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Integration of LED/SC chips (matrix) in reverse mode with solar energy storage

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Abstract. In this work, for the first time we investigated controlling the quantum efficiencies of III-nitride LED/SC (solar cells) new energy accumulating elements and supercapacitors as energy storage devices (Enestors). It has been shown that the atomic content in these microenergetic devices gives large possibilities for energy storage from solar light. The developed technique is promising to make ideal new functional LED, LD and SC with a high quantum efficiency and small leakage. This technology can be realized using Si/A^3B^5 integrated processor technology epitaxy with computer driving.

Keywords: III-nitrides, reversible LED/SC, cation operation, supercapacitor, energy storage.

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1. Introduction

The most urgent problem in solid state lighting technology based on III-nitride heterostructures is the high reverses optoelectronic conversion of electron and photon energy that can be accumulated.

We investigated novel LED heterostructures on binary and multicomponent A^3B^5 compounds and their solid solutions (SS) [1].

Nevertheless, all the commercially III-nitride LEDs are now predominantly made on (0001) plane of sapphire, SiC or Si substrates. This direction is polar, which creates strong polarization-induced internal electric field leading to a reduced overlap between the electron and hole wavefunctions. In order to overcome this problem, the growth of the III-nitride structure along polar directions is preferable. But the growth along nonpolar directions offers a number of advantages over devices currently grown along the (0001) direction. In this sense, it is interesting to grow III-nitride heterostructure on III-oxide layer, for example, Al_2O_3 or α-plane $(AlGa)_2O_3$ substrate instead of α-plane of sapphire [2].

In this paper, we introduce elements for energy accumulation (energy storage), which can be characterized as energy memory and realized using ferroelectric layers or semiconductor solid solutions with the potential wells. In this research of hybrid variant as accumulator was used supercapacitors – electric double layer capacitors that by all their parameters simulate solid energy storage devices that are most suitable for monolithic integration. The most

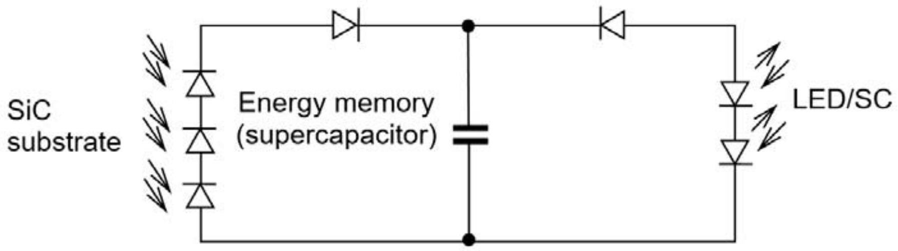

Fig. 1. LED's SC chips for lighting and Solar Cells Energy.

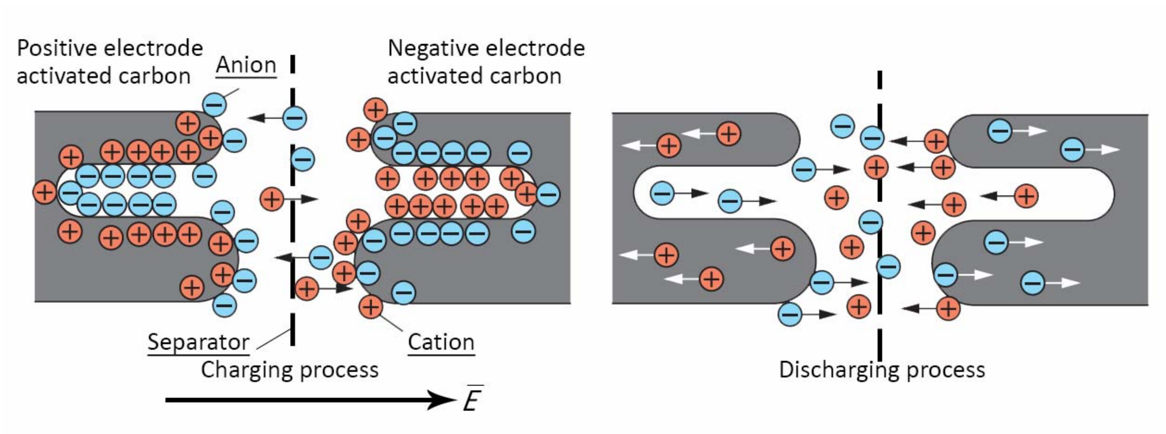

Fig. 2. Formation process of a double electric layer at the surfaces of the positive and negative electrodes, for example from activated carbon.

acceptable for monolithic integration are silicon substrates that are used in making drivers, solar cells and controlling microprocessors. Fig. 1 shows a simple scheme of a monolithic energy storage device, where energy was received from the double purpose LEDs based on SiC substrates that can also act as an accumulation layer.

These devices require an in-depth understanding of the specific application. It also involves numerous tradeoffs and selection from a wide variety of possible solutions, usage of analog circuits and microprocessors to control operation of these devices.

2. Supercapacitor materials and device construction

Materials characterized by high reliability and durability were applied in our own designed supercapacitors that have capacitance 6.3 to 12.4 F.

For electrodes, activated carbon was subjected to baking directly before electrolyte impregnation. Then electrodes were placed in the plate volumes made of stainless steel and were separated using a special wall made of a thin porous heat-resistant membrane that was produced by Nippon Kodoshi company.

As electrolyte, we applied solution of organic salts in mix of organic solvents with the high dissolving ability and a low volatility. The chosen electrolyte composition enabled to obtain a higher output voltage of electric double layer supercapacitors (2.1…2.5 V).

Case parts were made of heat-resistant polymers based on polyester resins and duralumin. For hermetic sealing, we used a compound based on epoxy-polyamide resin that has a long pot life and low polymerization temperature (18…25 °C). To improve operational properties of supercapacitors, charge processes were performed in stabilized training mode.

Practice has shown that the electric double layer capacitors, made in 2012, to the present time (June 2016) are almost unchanged and retain their performances.

3. Experimental results and their discussion

In order to investigate LED crystals in the reverse mode, we used metal-ceramic packages to place them there with thermocompression bonding (Fig. 3). Blue, green, yellow and red LEDs were tested in the reverse mode as photovoltaic cells. During our experiments with different LEDs, we figured out that the best performance was obtained using red and yellow chips (see Table).

We used a condensing lens to concentrate solar emission on chips. The output current was increased up to $2\cdot10^2$ times. We made LEDs matrix for accumulating the energy specifically in Si/GaN/AlGaIn/GaInN chips (see Fig. 3).

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Table. Comparing the output current and voltage values at different irradiation LED structures.

No.	Color	λ, nm	Photovoltage, V	Photocurrent, mA	Photocurrent, mA, with light concentrated by glass lense	Size of the emitting surface, mm^2
1	Red	621.02	1.50	0.030	5.2	2.10
2	Yellow	590.40	1.54	0.021	2.6	1.96
3	Green	517.8	1.45	0.006	1.2	2.56
4	Green	526.6	1.40	0.006	1.17	2.56
5	Blue	457.2	1.93	0.005	0.36	2.56

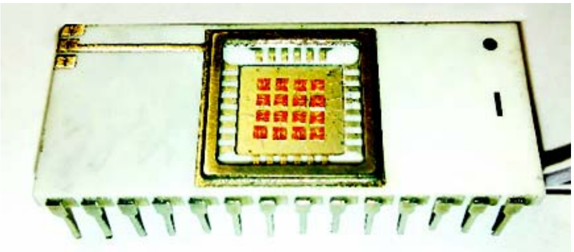

Fig. 3. LED matrix for harvesting solar energy.

The III-nitride semiconductors and their alloys are direct bandgap semiconductors. The bandgap energy of semiconductor is an important parameter that determines its transport and optical properties as well as many other phenomena. III-nitride semiconductors have a high melting point, mechanical strength and chemical stability. In addition, their strong bonding makes them resistant to high-current electrical degradation and radiation damage that is present in the active regions of light emitting devices. These materials also possess good thermal conductivity. III-nitride based devices can operate at high temperatures as well as in hostile environments [4, 5].

These properties of materials allow to concentrate radiation to reach more power by using glass and sapphire lenses without any risk of damage or degradation of semiconductor properties.

On the schematic diagram (Fig. 4) shows two photovoltaic matrix connected in parallel to supercapacitor to reach a higher output power.

In general, for charging and discharging a supercapacitor, there are two major options. One is the charging or discharging at a constant cell voltage to record the cell current change with time, and the other is charging or discharging at a constant current to record that cell voltage change with time [3].

We focused only on charging and discharging at a constant current. All measurements were made at room temperature and ambient pressure.

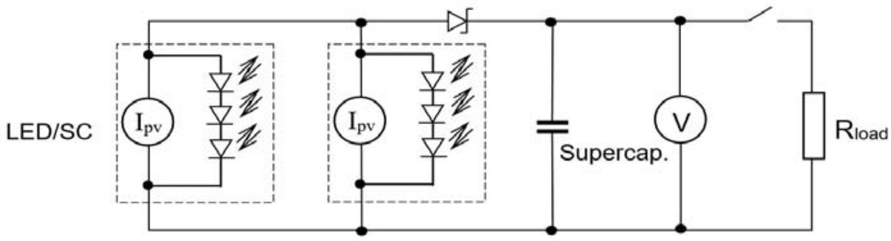

Fig 4. Schematic diagram of experimental model coupling LED matrix with energy storage.

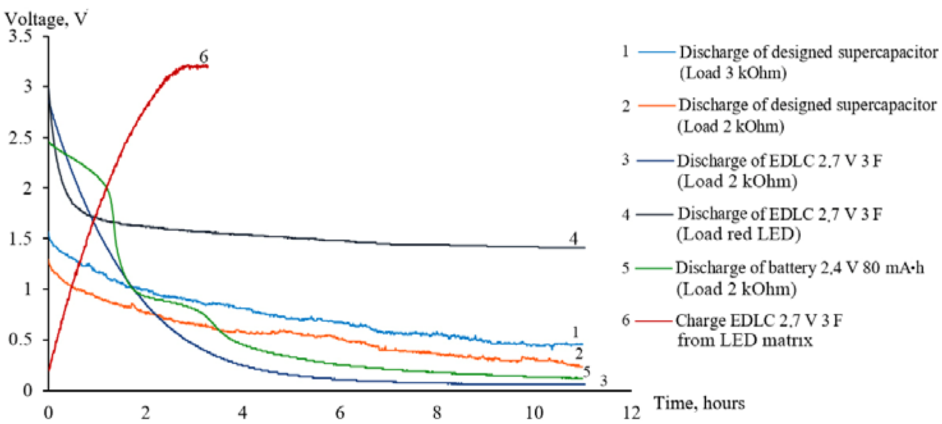

Fig. 5. Charging and discharging processes in the tested supercapacitors.

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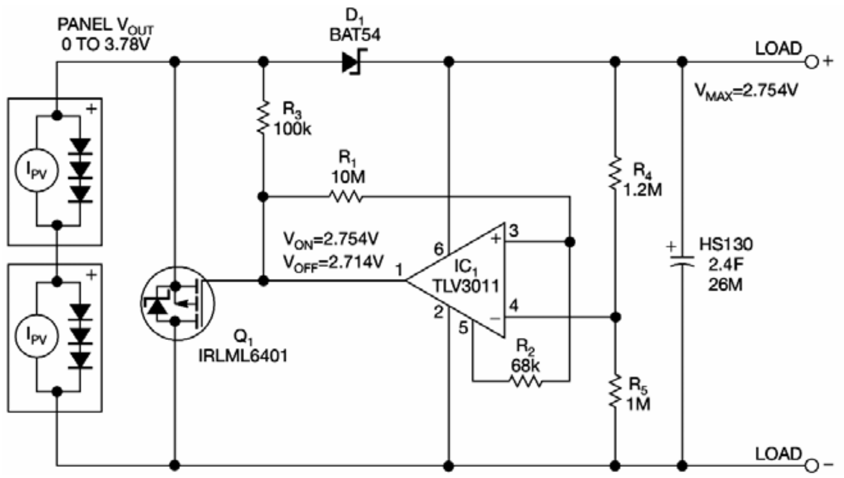

Fig. 6. If the energy source's open-circuit voltage is higher than the supercapacitor one, then the supercapacitor requires overvoltage protection using a shunt regulator [6].

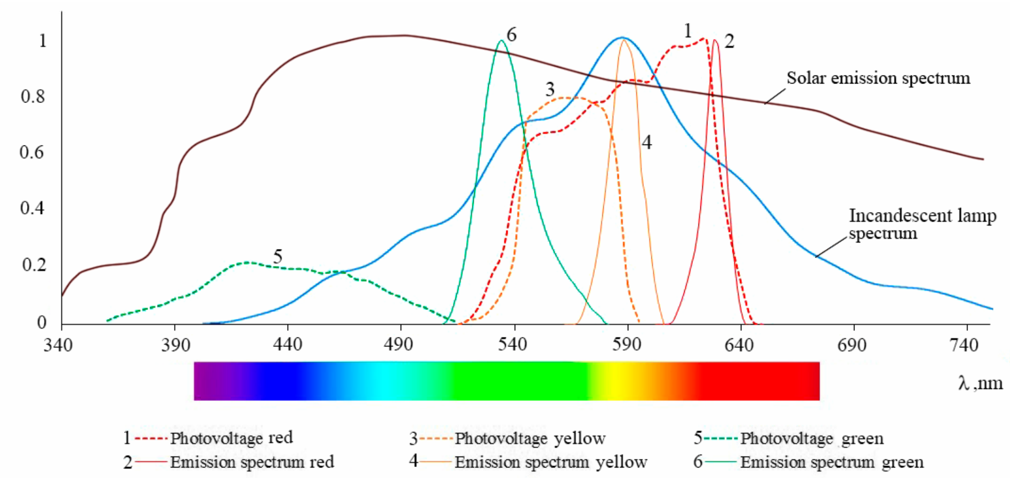

Fig. 7. Emission and photovoltage spectrum of LED/SC, solar and lamp.

Before the charging starts, the supercapacitor is at zero-charge state, that is, the voltage across the supercapacitor is equal to zero [3].

Experimental data in Fig. 5, received from the multimeter which was connected to computer via serial interface (RS-232). Using this plot, we compared capacitance and performance of our designed prototype as well as industrial supercapacitors and batteries. Prototype capacity is about 10 F. The second sample is electric double layer capacitor (EDLC) that has capacitance 3 F was overcharged from solar radiation after 2 hours. Even this capacitance is sufficient to supply analog circuits with OpAmp for protection against overcharging (Fig. 6) or load balancing. It could be implemented into integration circuits including collection, accumulation and emission structures on a single substrate. GaN, III-nitride heterostructures are applicable for developing new generation of standalone devices.

In this paper, we investigated the reversible photosensitivity of LED heterostructures (see Fig. 7).

As the high-brightness LEDs are realized in the direct-gap materials with a sharp boundary of light absorption, their heterostructures have selective sensitivity with its sharp suppression at longer wavelengths than low-energy wing of the emission spectrum, for which heterostructure material is mostly transparent and the absorption of light in it does not create electron-hole pairs for photocurrent [7].

4. Conclusion

We have developed hybrid integration of LED chips with energy storage elements that were charged from these LEDs in the reverse photovoltaic mode by solar radiation. It has been ascertained that many parameters of LED/SC modes can be stabilized using the Si transistor or IC microprocessor that have produced on Si substrate. LED light and energetic efficiencies were 110 lm/W and 45%, respectively. The experimental technological investigation presented in this work shows the way for monolithic integration that gives better parameters and low cost of RGB LED sources.

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