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Electrical properties of GaAs-GaAlAs near infrared light emitting diodes

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The electrical properties have been studied for GaAs/$Al_xGa_{1-x}As$ based infrared light emitting diode. The characteristics of the device have been analyzed and unusual feature of the device was observed. It operates as avalanche photodiode when it is reverse biased, while it operates as light emitting diode (LED) when it is forward biased.

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1. Introduction

The standard device for detecting near IR light in the 850–950 nm region has for many years been the silicon photodiode or silicon phototransistor. These detectors are reasonably inexpensive and readily available from a number of suppliers. Their greatest disadvantage has been their broad spectral response, which often necessitates additional circuit components for source modulation and electrical filtering for the detector and/or external optical components for optical filtering. A new detector featuring limited spectral response completely eliminates the need for additional electrical or optical components.

Light emitting diodes (LEDs) are p – n junctions that can emit spontaneous radiation in ultraviolet, visible or infrared regions. Infrared LEDs include gallium arsenide LEDs which emit light near 0,9 μm, and many III – V compounds, such as the quaternary GaInAsP LEDs, which emit light from 1,1 to 1,6 μm [1]. Commercial LED used in this paper has GaAs/$Al_xGa_{1-x}As$ material system. This system has very important advantage over the other materials, the entire alloy range from $x = 0$ to $x = 1$ can be lattice matched to GaAs [2].

Direct-gap $Al_xGa_{1-x}As$ system is favorable for semiconductor heterostructures used in LEDs owing to lattice match of the alloys of different compositions. The structures are fabricated by relatively inexpensive liquid-phase epitaxy (LPE) and cover the range of wavelengths from 870 nm (x = 0) to 624 nm (x = 0.45).

AlGaAs infrared LEDs are the most widely used modulated IR light sources. They produce light that matches the common silicon PIN detector response curve (900 nm) [3]. LED application areas include numeric displays, architectural lighting, traffic lights and signals, movement sensors (e.g., optical computer mice), remote control systems, optocouplers, fiber optics and also outdoor area and transportation lighting.

The GaAlAs IR LED could be used as an detector as well [4]. In optical signal detection, avalanche photodiodes (APDs) whose avalanche multiplication factor (M), increases with the increasing reverse bias.

This paper presents results of AlGaAs based device that operate as an avalanche photodiode in a reverse bias regime and as LED in a forward bias regime.

2. Experimental

The devices investigated in this work were GaAs/GaAlAs double heterojunction infrared LED's with the emission peak wavelength of 870 nm. LED 's with an active area of 0.1 mm were mounted into a glass Dewar with a cold shield for detailed electrical measurements at variable temperatures. $I-V$ characteristics of the samples were measured using a KEITHLEY 6517A Electrometer and capacity-voltage characteristics by TEGAM 3550 LCR Meter. All measurements were computer controlled.

3. Results and discussion

3.1 Electrical properties of GaAıAs LED's

The breakdown voltages of the structure were within the range 66 – 88 V. It is seen from Fig.1 that the breakdown voltage increases with increasing temperature.

In the investigated structure the breakdown was of purely avalanche nature, as indicated by the temperature coefficient of the breakdown voltage $\beta = \left(1/V_B\right)\cdot\left(dV_B/dT\right) > 0$, which was positive in the investigated temperature range 100-323 K.

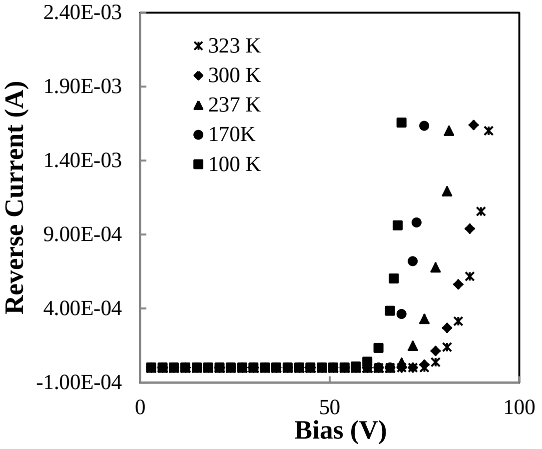

Fig. 1. I-V characteristics of reverse-biased structure at several temperatures.

The values of this coefficient were $\beta = 1{,}18 \cdot 10^{-3}\,\mathrm{K}^{-1}$, in good agreement with the values of the same coefficient reported for other III – V semiconductors [5]. Fig. 2 shows the temperature dependence of the reverse breakdown voltage V_B.

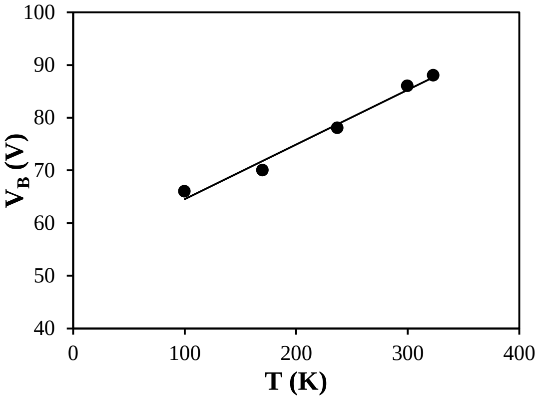

Fig. 2. Temperature dependence of the breakdown voltage.

For an abrupt junction, the avalanche breakdown voltage at room temperature is approximately given by a universal expression [6],

$$V_B = 60\,(E_g/1.1)^{3/2}(N_B/10^{16})^{3/4} \qquad (1)$$

where E_g is the bandgap which is equal to 1.4 eV and N_B is the impurity concentration in the lightly doped side of the p-n junction. It is calculated to be $N_B = N_d = 9.8\times10^{15}$ cm^{-3} from the capacitance – voltage (C – V) measurement results (see Fig. 3). We obtain V_B(300 K) = 84,98 V, which is in good agreement with the experimental value of about 86 V.

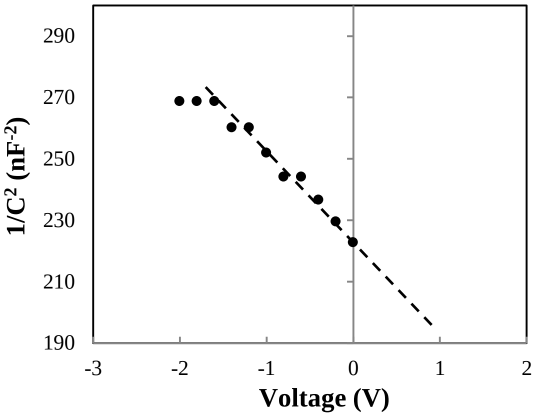

Fig. 3. C-V characteristic of the structure at room temperature.

For several temperatures, the forward I-V characteristics of the GaAlAs based LED are shown in Fig. 4.

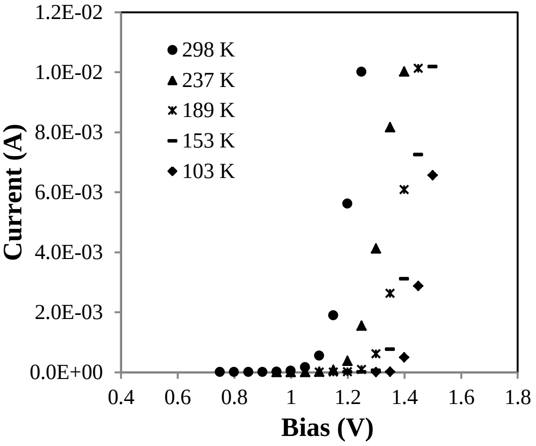

Fig. 4. I-V characteristics of a forward-biased structure at several temperatures.

3.2 The emission spectrum of an LED's

The room-temperature EL spectra of the LED measured with pulse forward injection current 1.0 mA are shown in Fig. 5. The radiant flux of an LED is defined as the total power radiated over the full range of emission. The spontaneous emission generates photons that travel in random directions, so the emission is isotropic; as we will show later, this greatly reduces the external efficiency of an LED. Furthermore, we note that the output does not consist only of light at the wavelength $\lambda_g = hc/E_g$ as a two-state model would imply. Because of the wide distribution of carrier energies within the conduction and valence band, the output is incoherent, with a spectrum consisting of a broad range of wavelengths (See Fig.5). The electron distribution normally peaks near an energy ~ 1/2 kT above the edge of the conduction band, and extends for several kT (~ 5/2 kT) above E_c. Similarly, the hole distribution peaks at around 1/2 kT below the valence band edge, extending for about 5/2 kT below E_v. Consequently, the possible photon energies lie in the range E_g to $E_g + 5kT$, and the most likely energy is ~$E_g + kT$ [5].

The optical wavelength corresponding to an energy $E_g+\alpha kT$ (where α is an arbitraryconstant) is $\lambda_o = hc/E_g+\alpha kT$. Since kT is typically much less than E_G, we may put:

$$\lambda_o= (hc/E_g) (1-\alpha kT/E_g) \quad (2)$$

If kT and E_g are measured in eV, and λ_o in µm, Equation may be written in the alternative form is $\lambda_o= (1.24/E_g) (1-\alpha kT/E_g)$. The output from an LED therefore peaks at a wavelength λ_p, given by:

$$\lambda_p= (hc/E_g) (1-kT/E_g) \quad (3)$$

Similarly, the half-power bandwidth of the emission spectrum is Δλ, where:

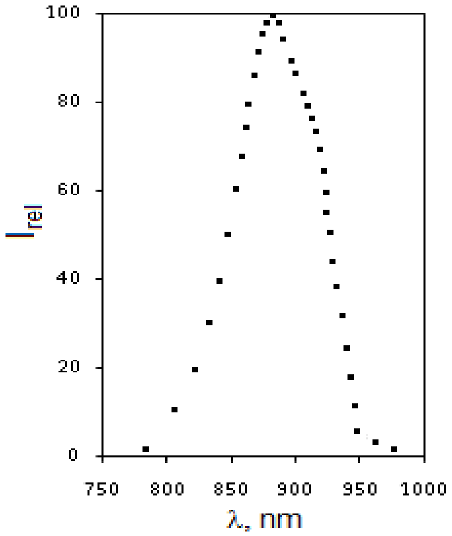

Fig. 5. The emission spectrum of an LED.

$$\Delta\lambda = 3.1\ kT/(E_g)^2 \quad (4)$$

Now, E_g for GaAs is 1.42 eV. For a GaAs LED at room temperature, for example, we therefore find that $\lambda_p = (1.24/1.4)(1 - 0.0258/1.4) = 0.870$ µm. Similarly, $\Delta\lambda = 3.1 \times 0.0258 / 1.4 = 0.057$ µm, or 57 nm. For materials with smaller bandgaps, designed to emitat longer wavelengths, Δλ is even larger.

4. Conclusion

In this paper, we have studied the electrical properties of $Al_xGa_{1-x}As$ based commercial light emitting diode. Forward and reverse bias characteristics were obtained for several temperatures and it was found that the structure shows LED properties in forward bias regime, while it shows avalanche diode properties in reverse bias regime. The reverse breakdown voltages of the structure increase with increasing temperature and it verifies the avalanche diode property of the diode.

Acknowledgments

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