Calorimetric Measurements for Conversion Efficiency of Optical Devices

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Conversion efficiencies of optical devices, both sources and receivers have been measured based on a calorimetric method. Radiant power output of a source can be evaluated by subtracting a heat power from the applied electrical power while radiant power input of a receiver can be evaluated by adding a heat power to the generated electrical power. The technique was validated firstly in the solar cell internal conversion efficiency measurements in a manual operation. To automatize the operation, a negative feedback control circuit to maintain constant temperature by adjusting the electrical power to the heater has been developed and proved to work successfully.

INTRODUCTION

Optoelectronic devices to convert between electrical power and optical power such as photovoltaic cells, laser diodes (LDs), light emitting diodes (LEDs) etc. are widely used in many fields. Among the characteristics of the optoelectronic devices, power conversion efficiency is essentially important.

The external power conversion efficiency is defined as a ratio of output power to the input power. More specifically in the case of solar cell/module, it is the ratio of the electrical power generated to the radiant power incident to the solar cell/module under the defined conditions. While the evaluation of the electrical power can be conducted very easily, the evaluation of the radiant power are usually more complicated and difficult especially when the radiation is spectrally broad as in the case of solar cells. The calorimetric method is advantageous since it enable us to directly determine the internal conversion efficiency of solar cells.

The technique to calorimetrically determine the internal quantum efficiency was developed, for the first time, by T. Inoue et al. for photodiodes receiving a laser beam[1]. Inoue et al. applied the similar technique also to measure total radiant power of a laser diode[2]. Our approach is unique in that constant temperature operation, which is required to substitute heat with electrical power, is achieved only by using self-heating of a temperature sensor without an additional heater. In addition, we applied the calorimetric method to solar cells to determine their internal conversion efficiencies, for the first time[3].

In this paper, we focus on the external conversion efficiency measurements of LEDs by using a constant temperature circuit with a platinum resistance thermometer working simultaneously as a heater to replace heat with electrical power.

PRINCIPLE OF OPERATION

The radiant power absorbed (for a receiver) or generated (for a source) can be determined by a calorimetric method in which the heat absorbed or generated in the device is substituted by the electrical power applied to a heater attached to the device.

For receivers such as solar cells, the applied electrical power is adjusted in the dark condition so that the device temperature becomes equal to the one in an illuminated condition. We can assume that the substituted electrical power is equal to the thermal power, or the absorbed radiant power (when an open- or short-circuit condition).

For sources such as LEDs, the electrical power is applied to the heater when the LED is off. When the LED is lit, the electrical power applied to the heater is decreased and adjusted so that the device temperature keeps the same temperature as the one in the dark condition. We can assume that the difference in the electrical power is equal to the thermal power generated when the LED is on and that the emitted radiant power can be given by the input electrical power applied to the LED minus the thermal power difference.

EXPERIMENTAL

Figure 1 shows a test specimen of RGB type LED (OptoSupply OSTCXBCBC1E) attached with a platinum resistance thermometer, Pt100. We have designed and fabricated a negative feedback control circuit to realize automatic temperature control using the Pt100 not only as a temperature sensor but also as an electric heater. The negative feedback control circuit works to automatically adjust the applied electrical power to the Pt100 to maintain a constant temperature, or a constant resistance. The constant temperature operation has been confirmed to work successfully not only for PTC (positive temperature coefficient) but also for NTC (negative temperature coefficient) sensors.

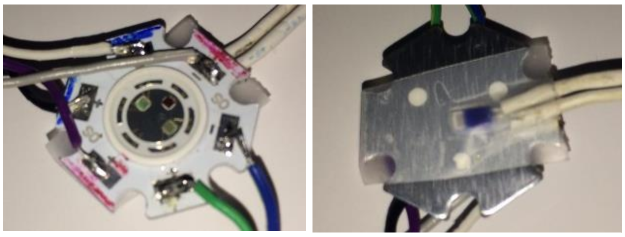

Figure 1. Left: Photograph of front side of RGB type LED. Right: Platinum resistance thermometer, Pt100 attached to the backside of the LED.

RESULTS

As an example of the measurements, Figure 2 shows a result for a red (dominant wavelength of 624 nm) LED. Radiant power of the LED is independently measured by a calibrated silicon photodiode (Hamamatsu S1227-1010BQ) and the square shaped waveform at the bottom clearly shows on and off operation of the LED. The second top curve shows a measured electrical power dissipated at Pt100 and follows with a delay oppositely the curve of emitted radiant power. When the LED is off, about 60 mW is dissipated at Pt100. Once the LED is turned on, the circuit automatically decreases the current flowing Pt100 and therefore the dissipated power to compensate the increased heat caused by LED operation and maintain the same temperature.

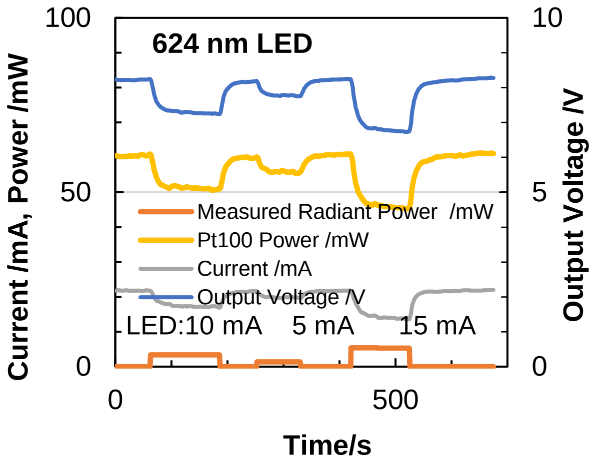

Figure 2. Temporal change in measured radiant power, electrical power dissipated at Pt100, etc..

Figure 3 shows the comparison results between the calorimetric measurements and the optical measurements. Although the calorimetric results correlate linearly with optical results, the former is about 2 times the latter. The disagreement is highly likely to be caused by the large heat leak through the wires supplying a current to the LEDs. To solve the problem, modifications in thermal design such as replacing the copper wires to high thermal resistance wires and/or adapting thermal anchors are in preparation.

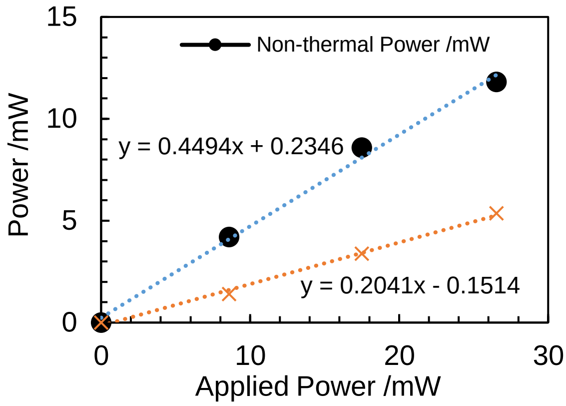

Figure 3. Non-thermal power (input electrical power applied to the LED minus the thermal power difference) and independently measured radiant power.

CONCLUSION

Constant temperature control using a self-heating of a temperature sensor without an additional heater has been proved to work as expected. With this system, it is possible to substitute heat power with electrical power and therefore possible to calorimetrically determine radiant power and conversion efficiency of optical devices, both sources and receivers. Preliminary results for a red LED with the constant temperature controller with Pt100 show two times overestimates for the radiant power. The disagreement is highly likely to be caused by the large heat leak through the wires. Modifications to solve the problem are in preparation.

REFERENCES

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