance analysis, challenges and future perspectives of nickel based nanostructured electrodes for electrochemical supercapacitors. In *Journal of Materials Research and Technology* (Vol. 11, pp. 564–599). Elsevier Editora Ltda. <https://doi.org/10.1016/j.jmrt.2021.01.027>
- Yadav, S., & Devi, A. (2020). Recent advancements of metal oxides/Nitrogen-doped graphene nanocomposites for supercapacitor electrode materials. In *Journal of Energy Storage* (Vol. 30). Elsevier Ltd. <https://doi.org/10.1016/j.est.2020.101486>
- Yoo, H. D., Markevich, E., Salitra, G., Sharon, D., & Aurbach, D. (2014). On the challenge of developing advanced technologies for electrochemical energy storage and conversion. In *Materials Today* (Vol. 17, Issue 3, pp. 110–121). Elsevier B.V. <https://doi.org/10.1016/j.mattod.2014.02.014>