Association Analysis of Nonlinear Saturation Characteristics Based on High-speed and High-output Photodetectors

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Abstract- With the development of optical communication system, the nonlinear saturation characteristics of photodetectors are necessary to consider. We observed the 1-dB compression current as DC photocurrent saturation point under high power illumination in PIN-PDs. Meanwhile, a new method of measuring AC saturated output power in the time domain is proposed. The quantitative relationship between DC saturation point and AC saturation point is given.

I. INTRODUTION

Nonlinearity has been an important factor for limiting the high-speed and high-output performance of photodetectors. The space charge effect, external loading and thermal effect are considered as the three main causes of nonlinear effects [1]. In recent years, some deep-seated causes are constantly found in more and more in-depth researches.

In this paper, we focus on the nonlinear saturation characteristics of photodetector at high power illumination. According to the nonlinear response characteristics of the detector under DC and AC excitation. We give the quantitative relationship between DC and AC saturation points which are measured by 1-dB compression current.

II. METHOD of NONLINEAR ANALYSIS

The PIN-PD is a single or double heterojunction device composed of InP and InGaAs materials [4]. The structure under investigation here is shown in Fig. 1.

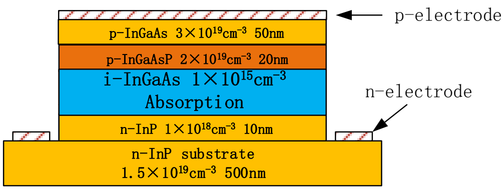

Fig. 1. Structure of the PIN-PD.

The intrinsic i-InGaAs layer of the PIN is generally thick, which occupies the entire depletion layer and is the main region of the optical absorption. The incident light is absorbed in this region to produce a large number of electron hole pairs, and then electrons and holes are separated by the external electric field to form the built-in field that weaken the external electric field. Hence, as the input light intensity increases, the output photocurrent is no longer proportional to the input.

In the case of DC signal input, we use 1-dB compression current [2], is defined as the photocurrent at which the output power is compressed from the linear response by 1-dB, to measure saturation. We focus on incident light intensity at the saturation point.

For AC signal input, we use a new method in the time domain. Assume that input light intensity modulated by single frequency signal is given by formula (1).

$$b(t)=\begin{cases} A-a\cdot A\sin(2\pi ft) & t>t_0 \\ A & 0>t>t_0 \end{cases} \qquad (1)$$

Where $b(t)$ is input light intensity, A is a DC signal, a is modulation depth. In order to reduce the influence of the high frequency on the photodetector, f (1GHz) is chosen as the AC signal frequency and period is T. Observe output photocurrent when we change modulation depth constantly. It is found that when the modulation depth a is comparatively small, the output current is basically linear, and the output has scarcely any other frequency components by performing the Fourier transform.

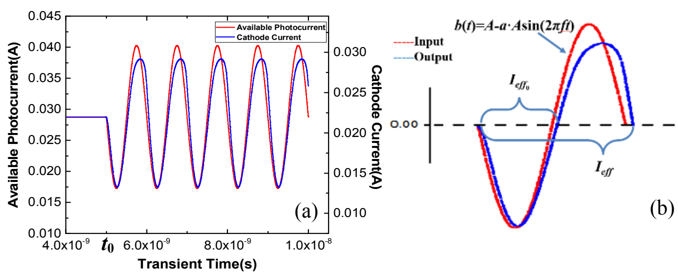

Fig. 2. (a) The time domain response to AC signal input under a 5e5W/cm^2 incident light intensity at 1GHz for PIN-PDs biased at 2V is shown. (b) Available photocurrent (input) and cathode current (output) without DC part are shown.

As the modulation depth increases, a=40%, the upper part of the image shows obvious distortion in Fig. 2(a). Because the process of light modulation is based on a higher DC light incident (A in formula) in the simulation, we filter out the DC part when we deal with the output current (Fig. 2(b)). Analogy to the definition stated above, we give a method to investigate

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the saturation point under AC response. Calculating output photocurrent (without DC part) effective value:

$$I_{eff}=\sqrt{\frac{1}{nT}\int_{t_0}^{t_0+nT} i^2(t)dt} \quad or \quad \sqrt{\frac{1}{n\cdot\Delta t}\sum_{x=1}^{n} i^2(x)\Delta t} \qquad (2)$$

Due to the lower intensity of the excitation light in the lower half, the detector is not saturated, and the output is approximately linear. We take it as a theoretical value. Calculating effective value:

$$I_{eff_0}=\sqrt{\frac{2}{T}\int_{t_0}^{t_0+T/2} i_0^{\,2}(t)dt} \quad or \quad \sqrt{\frac{1}{n\cdot\Delta t}\sum_{x=1}^{n} i_0^{\,2}(x)\Delta t} \qquad (3)$$

Then calculating P_{dB}:

$$P_{dB}=20\cdot\log_{10}\frac{I_{eff_0}}{I_{eff}} \qquad (4)$$

Define AC response reaches the saturation point, when P_{dB} equals 1dB. We also focus on incident light intensity at the saturation point.

III. Result and Analysis

A. DC Saturation Characteristics

The simulation for PIN-PD with absorption layer thickness of length ω_i=300nm biased at 2V [3] is shown in Fig. 3.

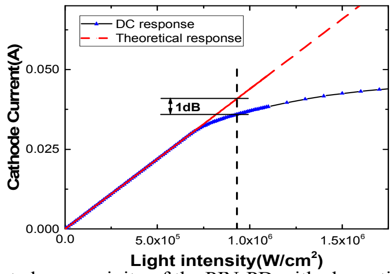

Fig. 3. Simulated responsivity of the PIN-PD with absorption layer thickness of length ω_i=300nm at the bias voltage of 2V. And the 1-dB compression level is marked.

The value of incident light intensity at the saturation point is 9.1e5W/cm^2.

B. AC Saturation Characteristics

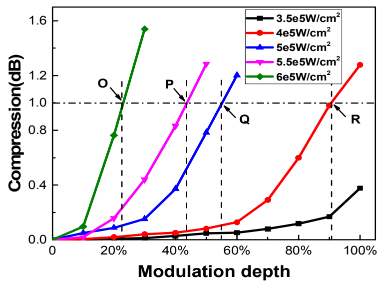

Fig. 4. Compression of a PIN-PD with 300nm absorption layer thickness at 1GHz at 2V reversed bias. The 1-dB compression level is marked to show saturation.

Set the DC signal A=3.5e5W/cm^2, 4e5W/cm^2, 5e5W/cm^2, 5.5e5W/cm^2, 6e5W/cm^2, and then calculate P_{dB} at different modulation depth a. At the points O, P and Q in Fig. 4, the PD reaches AC saturation. Calculate the peak of input light intensity by

$$b=A+a\cdot A \qquad (5)$$

The values of b at points O, P, Q, and R are 7.4e5W/cm^2, 7.8e5W/cm^2, 7.7e5W/cm^2 and 7.6e5W/cm^2. Taking into account the limited amount of data obtained in the simulation process, the four values can be considered approximately equal. The average value (b≈7.625e5W/cm^2) is taken as the input saturation intensity.

C. Association Analysis

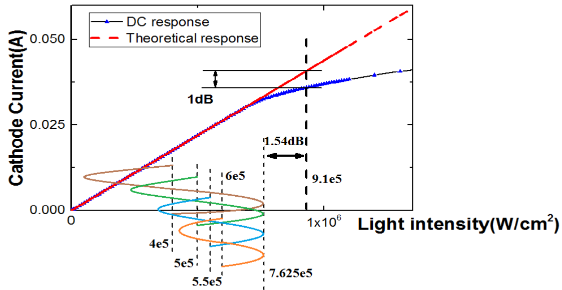

Fig. 5. Plot AC signal on the abscissa in Fig. 3.

Before the photodetector reaches DC 1-dB saturation point, DC response has appeared distortion. It has been calculated that the PD reaches AC 1-dB saturation point when the maximum value of the AC light intensity exceeds 7.625e5W/cm^2 (Fig.5). At saturation points, AC input light intensity is about 1.54-dB lower than DC input light intensity.

IV. Conclusion

The time domain method is used to analyze the AC saturation. An explicit quantitative relationship between DC and AC saturation points is given. Because the DC characteristics are relatively simple in both simulation and testing, the study of the relationship between the two provides a predictable conclusion for the test of the nonlinear AC characteristics of the photodetector.

Acknowledgment

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