



Study of effective carrier lifetime and ideality factor of BPW 21 and BPW 34B photodiodes from above room temperature to liquid nitrogen temperature



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ABSTRACT

In the present work we have studied the temperature dependence of two most important characteristics of the photodiodes (BPW 21 and BPW 34B), namely, the ideality factor and the carrier lifetime; both of which are found to change significantly at low temperature. The effective carrier lifetime measured by the Open Circuit Voltage Decay method (OCVD) shows a gradual increase in value from 350 K to about 250 K then sharply decreases by about thirty percent of its highest value at liquid nitrogen temperature, the trend being similar for both the devices. The dark forward current–voltage characteristics over the same temperature range yield the value of ideality factor which increases nearly by a factor of three for both the photodiodes at the liquid nitrogen temperature. The nature of variation of both the parameters has been qualitatively accounted for in terms of the recent tunneling models. The data generated for the first time for the devices and their broad theoretical understanding will help to improve design and application of the photodiodes, particularly at low temperature.

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1. Introduction

There are many instruments like cameras, light meters, smoke detectors, flame monitors etc used in the field of defence, oceanography, space research programmes and others that make use of detection of radiation of different wavelengths. The reliability of these instruments depends on the performance of the detector. It is expected that the performance of the detectors should remain stable over a wide range of temperature which may vary from around room temperature to temperatures far below it. But it is found that the performance of the detectors substantially changes with temperature. So, the temperature characterization of such detectors is important from the point of view of different applications as well as understanding of the underlying physics.

In recent years different types of commercial photodiodes have become available in the market. But the temperature characterization of such opto-devices has not been adequately studied.

In such devices the electrical characterization can provide important information about the current transport through the wide-band-gap p – n heterojunctions and layer materials. Such knowledge of the carrier transport mechanisms is essential for achieving a fundamental understanding and further improvement

of the device performance. In spite of the recent research efforts invested these carrier transport mechanisms are still not well understood.

Several publications on the measurement of temperature dependent effective carrier lifetime (τ) of Si based devices are now available. These literatures show that effective carrier lifetime (τ) in semiconductor physics is a fundamental physical parameter determining different terminal properties of semiconductor devices such as LEDs, solar cells and photodiodes [1–5]. The effective carrier lifetime (τ) plays a dominant role in semiconductor devices such as efficiency of solar cells, leakage current of diodes, emitter injection efficiency of bipolar transistors, and also influences recombination in the end regions of power devices operating by injection of minority carriers [1]. For a photodiode, the effective carrier lifetime plays an important role for data communication, response time and efficiency of the device. Several methods are generally employed to measure the effective carrier lifetime in a semiconductor p – n junction. Out of these, the Open Circuit Voltage Decay (OCVD) technique is one of the fastest and the interpretation of data is direct [3]. Temperature dependence of τ has been the subject of quite a number of current studies [3,6]. However, in most of the previous studies, the temperature dependence has been studied in a temperature range above room temperature and there are only limited data on the effective carrier lifetime at cryogenic temperatures [4]. In fact, we have not come across any measurement on carrier lifetime of

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photodiode devices at and around liquid nitrogen temperature. Absence of such data on the temperature dependence of the carrier lifetime is also a limitation in device modeling calculation.

In this report, we measure the temperature dependent OCVD characteristics as well as the variation of ideality factor (n) with temperature from I - V measurement for BPW 21 and BPW 34B Si based photodiodes. Further the data on the ideality factors of the devices have been analyzed in terms of two theoretical models, [7] namely, the tunneling enhanced interface recombination model (TEIR) as well as the tunneling enhanced bulk recombination model (TEBR) to have an insight into the electronic conduction mechanism of the devices and how it is affected by low temperature. Finally, using these data we calculate the temperature dependence of the effective carrier lifetime for both the devices.

2. Experimental detail

In our investigation we used two different types of silicon based photodiodes having the code name BPW 21 (124 deg. Human eye, Si photodiode) and BPW 34B (120 deg. w/Enh Blue Sens, PIN Photodiode) procured from RS Components, which operate in the visible-infrared region and their peak wavelength are 560 nm, and 850 nm respectively. Also their minimum and maximum wavelength detecting capacities are 460–750 nm and 350–1100 nm. The photodiode was placed inside a bath type optical cryostat designed in our laboratory [8,9]. With special care, liquid nitrogen was poured inside the liquid chamber of the cryostat which was pre-evacuated to a pressure 10^{-4} Torr by using a high vacuum pumping unit (Model No. PU-2 CH-8, manufactured by Vacuum Products & Consultants) to avoid moisture on the sample. The temperature measurement in the range 350–77 K was done by using a Chromel–Alumel thermocouple (TC). The TC output was recorded by a Keithley 2000 multimeter with accuracy of the order of ± 0.14 K. For OCVD measurement a GWINSTEK pulse generator (SFG-1013) was used as an input frequency pulse supplier and a 100 MHz agilent 54622D mixed signal oscilloscope to detect the output wave pattern of OCVD curves. I - V measurements were performed by Keithley 2400 source measure unit (maximum reading rate is 1700 readings per second). The details of the experimental set up are available in our previous work [2,10].

3. Results and discussion

3.1. I - V characteristics

The forward I - V curves of a typical BPW 21 and BPW 34B photodiodes at different temperatures are shown in Fig. 1.

We have analyzed the conduction mechanism by dividing the $\log I$ vs V curves into two distinct voltage regions where the merging and leveling of I - V data in region II may be due to space charge limited current. For region I total forward current is rewritten as [9,11]

$$I = I_0 \exp\left(\frac{qV}{nkT}\right) = I_{00} \exp\left(\frac{-E_a}{nkT}\right) \exp\left(\frac{qV}{nkT}\right) \quad (1)$$

where I_0 , saturation current, n , ideality factor, E_a , activation energy and I_{00} is a prefactor which depends on the transport mechanism [12]. The value of n is determined from the slope of the linear region of the forward bias $\ln I$ - V characteristics through the relation

$$n = \frac{q}{kT} \left(\frac{dV}{d(\ln I)} \right) \quad (2)$$

The variation of the ideality factor with temperature is shown in Fig. 2 and listed in Table 1.

In general, when n is between 1 and 2, then current flow is mainly diffusion recombination current; while if n is larger than 2, tunneling mechanism becomes dominant [13]. Below 181 K the value of n crosses the value 2 and increases to 3.56 and 3.71 for BPW 21 and BPW 34B when the temperature is lowered to 77 K which indicates in the temperature range 181–77 K the tunneling mechanism becomes significant.

In order to study the physics of the conduction mechanism of the photodiodes and how it is affected by low temperature we employ two transport models, namely, the tunneling enhanced interface recombination model (TEIR) and the tunneling enhanced bulk recombination in the space charge region model (TEBR) [7]. The models provide analytical tools for the quantitative analysis of observed data which will help to determine the dominant recombination mechanism in the devices. The previous models [14,15] on trap assisted tunneling were limited to cases under the approximation that the product nT is temperature independent, the experimental data on the devices under investigation exhibit strong deviation from the above approximation (see Fig. 5). However, both the present models under consideration take account of the temperature dependence of nT .

Before we present the actual calculations according to the above models we discuss the importance of lowering of the temperature on the phenomenon of tunneling. The recombination rate of tunneling assisted recombination in Shockley–Read–Hall SRH model is given by [7]

$$R = \frac{np - n_i^2}{\gamma_p(n + n^*) + \gamma_n(p + p^*)} \quad (3)$$

where $n^* = N_C \exp[(E_T - E_C)/KT]$ and $p^* = N_V \exp[(E_V - E_T)/KT]$ with N_C and N_V as the effective densities of states in the conduction band

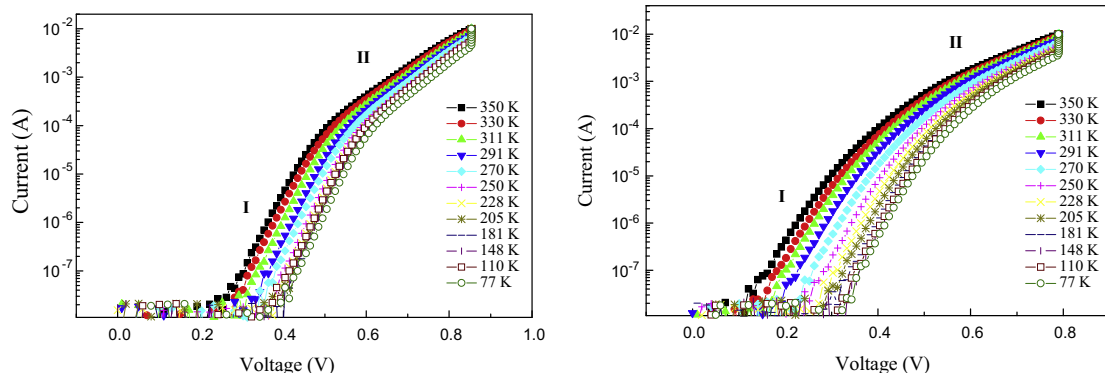


Fig. 1. The dark forward I - V characteristics of (a) BPW 21 and (b) BPW 34B photodiodes in the temperature range 350–77 K.

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