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LED Lighting with Ultracapacitors

Introduction

Light emitting diodes, or LEDs, have come to prominence in recent years in conventional lighting applications including flash lights, street lamps, traffic lights and emergency lighting. Their advantages over incandescent and compact fluorescent light sources include greater robustness, higher energy efficiency and a longer lifetime. Due to the constantly falling prices of LEDs, they are also now becoming more economical in the long term than traditional light sources.

With the luminous efficiency of LEDs undergoing exponential growth in recent years, modern LEDs are the most energy efficient form of lighting that is generally available. Typical efficiencies and lifetimes for LEDs compared to other light sources are shown in Figure 1.

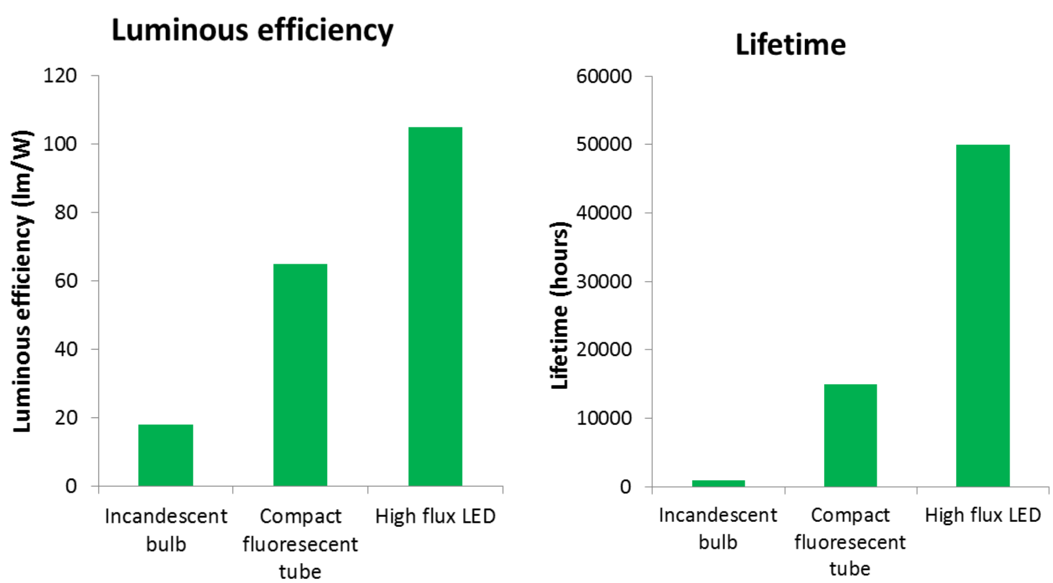

Figure 1: Luminous efficiency and lifetime of LEDs compared to other common light sources

LEDs with a luminous efficiency above 100 lumens per watt are now in mass production and are being used, for example, in street lamps. This is a major improvement even since 2009, when 50 lumens per watt was considered as cutting edge efficiency. The dramatically low energy required to power LEDs makes them perfect candidates for ultracapacitor powered illumination devices. The lifetime of LEDs is very high, in the tens of thousands of hours at a minimum. The price of LEDs has also declined significantly in recent years, and this trend

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is forecast to continue as production volumes and efficiency improve. As countries continue to legislate to phase-out incandescent bulbs, it is expected that LEDs will gradually fill a portion of the vacancy created which will further promote price reductions.

Ultracapacitors are high lifetime, high power devices that store relatively little energy compared to a battery. The low power requirements of LEDs means that a reasonably sized ultracapacitor power source can still provide several hours of lighting on a single charge, while the high lifetime and low-temperature performance advantage over batteries is maintained. The emergence of 3.0 V ultracapacitor cells as well as hybrids only strengthens the case for their use in LED applications due to the higher amount of energy stored in these new ultracapacitor types. Ultracapacitors are also free of lead, mercury, and cadmium, which eases any environmental concerns that may arise over the course of their long term use and eventual disposal/recycling.

Technical:

LEDs contain a semiconducting material that emits light in a process known as electroluminescence. When a suitable voltage is applied across the light emitting diode junction, current flows and negatively charged mobile electrons cross the energy band gap to recombine with positively charged holes in the semiconductor material, as illustrated in Figure 2. During this charge recombination process the change in potential energy of the electron valence level is released as monochromatic light. The process can be thought of as the direct conversion of electrical energy to light energy in the visible spectrum. In the case of incandescent lights, electric energy is used to heat a filament until it is glowing hot and emits light over a broad spectrum of visible and infrared light. In the case of fluorescent lights, toxic mercury vapor is excited by electrical discharge to emit short wave ultraviolet light which strikes a phosphor coating on the bulb to fluoresce visible light.

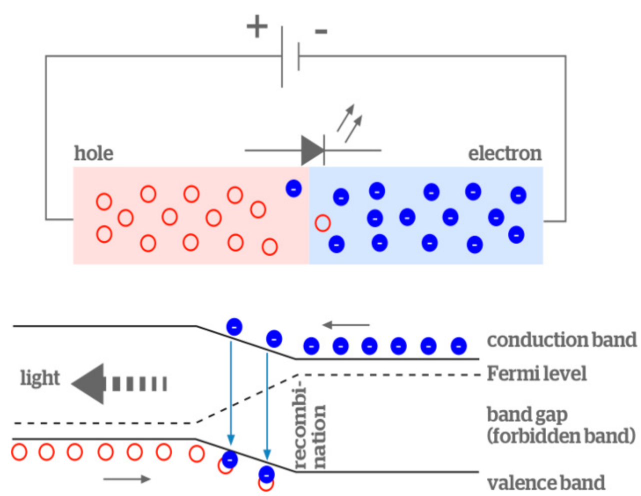

Figure 2: Charge recombination at LED p-n junction

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LEDs typically require a constant current for constant light output operation. The voltage-current relationship for LEDs is nonlinear; purpose built LED drivers (power supplies) are required to provide LEDs with the proper power input. Driver energy efficiencies are on the order of 85 percent, which slightly impacts the overall energy efficiency of a LED device. The load on the driver is an important factor here, as the driver will reach maximum efficiency when it is being used at its full power. A well designed driver is critical, not only for energy efficiency, but also for lifetime: a poorly designed driver can potentially have a shorter lifetime than the LED itself.

LEDs are typically rated for an ambient temperature of 25 °C. At higher temperatures their efficiency begins to decrease, while the opposite is true at lower temperatures. For outdoor night time applications the efficiency of LEDs can be greater than the manufacturer specified efficiency due to cooler temperatures. Thermal management is also important in maximizing the lifetime of the LED. All high luminosity LED devices employ some kind of heat dissipation hardware, often just a simple aluminum heat sink. Although it will reduce the light output, a lower input current to the LED will result in less heating and a longer lifetime.

Ultracapacitors have a linearly sloping voltage profile during charge and discharge. Because modern power electronics are only capable of harnessing the output of a cell down to about half of its rated voltage, it should be expected that in a LED application the full energy capacity of the ultracapacitor would not be accessed. The driver supporting the LED would preferably be designed provide a non-varying power input to the LED if a steady light output is desired. The energy stored in an ultracapacitor is given by the equation $E = 1/2CV^2$, where C is capacitance and V is voltage. By discharging to half of the rated cell voltage, 75 % of the cell's energy is utilized.

Applications:

Ultracapacitors are the perfect power source for a number of LED lighting applications. Figure 3 shows the nominal run time of a LED device over a range of Lumen output levels and ultracapacitor capacitances. Following, some examples of LED-ultracapacitor applications that are already emerging in the market are given.

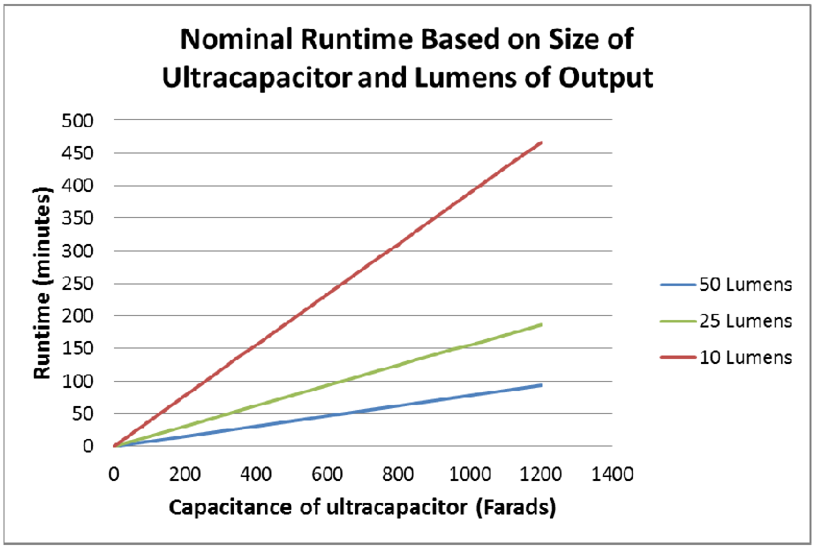

Figure 3: Runtime vs. capacitance for different LED Lumen outputs. Assumes: ultracapacitor is rated to 2.7 V and discharged to 1.35 V, a LED efficiency of 100 Lumens per Watt and a driver (power supply) efficiency of 85 %.

1) Handheld flashlights and lanterns

Imagine a rechargeable handheld flashlight that gives two hours of reliable operation, that can be charged in ninety seconds, and that works just as well at -40 °C as it does at room temperature. The combination of modern efficient LED technology and ultracapacitors has made this kind of device a reality. The energy efficiency and greater shock resistance of LEDs compared to incandescent bulbs has already led to their incorporation in most flashlights available today. By using ultracapacitors to power a flashlight, the user is relieved from the nuisance of having to replace or slow-charge batteries. Combined emergency type radio-flashlights are also potentially low enough in their energy requirement to allow the use of ultracapacitors as a power source. In this application the lifetime, fast charge and reliability of ultracapacitors is especially attractive.

2) Solar powered outdoor lighting

LEDs, ultracapacitors and solar panels are all high lifetime devices. Unfortunately, solar power has always carried some bad baggage – batteries. The need to periodically replace the batteries in off-grid solar systems has discouraged the adoption of solar technology in numerous areas. However, if ultracapacitors are used as an energy storage medium, the cost and inconvenience of battery replacement is removed. However, because ultracapacitors store a relatively small amount of energy, they are most suitable when the energy demand of the system in question is relatively low.

Solar powered LED lights are a perfect example of the harmonious coupling of solar, LED and ultracapacitor technologies. The solar panel uses energy from the sun to charge the ultracapacitor during the day and at night a photo sensor switches on the LED to provide illumination, either temporarily or throughout the night. Even if outside temperatures drop to -40 °C the ability of the ultracapacitor to provide power to the LED will not be noticeably compromised, unlike a battery. An ultracapacitor cannot be over discharged like batteries can, so there is no damage to them if they stay at low state of charge for a long period of time. Because there is no incandescent or fluorescent bulb and no battery to curtail the lifetime and performance of the device, the last remaining disincentives to adopt the solar technology are removed. Garden lights, illuminated signs, navigational aids, pavement lights, traffic signals, and street lights are all potential applications of this technology.

3) Emergency interior lighting

Emergency lights are installed in buildings to provide temporary illumination in the event of a power outage. The replacement of batteries in these systems is a constant expense for building maintenance. By using LEDs as a low power light source, and ultracapacitors as the energy storage medium, the servicing requirements for such units can be reduced dramatically, saving money and time for building managers.

Conclusions

Ultracapacitors and LEDs exhibit several properties which are complimentary, allowing them to be harmoniously coupled in several applications. Ultracapacitors are low energy density devices, while LEDs require very little energy to operate. LEDs are high lifetime devices, and so are ultracapacitors. Of all electrical light sources, LEDs are best suited to operation at cold temperatures, which is also true of ultracapacitors with regard to power sources. Both ultracapacitors and LEDs have experienced dramatic price reductions since the year 2000, and are thus contemporaneously maturing as economical green technologies.