A Stabilized HBLED Suitable As Calibration Standard

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Abstract

High brightness LED's [HBLED] are susceptible to light intensity degradation from self-heating which reduces the quantum efficiency of photon production. Thermal management for these HBLED's, especially for calibration standards, is essential. We have developed a modular controller that can be used with HBLED's from several manufacturers. This controller provides a stable current drive to the HBLED and manages LED junction temperature so that the total light intensity output remains constant to less than 0.25% over time. Less than 0.03% variation per degree room temperature change is typically observed. In measurements of intensity vs. time, stabilization time in is approximately six minutes and total intensity variation (|max-min|/average) during operation is less than 0.2%. Intensity repeatability after cycling on/off multiple times over several days is less than 0.2%. Further experimental results of Intensity variation vs. time, spectral change vs. time, ambient temperature sensitivity, junction voltage correlation to intensity, and long term repeatability results are shown.

1. HBLED Controller Design

A new controller for High Brightness LEDs has been developed for LEDs which consume 3W to 5W of power, which will be called HBLED-1. To achieve stable color and intensity output of the new High Brightness LED, the junction temperature and the current are precisely controlled.

Temperature control

The controller achieves precise control by measuring temperatures at key points and by careful construction of the system to control thermal resistances from the LED to the cooler. . The power to the internal heater is varied depending on the measured temperatures of the controller. The mechanical system controls the heat transfer from the LED to the cooling block. A controlled thermal section is introduced between the heater and the cooling block. The electronic system is carefully matched to the mechanical system in order to achieve precise control.

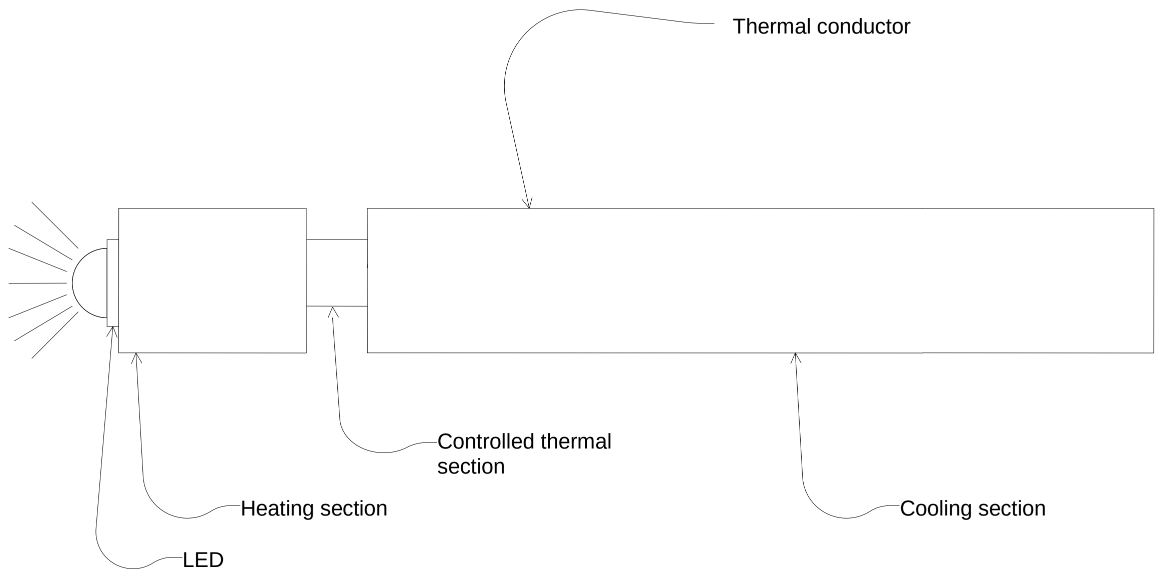


Figure 1: Schematic diagram of the HBLED Controller Head

Precision current control

The system maintains constant current to the LED. To achieve consistent light output the current to the LED is maintained within +/-1mA. The set point for the current is .920A +/- 2%. The LED current can be monitored via a test point.

Heat dissipater removed from measurement environment

Controlling the heat exhaust from interfering with other test equipment and setups is important. The design of the HBLED-1 can take 5 to 8W of exhaust heat and transfers this to a remote heat radiator. The heat radiator can be up to 10 feet from the HBLED-1 source, possibly into a different room. This minimizes the degradation of test setups to uncontrolled temperature rises from the exhaust heat.

Low current LED standards do not face this problem since they are producing 15x-20x less power. As the power levels increase, moving exhaust heat away from the test setup to a place where the exhaust heat will have little impact is becomes more important.

For precise measurements, radiative and non-radiative heat must be carefully controlled. As a note the light output of the LED is significant (~200mW), thus just the light output of the LED may cause heating of the test setup. We are doing our part to move heat away from the test setup for current generation LED's.

Provide ability to use multiple vendor LED's

A circuit board module which incorporates the LED can be easily replaced with a new one without changing the operation parameters (optimized for each HBLED). Thus different color LEDs, different vendors can be supported depending on customer requests.

Same form factor as current generation of LED standards

In order to conform to existing standards for port sizes on integrating spheres, optical benches and spectrometers, the form factor of the HBLED controller is similar to low power output LED controllers. The HBLED-1 uses 25mm OD tube. Flexible coupling allow rotation of the source by 360 degrees to allow testing of the HBLED in different orientations. The alignment of the HBLED in the housing is mechanically aligned to the axis of the tube housing to a precision of +/- 3°

Figure 2: Top view of the HBLED Controller Head

2. Experimental Setup Background

Automated measurement of HBLED parameters

The HBLED-1 controller unit has monitoring capability for junction voltage, current, base and LED temperature. Connected to a data acquisition system, these and other parameters such as room temperature can be monitored in real time. In software, the min/max, average, and standard deviation can be calculated for individual runs of the HBLED controller. The controller can be remotely turned off/on (with a safety feature with does not let the LED temperature go above a preset temperature. The LED can be operated in "continuous mode" or in cycled mode. In both cases, no statistics are calculated until the LED has warmed up for a preset time. In all cases for these measurements, the warm-up time is 6 minutes. In continuous mode, the statistics are calculated for the entire duration of the experiment, less the starting 6 minutes. In cycled mode, the statistics are separated tabulated for each hour duration less the warm-up time. The statistics for each "on cycle" are recorded, and can be plotted versus time. This is a very sensitive method to observe look term changes. In figure 3, the graph shows as a function of time the individual one hour durations in which the HBLED is turned on and off. The statistics calculated during each one hour period after the "warm up" include average, min, max, standard deviation and % change which is absolute value of max – min divided by the average, expressed as a percent. On the right, the results for the individual HBLED on times are tabulated.

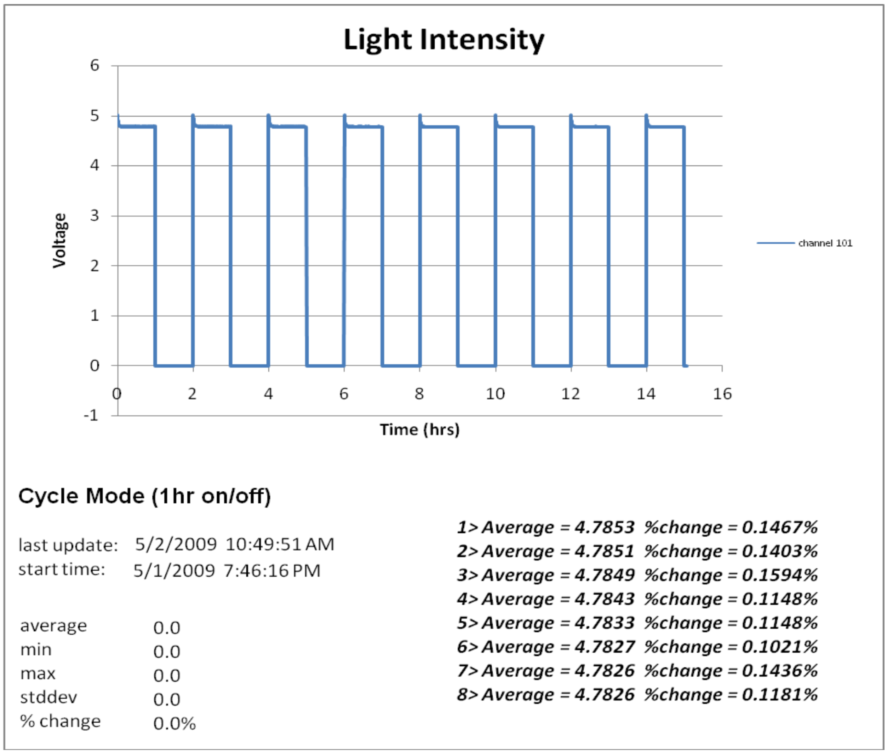


Figure 3: Long term monitoring of HBLED in cycle mode, where the HBLED is turned on for one hour and then turned off for one hour. The statistics for the on-time duration (less the warm up time) are shown on the right.

Spectrum analysis

Real time monitoring of the spectra from the HBLED was performed using an Ocean Optics HR4000 high resolution spectrometer, taking spectra once every hour. The spectra are compared are compared for changes in light output.

Traceability to NIST calibrated LED

All light intensity measurements were made under CIE condition A using a silicon photodector. Under this condition, a calibrated white led (low current) intensity is 0.201, compared to 4.78 for the HBLED. Thus the relative intensity of the HBLED compared to the standard is 23.78.

Ambient temperature sensitivity

To measure the susceptibility of the unit to room temperature, the room temperature was varied and the intensity measured after reaching equilibrium. For these experiments, the heat dissipater was placed outside the lab. Even though the temperature near the LED is carefully monitored and used in the control algorithm, atmospheric heating/cooling cannot be precisely controlled. This experiment measures the magnitude of this effect.

3. Measurement of HBLED-1

In this section, measurement results of the experiments described above have been performed on HBLED-1 prototype. The first experiment, figure 4a and b, show measurement of relative light intensity and junction voltage versus lab temperature with the heat dissipater located in an adjacent room. The intensity change per degree can be calculated from the linear fit to the data.

In the next set of measurements, light intensity and juncion voltage are continuously monitored versus time. The statistics are shown below the graphs in figures 5 and 6.

The next five figures, 7a-e, long term monitoring of the light intensity, junction voltage, led drive current, HBLED temperature, and Base temperature are shown. The horizontal axis shows operating time, which is the total time that the LED was on, but not elasped time since the LED was cycled on/off for these meaurements.

Finally, figure 8a-b show the change in intersity in the spectral range 350-750nm after operating the HBLED-1 unit in continuous on mode for 20 hours. The first spectrum is taken at hour one and the last spectrum is taken at hour twenty.   From these results, the total change in intensity in this spectral range is calculated, along with identifying the regions in the spectrum were the greatest changes are observed.

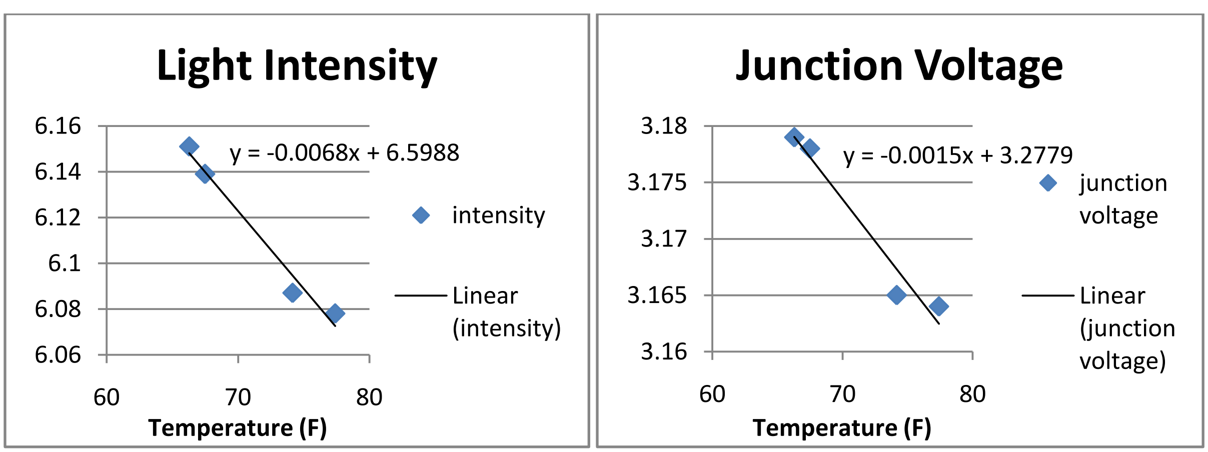
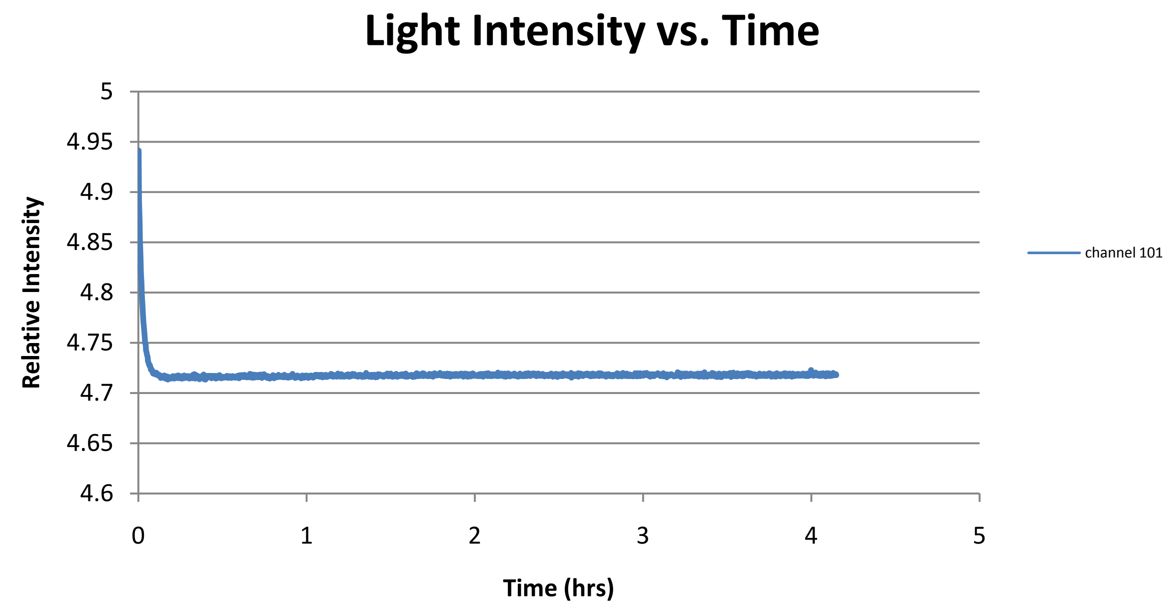


Figure 4: a) Light Intensity variation as a function of room temperature b) Junction Voltage variation as a function of room temperature

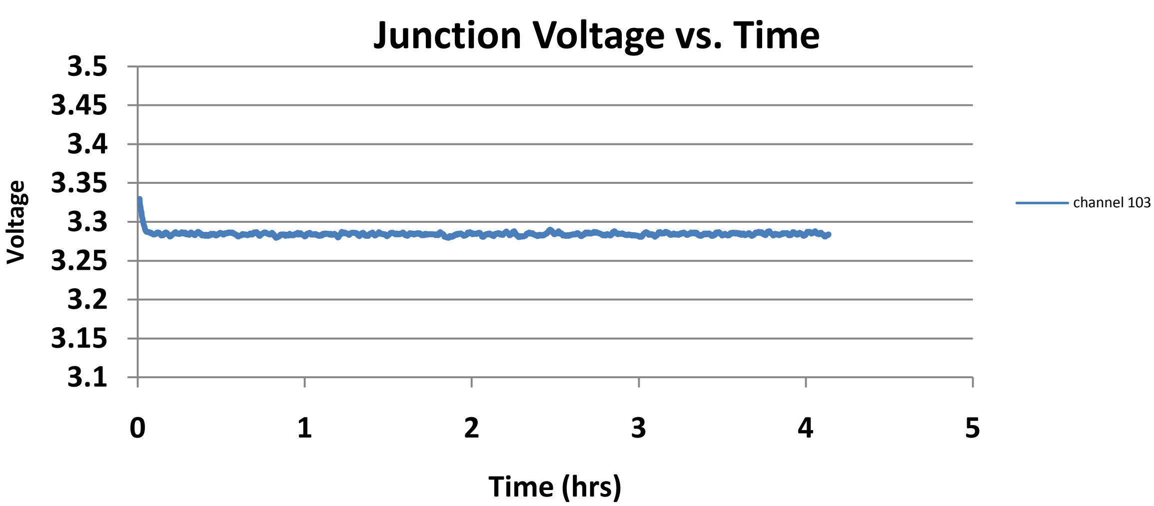


Continuous Run Mode

last update: 5/10/2009 8:34:55 PM
start time: 5/10/2009 4:27:12 PM

average	4.7174
min	4.7133
max	4.7229
stddev	0.0012
% change	0.2038%

Figure5: Light intensity as a function of time.



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stddev	0.0044
%change	0.6691%

Figure 6: HBLED junction voltage vs. time during operation

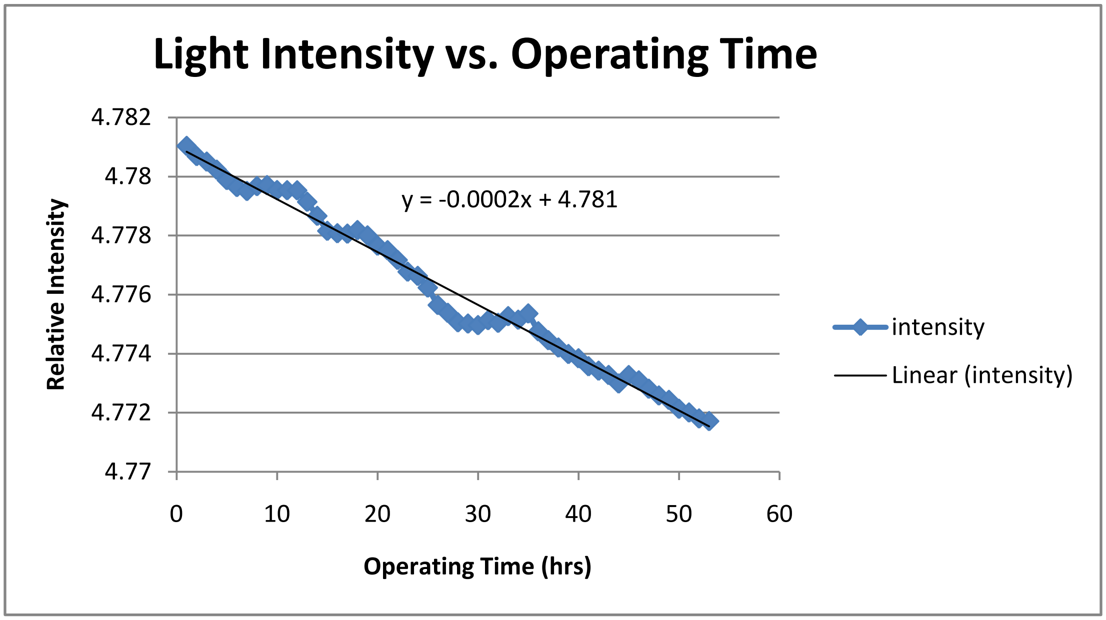

Figure 7a: Light Intensity vs. Operating Time taken in cycle mode operation

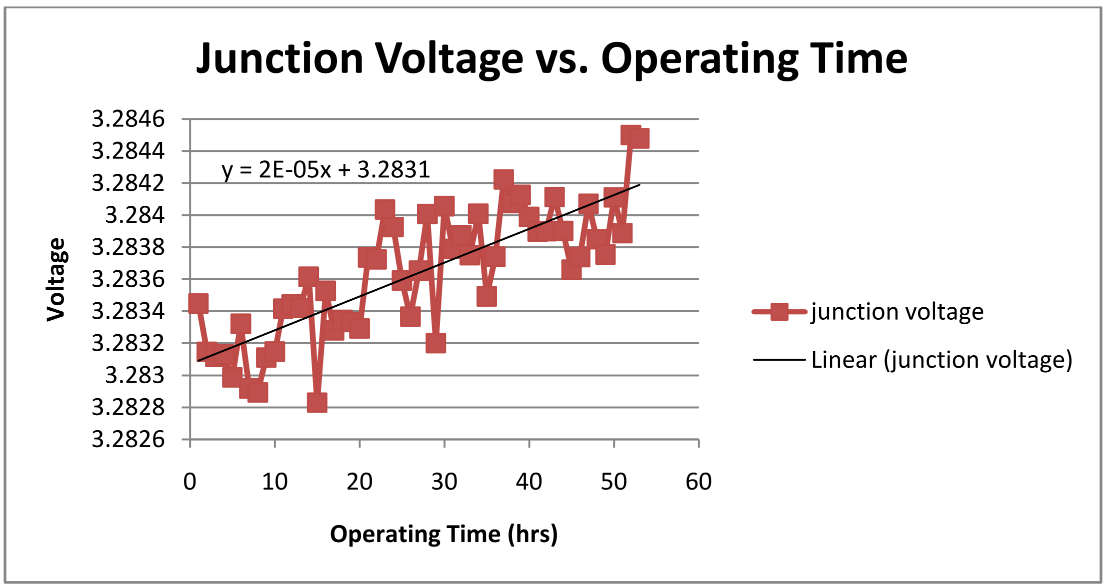

Figure 7b: Junction Voltage vs. Operating Time taken in cycle mode operation

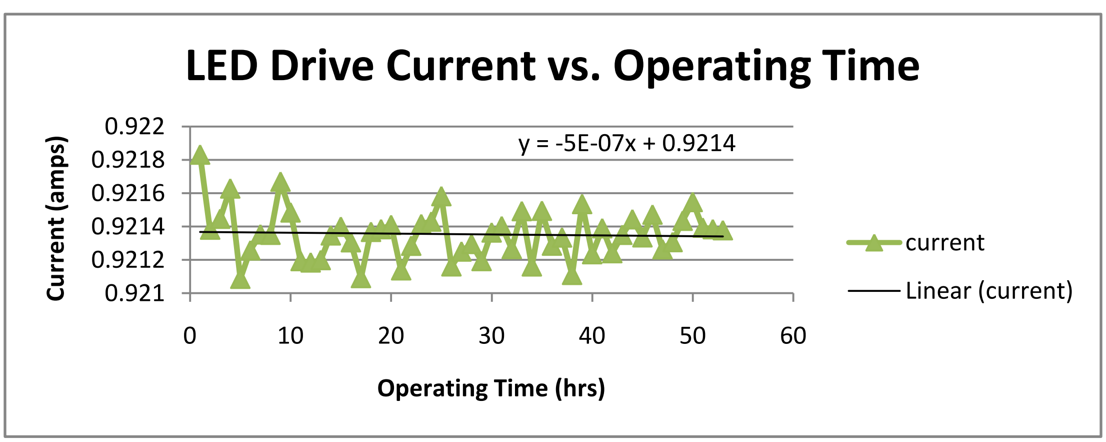

Figure 7c: LED Drive Current vs. Operating Time taken in cycle mode operation

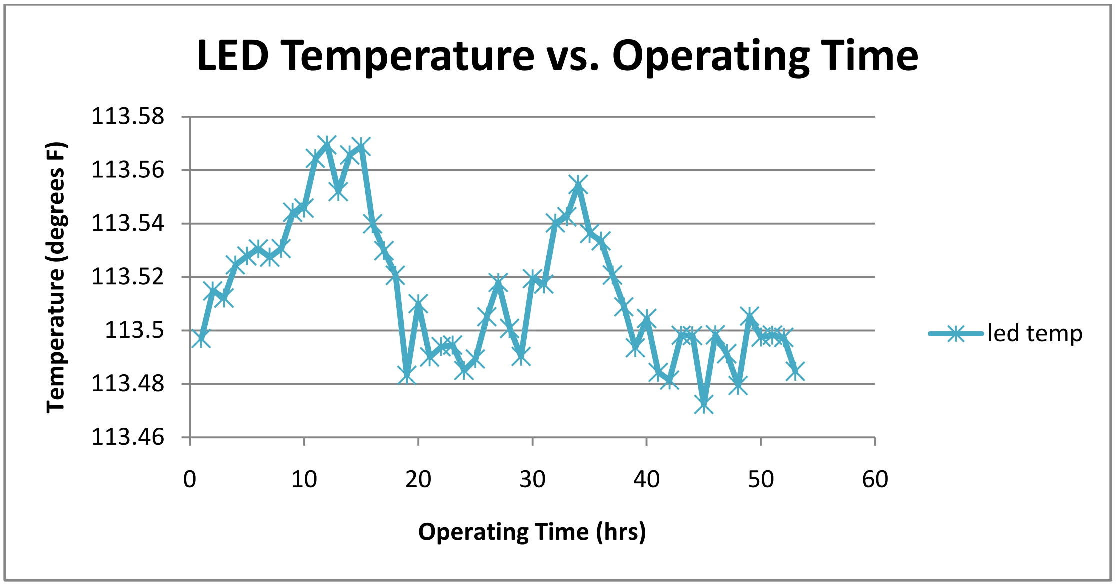

Figure 7d: LED temperature vs. Operating Time taking in cycle mode operation

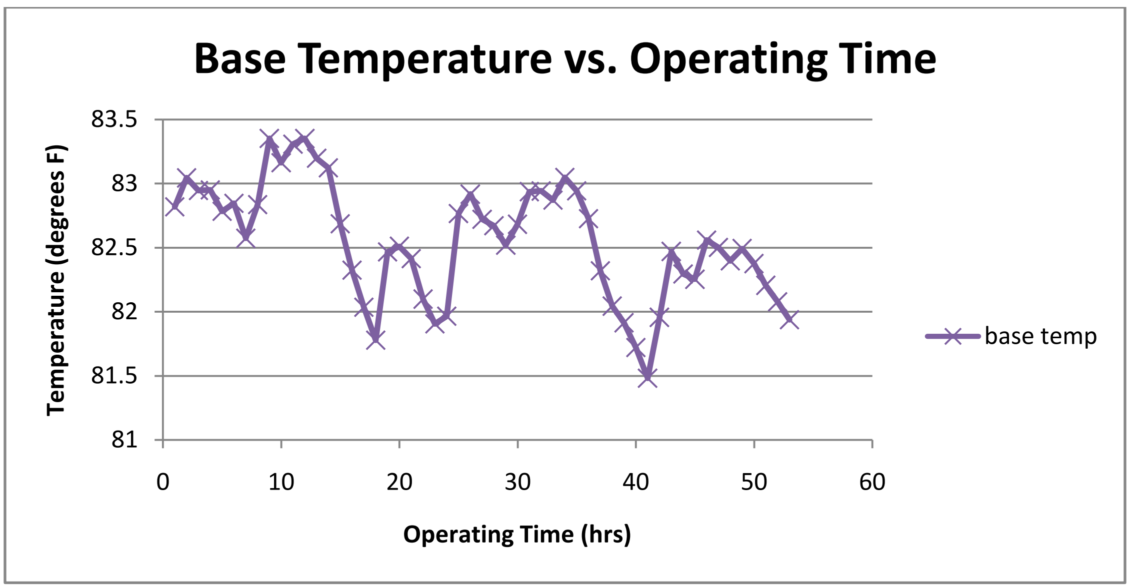

Figure 7e: Base Temperature vs. Operating Time taking in cycle mode operation

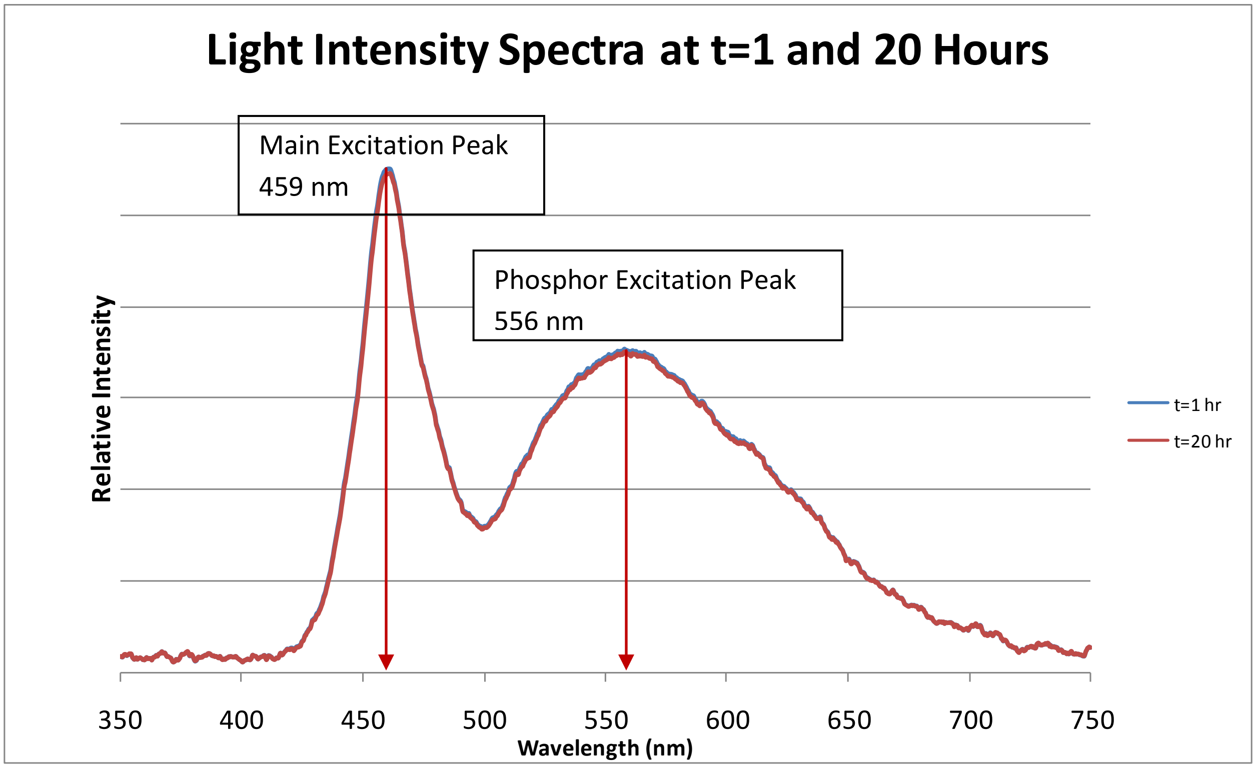

Figure 8a: Two spectra taken at time = 1 hour and time =20 hour are shown above while the LED remained in continuously on mode. The percentage change in intensity integrated from 350-740nm was 1.16% for 19 hours of operation. This translates into 0.0611% intensity reduction per hour.

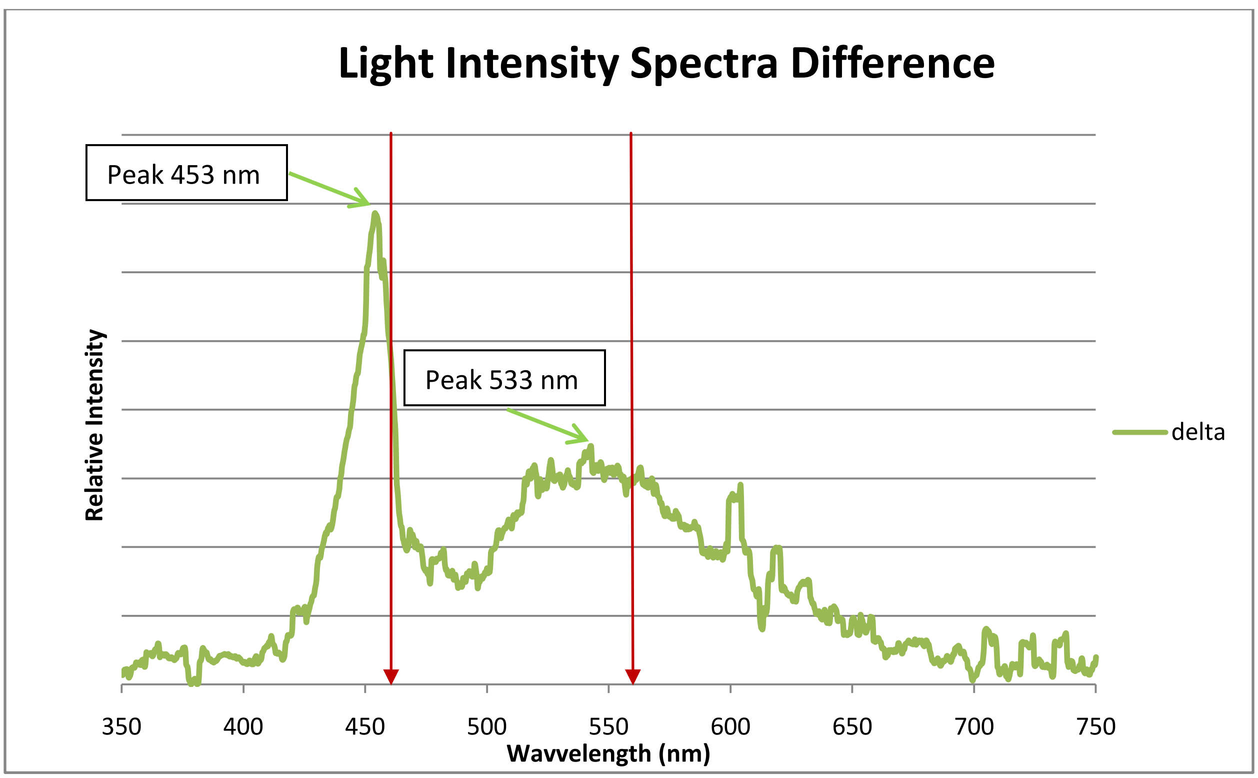

Figure 8b: This curve shows the difference between spectra taken at t=1 hour and t= 20 hours. Note that the peaks of the difference curves are occurring at wavelengths higher than the main excitation peak and phosphor excitation in Fig 8a.

Results

Intensity variation over time

After 50+ hours of testing in cycle mode (one hour off and one hour on operation) shown in figure 7a, the linear regression fit shows that the intensity is changing (decreasing) 0.00418% per hour. After 100 hours of operation, the change would be 0.41%, assuming it is linear. It should be noted all our data comes from one LED from one manufacturer where the total operation time has been less than 200 hours.

In comparison, data from continuous mode operation using spectral monitoring shows that the intensity loss is 0.0611% per hour (figure 8a), which is an order of magnitude greater than the results from cycle mode operation. Although more investigation is needed, perhaps continuous mode operation places more stress on the LED photo generation mechanisms.

Intensity variation vs. temperature

From the regression analysis in figure 4a, the percentage change in intensity per degree Fahrenheit is calculated to be 0.103% per degree Fahrenheit.

Error budget analysis

Since intensity variation is caused by both systematic terms and random terms the percentage total intensity variation is a sum of the following terms. Statistical factors are added in quadrature inside the dIstatistical term.

$$Dtotal\% = dtemp\% + dtime\% + dIstatistical\%$$

The dIstatistical% is taken from data in figure 3. Assuming 100 hours of operation in cycle mode, with a maximum ambient temperature range of 3 degrees F,

$$Dtotal\% = 0.31\% + 0.41\% + 0.15\% = 0.87\%$$

Conclusion

Preliminary experiments with our compact prototype HBLED-1 show that requirements for a practical stable high brightness LED source in the lab can be realized, opening up opportunities for accurate long term monitoring of optical properties of HBLEDs.

Long term changes in intensity that have been observed could be due to semiconductor changes and need further investigation. Also junction voltage changes slightly, therefore it might not be a precise temperature indicator over a long period of time. The observed linear change in junction voltage and the spectral changes may suggest that we are seeing change in the semiconductor properties and the phosphor florescence mechanism of the HBLED.

References

1) Light Emitting Diodes, E. Fred Schubert, 2nd Edition, Cambridge University Press, 2007
2) CORM 2007 Annual Conference and Business Meeting, “Optical Radiation Standards for Industry, May 8-11, 2007, Gaithersburg MD