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A MEASUREMENT OF WAVE LENGTH RESPONSE ON LIGHT EMITTING DIODE BY A SIMPLIFIED WAVEMETER WITH A SEMICONDUCTOR COLOR SENSOR

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Abstract

This paper describes the measured results upon monochromatic light, compound light, and light emanated from light emitting diodes by a simplified wavemeter with a semiconductor color sensor. Since a single unit element of a semiconductor color sensor with two PN junction photodiodes has been developed, the author has fabricated the simplified wave detector by using the element. The simplified wave detector has been measured results upon monochromatic light, compound light, and light emanated from light emitting diodes. Since luminescent color of each diode locates in luminosity region, comparison of measured values of PD-150 and PD-151 resulted no remarkable difference in averaged wave length. As for monochromatic light, PD-151 showed very cross value to the color filter peak value rather than PD-150. As for compound light, PD-150 has shown much influence of long wave length light which reaches to near infrared ray with respect to PD-151.

1. Introduction

In the past days, an optical filter and diffraction grating or a prism have been required for measurements on wave length and color temperature of reflected light from an object and transparent light through an object, and luminescent source. These facts have prevented optical analysis equipment from being more compact, light weighed, easy measurement, and low cost. Recently, since a single unit element of a semiconductor color sensor[1] with two PN junction photodiodes has been developed in order to avoid these problems, the author has fabricated a simplified wave detector by using the element.

A circuitry description upon the simplified wave detector has already been reported[2], however, measured results upon monochromatic light, compound light, and light emanated from light emitting diodes will be reported at this time.

2. Semiconductor Color Sensor and Signal Processing Circuit

2.1 Semiconductor Color Sensor

A semiconductor color sensor is a PNP junction type element as shown on Fig. 1, and a silicon layer in the element is used as an optical filter. A photodiode (hereafter called PD1) of the PN junction on the upper layer has characteristics of more higher sensitivity in short wave length region and a photodiode of the PN junction (hereafter called PD2) on the lower

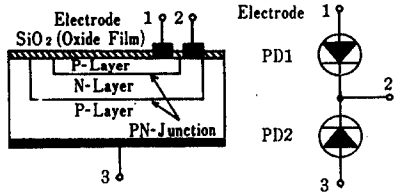

Fig. 1 Structure of a Semiconductor Color Sensor.

layer has characteristics of more higher sensitivity in long wave length region. Each spectrocharacteristics for semiconductor color sensor, PD-150, and for PD-151 with infrared

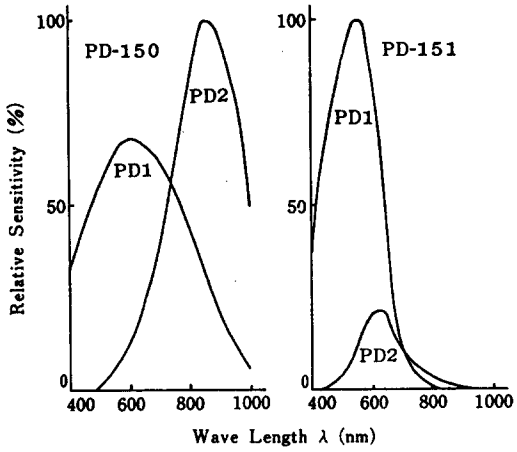

Fig. 2 Spectro Sensitivity Response.

rejection filter for making correspondense with luminosity region are shown on Fig. 2.

2.2 Signal Processing Circuit

A signal processing circuit of the wave detector used for the experiment is shown on Fig. 3. This circuit measures output voltage

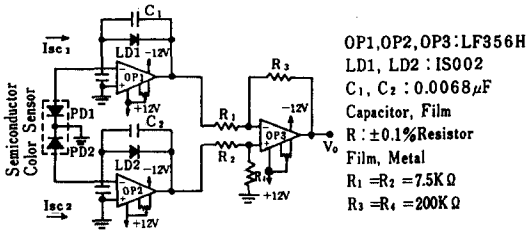

Fig. 3 Signal Processing Circuit.

derived from the ratio of short currents obtained from subtraction of the two short currents, Isc_1 and Isc_2, after passing through an operational amplifier[3] (hereafter called OP) and a logarithmic diode[4] (hereafter called LD). Namely, relationship between input current and output voltage of the circuits, OP1 and OP2, which logarithmically compress Isc_1 and Isc_2, are measured and the results are illustrated on Fig. 4. These two log-compression circuits have

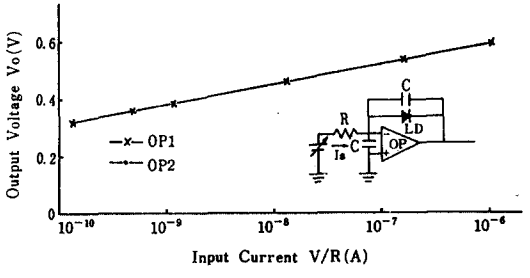

Fig. 4 Log-Compression Response.

the same output voltage and linear region is obtainable between 10^{-10} and 10^{-6} A. Isc_1 and Isc_2 which passed these circuits are log-compressed and equations, (1) and (2), are given as,

$$V_1 = -\frac{kT}{q} \ln Isc_1 + V_a \quad \text{---------- (1)}$$

$$V_2 = -\frac{kT}{q} \ln Isc_2 + V_a \quad \text{---------- (2)}$$

where k: Boltzmann's constant
$(1.38\times10^{-23}$ J/K)
T: Absolute temperature (K)
q: Electron charge
$(1.60\times10^{-19}$ Coulomb)

V_a: A value determined by off-set voltages of OP1 and OP2

Then, V_1 and V_2 are reduced by OP3, R_1, R_2, R_3 and R_4, and an output voltage, V_o, is given as (3),

$$V_o = \frac{R_4(R_1 + R_3)}{R_1(R_2 + R_4)} V_1 - \frac{R_3}{R_1} V_2 + V_b \quad \text{- (3)}$$

where V_b: A value determined by the off-set voltages of OP

In the signal processing circuit, since we put $R_1=R_2$, and $R_3=R_4$, substitute these conditions, (1), and (2), into (3); then we get,

$$V_o = \frac{R_3}{R_1}(V_1 - V_2) + V_b$$

$$= \frac{R_3}{R_1}\frac{kT}{q}(\ln Isc_2 - \ln Isc_1) + V_b$$

$$= \frac{R_2}{R_1}\frac{kT}{q}\ln\frac{Isc_2}{Isc_1} + V_b \quad \text{----- (4)}$$

Consequently, it is understood that output voltage of the semiconductor color sensor is proportional to the log ratio of short currents for PD1 and PD2[5]. Since the currents are proportional to input level of light, the current ratio becomes independent from the level.

3. The Relationship Between Output Voltage of the Signal Processing Circuit and Wave Length

In order to obtain output voltage corresponding to 460 ~ 1000 nm wave length, PD-150 and PD-151 were installed in the test piece part of the spectro-photometer (color wave length resolution is 1 nm at 500 nm) shown on Fig. 5,

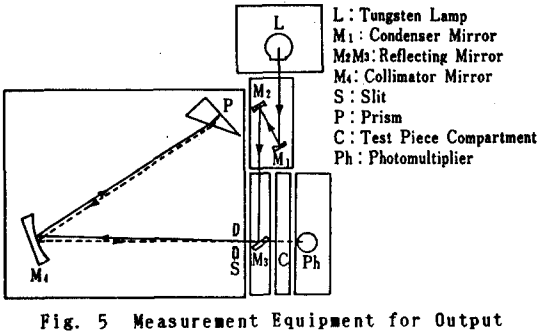

Fig. 5 Measurement Equipment for Output Voltage vs Wave Length Response.

output voltages were measured at every 20 nm increment. The results are shown on Fig. 6. Linear region was found between 460 ~ 1000 nm for PD-150 and 600 ~ 1000 nm for PD-151.

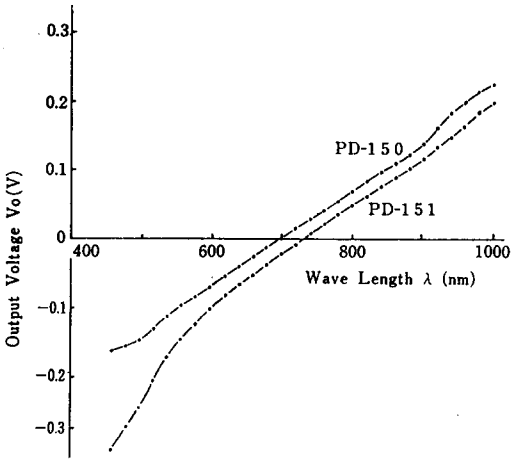

Fig. 6 Output Voltage vs Wave Length Response of the Signal Processing Circuit.

4. Measurement of Color Wave Length

4.1 Measurement of Monochromatic Light and Compound Light

General description for the experimental equipment of wave length measurement is illustrated on Fig. 7. Light which is emanated from

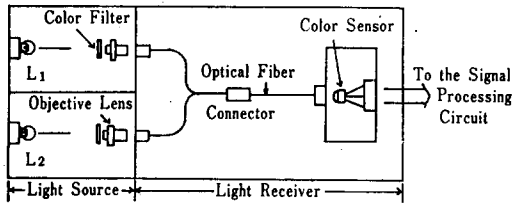

Fig. 7 Experimental Equipment for Wave Length Measurement.

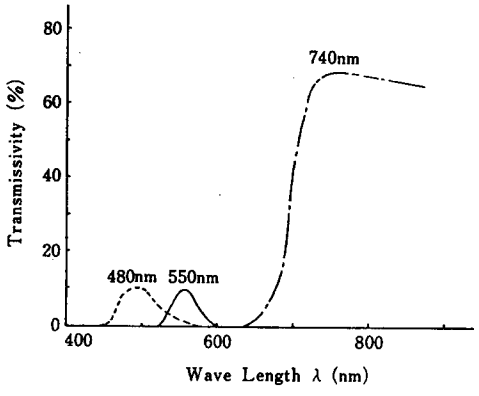

Fig. 8 Wave Length vs Transmission Rate of the Color Filter.

100 and 60 watt Krypton lamps, L_1 and L_2, are converged by a convex lens for adjusting focus and by an objective lens with × 30 magnifications, and is led through 140 $\mu m\phi$ optical fiber[6] to the semiconductor color sensor. By using Fig. 6, wave length is read from the measured output voltage. The experiments were repeated for ten times with using 480, 550, and 740 nm filter at the front of the objective lens as shown on Fig. 8, and were proceeded for separated experiment on monochromatic light and compound light with two different combination of color[2]. Averaged values and 95 % confidence intervals of measured both for PD-150 and PD-151 are shown on Table 1 which was obtained through the measurements repeated for ten times. Since measured wave length in average for PD-151 is cross to the peak wave length of the color filter with respect to that of PD-150, while 95 % confidence intervals are very small both for PD-150 and PD-151, there are considered that measurement reappearancy seems to be excellent.

Table 1 Measured Results for Monochromatic Light.

$\bar{X}$: Averaged Values, CL: 95 % confidence intervals

Color Filter (nm)	PD-150 (nm)	PD-151 (nm)
480	$\bar{X}$=453.0 452.9≦CL≦453.0	$\bar{X}$=503.0 502.4≦CL≦502.7
550	$\bar{X}$=541.0 540.4≦CL≦541.6	$\bar{X}$=553.9 553.7≦CL≦554.1
740	$\bar{X}$=783.1 783.0≦CL≦783.1	$\bar{X}$=743.9 743.6≦CL≦744.1

Similarly, 480 and 550 nm filter were installed at I_1 side of the equipment and a 740 nm filter was installed at I_2 side of the equipment for compound light, and the measurement was proceeded with both I_1 and I_2 were turned-on simultaneously. The results, as shown on Table 2, it was found out that PD-150 has getting influence of 740 nm filter which has capability of transparent light reaches to near infrared region rather than PD-151.

Table 2 Measured Results for Monochromatic Light.

L_1 (nm)	L_2 (nm)	PD-150 (nm)	PD-151 (nm)
480	740	$\bar{X}$=781.5 781.4≦CL≦781.5	$\bar{X}$=736.0 735.7≦CL≦736.2
550	740	$\bar{X}$=781.3 781.1≦CL≦781.5	$\bar{X}$=735.3 735.1≦CL≦735.5

4.2 Measurement of Light Emitting Diode

Twelve different kinds of light emitting diodes (hereafter called LED) with green, light green, yellow, red, etc., of 3 ~ 5 mmϕ light aperture which are available in local market and were used for the experiment are shown on Table 3. These diodes are conducted through 3 mmϕ optical fiber[6] directly to PD-150 and PD-151 and measurement was proceeded ten times for each LED. Wave length is obtainable from measured output voltages by using Fig. 6.

Table 3 LED's used for the Experiment.

LED	Dimension mmϕ	Luminescent Type	Luminescent Color	Luminescent Materials
No. 1	3	Colored Diffusion	Green	GaAs on GaP
2	3	Colored Diffusion	Light Green	GaP
3	3	Colored Transoarent	Yellow	GaAs on GaP
4	3	Colored Transoarent	Green	GaP
5	4	Colored Diffusion	Red	GaAsP on GaAs
6	4	Colored Diffusion	Green	GaP
7	4	Colored Diffusion	Light Green	GaP
8	5	Colored Diffusion	Red	GaAsP on GaAs
9	5	Colored Diffusion	Red	GaP
10	5	Colored Diffusion	Green	GaP
11	5	Colored Diffusion	Yellow	GaAsP on GaAs
12	5	Colored Transoarent	Light Green	GaP

Measured results are separated for PD-150 and PD-151, and averaged wave length and 95 % confidence intervals are obtained as shown on Table 4. Since luminescent color of each diode locates in luminosity region, comparison of measured values of PD-150 and PD-151 resulted no remarkable difference in averaged wave length.

Table 4 Measured Results for LED's.

LED	PD-150 (nm)	PD-151 (nm)
No. 1	$\bar{X}$=533.4 533.1≦CL≦533.7	$\bar{X}$=532.1 533.6≦CL≦532.5
2	$\bar{X}$=572.2 571.9≦CL≦572.5	$\bar{X}$=572.1 571.8≦CL≦572.4
3	$\bar{X}$=592.5 591.9≦CL≦573.0	$\bar{X}$=595.8 595.5≦CL≦596.1
4	$\bar{X}$=557.9 557.1≦CL≦558.7	$\bar{X}$=560.6 560.0≦CL≦561.2
5	$\bar{X}$=659.3 659.0≦CL≦659.6	$\bar{X}$=641.3 640.7≦CL≦641.8
6	$\bar{X}$=556.1 555.7≦CL≦556.5	$\bar{X}$=560.9 560.4≦CL≦561.4
7	$\bar{X}$=573.1 572.4≦CL≦573.8	$\bar{X}$=567.9 567.4≦CL≦568.3
8	$\bar{X}$=659.3 659.1≦CL≦659.4	$\bar{X}$=641.9 641.3≦CL≦642.4
9	$\bar{X}$=702.9 702.0≦CL≦703.8	$\bar{X}$=705.1 704.5≦CL≦705.7
10	$\bar{X}$=555.8 555.5≦CL≦556.1	$\bar{X}$=560.6 560.4≦CL≦560.7
11	$\bar{X}$=592.9 592.7≦CL≦593.1	$\bar{X}$=593.4 593.0≦CL≦593.8
12	$\bar{X}$=569.3 568.7≦CL≦569.8	$\bar{X}$=572.3 571.9≦CL≦572.7

Furthermore, when comparing measured wave length with LED light emitted color, it is considered that the measured wave length almost satisfies its wave length region. Also, 95 % confidence intervals shows on and around 1 nm in all cases, it is ascertained that measurement error of the wave length detector is very small and reappearancy is excellent.

5. Conclusion

The followings were understood through the measured results of wave length on monochromatic light, compound light, and LED by using a simplified wavemeter with a semiconductor color sensor, consisting of PD-150 and PD-151.

1) Regarding linear region of log-compressed

response of the signal processing circuit is between 10^{-10} and 10^{-6} A.

2) As for monochromatic light, PD-151 which cut off infrared part for only capable of measuring luminosity region showed very cross value to the color filter peak value rather than PD-150. As for compound light, PD-150 has shown much influence of long wave length light which reaches to near infrared ray with respect to PD-151.

Through the experiment, wave length measurement of luminescent elements by the simplified wavemeter becomes capable. Further application is expected for measurement on color temperature or for control use in future.

References

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