Estimation of Carrier Lifetime of Various Light Emitting Diodes by Using OCVD Method

Pradip Dalapati, Nabin Baran Manik*, Asok Nath Basu

Abstract– In this work we have studied and estimated carrier lifetime of a series of different light emitting diodes. Open circuit voltage decay (OCVD) technique and forward current–voltage characteristics have been used to evaluate the carrier lifetime of these devices at room temperature. It is an important parameter for the understanding of basic physics as well as the device applications for fast switching rate for digital data communication system. Our results reveal the rate of change of open circuit voltage influence on the voltage waveforms during the reverse recovery process of the diode. Such type of voltage decay gives information about the charge relaxation process of the diodes. The minimum and maximum carrier lifetime has been found to be 2.962 nS and 126.336 nS for UV3TZ-395-15 and LL2508JQHR4-A02 light emitting diode respectively.

Index Terms— LEDs, OCVD technique, Reverse recovery method, DCLA method, current–voltage characteristics, Ideality factor, Carrier lifetime.

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1 INTRODUCTION

LIGHT emitting diodes (LEDs) are commonly used in a digital data communication system essentially in high speed data communication and eventually the low value of carrier lifetime is helpful and important in achieving this purpose [1]. The carrier lifetime (τ) of a LED is an important parameter for determining the efficiency of some optoelectronic devices. Several methods have been proposed for the estimation of τ such as open circuit voltage decay (OCVD), reverse recovery, differential carrier lifetime analysis (DCLA), photoconductivity decay, open circuit capacitance, impedance measurement, light generated photovoltaic decay and open-to-short circuit switching etc. [1-3]. Among these, reverse recovery, DCLA and OCVD methods are widely used for the evaluation of carrier lifetime [1-2]. To evaluate the lifetime by reverse recovery method, one usually measures the total time (t_s) when the voltage across the junction becomes almost zero. But due to a slow discharge of the diode capacitance, the time, t_s increases and the measured value of τ is incorrect. Another difficulty with this method is that the error function is sensitive to small value of t_s/τ, for large reverse bias, and therefore, one has to work with a very sensitive time scale (smaller than τ). So, in reverse recovery method main source of error is the slow discharge of the space-charge capacitance [3]. Also, one can measure τ by DCLA method. It is reported that by using this method the measured carrier lifetimes in InGaN/GaN LEDs is found in the μS regime at low current densities [4]. The measured value of τ in DCLA is orders of magnitude higher than those measured in the present study by OCVD method which are in the nS regime.

However, the OCVD technique is quite straight forward, because, it involves measurement of single transient i.e. the decay of voltage with time. In this technique the minority carriers were injected in the base region of the LED with the help of a voltage pulse applied in the forward direction. In this method, a diode is forward biased and the excess carrier is established in the lightly doped region. Then the diode bias circuit is opened and subsequent excess carrier recombination is detected by monitoring the open circuit voltage [5].

2 EXPERIMENTAL DETAILS

In our investigations we used six different types of LEDs which are procured from RS Components. The experimental set-up for the carrier lifetime measurement by OCVD method is shown in circuit diagram of Fig. 1. The minority carriers were injected in the base region of the LED with the help of a voltage pulse applied in the forward direction from a GWINSTEK pulse generator model SFG-1013. The square pulse was applied through a current-limiting resistance R. The pulse generator connection to the LED was cut off when the pulse amplitude varies from high level to low level due to the presence of a p-n diode in the input circuit. The output wave pattern of OCVD curves was recorded on an 100 MHz agilent 54622D mixed signal oscilloscope. The current–voltage characteristics (I–V) measurements of LEDs were performed by Keithley 2400 source measure unit (maximum reading rate is 1700 readings per second). The details of the experimental setup are also available in our previous work [1-2]

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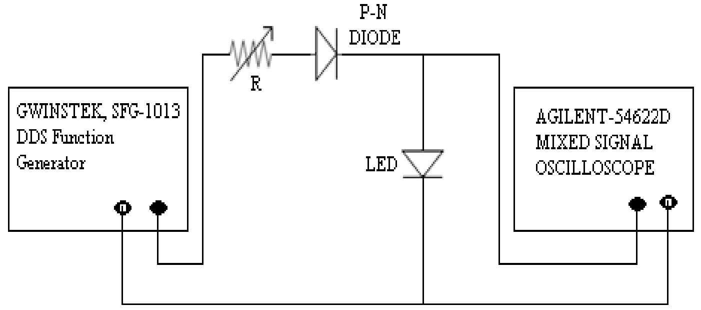
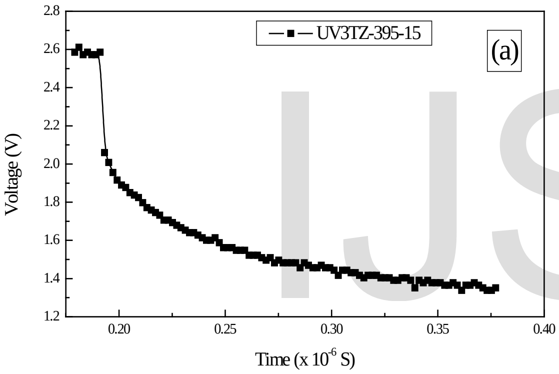
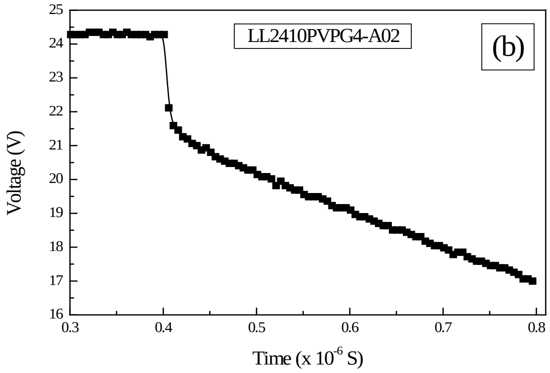


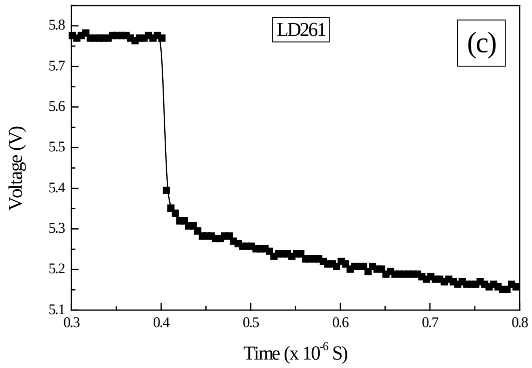
Fig. 1. Schematic diagram of the experimental set up used for the OCVD measurement of the LED.

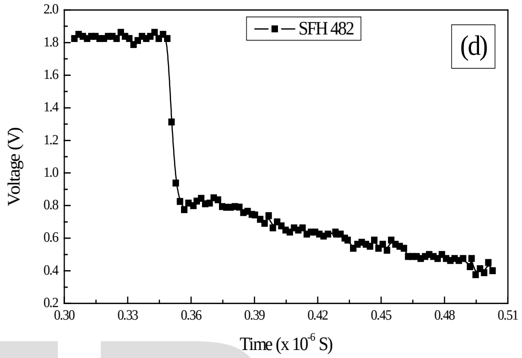
3 RESULTS AND DISCUSSION

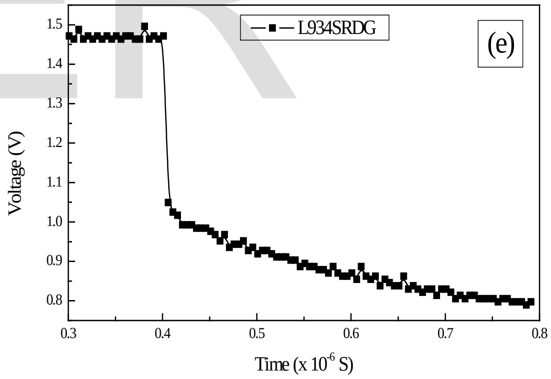
Open circuit voltage decay wave shape for six different commercial LEDs at room temperature is measured. Figure 2 represents the wave shapes for the LEDs.











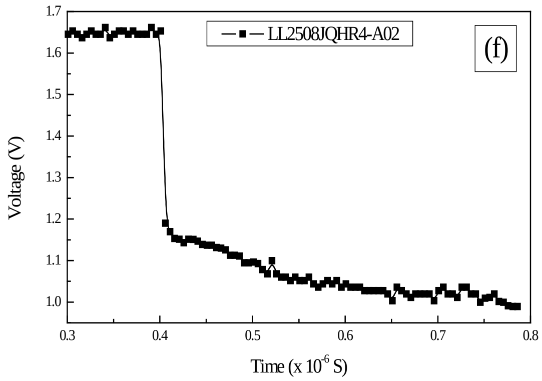
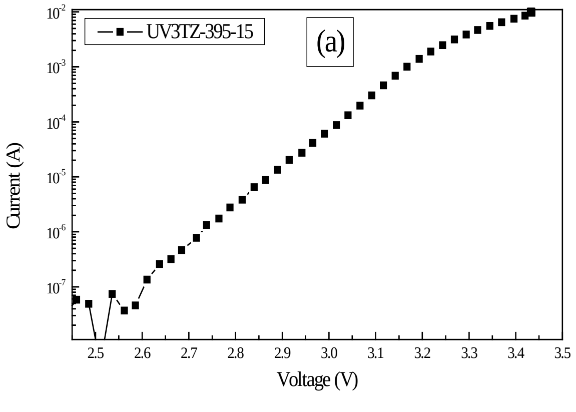


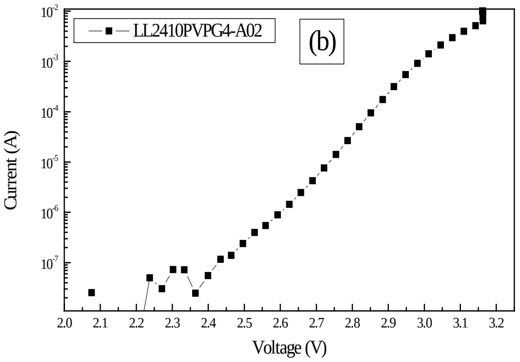
Fig. 2. Open circuit voltage decay wave shape for a) UV3TZ-395-15 LED, b) LL2410PVPG4-A02 LED, c) LD261 LED, d) SFH 482 LED, e) L934SRDG LED and f) LL2508JQHR4-A02 LED.

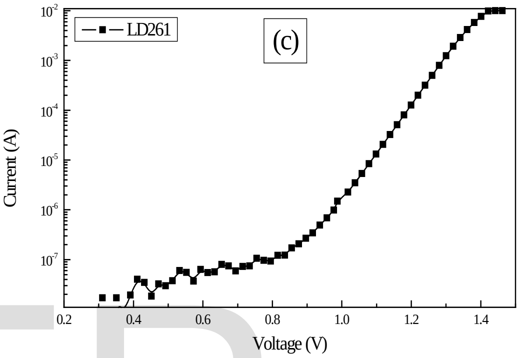
Figure 2 shows the direct pulse generator output superimposed on the OCVD curves for each LED. The pulse repetition frequency and the pulse width was always adjusted to allow the OCVD curve to fall to the ground level before the appearance of the next forward biasing pulse, as shown in Fig.2. The decay is characterized by two distinct regions. The first vertical drop is due to the series resistance of the LED. The next division of decay along the time axis clearly demonstrates an almost linear portion. This is followed by decay towards the zero voltage. This portion is complicated due to the combined effect of the junction voltage decay and the junction capacitance discharge [5]. From the OCVD τ is determined from the slope of the voltage decay by using the well known formula [2,4].

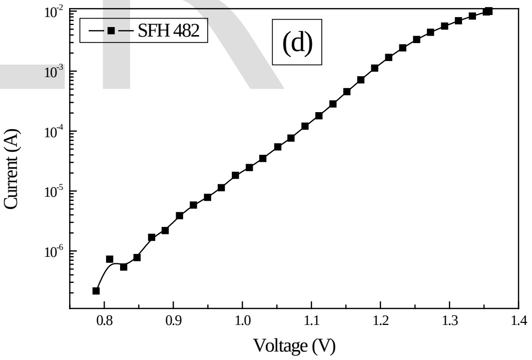
$$\tau = \frac{nKT}{q}\frac{1}{\frac{(dVoc)}{dt}} \qquad (1)$$

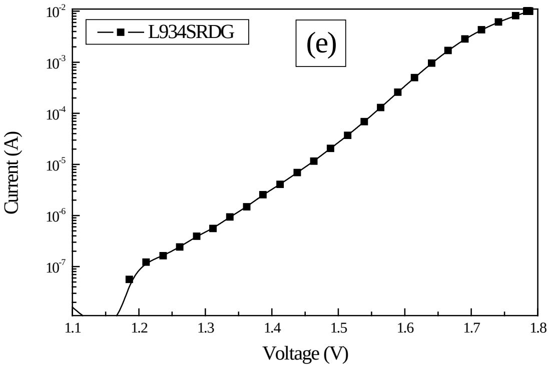
where, n is ideality factor, K is the Boltzmann constant, T is the temperature and q is the electronic charge. The value of $\frac{(dVoc)}{dt}$ was calculated from the linear portion of the OCVD curves. In order to evaluate τ, in addition to the time derivative of the open circuit voltage, we also require the value of the ideality factor n of the device. The value of n of the device was determined by measuring I–V characteristics of these devices. The forward logI versus V characteristic of these devices are shown in Fig. 3.











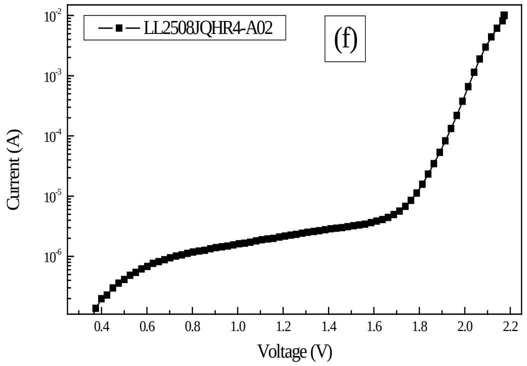


Fig.3. I–V curve (semilogarithmic plot) for a) UV3TZ-395-15 LED, b) LL2410PVPG4-A02 LED, c) LD261 LED, d) SFH 482 LED, e) L934SRDG LED and f) LL2508JQHR4-A02 LED.

The value of n is determined from the slope of the linear region of the forward bias lnI–V characteristics through the relation [2]

$$n = \frac{q}{KT}\left(\frac{dV}{d(lnI)}\right) \tag{2}$$

and listed in Table 1. The calculated values of n at the room temperature reveal that for InGaN based LED its takes the value above 2 which suggest the tunneling mechanism is the dominant carrier transport mechanism in such devices. For other LEDs the value of n are below 2 which suggest the diffusion mechanism is the dominant carrier transport mechanism in these devices at room temperature. Using the value of n we have evaluated τ for each LED at room temperature and presented in Table 1. From Table 1 the minimum and maximum carrier lifetime has been found to be 2.962 nS and 126.336 nS for UV3TZ-395-15 and LL2508JQHR4-A02 light emitting diode respectively. Hence, UV3TZ-395-15 LED will be comparably suitable for high speed data communication.

Table 1. Experimental values of ideality factor and carrier lifetime for each LED.

Type of LED	Materials	Ideality factor n	Carrier lifetime τ (nS)
UV3TZ-395-15	InGaN	2.454	2.962
LL2410PVPG4-A02	InGaN	2.194	4.881
LD261	GaAs	1.613	93.898
SFH 482	AlGaAs	1.524	104.326
L934SRDG	AlGaAs	1.959	109.606
LL2508JQHR4-A02	AlGaInP	1.392	126.336

4 CONCLUSION

This work investigates performance of the series of different LEDs by measuring their carrier lifetime (τ) with OCVD technique. In addition to the techniques, particularly the reverse recovery and DCLA methods, OCVD is another useful technique for carrier lifetime measurement. In the reverse recovery method the main error arises due to slow discharge of the space-charge capacitance. Also due to a slow discharge of the capacitance, the time, t_s increases and τ is incorrect. Another difficulty with this method is that the error function is sensitive to small value of t_s/τ, for large reverse bias, and therefore, one has to work with a very sensitive time scale (smaller than τ). Again the value of τ measured from DCLA method is significantly high and complex to analysis it. Whereas the OCVD is direct, because, it involves measurement of single transient i.e. the decay of voltage with time. In general the measured value of lifetime by OCVD technique has been observed to be smaller than that measured by other methods and a part of the deference may be attributed to the uncertainties of diode ideality factor and effects of junction capacitance. However, an investigation into the origin of difference between lifetimes obtained by different technique will be highly instructive. Finally, it is apparent from the present investigation that the LEDs with lower carrier lifetime, namely, the first two entries in the Table 1, will be extremely helpful for high speed data communication purpose, as there are orders of magnitude smaller than those of others.

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