

# A STUDY OF SUPERCAPACITORS WITH DIFFERENT TYPES AND PRINCIPLE

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## ABSTRACT

Supercapacitors are electronic devices used to store enormous quantities of electrical charge. They are also known as ultracapacitors and double-layer capacitors. Supercapacitors store electrical energy through double-layer capacitance and pseudo capacitance, as opposed to a conventional dielectric. The origin of double layer capacitance is electrostatic, whereas pseudo capacitance is electrochemical. To achieve improved efficacy, hybrid materials have been incorporated. The high specific capacitance and high surface area of the hybrid electrode materials make them a promising electrode for energy storage devices. When activated carbon, nanocarbon, or graphene with a high surface area improve power density with long-term stability, and when hydroxide materials with more electrochemically active molecules improve specific capacitance and energy density, this is the basic understanding. Numerous research groups have reported numerous composite electrode materials based on transition metal hydroxides; however, no one has yet reported that the electrochemical performance of rare earth hydroxide-based electrode materials has paved the way for better-than-anticipated performance and is still rarely investigated and reported. In light of this, it is proposed in the present study to develop pure rare earth hydroxide and rare earth hydroxide/graphene hybrids for use as electrode materials in supercapacitor applications.

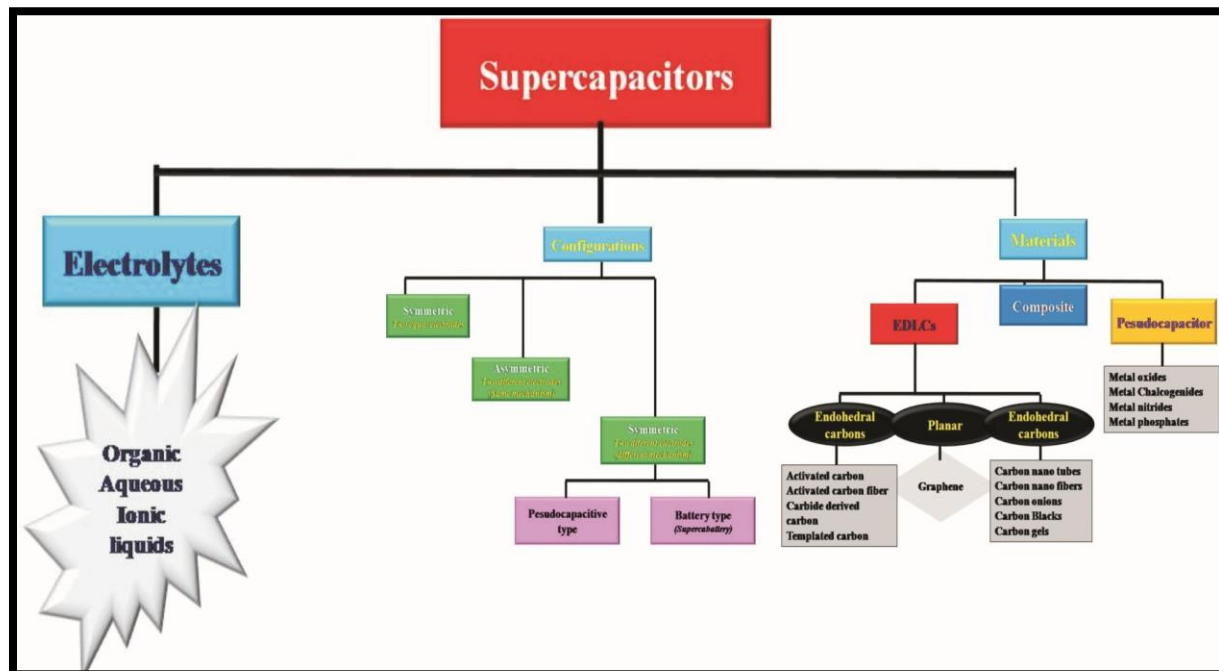
**KEY WORDS:** *Supercapacitors, Electronic Devices, Electrical Charge, Ultracapacitors.*

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## 1. INTRODUCTION

Super capacitors have a higher energy density than conventional capacitors and a higher power density than batteries. Due to these incalculable characteristics, the research community has been drawn to the field of supercapacitors. However, due to the unsatisfactory performance of electroactive materials, commercially available supercapacitors are limited to using carbon-based materials as electrically active materials, which offer a significantly lower energy density than batteries. Consequently, the development of energy devices with a high energy density and power density remains crucial. To increase the specific capacitance, the morphology, structure,

and degree of integration of the electroactive material are crucial factors. During the past decade, numerous 1D/2D nanostructured materials with unanticipated properties have been developed. In addition, multicomponent nanostructured hybrids have been reported to not only benefit from the characteristics of each nanostructure, but also inherit the advantages derived from both nanostructures. This contributes to the efficient exploitation of electroactive species, thereby enhancing the electrochemical performance of the entire electrode. As a result of the numerous transition modes involving the 4f shell of their ions, rare-earth materials received some attention, and there has been a great deal of interest in the design and fabrication of lanthanide compounds. As a result of their exceptional optical, magnetic, and electrical properties, they are extensively utilized as up-conversion materials. In recent years, there has been an increase in the use of rare-earth oxides as electrode materials for battery and supercapacitor applications. Therefore, supercapacitors incorporate the functionality of standard capacitors and a standard battery. This technology can attain capacitance values as high as 12,000 F. Compared to a supercapacitor, the self-capacitance of the entire planet Earth is approximately 710 F, which is more than 15 million times lower. Although an ordinary electrostatic capacitor may have a high maximum operating voltage, the maximum charge voltage of a supercapacitor is typically between 2.5 and 2.7 volts. As with electrolyte capacitors, supercapacitors are polar, requiring proper circuit connection.



**Figure.1.** Classification of supercapacitors by materials and configuration with electrolytes

With this technology, hybrid-electric and fuel-cell-powered vehicles require such a surge of energy to get started. Supercapacitors are also required in a variety of electronic and engineering applications that require a rapid, high-energy discharge. Double-layer capacitors, supercapacitors, ultracapacitors, power capacitors, gold capacitors, and power cache are terms for capacitors that store energy within the electrochemical double-layer at the electrode/electrolyte interface. Electrochemical double-layer capacitor describes the fundamental principle of charge storage in such capacitors. These capacitors are referred to as electrochemical capacitors (EC) due to the fact that there are typically additional contributions to the capacitance besides double layer effects. First patents date back to 1957, when Becker described a carbon capacitor with a high surface area; standard oil company, Ohio (SOHIO) made its first attempts in 1969. However, electrochemical capacitors did not become popular for hybrid electric vehicles until the 1990s. The EC was intended to enhance the hybrid electric vehicle's battery or fuel cell. It provides the necessary additional power for acceleration while storing energy during braking, which can be utilized during the subsequent acceleration process. Consequently, it facilitates rapid regeneration for hybrid electric vehicle applications.

Similar to batteries, supercapacitors are electrochemical energy storage devices. There are two electrodes that are separated by a separator. The electrolyte-soaked separator prevents electrical conduction between the electrodes. Low-thickness separators must be ion-permeable for rapid ionic charge transfer and high electric resistance for optimal performance. For symmetric SC, the electrodes are of the same type, while for asymmetric SC, they are distinct. Due to its storage mechanism and charge separation at the surface of the electrode/electrolyte interface, SCs have a high capacity, low internal resistance, and store or transport energy at higher rates than batteries. Attractive characteristics of supercapacitors include an extended cycle life, high power density, a wider operating temperature range (-40 °C to 70 °C), less weight, and a lower price. Based on their charge storage mechanism, these capacitors are divided into three categories: Electrochemical Double Layer Capacitor (EDLC), Pseudocapacitor, and Hybrid Capacitor.

Carbon-carbon electrode materials, a separator, and an electrolyte are used to construct the EDLC supercapacitor. The charge is stored electrostatically or through a non-faradic mechanism, and there is no charge transfer between the electrode and electrolyte. Charges accumulate on the surface of the electrode as a result of the applied potential difference between the electrodes. Electrolyte ions diffuse through the separator and into the pores of the oppositely charged electrode due to the orientation of charges. The construction of a double layer prevents the reorientation of the charges, thereby increasing the surface area and decreasing the distance between the electrodes, resulting in a high energy density. The schematic representation of the charge storage mechanism of EDLCs is shown. Due to

the double layer mechanism, EDLCs have fast energy uptake and delivery, exceptional performance, and no chemical reaction, which implies high cyclic stability. As electrode materials for EDLC capacitors, carbon materials such as activated carbons, carbon fibers, templated carbons, graphene, reduced graphene oxide, carbon nanotubes, carbon nanofibers, carbon onions, carbon blacks, and carbon jellies are utilized. All of these materials have a high surface area and excellent activation sites, resulting in a high electrolyte ion diffusion rate. The charge accumulation occurs only at the electrode's surface.

The charges are stored through a faradic process, and the charge transport between electrode and electrolyte occurs as depicted in a pseudocapacitor. When the potential is applied, the electrode materials of the pseudocapacitor undergo reduction and oxidation. Underpotential deposition, redox reactions of transition metal oxides, intercalation pseudocapacitance, and electrochemical doping and de-doping in conducting polymers are the charge storage mechanisms of pseudocapacitive electrodes.

This results in the migration of charges into the double layer, which generates faradic current in the SC cell. The faradic and redox processes in the pseudocapacitor result in greater specific capacitance and energy density than EDLC. Nevertheless, due to the recurrent contraction/expansion, the material's stability diminishes and its power density decreases during cycling. For pseudocapacitor materials, metal oxides/chalcogenides/nitrides/carbides/phosphates or conducting polymers are intensively researched.

With an electric double-layer capacitor (EDLC), the charge storage process is non-faradaic, meaning that, ideally, there is no electron transfer across the electrode interface and the storage of electric charge and energy is electrostatic. Electron charges accumulate on the electrode surface in conjunction with lateral repulsion and redox chemical reactions. Due to the absence of chemical phase and composition changes during the charge and discharging of such EDLCs, these capacitors have a high degree of cycleability on the order of 10 times and a high specific power density, but a relatively low specific energy density. In some cases of the supercapacitor based on pseudocapacitance (redox type of supercapacitor), however, the essential process is faradaic; that is, the charge storage is achieved by an electron transfer that produces a redox reaction (Faradaic reaction) in the electroactive materials according to Faraday's law. Due to the redox reaction as in a battery, supercapacitors based on pseudocapacitance have a higher specific capacitance than EDLCs. However, the redox reaction gives rise to high internal resistance in supercapacitors, resulting in a decrease in specific power density. Metal oxides (e.g., RuO<sub>2</sub>, IrO<sub>2</sub>, Co<sub>3</sub>O<sub>4</sub>) and conducting polymers (e.g., polypyrrole, polyaniline, polythiophene) are the typical electrode materials for pseudocapacitance-based supercapacitors.

A supercapacitor requires two electrodes, one of which is negatively charged relative to the other, with electrostatic charge storage and separation. Charge storage and separation are established across the electrode interface for each electrode.

Supercapacitor electrodes have a large surface area and porous matrices. Nevertheless, batteries have a bipolar electrode configuration for high voltage series combinations. The maximal Gibbs energy for a battery is the product of the charge  $Q$  and the potential difference  $E$  between the Nernstian reversible potentials of the two electrodes, or  $G = Q \cdot E$ . In the case of capacitors, however, for a given charge  $Q$ ,  $G$  equals  $1/2 QV$ . For a given electrode potential difference,  $E = V$ , it is evident that the energy stored by a two-electrode cell accommodating a given faradaic charge  $Q$  at voltage  $E = V$  is double the energy stored by a capacitor charged with the same  $Q$  at the same voltage. During the charging process, a pure electric double-layer capacitor must perform electrical work (Gibbs energy) against the charge density that has already accumulated on the electrodes, thereby progressively increasing the inter-electrode potential difference.

As long as two components (reduced and oxidized forms) of the electroactive material continue to exist together, a thermodynamic potential should (ideally) exist in a charging battery cell independent of the amount of charge  $Q$  added. Consequently, the potential difference (electromotive force) of the battery cell is ideally constant throughout the discharge or recharge half cycles, such that  $G = Q \cdot E$  as opposed to  $Q \cdot 1/2 E$  (or  $1/2 V$ ). where the voltage of a capacitor decreases linearly with increasing charge, whereas the voltage of an ideal battery remains constant so long as the two phases are in equilibrium. Formally, the decline in supercapacitor voltage results from  $C = Q/V$  or  $V = Q/C$ ; thus,  $dV/dQ = 1/C$ .

## 2. NEED FOR SUPERCAPACITORS

- Supercapacitors have abundant stationary and mobile application possibilities. Supercapacitors have many properties that complement those of batteries.
- They are well-suited for high-power applications They can be rapidly charged and discharged They can operate at low temperatures
- This can be challenging for the majority of batteries.
- "By combining the two batteries, the lifespan and operating temperatures can be increased by utilizing the supercapacitor to provide the initial power surge. As these batteries have a much higher energy density than current supercapacitors, a battery like lithium-ion can then take over for a constant, longer-duration

discharge.

- Supercapacitors can alleviate the strain placed on lithium-ion batteries that are primarily designed to deliver energy over a number of hours.

### 3. PRINCIPLE OF SUPERCAPACITORS

The same fundamental principles govern supercapacitors as conventional capacitors. However, they integrate electrodes with significantly larger surface areas and significantly thinner dielectrics, which reduce the distance between the electrodes. Supercapacitors are able to attain comparable power densities by maintaining the low ESR characteristic of conventional capacitors. In addition, supercapacitors have a number of advantages over electrochemical batteries and fuel cells, including a higher power density, shorter charging times, and an extended cycle life and shelf life.

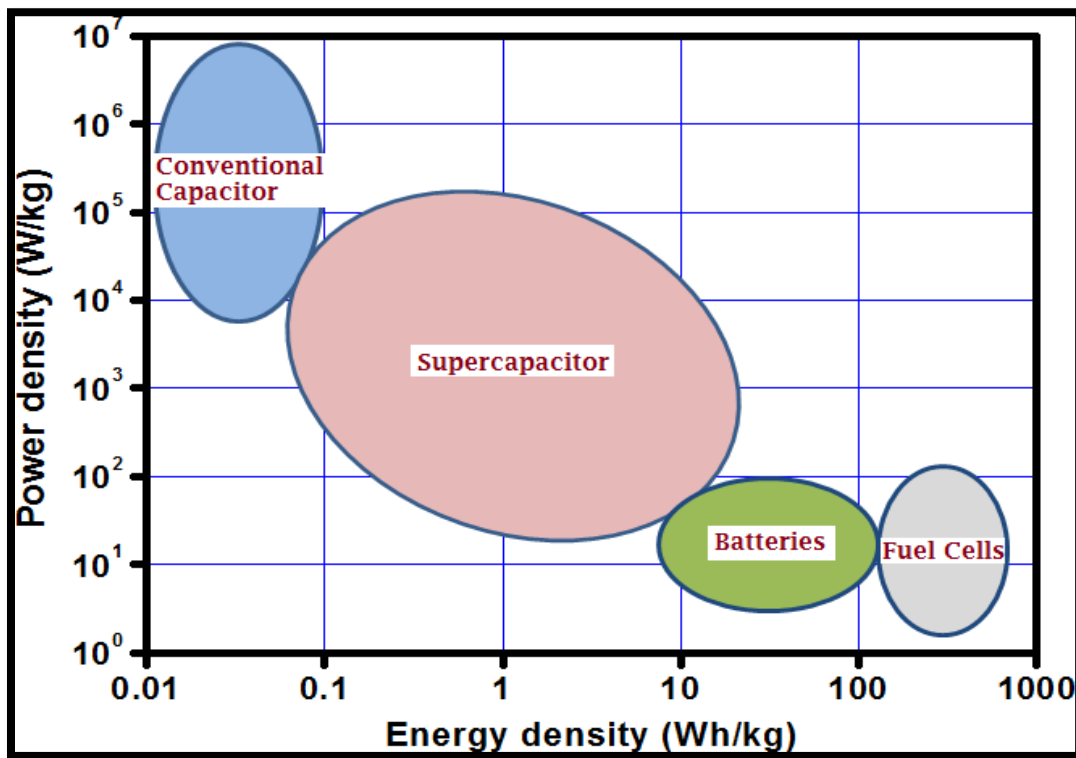


Fig. 2. Ragone plot of energy storage devices

The enhancement in supercapacitor performance is depicted, a graph known as a "Ragone plot." It illustrates the ideology with a graph of the power densities of various energy storage devices versus their energy densities. Figure

demonstrates that supercapacitors occupy a region between standard capacitors and batteries. Supercapacitors have yet to match the energy density of mid- to high-end batteries and fuel cells, despite possessing greater capacitances than conventional capacitors. Therefore, the literature review concentrates on developing improved supercapacitor types or programs to bring their energy densities closer to those of batteries.

#### **4. ELECTROCHEMICAL DOUBLE-LAYER CAPACITORS (EDLCS)**

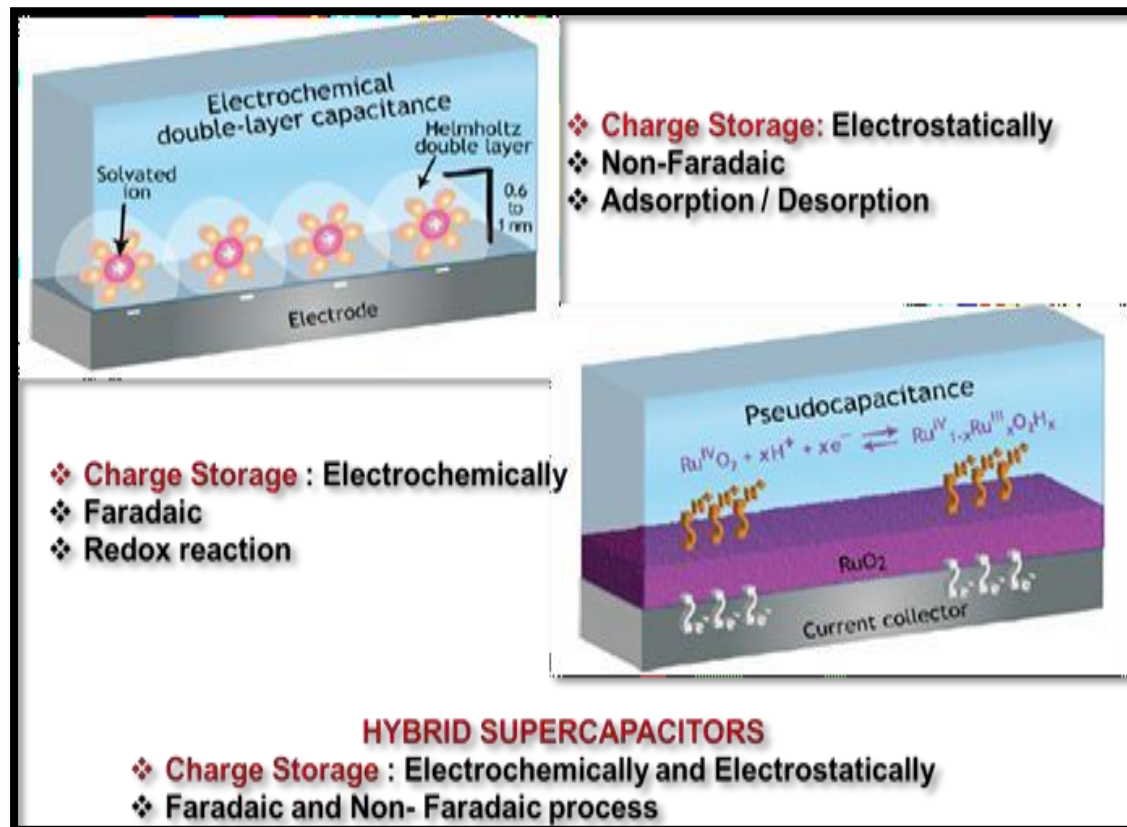
Electrochemical double-layer capacitors (EDLCs) are composed of two electrodes containing carbon, an electrolyte, and a separator. EDLCs store charge electrostatically, similar to conventional capacitors, with no charge transfer between electrode and electrolyte. EDLCs store energy using an electrochemical double layer of charge. As voltage is applied, the electrode surfaces accumulate charge. Ions in the electrolyte solution diffuse across the separator into the pores of the electrode with the opposite charge, as a result of the natural attraction between charges with opposite charges. However, the electrodes are designed to prevent the ions from recombining. At each electrode, a double layer of charge is produced. These double layers, in conjunction with an increase in surface area and a reduction in the distance between electrodes, enable EDLCs to attain greater energy densities than conventional capacitors.

Because there is no charge transfer between electrolyte and electrode, non-Faradic processes do not involve any chemical or compositional changes. Consequently, the charge storage in EDLCs is highly reversible, allowing them to attain extremely high cycling stabilities. The performance characteristics of EDLCs are typically stable for a large number of charge-discharge cycles, sometimes as many as  $10^6$  cycles. In contrast, electrochemical batteries are typically limited to approximately  $10^3$  cycles. Due to their cycling stability, EDLCs are well-suited for applications involving inaccessible environments, such as the deep sea or mountains.

#### **5. PSEUDOCAPACITORS**

Unlike EDLCs, which store charge electrostatically, pseudo capacitors store charge faradaically via the transfer of charge between the electrode and electrolyte. Electrosorption, reduction-oxidation reactions, and intercalation processes accomplish this. These Faradic processes may make it possible for pseudo capacitors to have greater capacitances and energy densities than EDLCs. In pseudo capacitors, two types of electrode materials are used to store charge. They are metal oxides and conducting polymers. Conductive Plastics: Compared to carbon-based electrode materials, conducting polymers have a relatively high capacitance and conductivity, as well as a relatively low ESR and cost. The n/p-type polymer configuration, with one negatively charged (n-doped) and one positively

charged (p-doped) conducting polymer electrode, has the highest potential energy and power densities; however, a lack of efficient, n-doped conducting polymer materials has prevented these pseudo capacitors from reaching their full potential. In addition, it is believed that the mechanical stress on conducting polymers during reduction-oxidation reactions limits the charge-discharge stability of these pseudo capacitors.



**Fig. 3. Working principle of the supercapacitor**

This decreased cycling stability has hindered the development of polymer pseudo capacitors. As a potential electrode material for pseudo capacitors, metal oxides have also been investigated. The capacitance of ruthenium oxide is accomplished through the intercalation of protons into and out of its amorphous structure. Capacitance is greater in its hydrous form than in carbon-based and conducting polymer materials. In addition, hydrous ruthenium oxide has a lower ESR than other electrode materials. Consequently, ruthenium oxide pseudo capacitors may attain greater energy and power densities than similar EDLCs and conducting polymer pseudo capacitors.

## 6. HYBRID CAPACITORS

Hybrid capacitors combine the relative benefits and drawbacks of EDLCs and pseudo capacitors to achieve superior performance characteristics. Using both Faradaic and non-Faradaic processes to store charge, hybrid capacitors



have achieved higher energy and power densities than EDLCs without sacrificing the cycling stability and affordability that have hindered the success of pseudo capacitors. The configuration of the electrodes distinguishes the three distinct varieties of hybrid capacitors: composite, asymmetric, and battery-type.

Electrodes made from carbon nanotubes and polypyrrole, a conducting polymer, to form a composite. Integrated on carbon-based materials with either conducting polymer or metal oxide materials, this electrode combines both physical and chemical charge storage mechanisms. The carbon-based materials enable a capacitive double-layer of charge and provide a high-surface-area backbone that enhances the contact between the deposited pseudo capacitive materials and electrolyte. Through Faradaic reactions, the pseudo capacitive materials can increase the capacitance of the composite electrode.

Asymmetric: Asymmetric supercapacitors are constructed with two distinct electrode materials and provide a distinct increase in operational voltage window width. By coupling an EDLC electrode with a pseudo capacitor electrode, it incorporates Faradaic and non-Faradaic processes.

Battery-type: It couples two distinct electrodes; however, the coupling of a supercapacitor electrode with a battery electrode is unique to battery varieties. Combining the energy characteristics of batteries with the power, cycle life, and recharging periods of supercapacitors, this specialized configuration satisfies the demand for higher energy supercapacitors and higher power batteries.

## ADVANTAGES

- High energy storage: The energy density of EDLCs is orders of magnitude greater than that of conventional capacitor technologies. Utilizing a porous activated carbon electrode to attain a high surface area has led to this result.
- Low equivalent series resistance (ESR): Compared to batteries, EDLCs have a low internal resistance, allowing for high power density.
- Low temperature performance: Utilizing patented technology, Tecate Group Power Burst® products are capable of delivering energy down to  $-40^{\circ}\text{C}$  with minimal impact on efficiency.
- Fast charge/discharge: Since EDLCs achieve charging and discharging via the absorption and release of ions, and in conjunction with its low ESR, high current charging and discharging is possible without causing any injury to the components.

## LIMITATIONS

The voltage per cell is modest. EDLC cells typically have a voltage of 2.7 V. Since, the majority of applications require a higher voltage. Consequently, the units must be connected in series. It is incompatible with AC and high-frequency circuits. Due to their time constant, EDLCs are unsuitable for use in alternating current or high frequency circuits.

## 7. CONCLUSION

SCs have a tremendous potential to meet human energy needs, but their energy density is limited. Therefore, extensive efforts are being made to overcome their limitations and enhance their efficacy. One method is to concentrate on the investigation of novel electrode materials, which are crucial to the design of supercapacitors. Improving the performance of supercapacitors requires new materials with a high surface area, low internal resistance, excellent porous network, suitable pore size distribution, and improved electrochemical and mechanical stability. Electronic materials, gadgets, and systems represent a second broad group of goods that are projected to be significantly enhanced by 'building tiny' nanotechnology. Let's have a look at a survey on the effects of nanotechnology on memory, data storage, display, and processing technologies in computers. The number of transistors that can be produced on a silicon-integrated circuit doubles every 18 to 24 months, according to Moore's Law, which is an empirical observation rather than a physical law. This is the path that microelectronics has taken to advance for almost forty years. The number of transistors on modern chips, which are a few square centimeters in size, is around 100 million. However, silicon electronics won't be able to keep up with the current rate of improvement in computer speed within the next 10 to 12 years. The silicon wave is anticipated to crash due to stray signals on the chip, thermal instability brought on by densely packed transistors, and high fabrication costs.

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