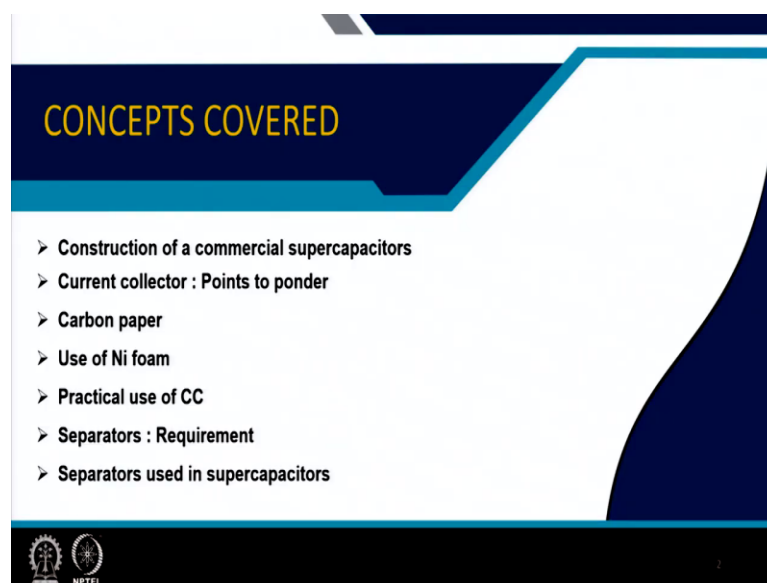


**Electrochemical Energy Storage**  
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**Module - 08**  
**Advanced materials and technologies for supercapacitors**  
**Lecture - 40**  
**Current Collectors, Separators etc. and their Effect on Performance**

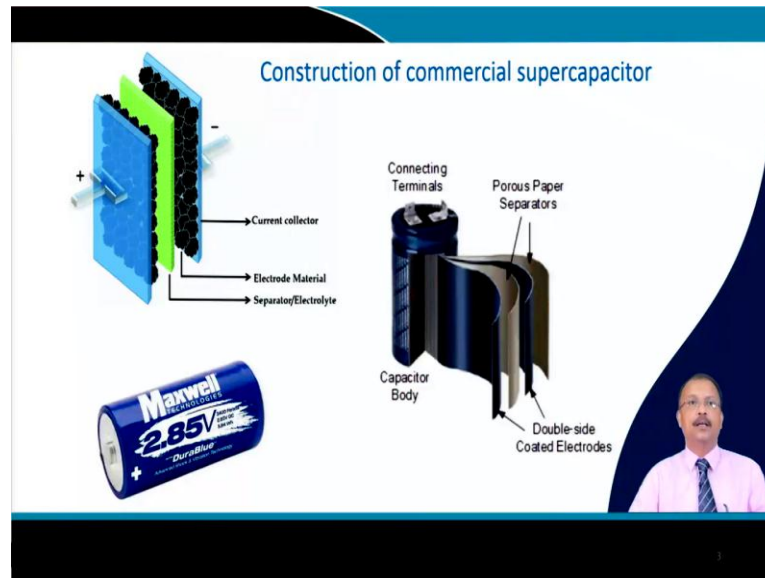
Welcome to my course Electrochemical Energy Storage and this is module number 8, where we are talking about Advanced materials and technologies for supercapacitors. This is lecture number 40, the last lecture of this module, where I will introduce the details of the Current Collectors and Separators, the construction of the super capacitors, what are their effect in their performance of the electrochemical performance of the supercapacitors.

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Now, if you I mean the concept that I want to cover in this lecture that is the first the construction of a commercial supercapacitor, how does it look like. And then, in current collectors, what are the important points that you should consider and there are different types of current collector that we will introduce and practical super capacitor, what are the current collectors that is used and then, the separator is another important part of the super capacitors and what are the super, what are the separators that is used in the super capacitors.

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So, if you see the construction, this is the basic construction. So, you should have a current collector and then, you have a coating of either EDLC or a pseudo capacitive material and then, you have a basically a separator which is soaked in electrolyte. And then, you have another electrode and then, you have some kind of contact made so that it is connected to the external circuitry.

So, this kind of thing basically in case of a cylindrical super capacitor is something similar to the type of construction which already I talked about while cylindrical lithium ion cell, I described. So, as you can see that usually they are double sided coated in order to increase the capacity and then, there is a porous paper separator is used.

That is also one of the type of separator that is used and then, you will have to connect it individually, take the connection of all the positive and negative electrode material and then, bring it, attach it to the connecting terminal. And once you close it, so you will see that this kind of supercapacitor; it looks like that. And just note at the capacity 3400 farad and operates at 2.85 volt DC and the energy is a bit low; 3.84 whatever.

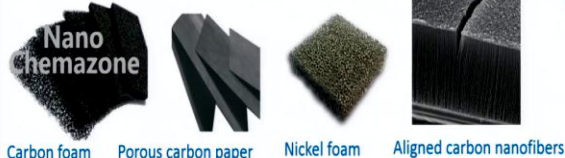
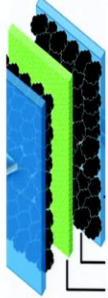
I would like you to calculate what is the similar type of energy that you see in a commercial lithium ion cell. So, you can calculate it back, you know what is the voltage and what is the capacity that one get from this kind of cylindrical cell. So,

can I mean estimate the energy and compare the capacity, charge capacitance of the super capacitor and battery just to get an idea.


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**Points to ponder**

- Most of the pseudocapacitive transition metal oxides have poor electrical conductivity (except RuO<sub>2</sub>). In addition, the surface redox reaction only take place within a very thin layer of the active materials.
- Fabrication of nanostructured pseudocapacitive materials to enhance the SSA and shorten the electron conduction length.
- Loading pseudocapacitive materials onto **conductive nanoarchitected current collectors** with large SSA for an efficient charge – transport process.



Carbon foam    Porous carbon paper    Nickel foam    Aligned carbon nanofibers



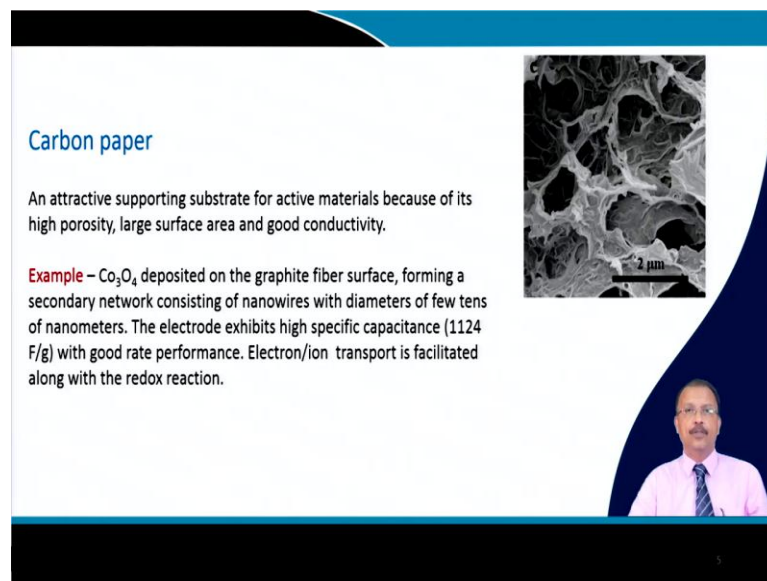
So, in case of a super capacitor, mostly pseudo capacitive transition metal oxide that is used and as I have told you that they have poor electrical conductivity except RuO<sub>2</sub>, they are metal like conductivity. So, the surface redox reaction only take place within a very small thin layer. So, therefore, this layer is pretty thin.

So, this is basically a nanostructured material that you know that is quite effective. Porous material is also effective and in case of EDLC, we talked about physical way of making this porosity or chemical way of making this porosity. So, the fabrication of this nanostructured pseudo capacitive material that is done in order to increase the specific surface area.

So, once the specific surface area is increased and the diffusion length is less, because a charge transfer reaction is involved. So, it shortens the path of diffusion and also, electron conduction. So, that is quite effective and another architecture which is commercially is not adapted yet I guess. That is the loading the super capacitive material onto a conductive nano-architected current collector which already is having large specific surface area.

So, the charge transport is quite efficient and many things are used; carbon foam is one of them. One can also use a porous carbon paper and nickel foam is another thing and aligned carbon nano fibers, so they are quite effective as far as the double layer kind of super capacitors. So, this will offer you quite reasonably good high performance I should say, ultra-capacitor one can actually make out of this structured conductive material as a current collector.

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**Carbon paper**

An attractive supporting substrate for active materials because of its high porosity, large surface area and good conductivity.

**Example** –  $\text{Co}_3\text{O}_4$  deposited on the graphite fiber surface, forming a secondary network consisting of nanowires with diameters of few tens of nanometers. The electrode exhibits high specific capacitance (1124 F/g) with good rate performance. Electron/ion transport is facilitated along with the redox reaction.

The slide features a micrograph of a porous carbon paper structure with a 2 μm scale bar and a small inset photo of a man in a pink shirt and tie.

So, if you consider this carbon paper, so that is a supportive substance for the active material. So, it has very high porosity and surface area is also large, conductivity is good. So, one example is that a graphite fiber surface, then this pseudo capacitor that is decide I mean deposited. So, it forms basically a secondary network that consist of the nanowires of this material with a few 10s of nanometer.

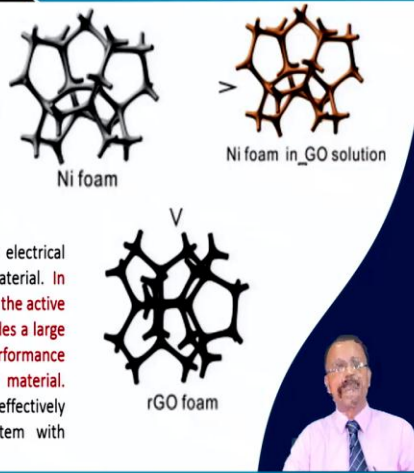
And this type of electrode they exhibit reasonably good, fantastic specific capacitance and because of this conductivity, you can expect very good rate performance. So, both electron transport as well as ion transport for this redox reaction, you know that pseudo capacitor they have this charge transfer. So, electron, I mean the charges they charge transfer is operative here; it is not only the addition of the counter ions.

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**Use of nickel foam**

3-d graphene network using Ni foam as sacrificial template. Then electrochemical deposition of NiO on 3-d graphene network.  
Specific capacitance reported ~ 816 F/g

Current collectors are used to gather and feed electrical charges stored within the active capacitive material. In most cases, the conduction of charge throughout the active material of an electrode is insufficient and provides a large amount of resistance that can ruin performance characteristics of an otherwise acceptable ES material. Efficient contacts and additives are needed to effectively transport charge current and provide a system with sufficient power.



So, carbon paper is considered one of this electrolyte and nickel foam that is also used. So, this is a typical structure one can make. So, this is a foam made out of nickel. And this is basically a sacrifice template and then, electrochemically deposit nickel oxide on a 3 - d graphene network. This is also important to increase this specific capacitance.

So, this current collectors basically, so here the nickel foam as you can see it is dipped in a graphene oxide solution and then, it is reduced to foam reduce graphene oxide and then, this is sacrificing layer. So, it is just is removed. So, you eventually get a foam of rGO.

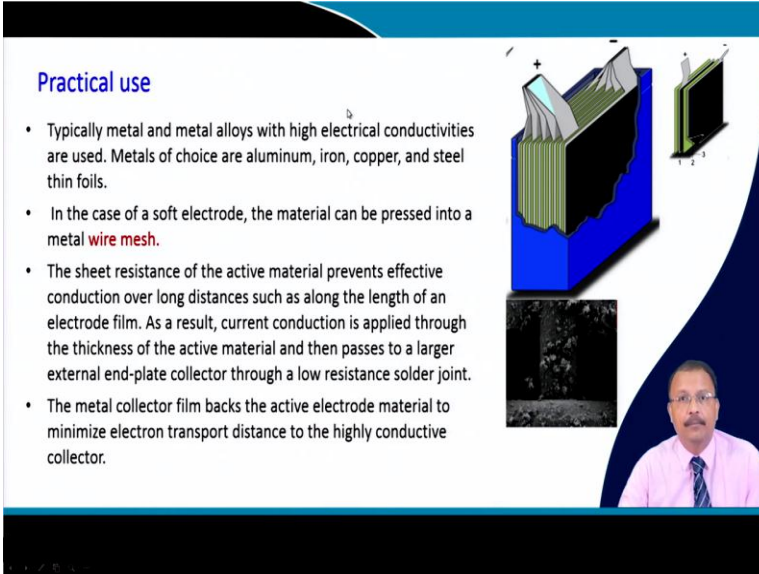
So, this current collector as you can understand, they take the electron or eject the electron into the active material. So, the conduction of charge throughout the active material that is really challenging and it is sometimes insufficient to provide a large amount of I mean it provides a large amount of resistance. So, that hampers the this thing the performance of the electrochemicals supercapacitors.

So, contact is important. So, this kind of architecture if one uses, then they have very good contact which is not otherwise if you do the tape casting on a simple metal foil. Then, this problem is there something similar to the battery what already we described that when the charge discharge takes place, volumetric expansion and depending on the material, volumetric expansion can be very severe and there is first

thing that it happens is the delamination from the current collector and then, the performance is gone. So, something similar happens to super capacitor as well.

So, if you have this kind of structure, where the active material is very intimately connected with the with the current collectors or you have a conducting structure like this throughout with a defined porosity. So, certainly, your performance will be much better.

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**Practical use**

- Typically metal and metal alloys with high electrical conductivities are used. Metals of choice are aluminum, iron, copper, and steel thin foils.
- In the case of a soft electrode, the material can be pressed into a metal **wire mesh**.
- The sheet resistance of the active material prevents effective conduction over long distances such as along the length of an electrode film. As a result, current conduction is applied through the thickness of the active material and then passes to a larger external end-plate collector through a low resistance solder joint.
- The metal collector film backs the active electrode material to minimize electron transport distance to the highly conductive collector.

But in practical case, this is not industrially viable to make this kind of structure for bigger capacitors. So, usually, metal and metal alloys which are having reasonably high electrical conductivity that is used. So, this is a type of orientation that is done so that you have a parallel connected capacitors.

So, it gives a huge capacitance and then, they are basically packed. So, this part is usually done and then, just like a pouch cell if you remember, then all the positive and negative they are tapped together and then, this is connected to the external circuit. So, as I was saying, this sheet resistance of the active material, this sheet resistance active material that actually prevents the conduction particularly in the large region.


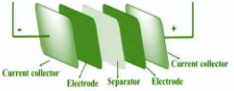
So, therefore, sometimes if the material is soft, then this kind of mesh is used, where this is this active material is pressed. So, you have a current collector mesh, where

you press the active material and the mesh is highly conducting and you have a proper contact. So, that is also quite useful to get good electrochemical performance.

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**Separator requirements**

- It is important that the material possesses strong ion conductance and electronic insulating capability.
- High ionic conductivity is promoted by high porosity and low tortuosity.
- Resistances to ion flow and interfacial contact resistance with an electrode can also be improved when separators exhibit sufficient wettability.
- A separator film should be thin, while maintaining mechanical stability.
- Separators must be chemically resistant to corrosion from electrolytes and by products of electrode degradation.
- It is also very important that separators prevent migration of active materials in order to eliminate short circuiting

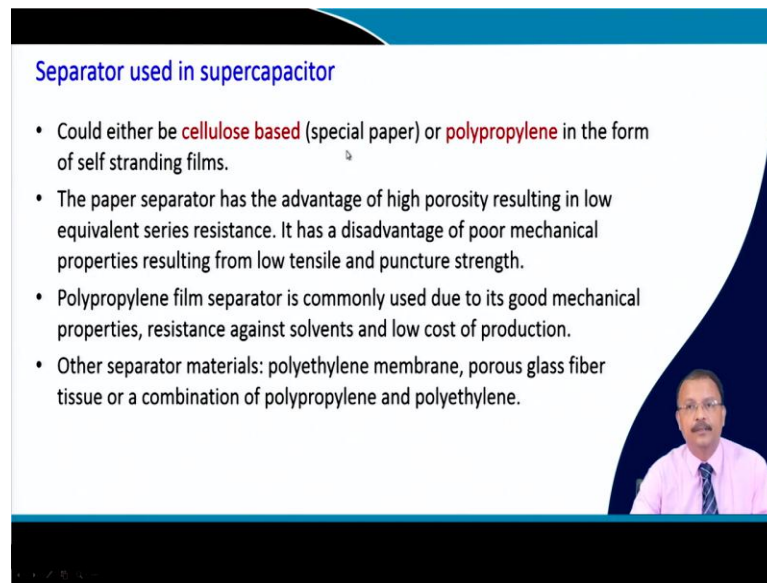


The separator is something similar. The use of it is something similar to that what we described in case of a battery. So, it should have a electronically insulating capability. So, the positive and negative electrodes should not touch and ion should pass through it and therefore, it should be porous in nature and resistance to ion flow and interfacial contact resistance with an electrode that also be improved when super separators, they exhibit sufficient wettability.

So, the electrolyte should properly wet the separators so that they are well connected with the electrode because the electrolyte this is not a bigger cell. But this is as you as I have shown that they are just connected with intimate contact. So, therefore, this should be quite thin as well because you need a defined volume, where you can pack maximum amount of active material by suitable rolling.

So, the separator itself, they are not electrochemically active. So, they should be thin and their stability should be there; mechanical stability should be there. If they are torn, then you know that the positive and negative electrode, they will connect to each other. They should be chemically resistant to the solvent that you are using, particularly when use the  $H_2SO_4$  or  $KOH$  and it is also important that this active material should not migrate through the separators.

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**Separator used in supercapacitor**

- Could either be **cellulose based** (special paper) or **polypropylene** in the form of self stranding films.
- The paper separator has the advantage of high porosity resulting in low equivalent series resistance. It has a disadvantage of poor mechanical properties resulting from low tensile and puncture strength.
- Polypropylene film separator is commonly used due to its good mechanical properties, resistance against solvents and low cost of production.
- Other separator materials: polyethylene membrane, porous glass fiber tissue or a combination of polypropylene and polyethylene.

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So, these are the primary requirement and usually, the cellulose base is a special paper some of one of the schematic, I showed that the paper separator is used or polypropylene, that is in the form of a self stranding films that is used. Paper separator, they are high porosity and therefore, low ESR value is obtained on the paper separator. But it has poor mechanical properties as you can understand.

So, polypropylene film separator, they are used due to their good mechanical properties and resistant again the solvent that is used and cost of production is also not that high. So, apart from that, people use polyethylene membrane, porous glass fiber, tissues or a combination of polypropylene and polyethylene. So, the separator material whatever has been used for lithium ion, many of them are similar to the lithium ion separators.





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**Separator**

Separators play a major role in preventing contact and electron transfer between anode and cathode. A separator must be mechanically strong to provide device durability and prevent migration of high carbon particles over time.

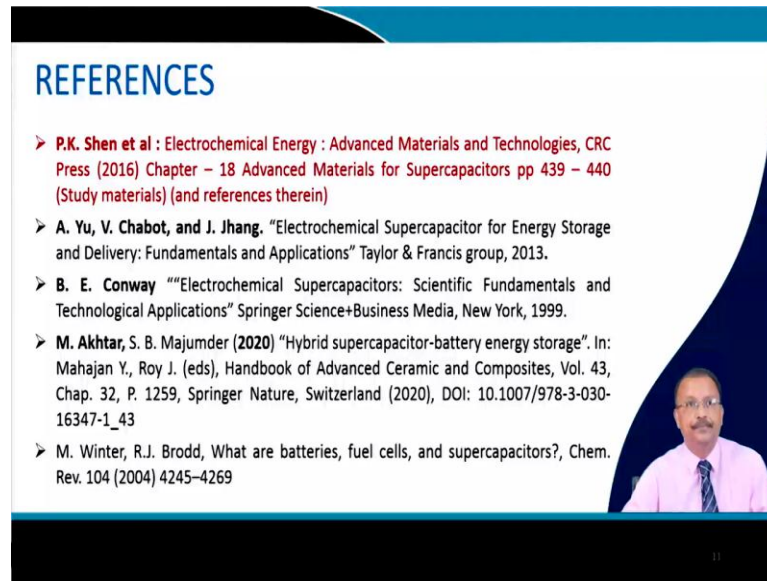
- Polyolefin-based microporous separators continue to displace natural materials such as glass and cellulose fibers because of high porosity, low cost, flexibility, corrosion resistance, and improved mechanical strength
- Polyolefin continue to see increased utilization in aqueous systems as well.
- **The problem with polyolefins for aqueous electrolytes** is that they are hydrophobic and cannot be effectively wetted by an electrolyte. Treatment of polyolefin films by graft polymerization enables modification of surface properties to increase surface hydrophilicity.



So, as I said that it prevents direct contact and electron transfer between the positive and negative electrode. It should be mechanically strong and durable. So, polyolefin based microporous separator. They are actually replacing this glass and cellulose fiber kind of things because of their porosity and cost of production is also quite low, they are flexible and for the flexible power I mean super capacitor they are quite adaptive for industrial use.

And in aqueous system also this type of separator is used, but it has a problem that usually they are hydrophobic. So, electrolyte cannot be effectively wetted particularly the aqueous electrolyte. So, sometimes this is graft polymerization people do which modifies the surface of this kind of separator and it increases their hydrophilic characteristics. So, it should wet with the electrolyte well. So, that process is adopted.

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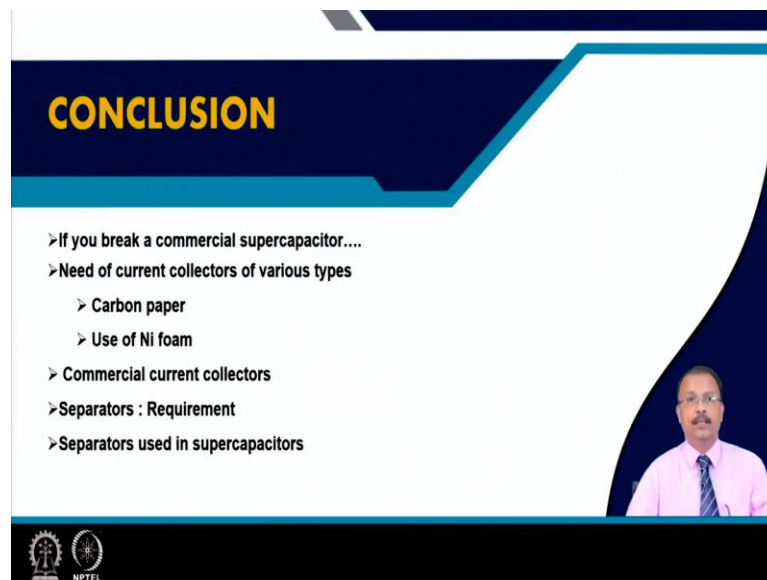


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So, this part of the lecture, you can find in the book given as a study material and apart from that the earlier references, what I told you should also look at it.

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## CONCLUSION

- If you break a commercial supercapacitor....
- Need of current collectors of various types
  - Carbon paper
  - Use of Ni foam
- Commercial current collectors
- Separators : Requirement
- Separators used in supercapacitors

So, in this particular lecture, we talked about that if you break a commercial capacitor, how it will look like and why this current collectors of various types, they are needed; particularly, the carbon paper or use of nickel foam to make a template base current collector. Commercially, it is not adaptable I guess, but research is going on to have a better contact between the active material and the current collector.

Then, commercial current collector, mostly it is metal or metal alloy type that has been described. The separator, what are their requirements and separator used in the supercapacitor that has been described.

Thank you for your attention.