Characterization of the Linearity of InGaAs Photodetectors Using Series Resistance

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Abstract

An economical technique has been developed to characterize photodiode linearity. The technique is based on measuring photodiode's series resistance and is designed for industry applications. The measurement set-up has been made very simple. Presented results clearly show advantages and validity of the proposed technique for characterizing linearity of InGaAs photodiodes using series resistance.

Introduction

Optical detectors with cut-off wavelengths from 1.7 to 2.6 µm do have many important applications [1].

In(x)Ga(1-x)As photodiodes grown on InP substrates are widely used. The In(x)Ga(1-x)As material can be grown lattice-matched to the InP (having 1.7 µm cut-off wavelength) or lattice-mismatched to the InP using buffer layer with cut-off wavelengths covering the range from 1.9 to 2.6 µm [2].

Detector linearity is a critical performance parameter besides the well-known low dark current. In some applications, accuracy is so critical that each detector has to be tested and experimentally verified for linearity. In these cases, a simple and reliable measurement to characterize linearity of a detector is very useful and critical.

A photodiode is defined to be linear when its photoelectric conversion efficiency (responsivity) is independent of the incident optical power. Each photodiode behaves as a linear detector for a certain range of optical power and becomes nonlinear for higher intensity optical power, the nonlinearity threshold being a characteristic of the particular photodiode.

The nonlinearity of a photodiode is a function of several factors like generated photocurrent, incident optical power, the ambient temperature, etc. However, the series resistance of the photodiode appears to be the most important factor in determining the linearity. One also needs to mention the incident beam diameter because it has been observed it has an influence on the linearity, but in a different manner for various types of photodiodes, however the influence is not wavelength dependent [3].

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As an example of the importance of photodiode detector linearity, Fourier Transform Infrared Spectroscopy (FTIR) is especially sensitive to the nonlinearity of the detectors [4]. The mathematics of the transformation requires the linearity of the measured data. Artificial features appear in the spectra if the linearity criterion is not satisfied. A typical nonlinearity induced feature in the FTIR spectra is observation of non-vanishing spectral response in the wavelength region beyond the cut-off wavelength of the detector, frequently accompanied by a dip (called "foot") at the detector cut-off. The linearity of a photodiode detector is generally characterized by measuring diode response to optical signals of varying intensities. These are usually complex optical setups. One method uses for instance the superposition of two interfering beams.

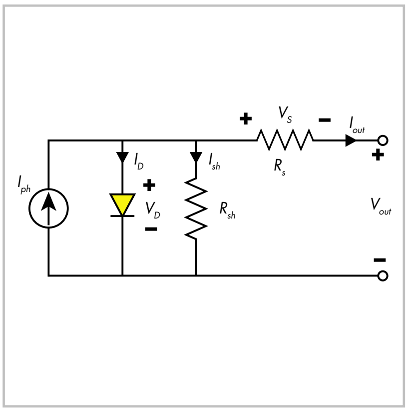

Fig. 1.
Photodiode equivalent circuit under illumination

At the optical power levels involved, the nonlinear response effects are caused by 'sinking' of a portion of the photogenerated current within the photodiode itself. The 'sinking' is caused by a slight forward bias of the photodiode induced by the voltage drop across its series resistance as shown in Figure 1. The Figure 1 shows the photodiode equivalent circuit in sufficient detail to explain the origin of the nonlinearity. The series resistance Rs usually arises from the contacts and the wire bonds of the photodiode. Nonlinear form of the forward biased I-V diode characteristics (Eq. 1) makes the 'sinking' nonlinear thus causing the nonlinear relationship between the photodiode output current Iout and the photogenerated current Iph which is the actual cause of the photodiode's nonlinear optical response.

$$I = I_0\left(\exp\frac{qV}{nKT} - 1\right) \qquad (1)$$

For the same photogenerated current values, lower series resistance values cause lower forward bias of the photodiode thus directing more photogenerated current to the output and keeping the optical response linear. Thus, the series resistance of a photodiode can be used to characterize its optical linearity and/or nonlinearity.

We estimate the series resistance value from measured forward biased I-V characteristics of a particular diode in the dark making this technique simpler than the usual optical measurements since no optical components are required.

Experimental Setup

The series resistance of a photodiode is estimated from its forward biased I-V curve.

The simplicity of this setup makes it very desirable involving just a source-measure unit such as a Keithley 237 that applies current and measures the resulting voltage and a computer software to collect data and plot I-V curve.

Figure 2 shows FTIR spectra of 3 LASER COMPONENTS photodiodes from 3 batches. These results indicate that the first two photodiodes are linear while the third photodiode is nonlinear for the power levels used in the measurements. The FTIR results also suggest that the series resistances of the first two photodiodes should be lower than the series resistance of the third photodiode.

Device Serial No.	Series Resistance (Ω)
L7359-IG26X1000T9	1.5
L6541-IG26X1000T9	2.5
L1986-IG26X1000T9	2.3
F1346-IG26X1000T9	1.9
I9417-IG26X1000T9	6.1

Tab. 1:
Series resistance values for different tested IG26X1000T9 detectors.

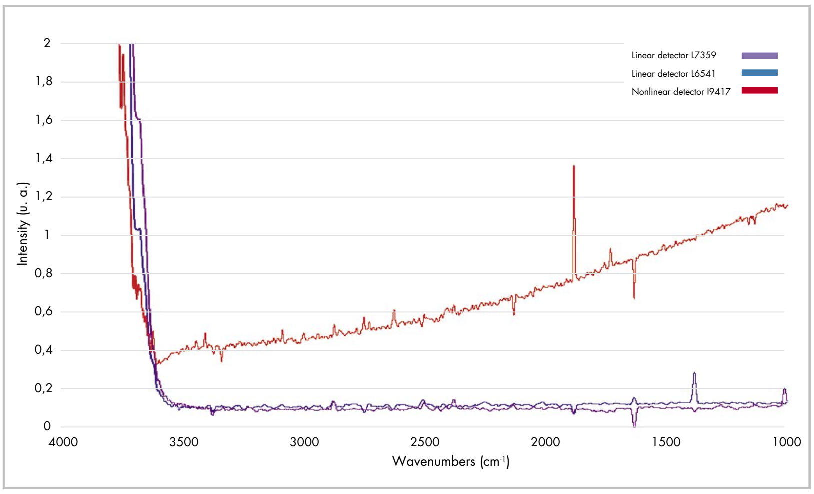

Fig.2.
FTIR spectra for linear and nonlinear photodiodes showing “foot” and sloped line beyond the detector cut-off (for nonlinear detector)

Figure 3 illustrates the series resistance value estimation steps, while Table I presents the estimated series resistance values for the photdiodes whose spectra are shown in the Figure 4 and a few additional detectors. The series resistances of the photodiode devices are estimated by the following steps:

1. The forward biased I-V curve for each device is measured.
2. The logarithm of current (Log(I)) versus voltage (V) is plotted. The ideal diode I-V curve is exponential so that the log(I) versus V curve should be linear, however, in the non-ideal case, at higher voltages the diode current does not exponentially change as the voltage increases and the Log(I)-V curve deviates from linear line due to the series resistance effect.
3. A tangent line of the linear part of Log(I)-V is drawn.
4. A horizontal (fixed current) line is drawn where the current does not exponentially change as the voltage increases.
5. We record the current corresponding to the intersection of the two lines (Is).
6. The two voltage values are needed to calculate the series resistance. One of them (V1) is taken at the intersection of the two lines (where the Is is registered) and the second voltage point (V2) is taken at the point where the horizontal line intersects the Log(I)-V curve.
7. Series resistance is calculated based on the conventional Ohm law:

$$R_s = \frac{\Delta V}{I_s} = \frac{(V_2 - V_1)}{I_s} \qquad (2)$$

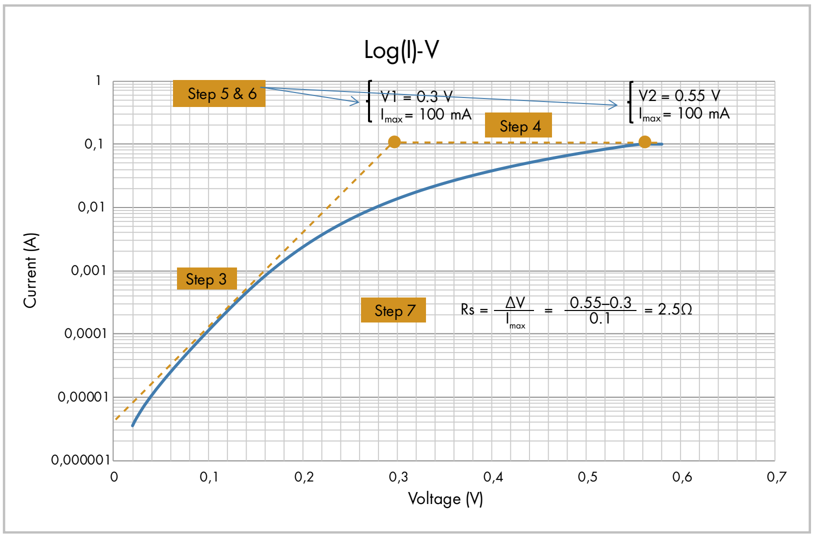

Fig.3
An illustration of the series resistance value estimation steps after measuring the forward bias I-V curve up to 100 mA and plotting the logarithm of current vs. voltage (Step 1 & 2).

Since the series resistance values are obtained from the curve fitting, the error of ± 0.1 Ω is estimated for the series resistances.

The series resistance values from the Table I correlate well with the observed linearity of the detectors shown in Figure 3.

The nonlinear device has by far the largest series resistance, above 6 Ω, while the linear detectors have series resistance values from 1.5 Ω to 2.5 Ω. The above results clearly show validity and advantages of the proposed technique for characterizing linearity of InGaAs photodiodes using series resistance.

Conclusions

Linearity of a photodetector is a critical performance parameter because the linearity is required for accurate electrical response of the photodetector as the incident optical power increases.

Usual techniques of characterizing the linearity are demanding necessitating a number of aligned optical components and sources besides usual electrical components.

An economical and simple technique to characterize the linearity of InGaAs photodiodes is being presented in this work.

The technique is suitable to many industrial applications. It is based on the fundamental relation between the linearity of a photodiode and its series resistance.

The technique involves measuring the forward biased I-V characteristics of a photodiode and applying the collected data to estimate the series resistance value.

Series resistances of several photodiodes have been evaluated by the above procedure and successfully correlated with their FTIR spectra.

The above results clearly show validity and advantages of the proposed technique for characterizing linearity of InGaAs photodiodes using series resistance.

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