INVESTIGATING THE PHOTOVOLTAIC BEHAVIOUR OF LIGHT-EMITTING DIODE (LED)

Ezeonu Stella O.[1], Okonkwo Godfrey N.[2,*] & Nweze Christian I.[3]
[1,3]Nnamdi Azikiwe University,Department of Physics and Industrial Physics, Awka, Nigeria
[2]Department of Science Laboratory Technology, Federal Polytechnic, Bida, Nigeria

ABSTRACT
The photovoltaic behaviour of light-emitting diodes (LEDs) was investigated at Awka (6.12°N, 7.05°E), Nigeria, for a period of three months, January - March 2010. The LEDs were exposed to solar radiation as single units and as multiple units having 36 pieces of LEDs connected in series on one hand and in parallel on the other hand, from 600 – 1800 hours each day. These irradiated LEDs were monitored for photo-generated voltage and current at hourly intervals. The solar radiation on a horizontal surface was measured using a digital luxmeter – (a Mastech Model MS6610). Ambient temperature was measured using mercury-in-glass thermometer while the photo-generated voltage and current were monitored using a standard digital multimeter. The results obtained show that voltage and current increased with the intensity of solar radiation, with maximum values recorded between 1200hours-1300hours. . The series-connected tri-colour LEDs yielded a voltage of 14.08V and a current of 23µA while the parallel unit gave a voltage of 0.47V and a current of 205µA. The tri-colour LED therefore behaved very much like a photovoltaic cell which generates a dc photovoltage of 0.5V-1V and, in short circuit, a photocurrent of some tens of milliamps as a single unit cell, but generates a dc output voltage of 12V when 28- 36 cells are connected in series. In contrast, the other colours of LED yielded a relatively high voltage and current in parallel connection but low voltage and low current in series connection.

Keywords: *Light Emitting Diode; Solar Radiation; Solar Flux; Colours Of LED; Photogenerated Voltage; Photogenerated Current; Series And Parallel Connections.*

1. INTRODUCTION

Light-emitting diode (LED) is a semiconductor diode that gives off visible light when forward biased [1-5]. LEDs are made of gallium arsenide (GaAs), gallium arsenide phosphide (GaAsP), or gallium phosphide (GaP). GaAs LEDs emit infrared (IR) radiation, GaAsP produces either red or yellow visible light, and GaP emits red or green visible light. LEDs that emit blue light (such as tri-colour LEDs) are based on the wide band gap semiconductors such as gallium nitride (GaN) and indium gallium nitride (InGaN) [1, 2, 5].

Semiconductors with band gaps in the range 0.5eV-3eV can absorb photons to excite electrons across the band gap, where they may be collected. The group III-V compound semiconductors such as gallium arsenide (GaAs) and indium phosphide (InP) have band gaps close to the optimum (1.42eV and 1.35eV, respectively, at 300K) and are favoured for high efficiency cells. The most popular solar cell material, silicon, has a less favourable band gap (1.1eV, maximum efficiency of 29%) but is cheap and abundant compared to these group III-V materials [6-8]. The semiconductor material must be a direct band gap semiconductor in order to have sufficient conversion efficiency [9]. In contrast to solar cell, LED converts electrical power to visible light. The light output is due to the recombination of electrons and holes within the LED device, which releases energy in the form of photons. A solar cell is essentially a PN junction with large surface area while LED has only a small surface area.

A few research works have been carried out on the effect of solar radiation on light-emitting diodes. One of the researchers working on a low cost solar tracker was experimenting with LEDs and noticed they generated voltage in sunlight. The green ones generated about 1.65V and some as much as 1.74V [10]. This is because green LEDs are made of Gallium Phosphide, a semiconductor with a much higher bandgap voltage [10]. Other researchers from 'Beam Project', made tiny solar powered robots using LED photo-sensors [10, 11].

We are not aware of any work where LEDs were constructed in series or parallel arrangement and radiated by sunlight. Therefore, one of the objectives of this research is to investigate the photovoltaic behaviour of Light Emitting Diode (LEDs).

2. MATERIALS AND METHOD

Different colours of LED (red, green, yellow, amber, orange, white, blue, tri-colour) were obtained locally from a component shop. These were separately arranged to stand erect on a breadboard. This setup was kept outside in a well-exposed area and positioned in a north–south direction to receive full solar radiation from 600–1800hours each day for a period of three months (January – March) in 2010. Again, 36 pieces of each LED were separately

connected together in series and parallel order respectively. The parameters measured every one hour interval were ambient temperature, solar flux and photogenerated voltage and current of the setup.
In the measurement of solar flux, a digital luxmeter – (a Mastech Model MS6610) with liquid crystal display was used . Its measurement rate is 2 times per second and it operates within the temperature range of 0^oC to $40^oC \leq 80\%$ relative humidity. The photogenerated voltage and current were measured with an ALDA model AVD-830D digital multimeter and a model Samwa YX-360TR_{ES} multitester respectively. In ambient temperature measurement, a mercury–in–glass thermometer with range -10 to 110^oC was used.

3. RESULTS AND DISCUSSION

Table 1 shows the average values of ambient temperature, solar flux and photogenerated voltage obtained for each colour LED as a single unit. Tables 2 – 5 present the average values of the measured parameters for the 36 pieces of each LED connected in series and parallel order respectively. The results from table 1 indicates that yellow colour LED yielded the highest photo-voltage of 0.99V as a single unit when the solar flux is highest, followed by green LED 0.93V, amber LED 0.5V and tri-colour LED 0.44V. The trend shows that the photogenerated voltage increased with solar flux and this behavior is photovoltaic in nature [6]. The results from tables 2 – 5 show that the 36 pieces of tri-colour LED in series, yielded the highest voltage of 14.08V and in parallel, yielded the highest current of 205μA, all at the highest solar flux. This is an indication that tricolour LED is photovoltaic in behaviour.
The relationship between the photo-generated voltage and solar flux for the single unit LEDs is shown in Fig. 1. Again the result shows that yellow LED yielded the highest voltage as a single unit. Figs. 2 and 3 show the relationships between the solar flux and photogenerated voltages of the 36 pieces of the various LEDs connected in series and parallel order respectively. It is observed that the generated voltage increased with the solar flux. The tri-colour LEDs connected in series generated the highest voltage of 14.08V while the rest LEDs in series generated between 0V and 0.54V. The parallel connected tri-colour LEDs yielded between 0V and 0.47V while the other colour LEDs in parallel, generated between 0V and 1.66V. The tri-colour LED therefore behaved like solar cells which generate high voltage when connected in series and low voltage when in parallel [6, 12, 13].
The relationships between photo-generated currents of the series and parallel connected LEDs and solar flux are shown in Figs. 4 and 5. It is observed also that photo-generated current increases with the solar flux. The tri-colour LEDs connected in parallel yielded the highest current of 205μA while the rest generated between 0μA and 30μA. This again indicates the solar cell behaviour of the tri-colour LED. Fig. 6 shows the relationships that the various voltages and currents of the LEDs have with solar flux. The results again show that the tricolour LED has the best performance among other LEDs under irradiation. Fig. 7 shows the relationship between the parallel current and series voltage of the tricolour LEDs. The result shows a current – voltage characteristics that are similar to the I-V characteristics of a practical solar cell [6].
Figs. 8 - 11 show the relationships between ambient temperature and photogenerated voltage and current for the series and parallel connected LEDs respectively. The results indicate that photogenerated voltage and current depend on the intensity of the solar flux and not on temperature, as they do not increase with ambient temperature. Again, it was observed that the highest photovoltage obtained in parallel connection was 1.66V, yielded by white colour LEDs and the highest photocurrent obtained in series connection was 23μA, yielded by tricolour LEDs.
Figs. 12 and 13 show the relationships between ambient temperature, solar flux and time respectively. The results show that highest solar flux and temperature were obtained between 1200hours and 1400hours. Ambient temperature depends on the intensity of solar flux and not on time of the day.

4. CONCLUSION

The investigation of the behaviour of different colour LEDs to solar radiation has been successfully carried out. The results have shown that the tri-colour LEDs behaved like photovoltaic (pv) cells. Its single unit yielded open-circuit dc voltage of 0.45V while 36 pieces connected in series yielded 14.08V and the same number in parallel, yielded 205μA. The other colour LEDs in series generated less than 1V while their parallel connection yielded between 0V and 1.6V. The current output from the other colour LEDs in parallel connection, was less than 1μA. Though it is evident from this work that all colour LEDs responded positively to incident solar radiation but the behaviour of the tri-colour LEDs is very much in agreement with that of solar cells. The 36 LEDs did not generate much electric power as a solar cell but it actually demonstrates its photovoltaic effect.

Table 1: Average values of Ambient Tempereture, Solar flux and Photogenerated voltages for single unit LEDs for three months period (January – March 2010)

Time (hrs)	Ambient Temp. (°C)	Solar flux (lux) x 100	Amber LED	Green LED	Red LED	White LED	Yellow LED	Blue LED	Orange LED	Tri-color LED
600	24	0	0	0	0	0	0	0	0	0.05
700	25	38	0	0.01	0	0	0.01	0	0	0.37
800	28	574	0.05	0.12	0.01	0.02	0.1	0.06	0.01	0.4
900	28	704	0.2	0.34	0.06	0.03	0.36	0.06	0.02	0.43
1000	32	759	0.24	0.4	0.08	0.03	0.48	0.08	0.06	0.44
1100	35	908	0.44	0.82	0.12	0.08	0.77	0.3	0.09	0.44
1200	36	936	0.5	0.93	0.14	0.09	0.99	0.35	0.12	0.44
1300	35	924	0.48	0.87	0.14	0.09	0.96	0.35	0.13	0.44
1400	37	883	0.37	0.72	0.12	0.08	0.78	0.31	0.11	0.43
1500	36	842	0.28	0.59	0.1	0.06	0.76	0.19	0.07	0.43
1600	34	668	0.18	0.44	0.07	0.04	0.46	0.12	0.05	0.42
1700	28	342	0.06	0.22	0.02	0.01	0.23	0.06	0.02	0.41
1800	25	43	0	0	0	0	0	0	0	0.22

Table 2. Average values of Ambient Tempereture, Solar flux and Photogenerated voltages for 36 pieces of LEDs connected in series for three months period (January – March 2010)

Time (hrs)	Ambient Temp (°C)	Solar flux (lux) x100	Amber LED Voltage Series	Green LED Voltage Series	Red LED Voltage Series	White LED Voltage Series	Yellow LED Voltage Series	Blue LED Voltage Series	Orange LED Voltage Series	Tricolor LED Voltage Series
600	22	0	0	0	0	0	0	0	0	0
700	23	10	0	0	0	0	0	0	0	0.31
800	24	100	0.02	0.03	0.01	0.02	0.01	0	0	1.22
900	28	402	0.04	0.18	0.02	0.03	0.11	0.01	0.04	4.73
1000	32	724	0.06	0.26	0.08	0.05	0.18	0.16	0.06	11.02
1100	35	782	0.08	0.33	0.12	0.06	0.2	0.2	0.09	12.22
1200	38	933	0.09	0.53	0.18	0.08	0.28	0.3	0.14	13.15
1300	39	948	0.11	0.54	0.22	0.09	0.28	0.34	0.16	14.08
1400	40	906	0.1	0.26	0.18	0.07	0.21	0.3	0.11	13.06
1500	40	742	0.08	0.23	0.12	0.06	0.1	0.21	0.1	11.77
1600	38	575	0.06	0.15	0.07	0.03	0.1	0.15	0.04	8.11
1700	37	260	0.02	0.1	0.04	0.02	0.09	0.06	0.01	6.08
1800	32	25	0	0	0	0	0	0.01	0	1.14

Table 3. Average values of Ambient Tempereture, Solar flux and Photogenerated voltages for 36 pieces of LEDs connected in parallel for three months period (January – March 2010)

Time (hrs)	Ambient Temp (°C)	Solar flux (lux) x100	Amber LED voltage Parallel	Green LED voltage Parallel	Red LED voltage Parallel	White LED voltage Parallel	Yellow LED voltage Parallel	Blue LED voltage Parallel	Orange LED voltage Parallel	Tri-Color LED voltage Parallel
600	22	0	0	0	0	0	0	0	0	0
700	23	10	0.14	0.28	0.07	0.04	0.18	0.08	0.22	0.32
800	24	100	1.2	1.12	0.3	0.08	0.68	0.13	0.34	0.41
900	28	402	1.32	1.32	0.89	0.12	0.98	0.2	1.31	0.42
1000	32	724	1.34	1.44	1.28	1.35	1.31	0.57	1.35	0.44
1100	35	782	1.39	1.44	1.3	1.37	1.32	0.58	1.37	0.45
1200	38	933	1.41	1.48	1.32	1.59	1.35	0.6	1.38	0.46
1300	39	948	1.43	1.52	1.34	1.66	1.4	0.66	1.39	0.47
1400	40	906	1.4	1.46	1.31	1.56	1.33	0.61	1.36	0.46
1500	40	742	1.35	1.41	1.3	1.36	1.32	0.56	1.34	0.43
1600	38	575	1.28	1.39	1.25	1.12	1.3	0.53	1.28	0.41
1700	37	260	1.22	1.36	1.14	0.88	1.26	0.42	1.08	0.38
1800	32	25	0.41	0.04	0.02	0.27	0.03	0.27	0.39	0.28

Table 4. Average values of Ambient Tempereture, Solar flux and Photogenerated currents for 36 pieces of LEDs connected in series for three months period (January – March 2010)

Time (hrs)	Ambient Temp. (°C)	Solar flux (lux) x 100	Amber current Series	Green current Series	Red current Series	White current Series	Yellow current Series	Blue current Series	Orange current Series	Tricolor current Series
600	22	0	0	0	0	0	0	0	0	0
700	23	10	0	0	0	0	0	0	0	0
800	24	100	0	0	0	0	0	0	0	2
900	28	402	0	0	0	0	0	0	0	8
1000	32	724	0	0	0	0	0	0	0	15
1100	35	782	0	0	0	0	0	0	0	20
1200	38	933	0	0	0	0	0	0	0	22
1300	39	948	0	0	0	0	0	0	0	23
1400	40	906	0	0	0	0	0	0	0	15
1500	40	742	0	0	0	0	0	0	0	11
1600	38	575	0	0	0	0	0	0	0	8
1700	37	260	0	0	0	0	0	0	0	7
1800	32	25	0	0	0	0	0	0	0	0

Table 5. Average values of Ambient Tempereture, Solar flux and Photogenerated currents for 36 pieces of LEDs connected in parallel for three months period (January – March 2010)

Time (hrs)	Ambient Temp. (°C)	Solar flux (lux) x 100	Amber LED current Parallel	Green LED current Parallel	Red LED current Parallel	White LED current Parallel	Yellow LED current Parallel	Blue LED current Parallel	Orange LED current Parallel	Tri-Color LED current Parallel
600	22	0	0	0	0	0	0	0	0	0
700	23	10	1	0	0	0	0	0	0	15
800	24	100	1	1	1	1	1	1	1	55
900	28	402	3	4	2	2	2	2	1	70
1000	32	724	7	10	3	3	6	7	2	160
1100	35	782	8	15	5	4	10	8	3	180
1200	38	933	10	30	11	6	35	20	5	200
1300	39	948	13	25	14	7	17	25	8	205
1400	40	906	9	22	8	5	10	19	6	198
1500	40	742	6	7	5	4	7	10	4	171
1600	38	575	5	6	3	3	5	7	3	155
1700	37	260	2	5	2	1	4	4	2	153
1800	32	25	1	1	1	0	1	1	0	20

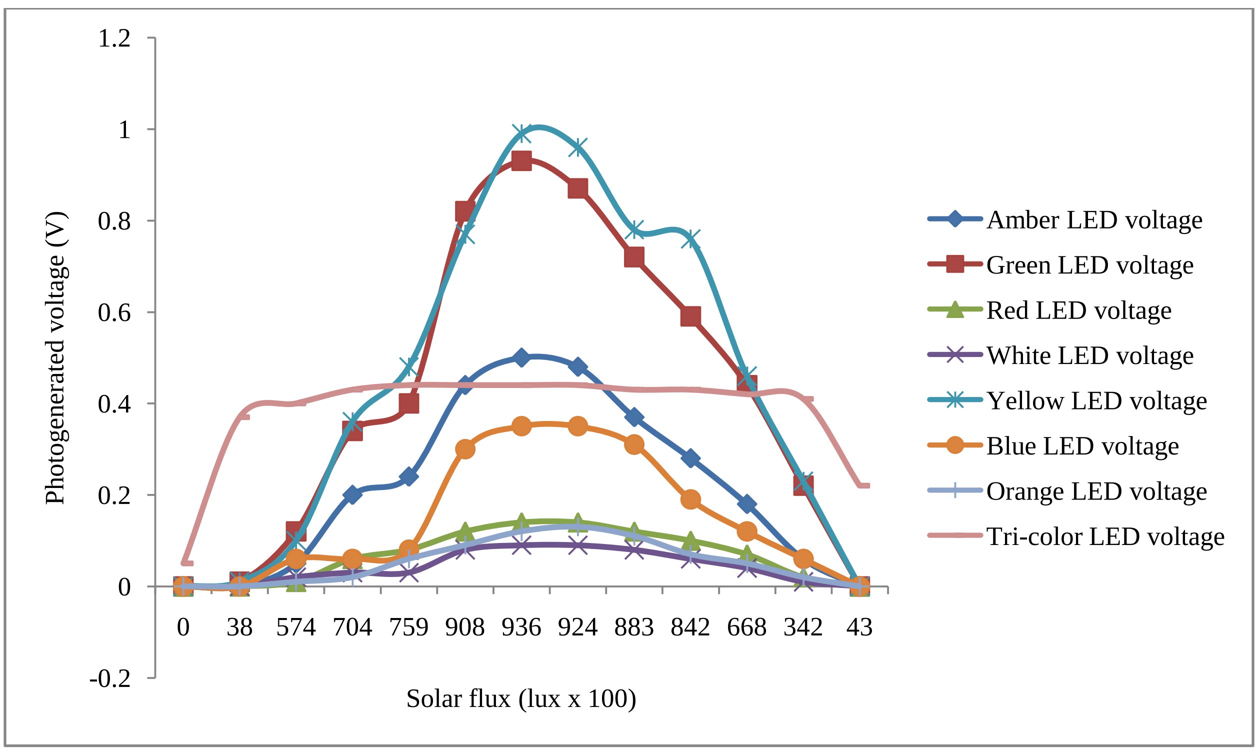

Fig. 1. Graph of Photogenerated voltage of single LEDs against Solar radiation (lux)

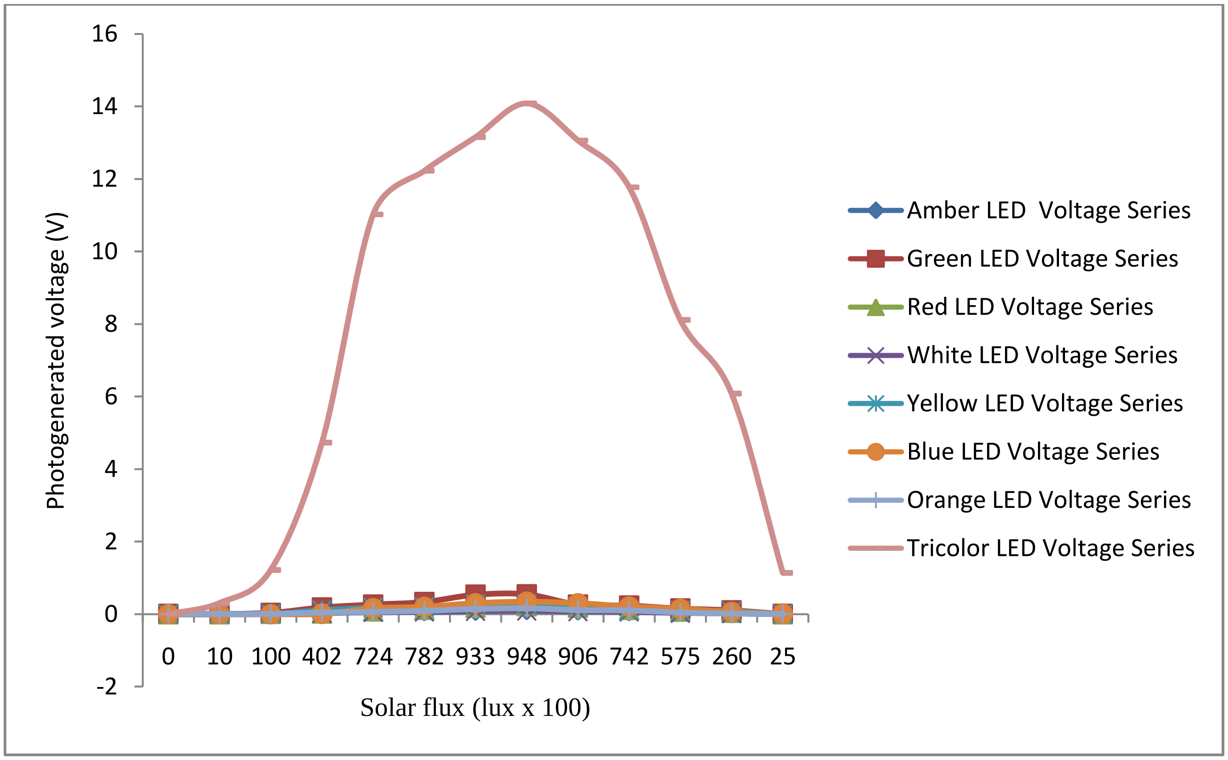

Fig. 2. Graph of Photogenerated voltage (V) of Series connected LEDs against Solar radiation (lux)

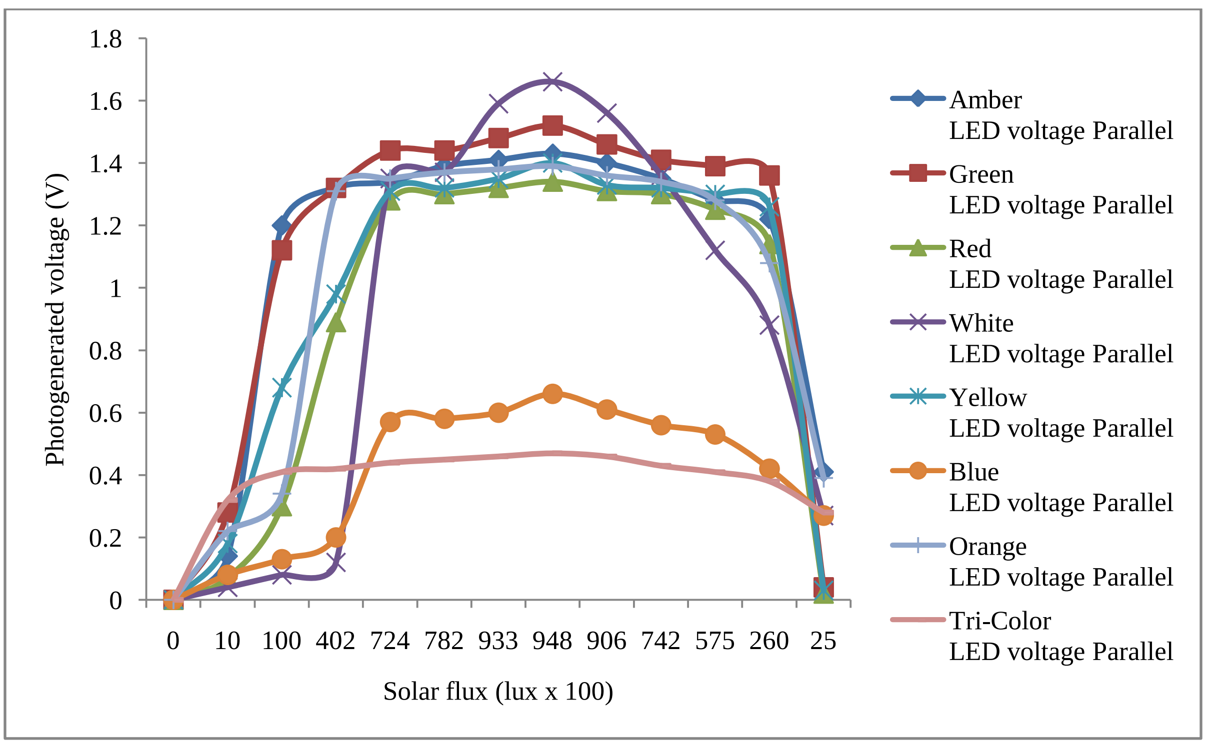

Fig. 3. Graph of Photogenerated voltage of parallel connected LEDs against Solar radiation (lux)

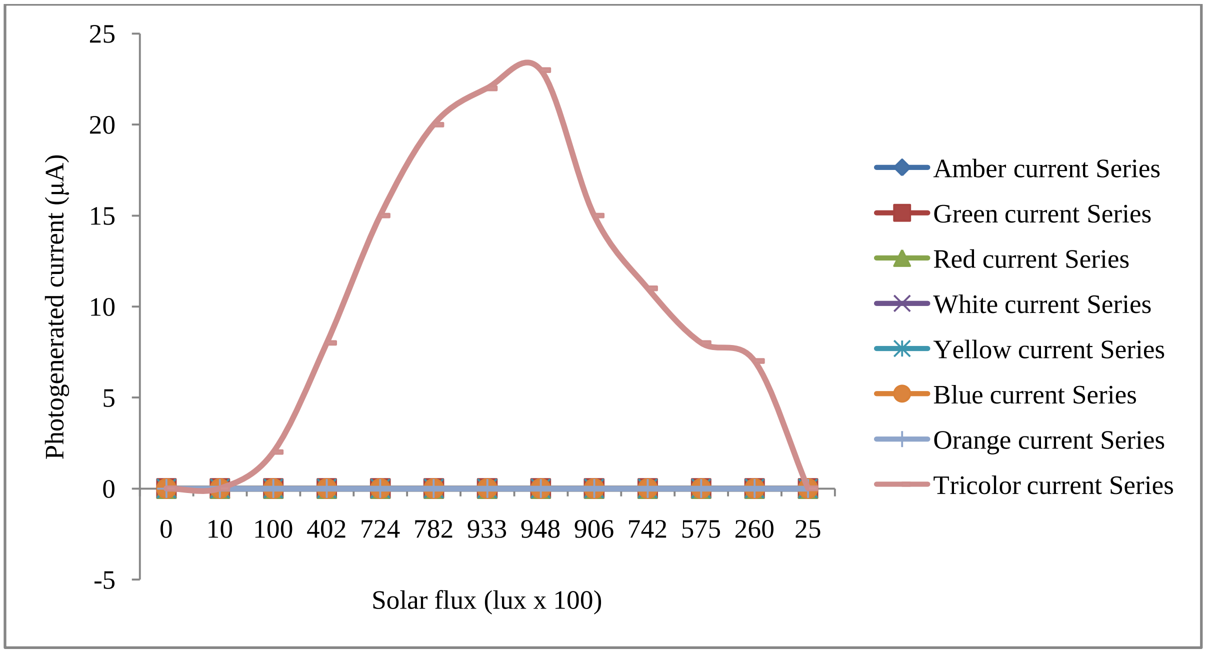

Fig. 4. Graph of Photogenerated current of series connected LEDs against Solar radiation (lux)

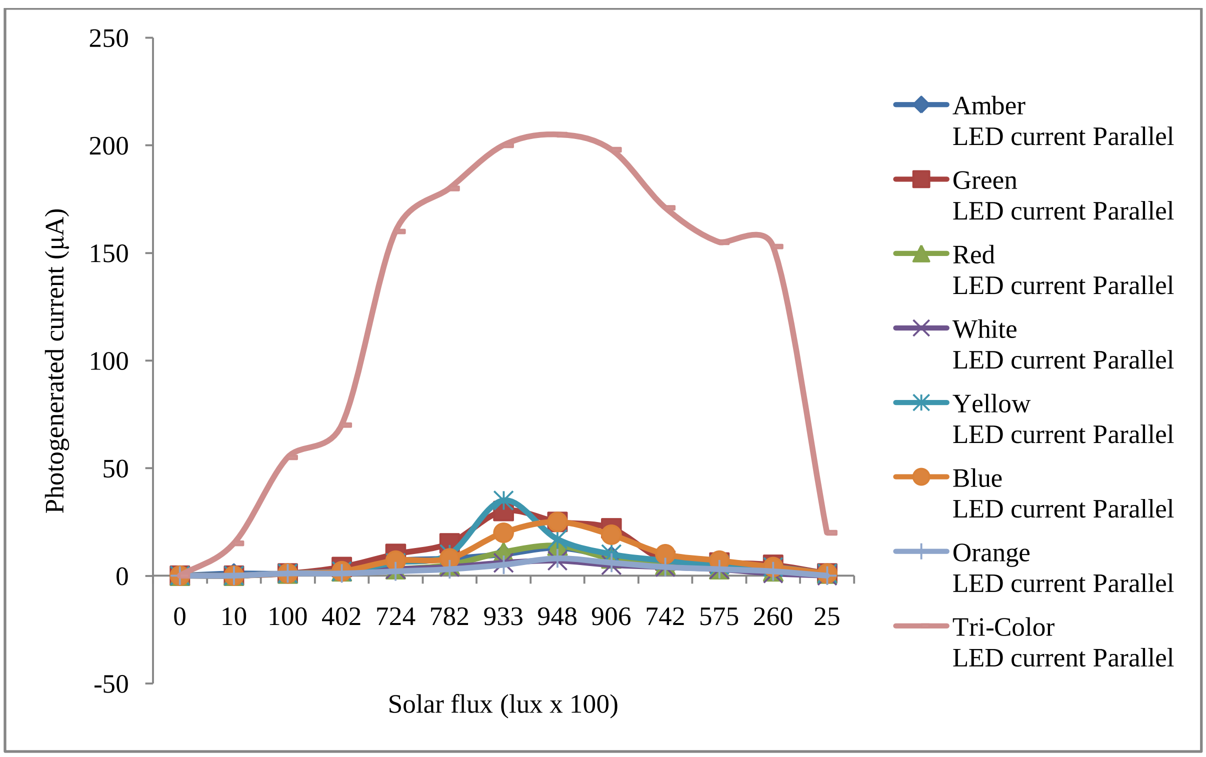

Fig. 5. Graph of Photogenerated current of parallel connected LEDs against Solar radiation (lux)

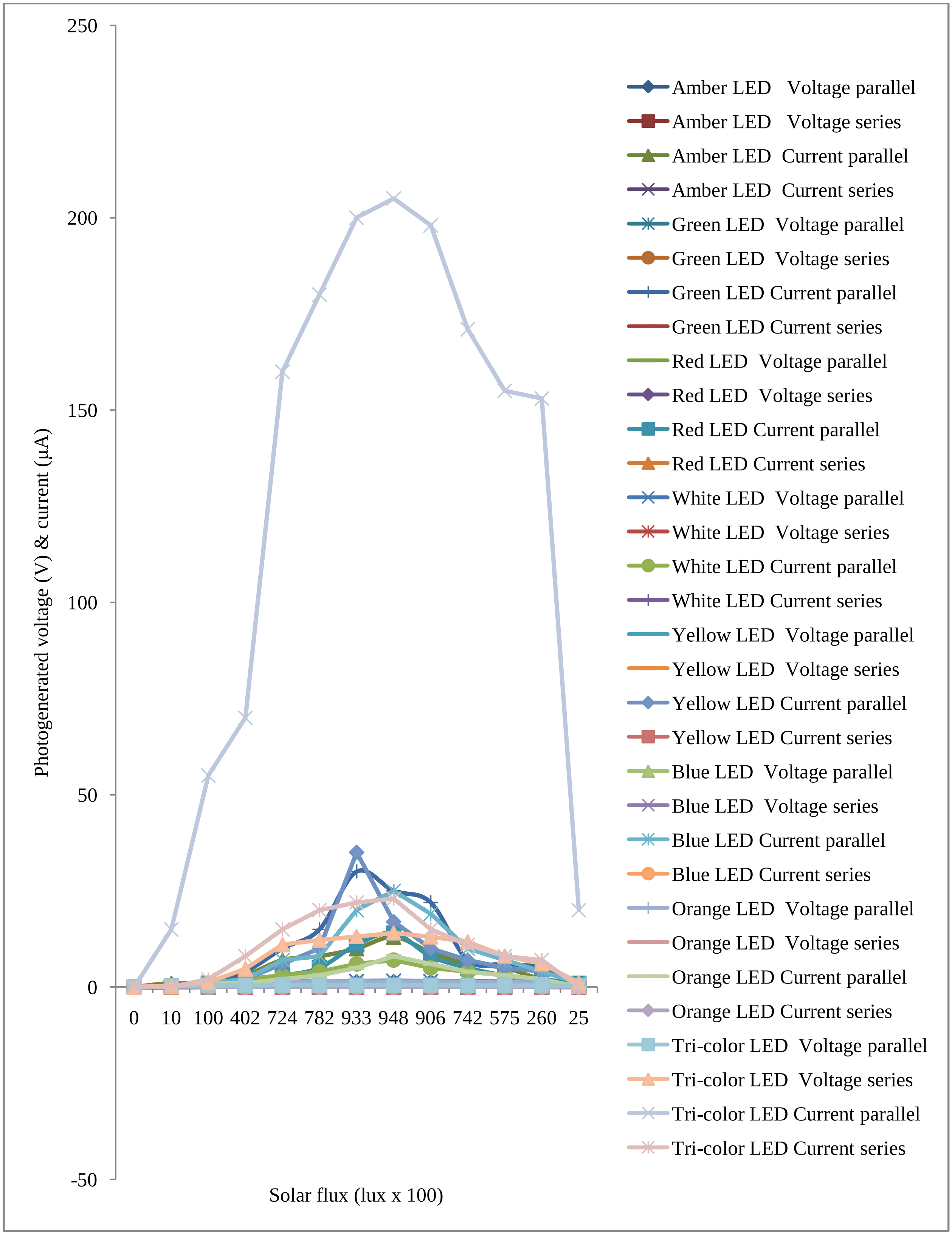

Fig.6. Graph of Photogenerated voltages and currents for parallel and series connected LEDs against Solar radiation (lux)

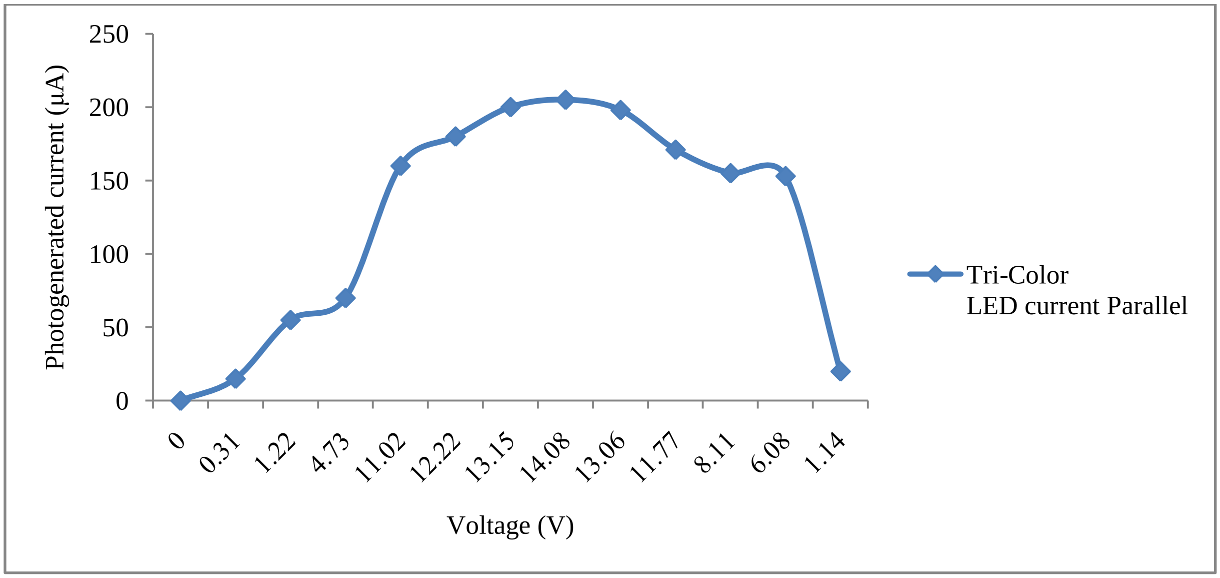

Fig. 7. Graph of Photogenerated current of parallel connected Tricolor LEDs against Photogenerated voltage of series connected Tricolor LEDs

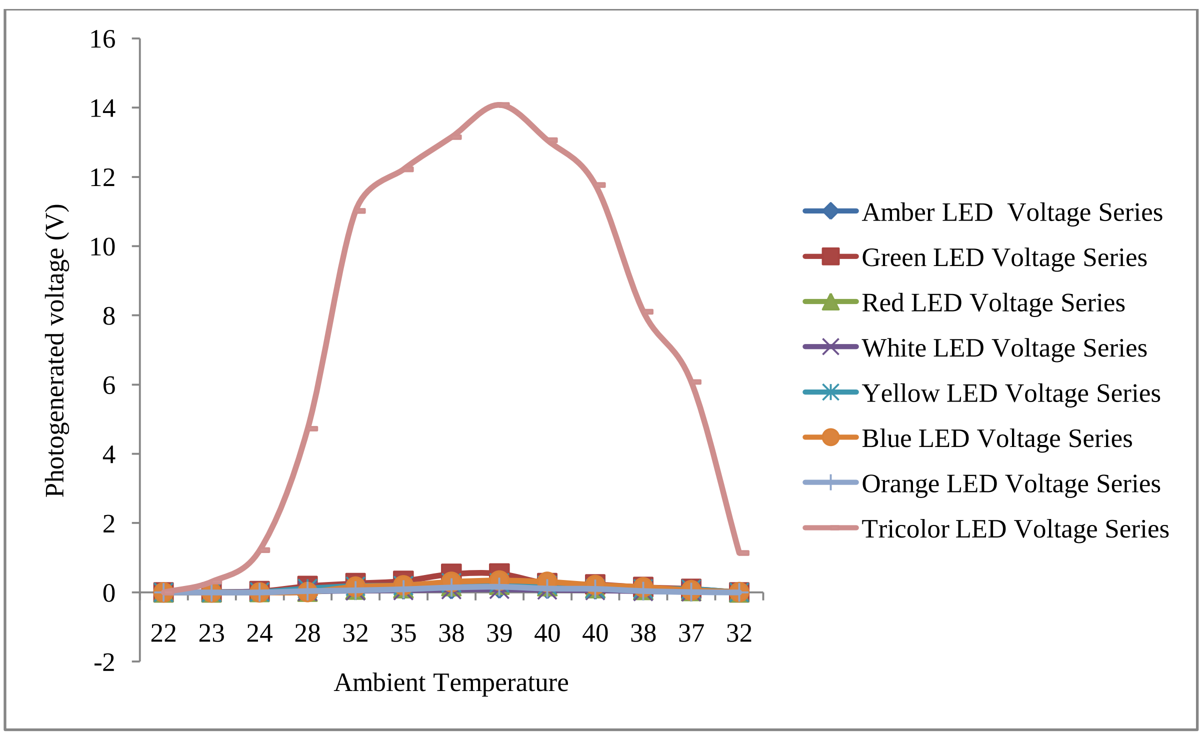

Fig. 8. Graph of Photogenerated voltage of series connected LEDs against Temperature

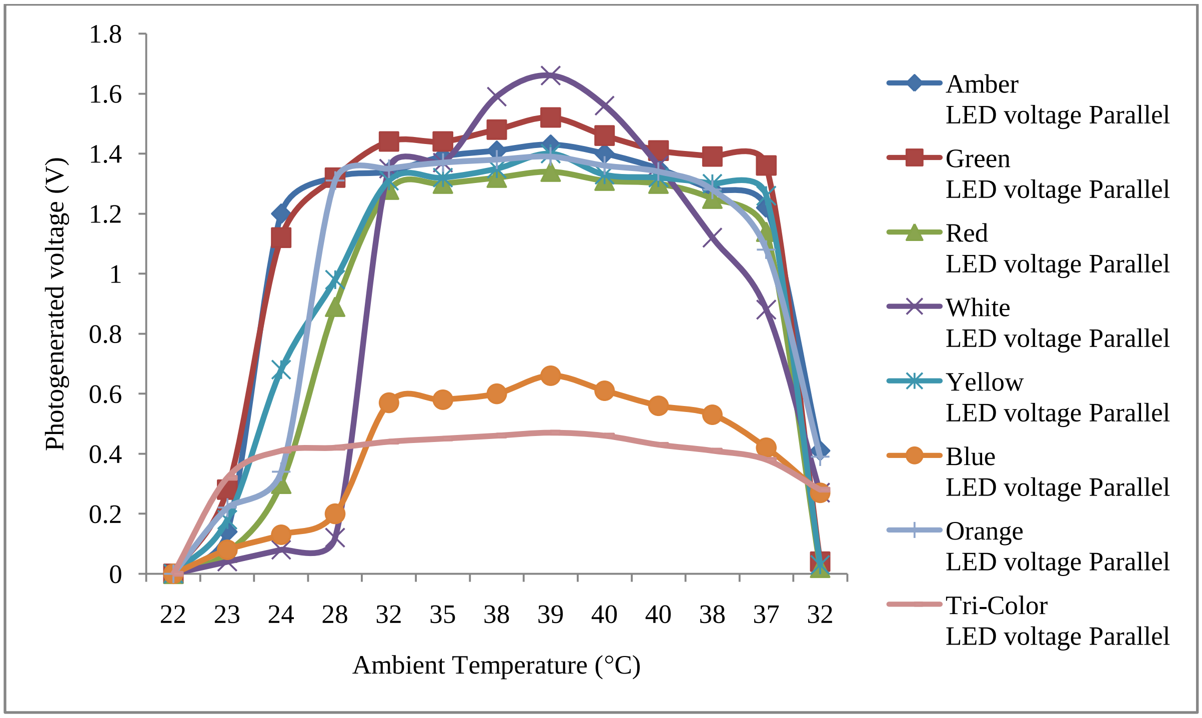

Fig. 9. Graph of Photogenerated voltage of parallel connected LEDs against Temperature

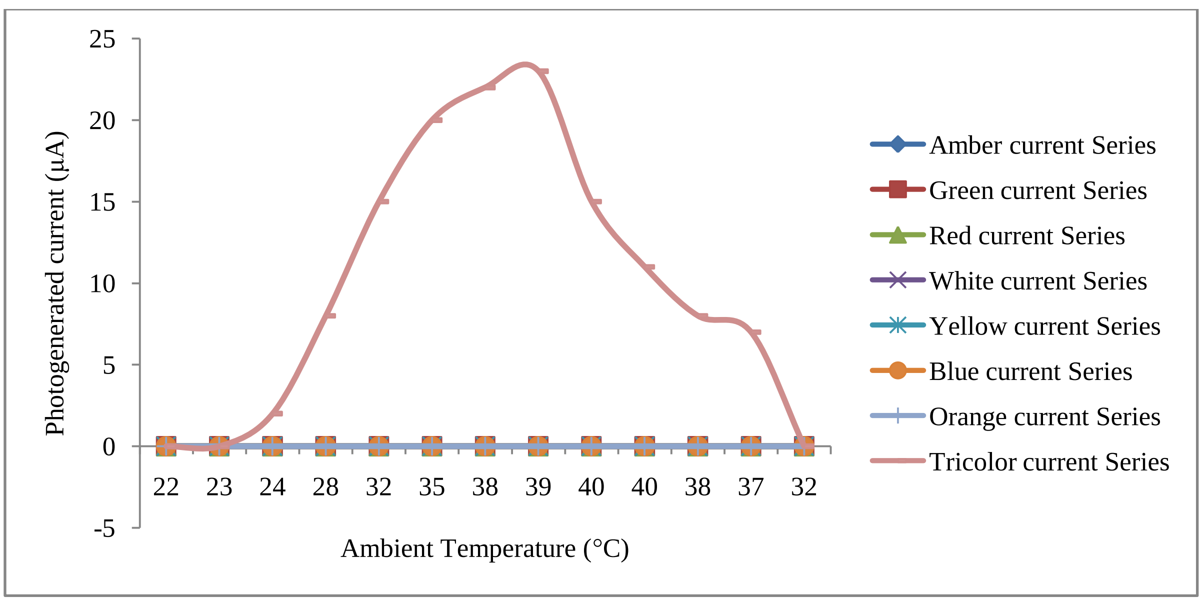

Fig. 10. Graph of Photogenerated current of series connected LEDs against Temperature

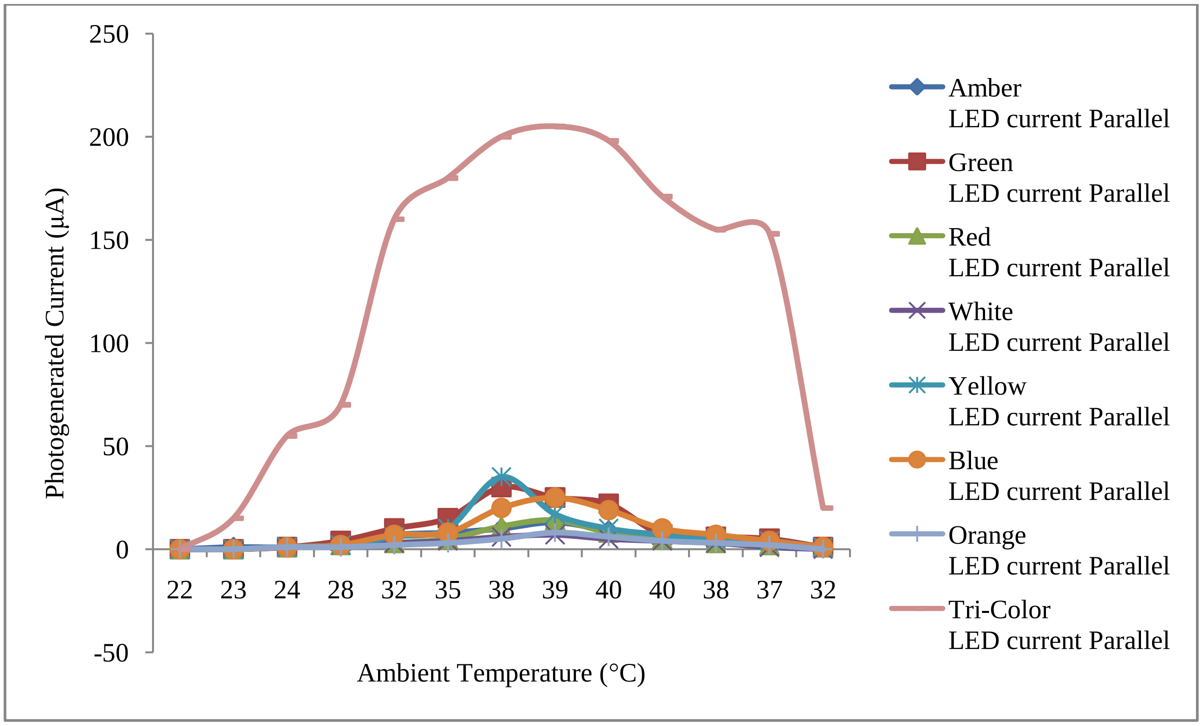

Fig. 11. Graph of Photogenerated current of parallel connected LEDs against Temperature

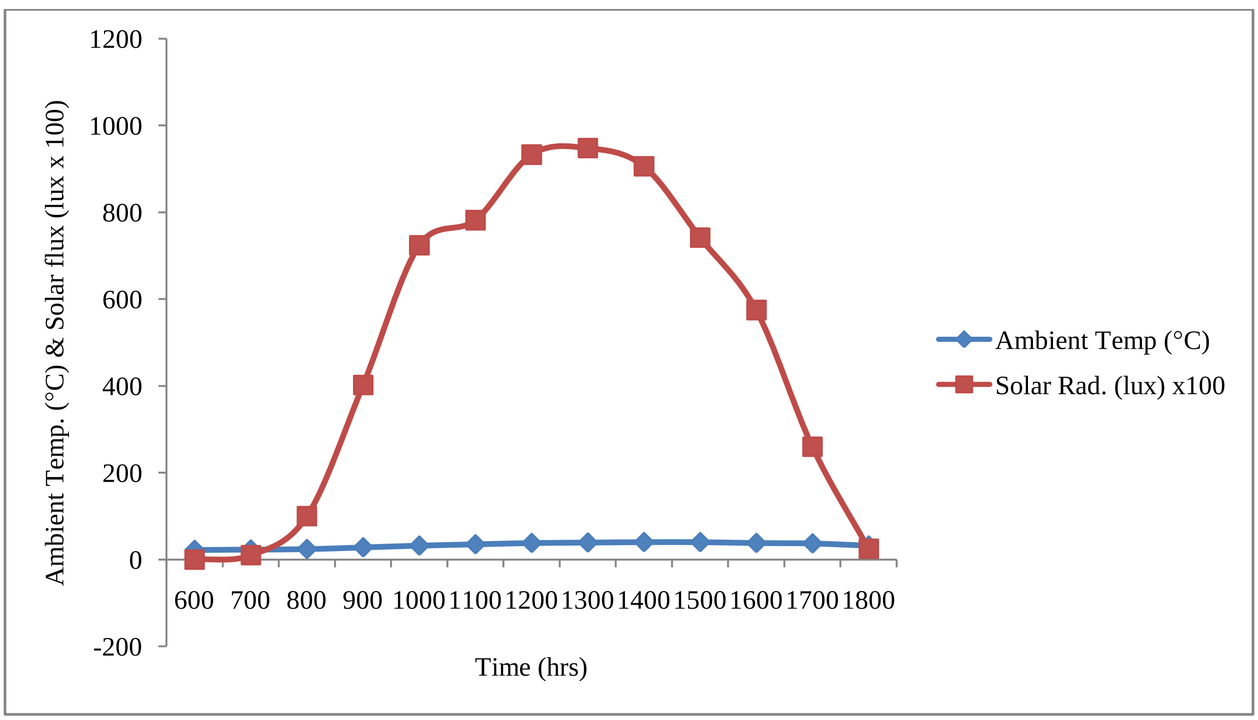

Fig. 12. Graph of Ambient Temperature and Solar radiation (lux) against Time

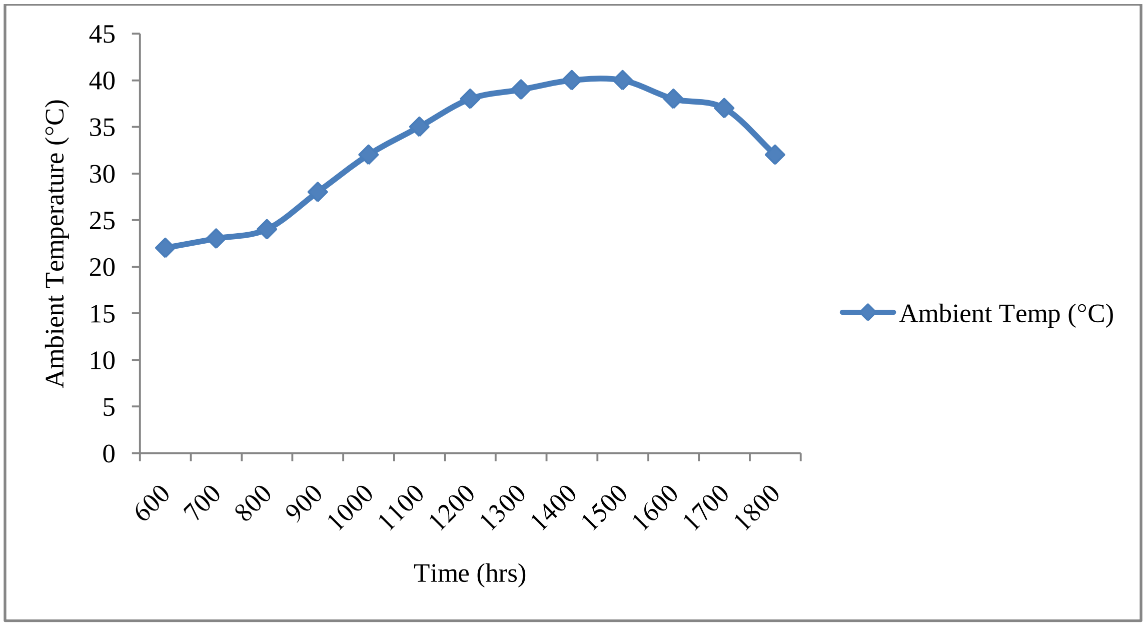

Fig. 13. Graph of Ambient Temperature against Time

5. REFERENCES

[1]. V.K. Mehta, R. Mehta. Principles of Electronics, S.Chand & Company Ltd, India, 181 – 182 (1980).
[2]. Light-emitting diode, http://en.wikipedia.org/wiki/light-emitting_diode, Retrieved 2010-04-13
[3]. J. Hewes. LEDs. The electronic club, (2009). http://www.kpsec.freeuk.com/, Retrieved 2010-04-13
[4]. ToolBase Services LED Lighting, (2008). http://www.toolbase.org>TechnologyInventory, Retrieved 2010-04-13
[5]. T.L. Floyd. Electronic Devices, Pearson Education Inc, India. 135, (2002).
[6]. J. Nelson. Physics of Solar Cells, Imperial College Press London, 177, (2003).
[7]. W. Shockley, H.J. Queisser. "Detailed balance limit of efficiency of p-n junction solar cells", J. Appl. Phys. 32, 510-519, (1961).
[8]. C.H. Henry. "Limiting efficiencies of ideal single and multiple energy gap terrestrial solar cells", J. Appl. Phys. 51, 4494-4499, (1980).
[9]. Direct and Indirect Band Gap semiconductor, http://wikipedia.org/wiki/Direct_and_indirectbandgap, Retrieved 2010-04-13
[10]. Red Rock Energy Electronic projects LED1LED sensor Relay Tracker Schematic, (2009). http://www.redrok.com/electron.htm Retrieved 2012-09-08.
[11]. B. Bowden. LED Photosensor, (2006). http://www.circuitdb.com/circuits/id/83, Retrieved 2010-04-13.
[12]. T. Markvart. Solar Electricity, John Wiley and Sons Ltd, England, 79-81, (1994).
[13]. A.O.C. Nwokoye. Solar Energy Technology: Other Alternative Energy Resources and Environmental Science, Rex Charles and Patrick Ltd, Nimo, 199, (2006).