

CAP-XX Supercapacitors

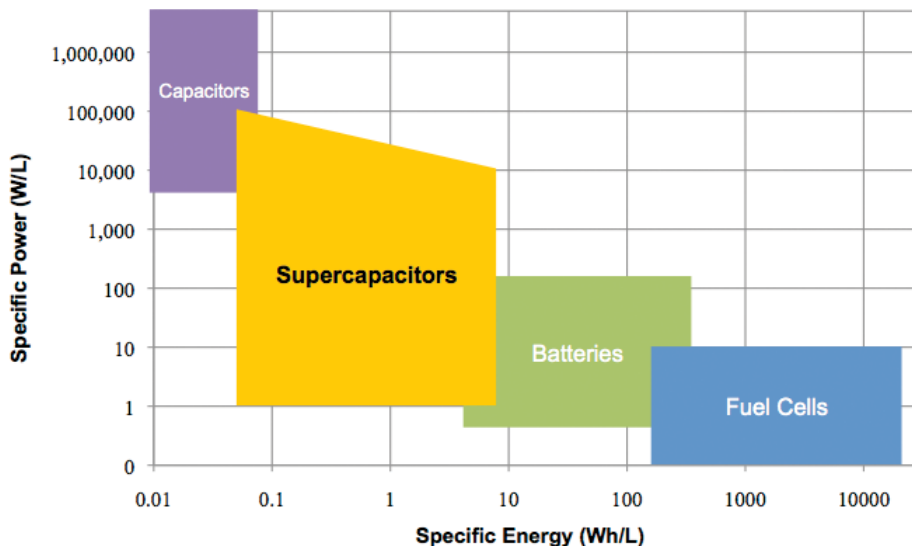
Supercapacitors are high power energy storage devices that fill a technology gap between high power but low energy capacitors and high energy but low power batteries.

CAP-XX develops and manufactures supercapacitors (also known as ultracapacitors and electric double-layer capacitors, or EDLC) for portable electronics, automotive applications and on/off grid storage. The technology is based on nano-structured interfaces and micron-sized materials to build the world's highest power electrodes which are then assembled into packaged supercapacitor devices for use in applications as varied as wireless sensors to mobile phones to hybrid electric vehicles.

'High power supercapacitors are a relatively new technology in the market. The concept of the double-layer has existed since Helmholtz described the electrochemical double-layer in the mid 1800's and this has been used in energy storage devices for memory back-up in electronics, but these devices are typically very high impedance.'

Technical Challenges

High power supercapacitors are a relatively new technology in the market. The concept of the double-layer has existed since Helmholtz described the electrochemical double-layer in the mid 1800's and this has been used in energy storage devices for memory back-up in electronics, but these devices are typically very high impedance. The technical challenge faced by CAP-XX



Ragone plots illustrate how CAP-XX supercapacitors fill the energy and power gap between capacitors and batteries

was to bridge the gap between very low energy capacitors based on dielectric charge separation and batteries based on chemical energy storage. The answer is in materials chemistry and engineering.

Supercapacitors are unique in that they can have potentially unlimited life. Unlike batteries, charging and discharging does not damage the active materials. Energy storage comes from the separation of charged ions in organic salt solutions. This absence of "chemistry" means millions of cycles can be readily demonstrated. However, the presence of chemicals and voltage gives rise to electrochemistry, which can manifest itself in many weird and wonderful ways. This is particularly pertinent to high power (low impedance) supercapacitors where small changes in the resistance can substantially change the performance of the device.

Activated carbons are well known to have very high surface areas (1000 to 3000 m².g⁻¹) and have been used in a wide variety of applications from water treatment through to supercapacitors. Generally activated carbons are glorified charcoal with all the associated vagaries in quality that you get with natural products. For CAP-XX to attain the high power and reproducibility required for cutting-edge electronics the activated carbon had to become an engineered material with low and known impurities,

Company History

CAP-XX was founded in 1997 with an Australian Government R&D Start grant. This followed-on from a research collaboration with CSIRO that began in 1995. Early investors included Australian venture capital firms and Intel and Acer, who saw the potential of the technology. First customer sales began in 2002 and the technology was widely recognised as a significant milestone. The World Economic Forum (Davos) selected CAP-XX as global technology pioneer in 2005 and CAP-XX listed on the AIM (UK) stock exchange in 2006. In 2008 CAP-XX licensed it's first generation technology to Murata of Japan for use in electronics, particularly targeting the mobile phone market.



Thin, small prismatic supercapacitors from CAP-XX have a unique market position compared to traditional form factors like cans



A broad range of device sizes and capacities

controlled hierarchical pore structure to maximise ionic conductivity, high surface area to deliver the energy needed and low electrical resistance.

Over the previous 15 years CAP-XX have carefully researched the properties of various high surface area carbons (activated and not) to build electrodes with very high energy storage, but more importantly to maximise power. Early on it was discovered that the electrical resistance of the electrode limited power and many substrates are unstable under the aggressive electrochemical conditions present in a non-aqueous supercapacitor.

Aluminium is an ideal substrate if the resistance of the oxide layer can be minimised without compromising electrochemical stability. To achieve both aims CAP-XX have created and patented a highly modified oxide layer that is both stable and has low electrical resistance.

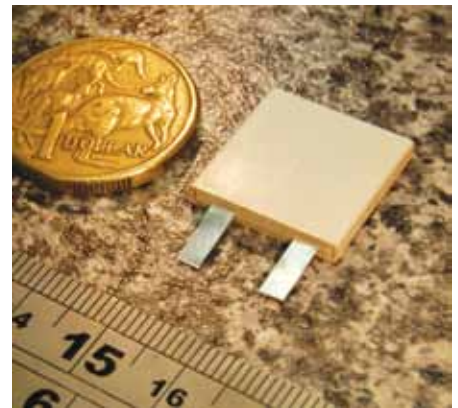
The novel aspects of CAP-XX's product also meant that a novel method of manufacturing was required. Every single step and piece of equipment in CAP-XX's manufacturing process is bespoke. The challenges in developing and bedding-down this manufacturing technology were innumerable, with many revolving around pushing materials technology (such as packaging) to extremes never before attempted and not yet matched elsewhere. While CAP-XX retains the electrode ("secret sauce") manufacturing in Australia the device assembly equipment was outsourced to two contract manufacturers in Malaysia. The first of those began in late 2005 and both now reliably produce CAP-XX product in high yield.

Market Development

With any new technology one of the major hurdles to overcome is market acceptance. The gap in performance between capacitors and batteries that existed prior to supercapacitors also means that there is a gap in knowledge. Although the situation is improving, many electrical engineers do not know that they have supercapacitors in their design toolbox. As a small company with new technology finding a market fast has been crucial and education has played an important role in CAP-XX's penetration of new markets.

After dipping a toe in the automotive market in the late 90's it became clear that hybrid and electric vehicles were still a long way from commercialisation and CAP-XX chose to focus on portable electronics with mobile phones being the obvious high volume market. This approach overcame two major hurdles: design cycle times were measured in months rather than years, allowing new and innovative technologies to get a foothold; and required product performance was measured in years rather than decades allowing a relatively unproven technology to generate confidence in the market.

Combining CAP-XX's high energy, high power electrodes with thin form packaging gave CAP-XX a unique market position that is still unmatched.

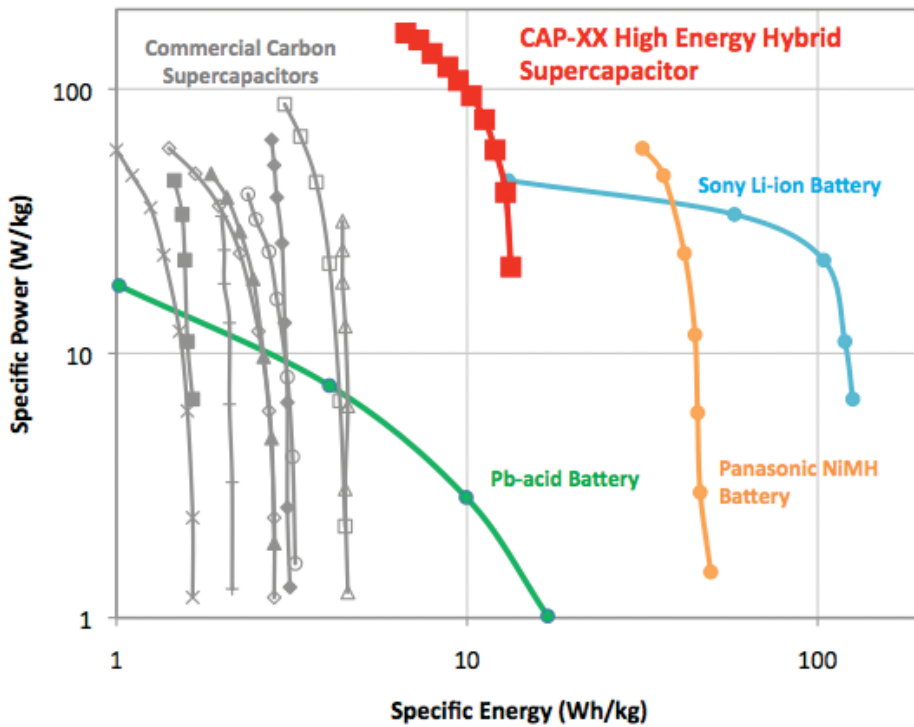


An engineering sample of the world's first high power SMD supercapacitor

'After dipping a toe in the automotive market in the late 90's it became clear that hybrid and electric vehicles were still a long way from commercialisation and CAP-XX chose to focus on portable electronics with mobile phones being the obvious high volume market.'

In mobile phones CAP-XX supercapacitors allowed increased run time, improved audio quality and perhaps the "killer application" of a high quality camera flash using high brightness white LEDs. However, despite obvious technological benefits to mobile phones it became clear that CAP-XX was unlikely to be able to supply the market without partners. In 2008 CAP-XX non-exclusively licensed the technology for small devices to Murata of Japan, a major supplier of mobile phone components and the world's largest manufacturer of multi-layer ceramic capacitors (MLCC), producing over two billion MLCCs per day.

CAP-XX now focuses its existing manufacturing capacity of several million devices per year on growing supply to our customer base of high value niche applications, such as: handheld computers (PDAs), wireless communication modules, portable medical devices (inhalers & insulin pumps) and solid state disc drives (SSDs) amongst others. A suite of products ranging



Ragone plot showing the high energy and power of CAP-XX's hybrid supercapacitor



Supercapacitor testing module (14V) for Automotive Stop/Start

from the ultra-small 20 X 15 X 1mm and 150 mF intended for USB drives through to 2.5 F for actuators ensures that a broad range of applications can be covered.

Market development occurs through a global network of distributors assisted by CAP-XX's sales and applications engineering teams. The novel nature of supercapacitors makes expert customer support a necessity. Often CAP-XX will design solutions for customers to assist them to ensure an optimal design.

Next Generation SMD Product

One of the hurdles holding back wider uptake of supercapacitors in the electronics industry was the inability of the parts to be soldered under reflow conditions. Most electronic components are assembled onto printed circuit boards (PCBs) by being robotically placed on a solder pad on the PCB followed by the whole passing through an oven at 260 °C. These surface mount devices (SMD) are the industry norm. Currently available supercapacitors today are most emphatically not SMD, with exposure to above about 100 °C having catastrophic consequences for the supercapacitor.

The fruit of a seven-year project was that in mid 2011 CAP-XX demonstrated an SMD supercapacitor containing unique technology that overcame all of the problems. This required changing every single component of the supercapacitor to overcome the multitude of materials problems that such high temperatures create, inventing new materials in several cases and again, pushing manufacturing technologies to levels never before obtained.

The result is the world's first low impedance (0.7 Ω.cm²) SMD electrode assembly. In addition to allowing an SMD part, the ground-up redevelopment allowed design

improvements to be incorporated that overcome the drawbacks of having to rate the SMD to over 260 °C and have resulted in a device with even better performance than the first generation, non-SMD part.

Automotive Opportunity

Murata's move into mass production and recent developments in the global automotive market have re-ignited CAP-XX's efforts in large devices, especially for application in hybrid internal combustion engine (ICE) passenger and commercial vehicles (cars, buses, trucks and trains) where the market is crying out for immediate application for start-stop and micro-hybrids.

CAP-XX has identified four segments where our supercapacitors can be used in passenger, light commercial and heavy commercial vehicles:

- > **eCall** - A stand-alone wireless communications unit used to notify authorities of an accident
- > **Distributed Power** - Numerous small supercapacitors distributed throughout the vehicle allowing a reduction in the cost and weight of the wiring harness
- > **Engine Cranking** - Enabling Stop/Start applications in micro-hybrids (μHEV) and/or to provide cranking power in cold weather. Can also act as regenerative capture
- > **Drive Train** - Integrated into the hybrid (HEV) or electric vehicle (EV) drive-train the supercapacitors decrease required battery size, reduce system complexity and increase battery life

Both eCall and distributed power applications can be met by CAP-XX's existing product range, although there has been little call for distributed power to date.

A global resurgence in hybrid (HEV) and electric vehicle (EV) development has spurred CAP-XX to re-launch our technology in automotive products. The demand from Europe and China in particular for Stop/Start systems is rapidly accelerating. Supercapacitors can play a key role in Stop/Start by removing the engine cranking load from existing lead acid batteries.

Start/Stop turns off the car engine when no acceleration is required, such as when coasting or when stopped at an intersection. This reduction in engine use improves efficiency and cuts emissions by

The Technical Stuff

At the heart of CAP-XX's technology is control of two fundamental issues: electrical and ionic resistance (power) and surface area (energy).

$$C = \epsilon_r \epsilon_0 A / d \quad E = \frac{1}{2} CV^2$$

Supercapacitors are special due to their relatively high energy. The high capacitance (C) comes from very high surface area (A) due to special nano-structured carbons which have up to 3000 m².g⁻¹ of surface area and very small charge separation (d). The sub-nanometer charge separation comes about by using chemicals (organic salts dissolved in organic solvents). There is no dielectric in a supercapacitor.

$$P = \frac{1}{4} V^2 / R$$

By ensuring very low resistance (R) through nano-structured materials and interfaces CAP-XX makes exceptionally low resistance electrode assemblies (less than 0.3 Ω.cm²). Through the use of an organic electrolyte voltages (V) are as high as 2.75 V per cell. When CAP-XX put these two advantages together in a cell CAP-XX can obtain over two megawatts per kilogram (2 MW/kg) of active material. When these high power materials are incorporated into electrodes and assembled into devices ready for sale, a single cell CAP-XX supercapacitor can deliver over 200 kW/kg of power.

5 to 30%. However, the very high power required to rapidly restart the engine places a heavy drain on the battery, reducing efficiency and battery life. Supercapacitors are an ideal, plug-in solution to Stop/Start and are already being implemented in Europe.

In addition to CAP-XX's normal supercapacitor technology, a hybrid supercapacitor has been developed that allows at least double the energy density, whilst maintaining the required high power.

Hybrid supercapacitors use one electrode from a battery and another from a supercapacitor and places them in the same cell. In its ideal incarnation the best aspects of the battery (high energy) are combined with the best aspects of the supercapacitor (long life, high power).

CAP-XX's hybrid supercapacitor has an energy density (>10 Wh/L) up to four times that of a state-of-the-art supercapacitor, high power (>22 kW/L) and very long life, with over one million cycles already demonstrated.

'A key advantage of CAP-XX's hybrid is to reduce cost. This is the key hurdle holding back supercapacitors from wider acceptance in the automotive field. With a BoM cost of one fifth of one cent (\$0.002) per Farad the hybrid easily beats the US Department of Energy milestone of one cent per Farad.'

A key advantage of CAP-XX's hybrid is to reduce cost. This is the key hurdle holding back supercapacitors from wider acceptance in the automotive field. With a BoM cost of one fifth of one cent (\$0.002) per Farad the hybrid easily beats the US Department of Energy milestone of one cent per Farad.

CAP-XX's supercapacitor platform technology is well proven and is gradually being applied to increasingly diverse applications and markets. As a technology developer CAP-XX is partnering with established and developing manufacturers to make inroads into large markets beyond the reach of small companies. Having successfully penetrated the electronics market through a licensing agreement with Murata, CAP-XX is now targeting the automotive market via Tier One automotive suppliers and their manufacturing partners with the goal of getting CAP-XX -powered Stop/Start systems in passenger vehicles within two years. Just like the Murata partnership CAP-XX is looking for partners to work with in the global automotive markets.

Contact

Anthony Kongats
CEO
CAP-XX (Australia) Pty Ltd
anthony.kongats@cap-xx.com
www.cap-xx.com

Author

Phillip Aitchison, Vice President Research,
CAP-XX (Australia) Pty Ltd

Phillip is responsible for all aspects of CAP-XX's research, product & process development and intellectual property. Phillip is a materials scientist with nearly twenty years' experience with high-power energy storage technologies. He has a Doctorate in Chemistry awarded jointly by the University of Montpellier, France and Victoria University of Wellington, New Zealand. Phillip has spent the last twelve years in leading-edge technology companies, initially at lithium-ion battery company Pacific Lithium Ltd., New Zealand and since 2002 at CAP-XX in Australia.

CAP-XX (Australia) Pty Ltd
Units 9 & 10
12 Mars Rd
Lane Cove 2066
NSW, Australia

(+61 2) 9428 0145 wk (DDI)
(+61 2) 9420 0690 wk (reception)
(+61 2) 9420 0692 fax
phil.aitchison@cap-xx.com
www.cap-xx.com