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An equivalent circuit model of a novel photodetector

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ABSTRACT

An equivalent circuit model of a novel photodetector (PD) is proposed in this article. We use this model to describe the relation between the bias voltage and current (*I–V*), also the bias voltage and capacitance(*C–V*) of this kind of novel PD. The circuit model could optimize the structure of the circuit and could be linked with the readout circuit. According to the comparison between the simulation result and the experimental result by circuit testing, we could find they are in good agreement, which proving the correctness of the equivalent circuit model. The signification of this equivalent circuit model is to design an optimal readout circuit (ROIC) for the novel PD.

1. Introduction

The dominant properties of low-dimension heterojunction structures are widely used to develop novel photoelectric devices and structure of solid-state electronics devices because of their superiority to homojunction structures, which have gained much attention for many years [1]. Photoelectric detectors (PD) are the key components both in fiber-optic communication and photoelectric detection system, which could exchange the optical signal [2]. Building up equivalent circuit models of photoelectric device are quiet necessary before designing the readout circuits for photoelectric devices. Up to now, the equivalent circuit models of several kinds of typical photoelectric detectors have been built up and most of them are obtained on the base on solving a set of the PD intrinsic physical characteristics equations [3–5]. However, research shown that excess intrinsic physical characteristics parameters on PD modeling would impact the model accuracy and these equations cannot be used directly when the detector is connected with its readout circuit for simulating design, also the complex circuit programming would made the problem become more complicated [6].

This paper reports the modeling way by fitting of curves for a high sensitivity near infrared photodetector. The equivalent circuit model is presented in combination with the result of curve fitting by simulated with Cadence EDA platform. It not only shows the characteristics of the PD, but also avoids the problems in solving physical equations. According to the comparison between the simulation result and the experimental result, the good agreement could find, and proving the correctness of the equivalent circuit model. Finally, the equivalent circuit model is used for designing readout circuit (ROIC) [6–8], which is optimal for the novel PD.

2. Characters of the device

The direct current characteristic was measured by the Keithly 4200-SCS on a probe station, computer automatically sweeping, acquisition and disposing under room temperature (293 K). The range of the sweeping bias voltage was from −4 V to 0 V and the voltage step was 0.02 V at 1300 nm photo source. Fig. 1 shows the *I–V* curve of the novel PD when the power of the photo source was 200 nW. The PD is a high sensitive near infrared quantum dot device.

The *C–V* characters of the photoelectric device could be measured by a DC bias voltage and a small signal AC bias voltage was added at same time. The range of the sweeping bias voltage

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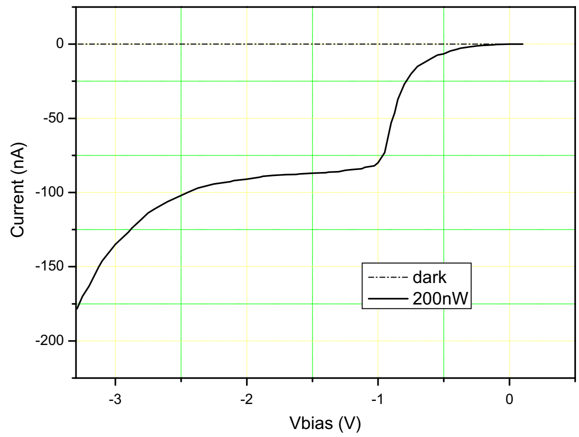

Fig. 1. *I–V* character of the PD.

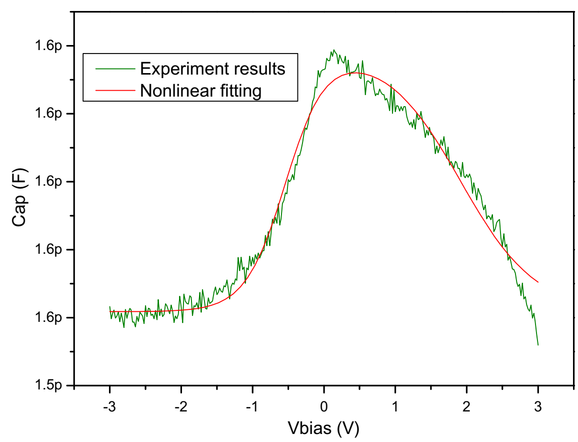

Fig. 2. *C–V* character of the PD and fitting of curve.

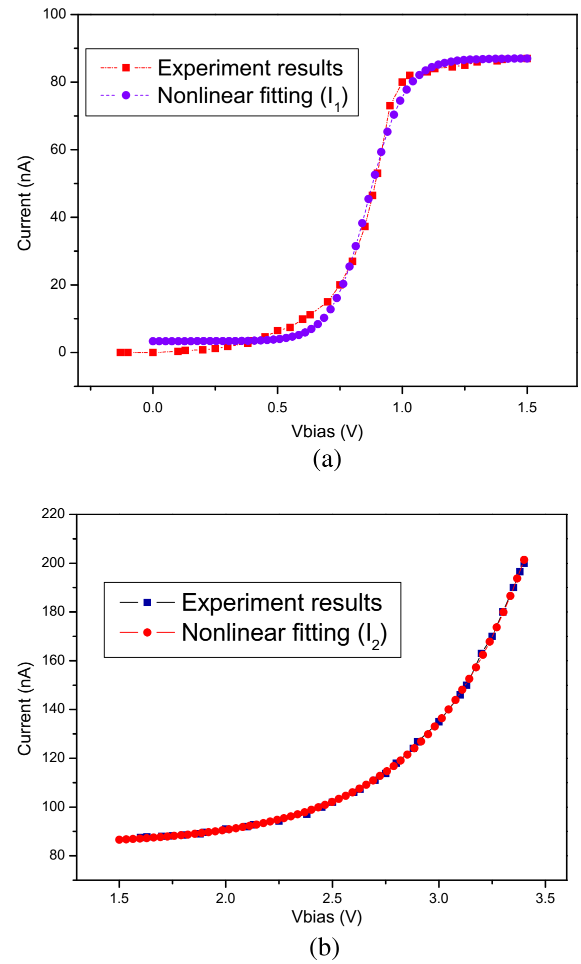

Fig. 3. Sectional fitting results of *I–V* characteristic curve.

was selected from −3 V to +3 V and the voltage step was 0.02 V. Fig. 2 shows the *C–V* curve of the novel PD which in the frequency of 1 MHz at room temperature.

3. Modeling

Equivalent circuit model is composed of basic circuit components, such as resistance, capacitance, controlled source. The accuracy parameters of the components are very important. The fitting of curve can get these parameters effectively and accurately.

3.1. I–V curve fitting

Nonlinear fitting of *I–V* characteristic curve in Fig. 1 is completed by applying Origin software. Curve fitting method includes full fitting and sectional fitting for ordinary curves. The results of full fitting can be applied to circuit modeling directly. The sectional fitting is suitable for special curves, but its accuracy is high. The curves in Fig. 1 is divided into two sections in flat parts of the curve. Here, V_{bias} = 1.5 V is the dividing point. Because the characteristic curve of *I–V* shows exponential function relation, the fitting need change the direction of abscissa and ordinate. Fig. 3 a shows the nonlinear fitting curve and experimental curve at V_{bias} range [0, 1.5] and Fig. 3b shows the curves at V_{bias} range [1.5, 3.5]. The result of sectional fitting is given by:

$$\begin{cases} I_1 = 86.97 + \frac{3.35-86.97}{1+e^{(V-0.86)/0.07}}\,(\text{nA}) \quad V \in [0\,1.5] \\ I_2 = 84.44 + 5.46 \times e^{(V-1.94)/0.47}\,(\text{nA}) \quad V \in [1.5\,3.5] \end{cases} \tag{1}$$

3.2. C–V curve fitting

The intrinsic capacitance of the novel PD is composed of depletion capacitance and storage capacitance. In the optical radiation condition, the polarization effect of photo-generated carrier effects the intrinsic capacitance of the PD. The full fitting is suitable for *C–V* curves fitting. Fig. 2 shows the nonlinear fitting curve and experimental curve. The result of full fitting is given by:

$$C_p = 1.56 + \frac{7.69}{1+e^{-(V-0.69+1.22)/0.28}} \times \left(1 - \frac{1}{1+e^{-(V-0.69-1.22)/0.52}}\right)\ (\text{pF}) \tag{2}$$

3.3. Equivalent circuit modeling

According to the result of *I–V* curve fitting above, the equivalent circuit model needs two voltage controlled current sources. In order to get a smooth curve, a switching function is needed at the dividing point of 1.5 V, it can be achieve by the integral. The switching function is expressed as follows:

$$K(V) = \text{int}\left(\frac{V-1.5}{V-1.5-\delta}\right) \quad 0 < \delta \ll 1 \tag{3}$$