Form as a design factor for energy storage devices: Ultrathin, flexible, low ESR supercapacitors for Optimal space utilization

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Introduction

Supercapacitors, also known as Ultracapacitors or Electric Double Layer capacitors, are energy storage devices that bridge the energy density and power density gap between traditional capacitors and batteries. Compared to capacitors, Supercapacitors have higher energy density but lower power density, and relative to batteries they have higher power density but lower energy density. These properties have thus made Supercapacitors increasingly popular for a wide range of applications where battery or capacitor alone may not work.

Currently all supercapacitors are evaluated based on parameters such as capacitance, operating voltage, Equivalent Series Resistance (ESR) and so forth. However, until now, the form factor or the shape of the supercapacitor, another important parameter, has not been offered as a design choice for users. Therefore, while portable electronic devices are becoming increasingly small and ultrathin, and may even become flexible in the future, energy storage components, notably supercapacitors, have remained bulky and inflexible and not suited to filling the space requirements of these devices.

Users have thus been forced to pack non-conformal shaped supercapacitors into their device packages, leading to wasteful use of both material and space. For example, consider the use of supercapacitors inside specially engineered cylinders for space applications. A flexible, ultrathin supercapacitor can easily wrap around the inside surface of the cylinder, which space is not conventionally used. This accommodation gives designers freedom to either pack more components inside the same cylinder or to opt for a smaller cylinder that has longer range and is lighter.

This situation is illustrated in Fig 1 (a) which shows the packing of one cylinder of diameter D and length L into a box of dimension D X D X L. Fig 1(b) shows 6 cylinders packed into a larger space. We note that the scenario illustrated in the figures can also apply to many other situations including the packing of cylindrical supercap cells for hybrid/electric vehicles. A simple calculation shows that at least 21.4% space is wasted; the wasted space is shown as the shaded space in the figures below. The use of “form-factor-enabled” supercapacitors thus can save substantial weight and volume for designers and architects.

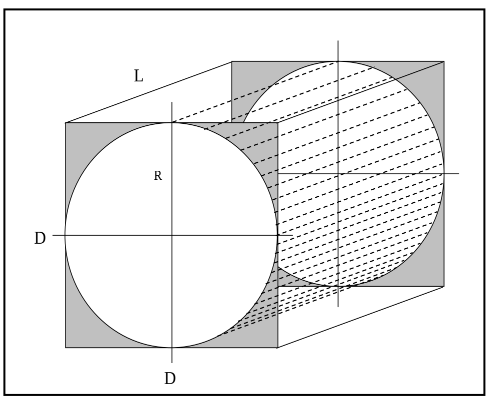


Fig. 1(a)

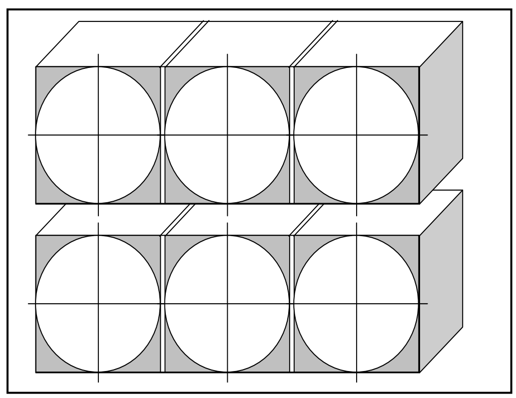


Fig. 1(b)

OptiXtal, Inc. was formed to fulfill this (so far) unmet market need for conformal-shaped supercapacitors. Our SuperXcapacitors are ultrathin, flexible and custom-shaped to fit user needs. For example, we believe that the incorporation of such supercapacitors in portable electronic devices will make it possible for power management designers to run more applications than otherwise possible. Currently many of these applications are limited by battery size, and the adaptation of new power draining “apps” is only possible by using a larger battery. This inevitably leads to an increased package size, which requires an extensive and costly redesign of the portable device. The implication here is that the design thus “locks” portable devices into the apps they can use and prevent them from being expandable to use newer and more power-consuming apps. Our space-conforming SuperXcaps can overcome this limitation because they can be made to reside in the space available, and will be used with the existing battery, thus making the device more updatable to newer and power-hungry apps.

In this paper we will show ultrathin, SuperXcapacitors of various shapes made by OptiXtal. These supercapacitors have flexible 2D packages that conform to the space available. We note that our supercapacitors also have lowest ESRs among comparable supercapacitors; consequently they have low energy storage losses and high power densities.

Results and Discussion

SuperXcapacitors™ of various shapes and sizes were manufactured by us and tested using an Arbin Instruments BT-2000 Supercapacitor tester. The digital image of Fig. 2 shows SuperXcaps of various sizes and shapes and Table 1 contains their sizes and shapes.

Fig. 2

The small SuperXcap in Fig. 2 (#9) is what we call the "mini" and it is about the size of a SIM card that is found in cell phones. This 2.7V cell has a capacitance of

173 mF, and ESR of 14.6Ω [1]. To our knowledge, this is the smallest commercially available supercapacitor cell.

The table below points out that our supercapacitors are ultrathin (e.g., less than 0.9mm) and flexible. Other makers' supercapacitors are much thicker and inflexible [2]. The closest comparable in the market are the ones produced by CapXX, which have the thickness of 1.1 mm, more than twice of our thinnest supercapacitor [3].

Name	Dimension	Shape
Mini	8 mm x 11 mm x 0.5 mm	Rectangle
Circle	25 mm x 25 mm x 0.8 mm	Circle
Oval	35 mm x 135 mm x 0.8 mm	Oval
M	60 mm x 65 mm x 0.8 mm	Rectangle
L	110 mm x 165 mm x 0.8 mm	Rectangle

Table 1

We want to add here that Fig. 2 and Table 1 are merely to illustrate the unique shapes and sizes that we have custom-built to market demand. The technology of OptiXtal can provide SuperXcapacitors with lateral dimensions as large as 10m or as small as a few mm, and with shapes that customers demand.

Fig. 3 shows applied voltage as a function of time for the newly made mini SuperXcap shown in Fig. 2. The initial formation began with the charge at the constant current of 2mA up to 1.9V. At this point the charging was increased to 4mA up to the maximum voltage of 2.7V. After a rest of 15 seconds, the mini SuperXcap was discharged at 2mA to 1.35V and then subject to three additional charge discharge cycles between 2.5V and 1.25V at 15mA, when Capacitance and ESR were measured. The voltage curve clearly exhibits the behavior of a good supercapacitor. Our calculation shows that this mini SuperXcap had a capacitance of 173 mF and an ESR of 14.6Ω [1] measured at the constant discharge current of 15mA.

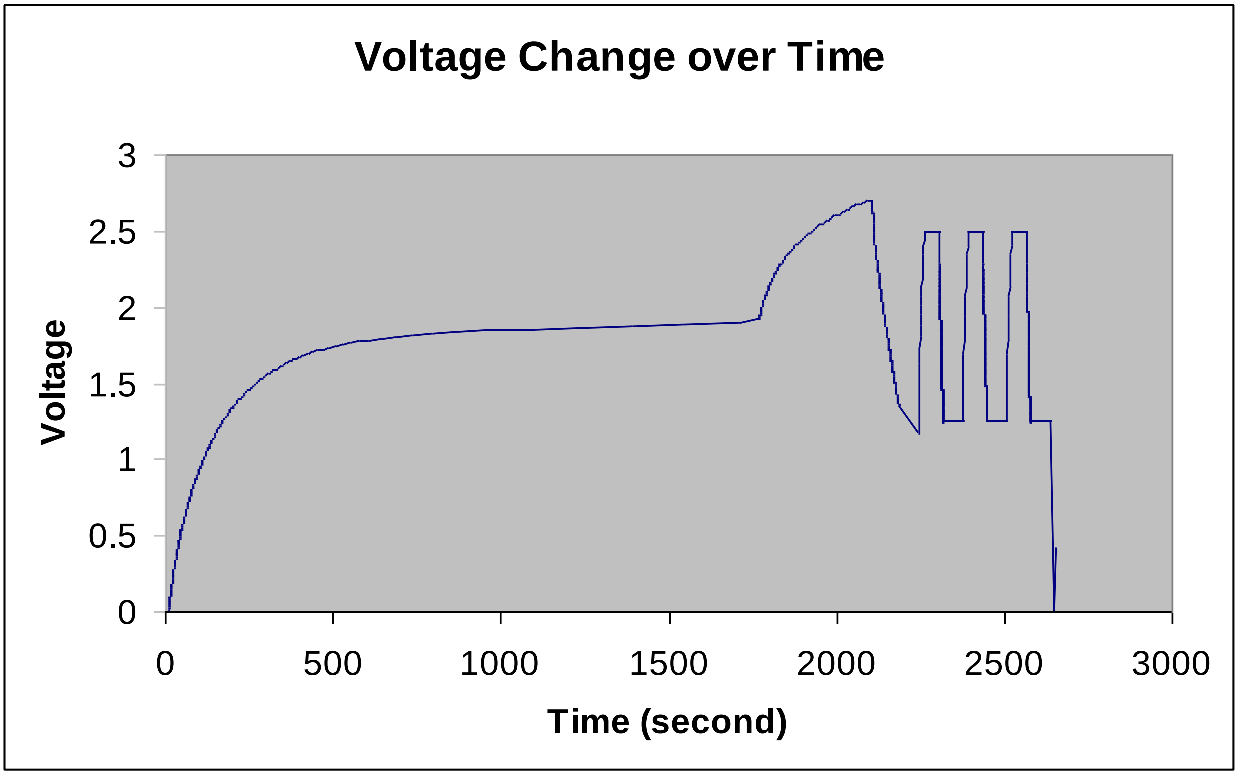
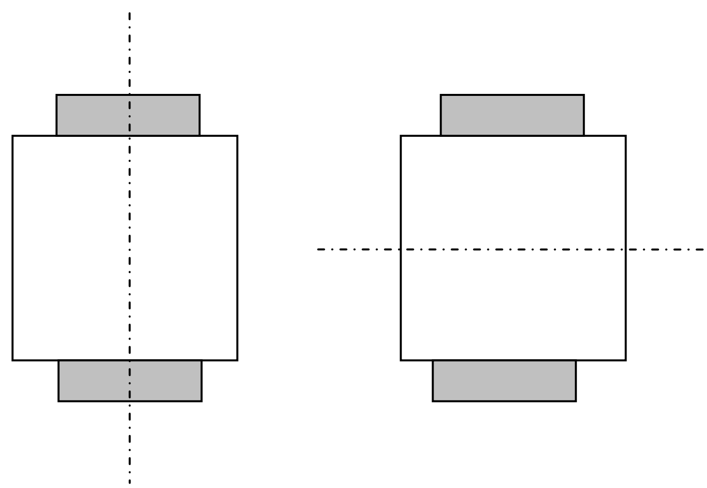


Fig.3 Data for the Mini SuperXCapacitor shown in Fig. 2

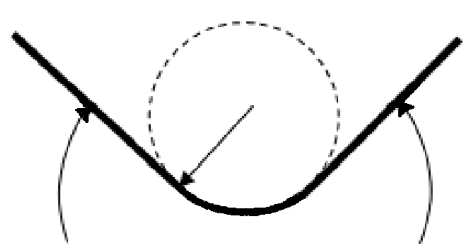
Our next set of data relate to experiments that tested the flexibility of our SuperXcapacitors. We measured the changes to Capacitance and ESR from bending and unbending of our SuperXcaps.

In the figures below, an illustration of our bending method is shown. M sized SuperXcaps (60mm x 65mm) were bent completely around a cylinder, around both X and Y axes as shown. We measured Capacitance and ESR of the SuperXcap after it was bent and also after it was unbent to original shape, and this data is shown in Fig. 4(c).



Bending Type A Bending Type B

Fig. 4 (a) M sized SuperXcaps were bent around Y and X axis as shown above.



Wrapping around a Cylinder

Fig. 4(b)

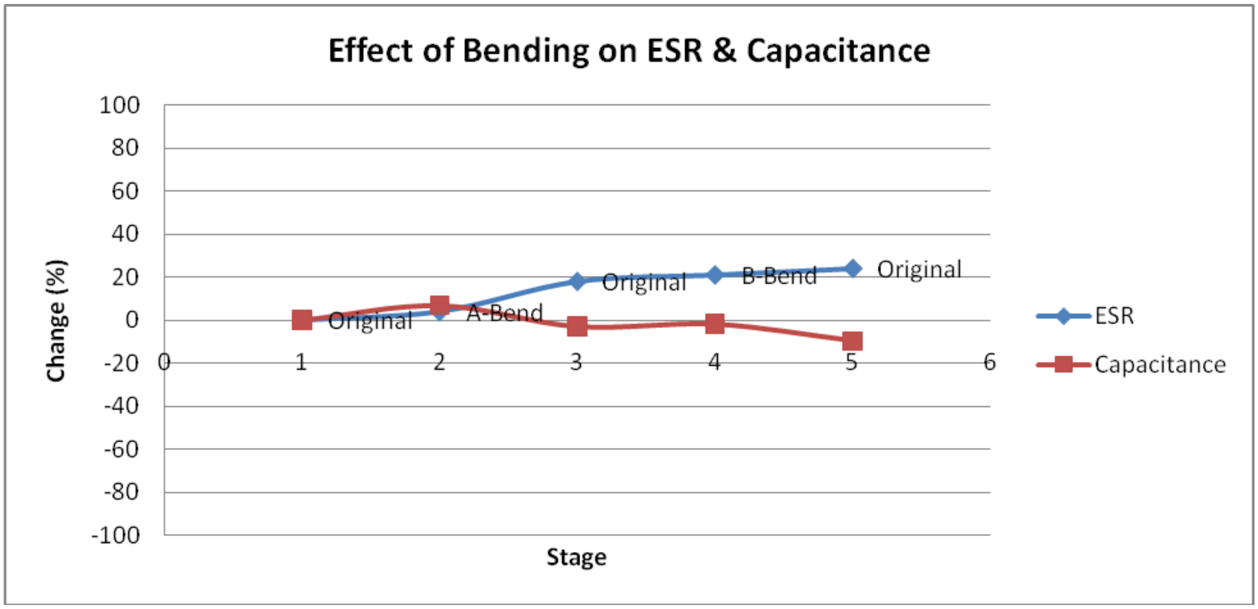


Fig.4(c) The change in Capacitance and ESR is shown

as the SuperXcap was bent along both Y and X axes.

Figure 4(c) shows the changes in both Capacitance and ESR that were measured as the SuperXcap was bent along Y axis (Stage 2), and then unbent (Stage 3) and then bent along X axis (Stage 4) and then unbent (Stage 5). Except for one data point (between stage 2 and stage 3 for ESR), all of the other data show changes for ESR and C that are within ±10% from the starting point. When we measured ESR after unbending the M size SuperXcap from its original bend (stage 2) around Y axis, a slightly larger increase (roughly 17%) increase in ESR was measured. But all the data are within the 20% uncertainties typical of both Capacitance and ESR measurements. This leads us to conclude that a single bending along any axis creates a cylindrically conformal SuperXcap whose C and ESR are very close to the C and ESR values of an unbent one.

We have also conducted multiple bending and unbending tests and our data show that this leads to significant deterioration and can even damage the SuperXcap. In a realistic situation, our SuperXcaps will not be undergoing multiple bending and unbending. In fact, the SuperXCaps will mostly go thru a single bending to get the conformal coverage, and then held in place in that configuration. In such a realistic scenario, our data suggest that our SuperXcaps will maintain their "as manufactured unbent" quality, as measured by ESR and C.

Conclusions

The incorporation of form as a design element will be important in packing more components in limited space. This will reduce wastage in materials and can also improve, in many cases, the functionality of the devices.

OptiXtal has shown SuperXcaps in unique shapes and in sizes as small as a cell phone SIM card to as large as 100 mm x 175 mm. These SuperXCaps are ultrathin with thinness from 0.5-0.8 mm, have the lowest ESR in their class and are flexible. Other sizes and shapes can be manufactured based on customer needs.

References and Notes

1. ESR is measured as the instantaneous drop in voltage at the beginning of a constant current discharge cycle. Typically, our ESR data is acquired after 31 milliseconds' lapse from the start of discharging. Other companies use significantly shorter acquisition times for ESR measurements. For example, CapXX measures ESR after 50 microseconds [4]. By using the pulse data that is also available in our instrument, we get a significant lower ESR, about 7Ω (for the mini) that was measured after 1 millisecond. We suggest that our ESR (if measured at a fast 50μs) would be even less.

2. This conclusion was based on the examination of the product catalogs of 20 worldwide capacitor makers.

3. www.cap-xx.com/resources/prodspecs/CAP-XX_Product_List_2009.pdf