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Research and technical note

Characterisation of the photodetector and light emitting diode at above liquid nitrogen temperature

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Abstract

In this article, we have studied the behaviour of photodetectors and Light emitting diodes (LEDs) at above the liquid nitrogen (LN_2) temperature. An optical cryostat has been used for this purpose. The data obtained from this investigation will be of help to decide the use of these devices for precision work at different cryogenic temperatures. A preliminary attempt has been made to develop a theoretical basis for the experimental data, which is also important to understand the operation of these devices from room temperature to LN_2 temperature. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Photodetector; LED

1. Introduction

During the last decade, opto-electronics have played a significant role in different areas of fundamental science as well as in technological applications. The present work describes the characterisation of the photodetector and light emitting diode (LED) at above the liquid nitrogen (LN_2) temperature. While designing a continuous liquid level meter for liquid nitrogen by an opto-sensor, the authors required data on the variation of the behaviour of photodetectors and LEDs with the lowering of temperature. No such experimental data of commercially available devices at above LN_2 temperature are commonly found. To carry out the investigation, the LED and the photodetector are placed inside an optical cryostat. For proper choice and effective functioning of the opto-systems at different cryogenic areas, one requires detailed information on the variation of their parameters with temperature. A theoretical model has also been suggested to interpret these experimental data.

2. Characterisation of the photodetector

The experimental set-up for the characterisation of the photodetector is shown in the block diagram of Fig. 1. The detector is placed inside an optical cryostat designed in our laboratory. The optical measurement below the room temperature is associated with many difficulties [1]. Care has been taken in this respect. By using LN_2 and a suitable heater coil inside the optical cryostat, the temperature can be fixed anywhere between 77 K (LN_2 temperature) and 325 K with an accuracy of the order of ±0.14 K around the set temperature. Temperature measurement is done by using a Chromel–Alumel thermocouple (TC). The TC output is recorded by a Keithley 6-1/2 digit multimeter. The TC junction has been mounted in such a way that direct heating of the junction from optical and in particular, the infrared radiation, becomes minimum and at the same time, the mechanical and thermal contacts between the sample and the TC are ensured. For a temperature control, a continuous type pulse-width-modulated (PWM) temperature controller has been used.

The photodetector is reverse biased with a 2.0 Volt dc source and a 100 K sensing resistance in series. The LED is placed outside the cryostat and driven by a constant current source. The output of the LED intensity varies linearly with its driving current. For a particular LED

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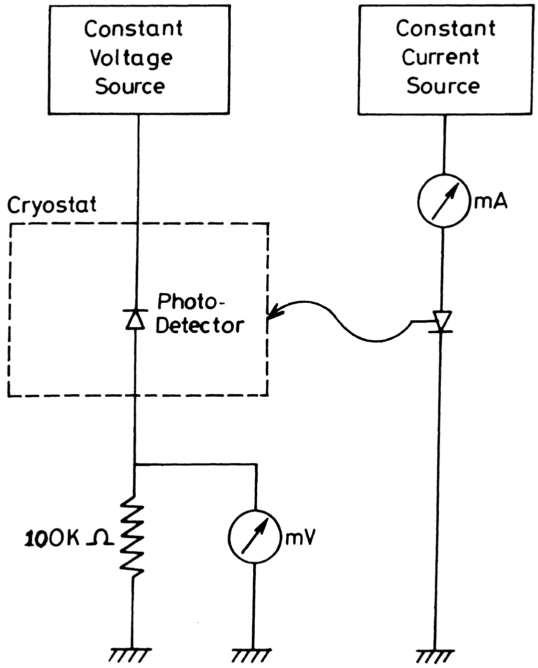

Fig. 1. Block diagram of the experimental set-up.

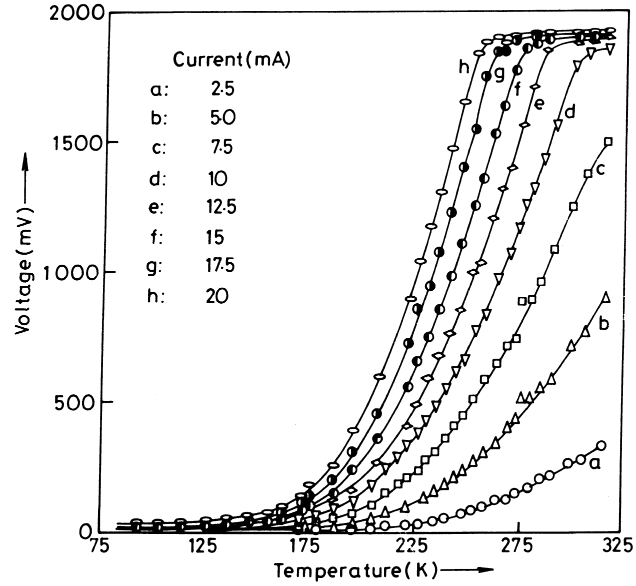

Fig. 2. Variation of the photodetector's output with temperature for different illumination incidents on it.

driving current, a fixed amount of radiation is incident on the detector and the corresponding detector voltage is measured by another 6-1/2 digit Keithley multimeter across this 100 K sensing resistance.

The photodetector output voltage is measured at different temperatures for a particular value of the LED driving current. The experiment is repeated for different LED driving currents (i.e. for different incident lights on the photodetector). The specification of the photodetector used in this experiment is mentioned in Table 1. The variations of the photodetector voltage with temperature for different incident lights on it are shown in Fig. 2. In order to qualitatively understand the effect of lowering of temperature on the performance of the photodetector, which is a reverse-biased p–n junction photodiode, we note that an optically-generated charge carrier concentration of n- and p-type regions of the photodetector will take place when a steady beam of light (radiation) is incident on it [2–5]. An optical generation rate g_{op}, characteristic of the material property, determines the excess charge carrier concentration of electrons and holes given by

$$\delta n = \tau_n g_{op} \quad \text{and} \quad \delta p = \tau_p g_{op} \tag{1}$$

with τ_n and τ_p being the meantime each carrier spends in its respective band, when the change in photoconductivity is

$$\Delta\sigma = q g_{op}(\tau_n \mu_n + \tau_p \mu_p), \tag{2}$$

where μ_n and μ_p are the mobilities of electrons and holes. Assuming simple recombination which implies that $\tau_n \cong \tau_p$, the variation of photocurrent with temperature is given by

$$i_{ph} \sim T^{-3} \exp(-E_g/KT), \tag{3}$$

where the temperature dependence of μ and τ are assumed to be $\sim T^{-3/2}$ and $g_{op} \sim \exp(-E_g/KT)$, respectively and E_g being the bandgap of the material. So, we may get the variation of this current with temperature as

$$i_{ph} = AT^{-3} \exp(-\alpha/T), \tag{4}$$

where A and α are constants independent of temperature and to get only the dominant effect, Eq. (4) may be further simplified as

$$i_{ph} \sim \exp(-\alpha/T). \tag{5}$$

This current is allowed to pass through a sensing resistance across which the voltage drop (V_f) is measured and shown in Fig. 2. Eq. (5) describes approximately, the variation of the photocurrent with temperature,

Table 1
Photodetector used in our experiment[a]

Detector used with the materials specification	Max. reverse voltage (V)	Dark current (nA)	Peak wavelength λ (nm)	Temperature (K)
Wide angle detector, TIL-78	30	50 at 298 K at 10 V	915–975	253–373

[a] Type numbers refer to R.S. Components and Controls (India) Ltd. Catalog, Kanpur, India.

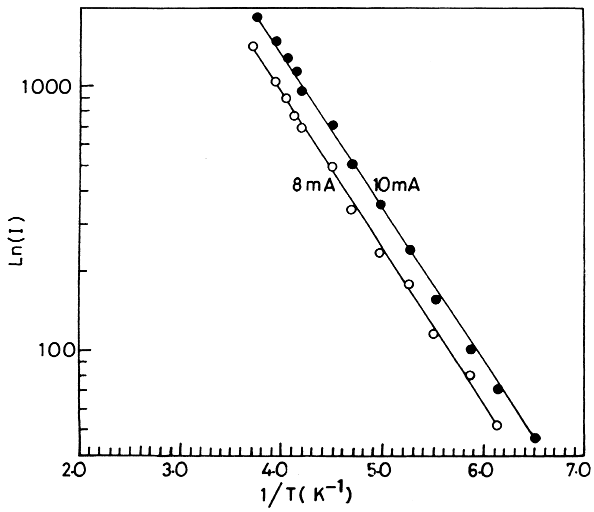

Fig. 3. Fitting of the experimental points of the photodetector's output with temperature.

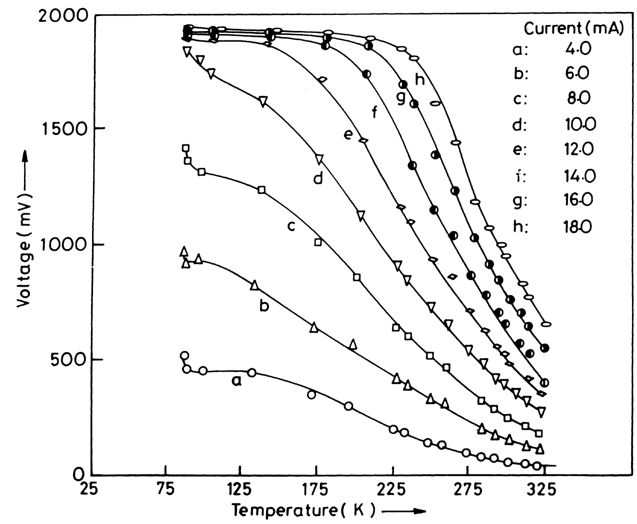

Fig. 4. Variation of the LED output with temperature for different driving currents.

which implies that $\ln V_f$ plotted against $1/T$ should be a straight line. Fig. 3 indicates that our data qualitatively corroborate with the above relation.

Another important point in the performance of a photoconducting device is noise generation which is primarily due to the dark current of the device known as Johnson noise which decreases with the lowering of temperature, enhancing the signal to noise ratio. The present set-up may also be used to study the dark current variation with temperature.

3. Characterisation of LED

For the characterisation of the LED, the experimental set-up is almost the same as shown in the block diagram of Fig. 1. Here instead of the photodetector, the LED is placed inside the optical cryostat. The photodetector was placed outside the cryostat and reverse biased with a 2.0 Volt dc source and a sensing resistance of 100 K as before. The LED is driven by a constant current source. The corresponding photodetector voltage is measured by the 6-1/2 digit Keithley multimeter across this sensing resistance.

Detector output voltage variation with temperature is observed. The above process has been repeated with different LED currents. The different curves for the detector voltage with temperature are shown in Fig. 4 for the LED specified in Table 2. It has been observed that for the LED, the photovoltage decreases with rise in temperature, which indicates that the emission from the LED decreases with increasing temperature.

From the experimental curves, it is observed that the LEDs are extremely temperature sensitive. At a lower temperature, the change in photovoltage is small but with rise in temperature, the voltage decreases drastically. The results obtained have good reproducibility and consistency. The data on LED indicate how the temperature affects its performance. The luminous intensity is reported to drop by about one percent per degree Kelvin rise in temperature. Sharupich and Tugar [6] have suggested the following form for the variation of luminous intensity of an LED with temperature

$$I_v = I_{vo} \exp[-K(T' - T_o)], \tag{6}$$

where I_v and I_{vo} are the luminous intensities of LED at temperature T' and at some other reference temperature T_o respectively, and $K = \ln \alpha I_v$ where α is the temperature coefficient of the luminous intensity. Assuming the LED and the photodetector to be operating in the linear region, we may utilize the above relation to analyse our data qualitatively. The current generated in the detector by the radiation from the LED is allowed to pass through a sensing resistance across which the voltage drop is measured and shown in Fig. 4. This output voltage (V_{out}) is proportional to the current in the photodetector (I_d), which in turn is assumed to vary linearly with the luminous intensity of LED incident on the photodetector, given by Eq. (6). So, the output voltage, V_{out} is given by

$$V_{out} = K' I_{vo} \exp[-K(T' - T_o)], \tag{7}$$

where K' is assumed, for simplicity, to be a temperature-independent constant. Further, assuming α to be independent of temperature, Eq. (7) may be rewritten as

$$\ln V_{out} = -[\ln A + T \ln B]/[1 - T], \tag{8}$$

where $A = K' I_{vo}$, $B = \alpha/K'$, and $T = T' - T$ which reduces to the following simple form

$$\ln V_{out} \sim \ln A/T - \ln B \tag{9}$$

when $T \gg 1$.

Table 2
LED used in our experiment[a]

LED used in the experiment	Viewing angle (degree)	Forward current, I (mA)	Forward voltage, V_f (V)	Peak wavelength λ (nm)	Max power (nW)
Red LED (GaAS)	25	20	2.1 at $I = 10$ mA	650	75

[a] Type numbers refer to R.S. Components and Controls (India) Ltd. Catalog, Kanpur, India.

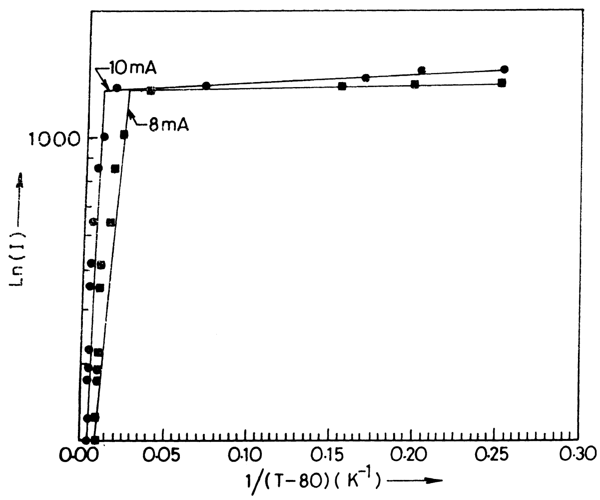

Fig. 5. Experimental fit of the LED output with temperature.

This relation (Eq. 9) is satisfied for a limited range of temperatures as is found in Fig. 5. However, a sharp break is found in all the curves above and below certain temperatures where the gradient is different. However, it has to be pointed out that the simple relation given above describes only the gross feature of the effect of temperature. When carriers are injected across a forward-biased p–n junction, the current is usually accounted for by a recombination in the transition and neutral regions near the junction [7]. In a material characterised by direct recombination, considerable light may be given off from the junction under forward-biased condition. This effect is termed as injection electro-luminescence which can be precisely studied with the present set-up.

4. Summary and conclusion

The optical studies at above the LN_2 temperature of available LEDs and photodetectors are necessary to use them in this temperature range. Since these data are not available, in particular, for commercial opto-sensor products, the present measurements on the LED and photodetector provide new information. All the measurements have been carried out by using a miniature optical cryostat specially developed by us [8]. From the experimental curves, it is observed that the photodetectors are extremely temperature sensitive. The results obtained have good reproducibility and consistency. An attempt has also been made to interpret these experimental data with a theoretical model. It appears that the generation of the minority carriers due to optical radiation as expected is reduced with the lowering of temperature. Apart from the fact that the present data contain important information about the total mechanism which is complex and not completely known at present, these experimental findings have significant importance in different applications. These data will be especially helpful to apply the opto-sensors in below room temperature ambience like the polar region, middle and upper atmospheres and other environments down to LN_2 temperature.

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