International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

OP57

NONLINEARITY OF PHOTODETECTOR USING LASER FACILITY

Zhifeng Wu et al.

DOI 10.25039/x46.2019.OP57

from

CIE x046:2019

Proceedings
of the
29th CIE SESSION
Washington D.C., USA, June 14 – 22, 2019

(DOI 10.25039/x46.2019)

CIE Central Bureau
Babenbergerstrasse 9
A-1010 Vienna
Austria
Tel.: +43 1 714 3187
e-mail: ciecb@cie.co.at
www.cie.co.at

NONLINEARITY OF PHOTODETECTOR USING LASER FACILITY

Wu, Z.F., Dai, C.H., Li, L., Wang, Y.F.
National Institute of Metrology, Beijing, CHINA
wuzf@nim.ac.cn

DOI 10.25039/x46.2019.OP57

Abstract

We presented a nonlinearity measurement facility of the photodetector using laser beam in this paper, with both the power mode and the irradiance mode. Lasers with different wavelengths are used to investigate nonlinearity upon wavelength. For the power mode, the laser spot size is much smaller than the sensitive area of the photodetector. The nonlinear factor is measured with the laser power varying over six orders of magnitude. For the irradiance mode, the laser is guided into an integrating sphere to make the spot size much bigger than sensitive area of the detector. The linearity of the photodetector is measured over three orders of magnitude. Combing both modes, the nonlinearity of the silicon photodetector can be measured in a much larger dynamic range. At 632.8 nm, the nonlinear factor is found to be less than 0.015%. At other wavelengths, the nonlinear factor is found to less than 0.03%.

Keywords: nonlinearity, photodetector, large-scale

1 Introduction

Photodetector is the most important detector element in optical radiometry and its responsivity characteristics affects the accuracy of optical radiation measurement. If the photodetector is used to measure two light sources at different power level, whether the responsivity of the photodetector is constant at various light levels must be considered.

Beam-addition method is most frequently used to investigate the nonlinearity. Broadband light sources are most widely used in linearity measurement, such as blackbody, halogen tungsten lamp, and Nester light source. Shin measured the linearity based on flux addition using two LEDs with FWHM of 20 nm. However, for a broadband light source, the linearity is measured while the photodetector responding to the whole spectrum. Whether the linearity responsivity at every wavelength is the same is not known. Although light source combined with monochromator can realize the linearity measurement at each wavelength, the variation of the power can’t be varied over a large range. With the progress of laser technology, linearity measurement using lasers show great advantages. Especially tunable lasers can be used to measure the linearity at every wavelength like the monchromator method. Toomas tested the linearity of photodetector through comparison with a reference photodetector using lasers. Atte investigated the absolute linearity of photodetector at 633 nm. The results show that laser facility has advantage in nonlinearity measurement.

2 Principle and Experiment setup

2.1 Principle

In this paper, laser beam addition method is adopted. The nonlinear factor is calculated using the recommended formulae.

$$\mathrm{I}_{\text{nonliner}} = 1 - \frac{I_1 + I_2}{I_{1+2}} \tag{1}$$

where

I_1 is the signal when light path 1 is open;

I_2 is the signal of light path 2;

I_{1+2} is the signal when both light path 1 and 2 are open.

2.2 Experiment setup

2.2.1 Laser power mode

Figure 1 shows the laser nonlinearity measurement facility in power mode. The laser is first stabilized by a BEOC power stabilizer. Then two glan-taylor prisms are placed on the light path. After the second glan-taylor prism, a beam splitter is used to separate the light into “A” path and “B” path. The direction of the second glan-taylor prism is adjusted to make the power of the “A” path and “B” path nearly equal and then fixed. The direction of the first one is adjusted to change the whole power of the laser. The laser power can be varied over six orders of magnitude by the two glan-taylor prisms, and be adjusted nearly 20 times by the laser power stabilizer. All in all, the laser power can be varied over 7 orders of magnitude. Finally, the separated laser is lead directed onto the surface of the photodetector in power mode, with the diameter of the laser smaller than the sensitive area of the photodector. S1337 is used as the photodetector under test. The current of S1337 is monitored by Keithley 6517B.

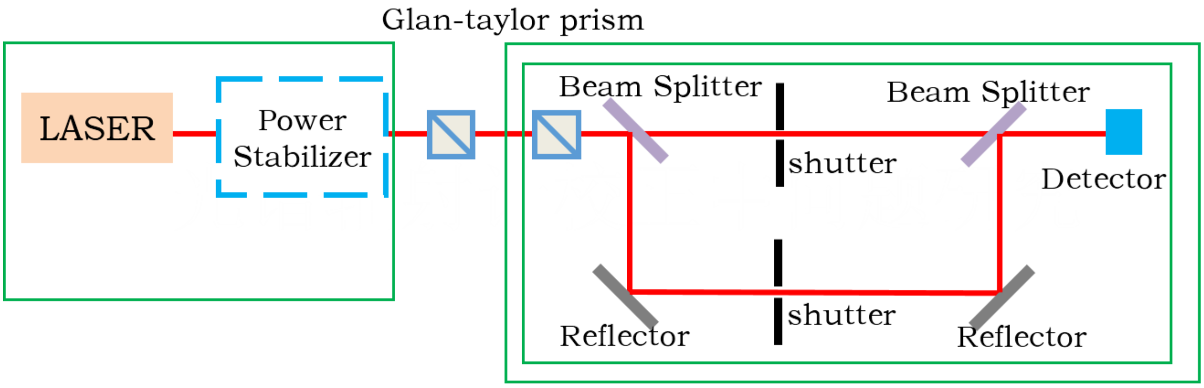

Figure 1 – Laser nonlinearity measurement facility in power mode

The measurement is carried out in a symmetrical operation. 1) the background signal S_{bg1}. 2) the signal of “A” path is recorded as S_1. 3) the signal of “B” path is recorded as S_2. 4) the signal of both “A” and “B” paths are recorded as S_{1+2}. 5) the signal of “B” path is recorded as S_2’. 6) the signal of “A” path is recorded as S_1’. 7) the background signal S_{bg2}. The nonlinearity formulae is calculated using equation (2).

$$\mathrm{I}_{\mathrm{nonliner}} = 1 - \frac{S_1 + S_2 + S_1' + S_2' - 2S_{bg1} - 2S_{bg2}}{2S_{1+2} - S_{bg1} - S_{bg2}} \tag{2}$$

where

S_1 *and* S_1' are the signals of light path A;

S_2 *and* S_2' are the signals of light path B;

S_{1+2} is the signal when both light path A and B are open;

S_{bg1} *and* S_{bg2} are the signals of background.

When the current of the detector is less than 1 nA, 20 times average is used. Several lasers are used to test the nonlinearity of the photodetector, including the 405nm, 632.8nm, 780nm and 940nm. Two apertures are used to define the optical path before the power stabilizer. For 780 nm and 940 nm, a Thorlab card is used to observe the light path to make the laser go through the two apertures. The measurement optical paths are fixed without any change when the laser is changed.

2.2.2 Irradiance mode

Figure 2 shows the laser nonlinearity measurement facility in irradiance mode. Different from figure 1, the combined laser is guided into an integrating sphere. Then the laser fulfills the sensitive area of the photodetector. The distance between the photodetector and the exit of the integrating sphere can be changed according to the maximum current needed.

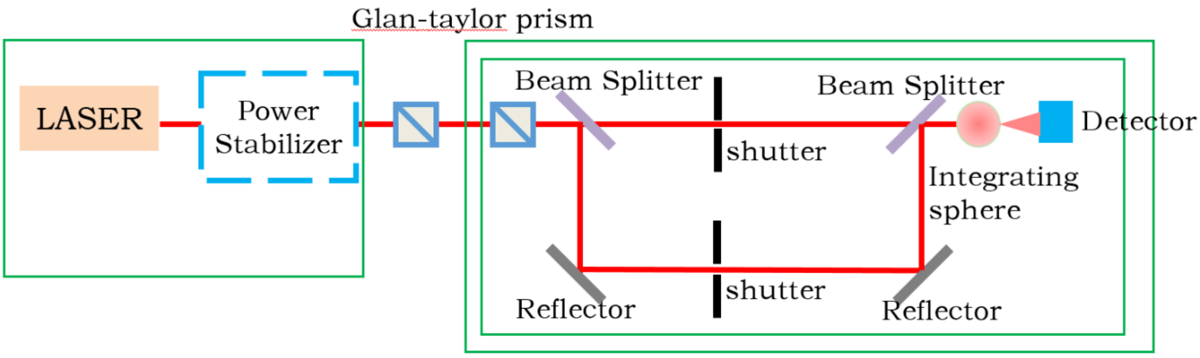

Figure 2 – Laser nonlinearity measurement facility in irradiance mode

3 Results

3.1 Power mode

Figure 3 shows the nonlinearity factor at 632.8 nm, with the current of the photodetector varying from 0.15 mA to 125 pA. Results show that the factor is less than 0.015% through the whole region. When the current is less than 500 pA, the absolute value is larger than 0.01%. At 500 pA level, 100 fA fluctuation will result 0.02% change. It seems that if the signal-to-noise can be controlled better, the result will be more close to zero. Also, the factor has both positive and negative value around zero. When multiply all the nonlinearity factor from 100 pA to 0.2 mA, the result is 1.0003, which means that the photodetector at 632.8 nm has a good linearity not more than 0.03% over six orders of magnitude.

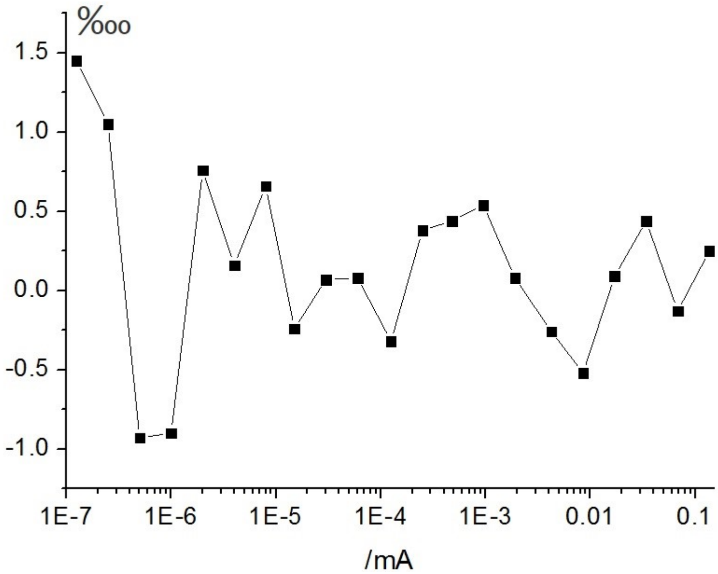

Figure 3 – The nonlinearity factor at 632.8nm

Figure 4 shows the nonlinearity factor at 940nm and the nonlinear factor is less than 0.025%. The current is varied from 0.7 mA to 100 pA, nearly covering seven orders of magnitude. When multiply all the factors, the difference between the product and one is about 0.05%. Comparing with the result at 632.8 nm, the result shows a much larger fluctuation. The recorded current data of the photodetector at 940 nm show a much large standard deviation.

Also, the results at 405 and 780 nm show similar result as 632.8 nm, but with a larger fluctuation too, like 940 nm. The stability of the laser at other wavelengths is not as good as He-Ne laser.

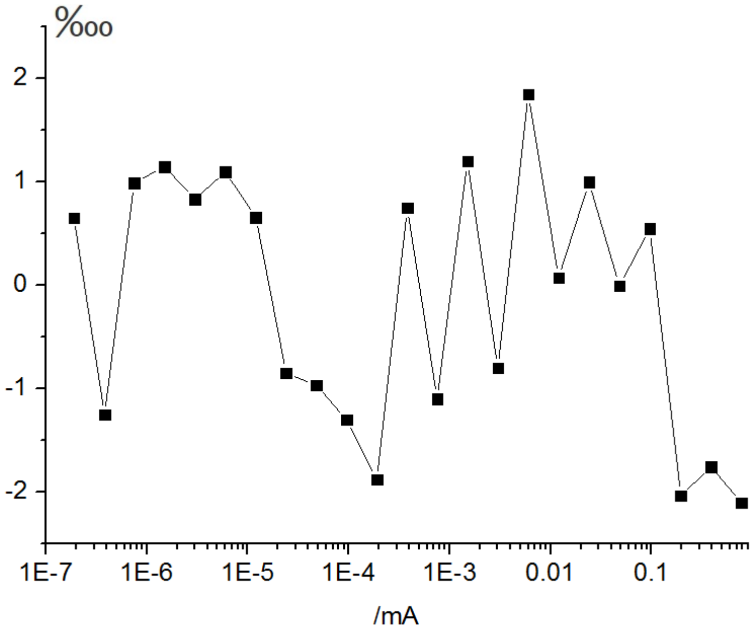

Figure 4 – The linearity factor at 940nm

3.2 Irradiance mode

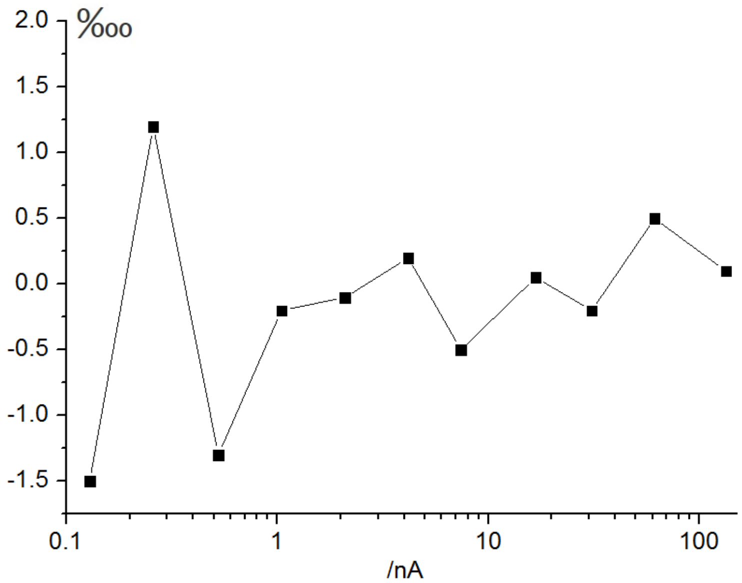

Figure 5 – The nonlinearity factor at 632.8 nm

Figure 5 shows the nonlinearity factor when the current of the detector is changing from 136 nA to 0.1 nA. Results show the factor is less than 0.02% over the whole scope like in the power mode. For comparison, the linearity in irradiance mode is tested at approximate current like the power mode.

On the other hand, the current of the photodetector can be decreased less than 0.1 pA. So the nonlinearity can be measured in nine orders of magnitude with the help of the two different modes. Also, if the distance between the photodetector and the integrating sphere can be varied, the nonlinearity can be tested at a much lower laser power level. However, with the decrease of the current, the fluctuation of the nonlinear factor increases due to the signal-to-noise. Many times average is needed to obtain a better result.

4 Conclusions

Nonlinearity of photodetector is investigated using lasers in both power mode and irradiance mode. The nonlinearity is measured in the low current range below 10^{-9} A. With the help of different lasers, the nonlinearity can be realized at different wavelengths to check the wavelength dependence. On the other hand, by combining the power and irradiance mode, the laser nonlinearity facility can test the nonlinearity over nine orders of magnitude and be used as a low light level radiation source.

References

1) Friedrich R. 2003. Accurate calibration of filter radiometers against a cryogenic radiometer using a trap detector. *Metrologia*, 32(6): 509.
2) Klaus D. Mielenz. 1972. Spectrophotometer linearity testing using the double-aperture method, *Appl. Opt.*, 11, 2294-2303.
3) Thompson A. 1994. A linearity measurement instrument for optical detectors, *J. Res. Natl Inst. Stand. Technol.*, 99, 751–755.
4) Evangelos Theocharous. 2004. Absolute linearity measurements on HgCdTe detectors in the infrared region, *Appl. Opt.*, 43, 4182-4188.
5) Tamer F. Refaatand. 2012. Absolute linearity measurement of photodetectors using sinusoidal modulated radiation, *Appl. Opt.*, 51, 4420-4429.
6) Dong-Joo Shin. 2014. High-accuracy measurement of linearity of optical detectors based on flux addition of LEDs in an integrating sphere, *Metrologia*, 51, 25-32.
7) Zaid G. 2010. Differential spectral responsivity measurement of photovoltaic detectors with a light-emitting-diode based integrating sphere source, *Appl. Opt.*, 49, 6772–83.
8) Toomas Kübarsepp. 1998. Nonlinearity measurements of silicon photodetectors. *Appl. Opt.*, 1998, 37, 2716-2722.
9) Atte Haapalinna. 1999. Measurement of the absolute linearity of photodetectors with a diode laser[J], Meas. Sci. Technol., 10, 1075-1078