Light Emitting Diode

LED Photovoltaic Effect

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NCSW170F, NCSA170F, NJSW170F, NCSW193F, NC5W193F, NFSW172C, and NFSA172C refer to Nichia part numbers. These Nichia part numbers within this document are merely Nichia's part numbers for those Nichia products and are not related nor bear resemblance to any other company's product that might bear a trademark.

1. Overview

When a semiconductor is illuminated with light, an electromotive force may be generated. This is called the photovoltaic effect; the electromotive force generated by the photovoltaic effect is called the photovoltage. The photovoltaic effect is used for photodiodes, solar cells, etc.
LEDs can have a photovoltaic effect since LEDs are a semiconductor. If a photovoltage is unintentionally generated in an LED, it may cause the operating circuit to malfunction and/or the components used within the operating circuit to be damaged.
This application note provides general information on the photovoltaic effect and the results of the evaluations Nichia performed using Nichia's LEDs.

2. Photovoltaic Effect for LEDs

2.1 How an LED Emits Light and How a Photovoltage is Generated

Figures 1 and 2 are reference images for how an LED emits light and how a photovoltage is generated in an LED; the LED referenced is a typical p-n junction LED.

How an LED emits light

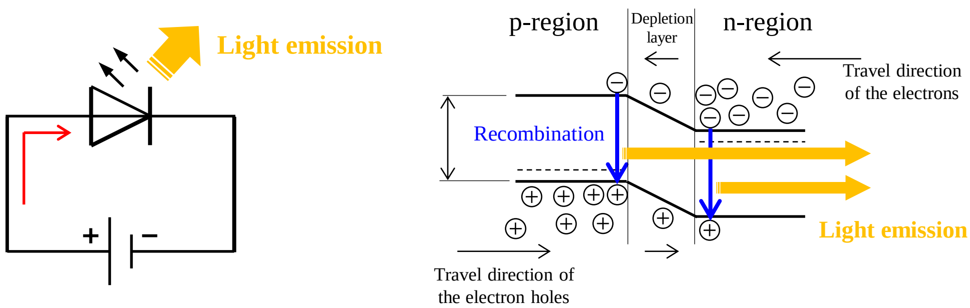


Figure 1. How an LED Emits Light

When electrical current flows through an LED, carriers (i.e. electrons and electron holes) are provided to the LED. The electrons and the electron holes travel towards the p-region and the n-region respectively through the depletion layer[1] to recombine with each other. The energy that is lost during the recombination is released as light. The wavelength of the released light (i.e. emitted color) depends on the energy band gap of the LED.

[1] A region near the p-n junction interface where almost no carriers are present.

How a Photovoltage is Generated

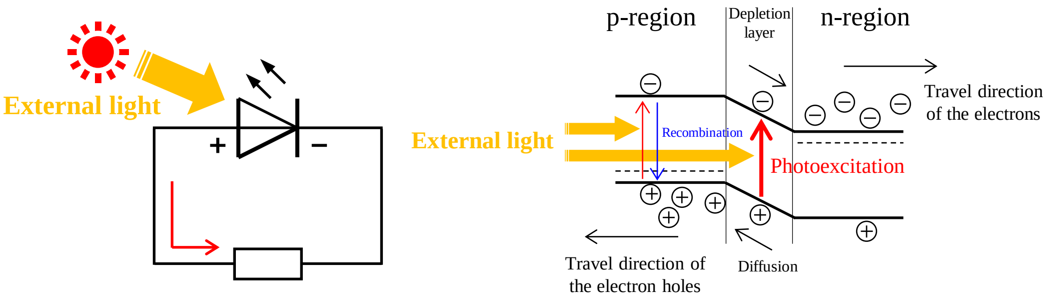


Figure 2. How a Photovoltage is Generated

When an LED is exposed to external light[2] while current is not flowing through the LED, photoexcitation occurs and creates carriers. Carriers that are created within the depletion layer do not recombine immediately and instead travel (i.e. diffuse) away from the depletion layer due to the electric field in the depletion layer; the diffusion causes a potential difference (i.e. an electromotive force is generated). If the LED is in a circuit, current may flow from the LED causing the circuit to malfunction and/or the components used within the circuit to be damaged.

2.2 Photovoltaic Effect for LEDs

Figures 3 and 4 are reference images to show the structural difference between a typical rectifier diode and an LED. For a rectifier diode, the chip is enclosed by a black resin package that shields the chip from external light; see Figure 3. Since the chip is not affected by external light, a photovoltage will not be generated in a rectifier diode. An LED has a structure with which the light emitted from the chip and/or the phosphor can be released to the outside of the package; external light can penetrate inside the package with this structure. When the external light illuminates the surface of the LED, the light can reach the chip through the phosphor to generate a photovoltage; see Figure 4.

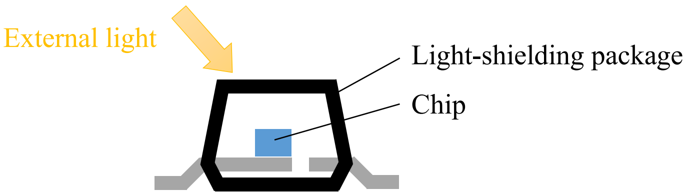


Figure 3. Example Image of the Structure of a Typical Diode

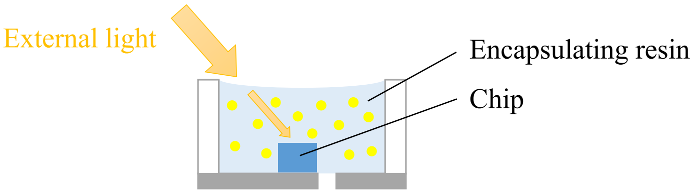


Figure 4. Example Image of the Structure of an LED

[2] To generate a photovoltage, the LED needs to be illuminated with light that has an energy larger than the energy band gap of the LED.

2.3 Environment/Conditions Where the Photovoltage is Likely to be Generated

The brighter the light that illuminates an LED (i.e. high illuminance), the larger the photovoltage that is generated in the LED. Figure 5 shows examples of illuminance values for the environments of typical daily situations for reference. Since the illuminance of direct sunlight is very high outdoors, a photovoltage is more likely to be generated for outdoor applications containing LEDs (e.g. traffic lights, outdoor displays, automotive lighting systems, etc.).

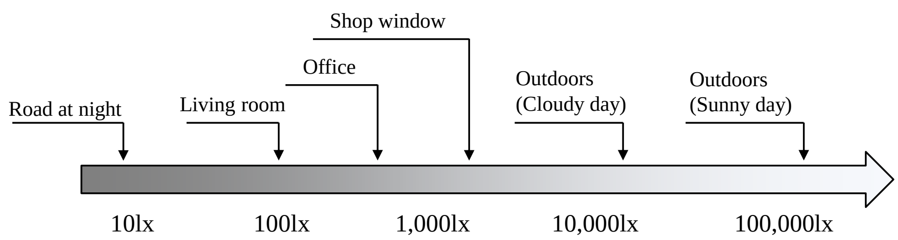


Figure 5. Examples of Illuminance Measured for Daily Situations (for reference)

The illuminance varies depending on the distance between the light source and the illuminated object even when the brightness of the light source is constant. For reference, Figure 6 shows the illuminance values for an automotive headlamp measured for different illumination distances. From this figure, it is easy to see that the rate of change in the illuminance increases as the illumination distance becomes shorter; it should be noted that the illuminance may be unexpectedly high when the illumination distance is short.

Nichia performed evaluations for the relationship between the illuminance and photovoltage using Nichia's LEDs. Refer to the next section for the evaluation results.

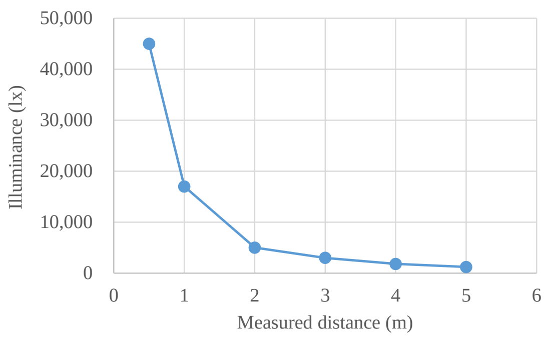


Figure 6. Illuminance for an Automotive Headlamp (for reference)

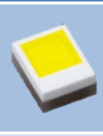
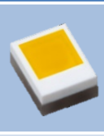
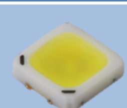
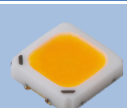
3. Evaluations for the Photovoltage

Nichia performed evaluations for the photovoltage (i.e. potential difference) that was generated when Nichia's LEDs were illuminated on their emitting surfaces with an external light.

3.1 Evaluation Conditions

Evaluated LEDs: Nichia selected LEDs with different structures. See Table 1.

Table 1. Evaluated LEDs

LED No.	1	2	3	4	5	6	7
Appearance							
Part No.	NCSW170F	NCSA170F	NJSW170F	NCSW193F	NC5W193F	NFSW172C	NFSA172C
Emitted color	Equivalent to 6000K	Amber	Equivalent to 6000K	Equivalent to 6000K	Equivalent to 6000K	Equivalent to 6000K	Amber
Forward Voltage[3]	3.25	3.25	3.25	3.25	16.25	3.0	3.0

Test light source: Nichia used a typical white LED to illuminate the evaluated LEDs. See Figure 7 for its typical wavelength.

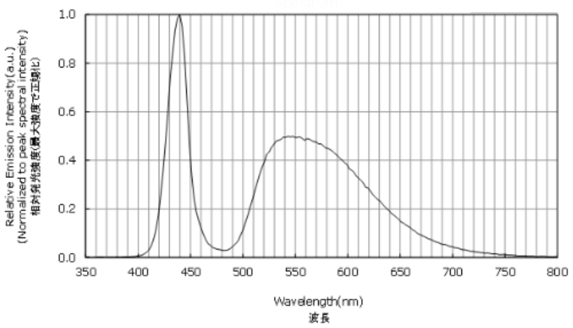


Figure 7. Wavelength of the Test Light Source

Evaluated illuminances: 500-100,000 lx

Evaluation method: Nichia illuminated the evaluated LEDs at different levels of brightness (i.e. illuminance) using the test light source and measured the photovoltages (i.e. potential difference between the terminals of the LED) that were generated with an oscilloscope. See Figures 8 and 9.

[3] Typical forward voltage value when the LED is operated at its sorting current.

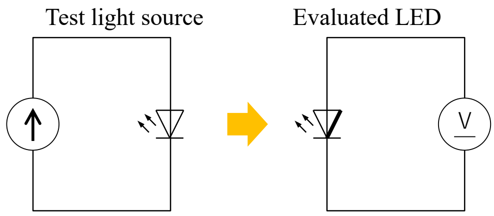


Figure 8. Evaluation Circuits

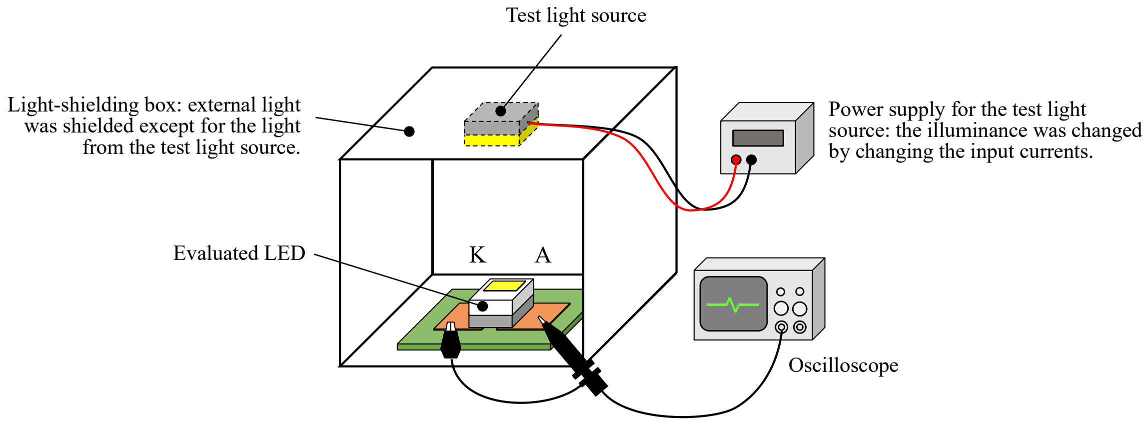


Figure 9. Evaluation Set-up

3.2 Evaluation Results

Figures 10 and 11 show the evaluation results.

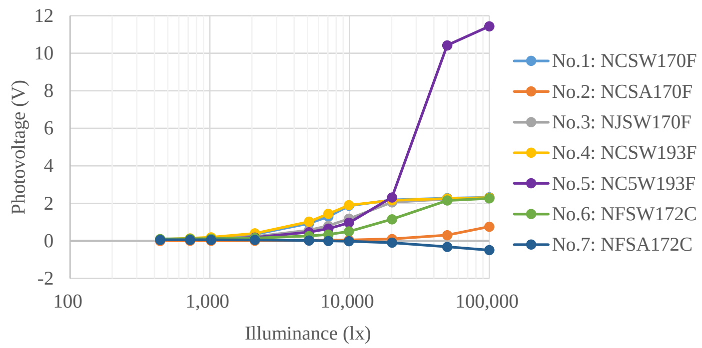


Figure 10. Evaluation Results

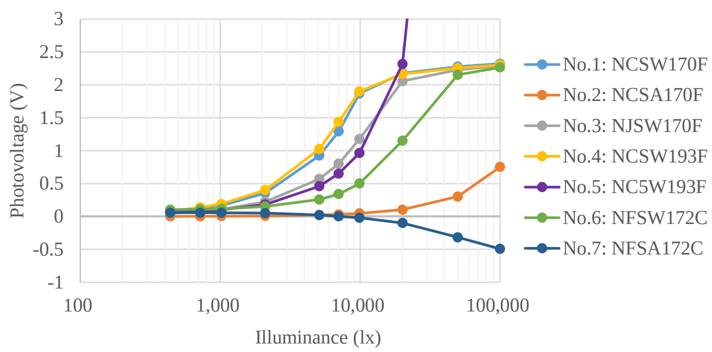


Figure 11. Evaluation Results (with smaller increments for the photovoltage)

The evaluation results show the following:

- The higher the illuminance was, the larger the photovoltage generated became. This result indicates that a large photovoltage can be generated in outdoor applications or equivalent environments (i.e. equivalent to 10,000 lx) which may affect the components used within the operating circuit.

- The amount of the photovoltage generated was different depending on the size of the LED chip, package structure, etc. The difference became smaller after the illuminance was high enough to have the photovoltage saturate; see the measurement results for LEDs No. 1, 3, 4, and 6. The maximum value for the photovoltage (i.e. saturation value) depends on the energy band gap of the LED; the saturation values for those LEDs were almost the same. Nichia believes this is because the blue chips used within those LEDs had an equivalent energy band gap. Before saturation, the amount of the generated photovoltage was different for each of those LEDs; Nichia assumes it was because the amount of the external light that reached the chip was different due to the difference in the package structure.

- LED No. 5 (NC5W193F) generated approximately a photovoltage five times larger than LED No. 4 (NCSW193F); those LEDs had the same structure just with a different number of chips (i.e. LED No. 4 had one chip and LED No. 5 had five chips connected in series). This result indicates that the amount of photovoltage generated in an LED is proportional to the number of chips that are connected in series.

- LED No. 1 (NCSW170F) generated more photovoltage than LED No. 2 (NCSA170F); those LEDs had the same structure just with different emission colors (i.e. white for LED No. 1 and amber for LED No. 2). The reason for this result is believed to be that the amount of the external light that reached the chip was smaller for LED No. 2 than LED No. 1 because an amber LED has a higher phosphor concentration than a white LED.

- For LED No. 7 (NFSA172C, amber), a photovoltage was generated in the reverse direction. Nichia assumes this was due to the photovoltage generated in the protection device (i.e. Zener diode) within the LED. As mentioned above, an amber LED has a higher phosphor concentration; most of the external light is converted into yellow or red light by the phosphor before reaching the chip. This converted light does not have a photovoltage generated in the chip if it is a blue chip; this is because the energy for yellow or red light is smaller than that for blue light. The chip used within LED No. 7 was a blue chip; Nichia assumes a photovoltage was not generated in the chip due to this reason. However, a photovoltage can be generated in a Zener diode since the energy band gap for a Zener diode is smaller than that for yellow or red light. As shown in Figure 12, a Zener diode is connected in parallel with reverse polarity with the LED to function as a protection device; in the Zener diode, the photovoltage is generated in reverse polarity. LED No. 2 (NCSA170F) is also an amber LED with a Zener diode; however, that Zener diode has a reflecting material covering it, that is why no photovoltage was generated in the reverse direction.

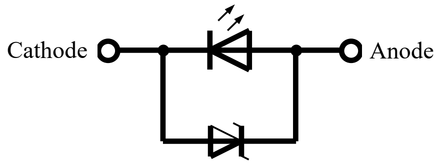


Figure 12. Example of the Internal Circuit for an LED with a Zener diode

4. Summary

An LED is a device in which a photovoltage is likely to be generated due to its structure. A large photovoltage may be generated depending on the operating environments and/or conditions for the LED causing the peripheral circuits in the chosen application to malfunction and/or the components used within the circuits to be damaged. Examples for effective measures to prevent this from occurring are designing the chosen application to not allow an external light to enter the LED package, incorporating a protection circuit that can prevent the generated photovoltage from affecting the peripheral circuits, etc.

In this application note, Nichia has provided the results for Nichia's evaluations; however, the amount of the photovoltage generated varies depending on various factors. Ensure that the photovoltage generated in the LED will not affect the peripheral circuits when the LED is operated in the conditions under which the LED will actually be used.

Light Emitting Diode

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