(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 273 851 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.01.2011 Bulletin 2011/02

(51) Int Cl.:
H05B 33/08 *(2006.01)*

(21) Application number: **09163687.8**

(22) Date of filing: **24.06.2009**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA RS

(71) Applicant: **NXP B.V.**
5656 AG Eindhoven (NL)

(72) Inventors:
- **Nguyen, Viet**
Redhill, Surrey RH1 1DL (GB)
- **Bancken, Pascal**
Redhill, Surrey RH1 1DL (GB)
- **Surdeanu, Radu**
Redhill, Surrey RH1 1DL (GB)
- **Lammers, Matheus**
Redhill, Surrey RH1 1DL (GB)
- **Deurenberg, Peter**
Redhill, Surrey RH1 1DL (GB)

(74) Representative: **Burton, Nick et al**
NXP Semiconductors
IP&L Department
Betchworth House
57-65 Station Road
Redhill, Surrey RH1 1DL (GB)

(54) System and method for controlling LED cluster

(57) In one embodiment, a control system is for controlling a lighting system which comprises a cluster (20) of different colour LEDs. The control system comprises a first control unit (24) for generating amplitude values for the different LEDs of the cluster to provide a desired colour point and a second control unit (38) for controlling pulse width values for the different LEDs to provide a desired brightness. Current sources (32) are provided for individually driving the LEDs of the cluster.

This system allows the control of colour point to be independent from the control of brightness of the LED cluster. This provides a low cost solution and a fast, accurate and flexible control to a LED cluster.

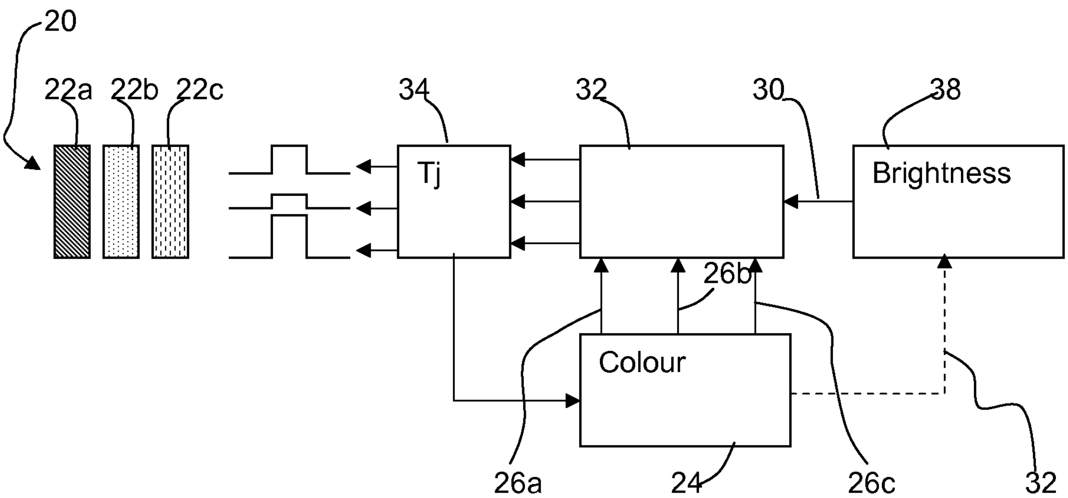


Figure 4

EP 2 273 851 A2

Description

[0001] This invention relates to lighting devices using light emitting diodes (LEDs), and particularly to the control of the output colour and intensity of LED clusters.

[0002] Lighting using solid-state devices such as LEDs is gaining momentum. Generating light of different colours by combining lights from LEDs of primary colours such as red, green and blue is a well known practice. The applications for such light sources range from entertainment (stage) lighting, atmosphere creation interior lighting, architectural lighting, large panel displays and more recently as backlights for LCD panels.

[0003] In order to change the colour and the brightness of the combined light, the mixing ratio and brightness of primary light sources need to be adjusted.

[0004] The use of LEDs for lighting has several advantages over the use of conventional light sources, including a better light output/dimension ratio and improved power efficiency. The light output intensity of a LED can be controlled by either:

(a) regulating the amplitude of the current through the LED, or
(b) regulating the frequency and duty cycle of the current pulse through the LED.

[0005] A combination of both techniques can also be used.

[0006] It is well known that the colour of light generated by an LED changes with a change in the amplitude of driving current, as shown in Figure 1. Figure 1 shows the LED wavelength shift as a function of the drive current. Therefore, to control the brightness of an LED, the preferred method is to modulate the current pulse width so that the amplitude (and therefore wavelength) remains constant.

[0007] During operation, the LED temperature increases and this influences the amount of light output from the LED as well as the dominant wavelength of the output light. In particular, the LED generates not only light but also heat due to the below 100% electricity - light conversion efficiency. The heating of the LED has a strong impact on the brightness and the colour of light generated from the LED, as shown in Figure 2. Figure 2 shows the LED light colour and intensity changes as function of junction temperature.

[0008] This shift in colour and brightness resulting from temperature changes needs to be controlled in order to produce a correct colour and brightness of light from a cluster of LEDs. Thus, some form of temperature measurement is desirable to provide a feedback value for use in controlling the LED driver conditions. Typically, the LED junction temperature is measured using an external temperature sensor located close to the LED.

[0009] The conventional approach of controlling the colour and brightness of an LED cluster by current pulse width modulation of the individual LEDs has four potential problems which are:

(1) inaccuracy
(2) slow response
(3) interdependency and
(4) inflexibility.

[0010] The reason the conventional method can be inaccurate is that there are only a finite number of pulse width values that need to be shared between colour point control and brightness control of the LED cluster. This leads to a poor control resolution in either or both variables. It is possible to provide a sufficiently large number of pulse width values that will give a good control resolution. This is however an expensive solution.

[0011] The reason the method is slow is that it requires a large amount of calculation based on actual LED conditions to derive the appropriate widths for current pulses. For a fast-changing lighting application such as concert lighting or the backlight of an LCD display, this means a fast (expensive) processor to calculate pulse width values would be needed.

[0012] The conventional control method requires carefully chosen (binned) LEDs because of the interdependence between colour point and brightness, any variation of the LEDs properties will have detrimental impact on the accuracy of the control. Furthermore, the complexity of the control model prohibits it to from being easily adapted for any chosen LED combination making the method inflexible.

[0013] This invention is based in part on the recognition that, of all the disadvantages of the conventional controlling scheme, the fact that both colour and brightness controls are interdependent is particularly problematic, as one variable cannot be adjusted without re-adjusting the other.

[0014] According to a first aspect of the invention, there is provided a control system for controlling a lighting system which comprises a cluster of different colour LEDs, wherein the control system comprises:

a first control unit for generating amplitude values for the different LEDs of the cluster to provide a desired colour point;
a second control unit for controlling pulse width values for the different LEDs to provide a desired brightness; and

current sources for individually driving the LEDs of the cluster.

[0015] This control system controls the colour point and brightness of an LED cluster which comprises LEDs of different colours. This system allows the control of the colour point to be independent from the control of the brightness of the LED cluster. This provides a low cost solution and a fast, accurate and flexible control to a LED cluster.
[0016] In one arrangement, the amplitude values generated by the first control unit provide the desired colour point at a predetermined brightness which is constant for all colour points. This means that the brightness control can be implemented simply as a scaling function. A single scaling value can be used for all LEDs, or else different scaling values can be used for different LED colours.
[0017] Alternatively, the first control unit can provide brightness information concerning the generated amplitude values to the second control unit. The second control unit then takes into account this brightness information when setting the pulse width values.
[0018] Preferably, a temperature sensing arrangement provides a temperature feedback value to the first control unit. Thus, the colour control takes account of temperature variations - but the brightness control can still be implemented as a simple scaling function.
[0019] According to a second aspect of the invention, there is provided a control system for controlling a lighting system which comprises a cluster of one or more same colour LEDs, wherein the control system comprises:

a temperature sensing arrangement, providing a temperature feedback value;
a first control unit for generating amplitude values for the different LEDs of the cluster to maintain a desired output brightness which takes account of the temperature feedback value;
a second control unit for controlling pulse width values for the different LEDs to provide a desired brightness in response to a desired change in brightness; and
current sources for individually driving the LEDs of the cluster.

[0020] This system again uses separate control units for the amplitude control and the pulse width control. The amplitude control uses temperature feedback, whereas the pulse width control can again be implemented by simple scaling.
[0021] In both aspects, the temperature sensing arrangement can be for estimating the junction temperature of each LED, wherein the current source is for driving a forward bias current through the diode, the current comprising a square wave which toggles between high and low current values, the high current value (I_{high}) comprising the LED operation current, and the low current (I_{low}) comprising a non-zero measurement current, wherein the temperature sensing arrangement comprises:

means for sampling the forward bias voltage drop, and determining the forward bias voltage drop at the measurement current; and
means for deriving the temperature from the determined forward bias voltage drop.

[0022] This arrangement measures the junction temperature of an LED with good accuracy by using square wave current pulses, in which the high level (I_{high}) is an operational current of the LED and the low level is a measurement current. By monitoring the forward voltage (Vf) of the LED over time, two dominant values will be found (if the operational current is constant over the monitoring period), one of which is representative of the real temperature at the LED junction during operation. A histogram of the forward voltage drops can be used for the data analysis. The forward voltage is temperature dependent in a known way.
[0023] Thus, the means for sampling can comprise means for analysing the samples to find a forward bias voltage drop which corresponds to a peak in the number of occurrences of that voltage drop.
[0024] The invention also provides a lighting system comprising a control system of the invention and the LED cluster.
[0025] The invention also provides lighting system comprising a control system of the first aspect of the invention and a colour output characteristic determination system for determining the colour output characteristics of the LED cluster. This is used to calibrate the operation of the first control unit.
[0026] The colour output characteristic determination system can comprise a heater for heating the LED cluster, and a colour sensor and brightness sensor, thereby enabling a relationship to be derived for each LED between the drive current required and the temperature to provide a given colour point output.
[0027] The first aspect of the invention also provides a method of controlling a lighting system which comprises a cluster of different colour LEDs, wherein the method comprises:

generating amplitude values for the different LEDs of the cluster to provide a desired colour point;
controlling pulse width values for the different LEDs to provide a desired brightness; and
using the amplitude and pulse width values to drive current sources for individually driving the LEDs of the cluster.

[0028] The amplitude values generated provide the desired colour point at a predetermined brightness which is constant for all colour points and the pulse width values are generated using scaling values the LEDs. A temperature feedback value can be used in generating the amplitude values.

[0029] The second aspect of the invention also provides a method of controlling a lighting system which comprises a cluster of same colour LEDs, wherein the method comprises:

providing a temperature feedback value;
generating amplitude values for the different LEDs of the cluster to maintain a desired output brightness which takes account of the temperature feedback value;
controlling pulse width values for the different LEDs to provide a desired brightness in response to a desired change in brightness; and
using the amplitude and pulse width values to drive current sources for individually driving the LEDs of the cluster.

[0030] Examples of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows the LED wavelength shift as a function of the drive current;
Figure 2 shows the LED light colour and intensity changes as function of junction temperature;
Figure 3 is a graphical presentation of one current pulse sent to an LED with the proposed control method of the colour implementation of the invention;
Figure 4 is a block diagram showing the control system (and method) of the colour implementation of the invention;
Figure 5 is a block diagram of a colour output characteristic determination system for determining the colour output characteristics of an LED cluster;
Figure 6 shows a derived relationship for each LED between the drive current required and the temperature for a given colour point;
Figure 7 shows a system of the invention for an LED fixture containing one or more LEDs of the same colour;
Figure 8 shows the way the drive pulse is controlled in the system of Figure 7;
Figures 9A to 9D are graphs which schematically represent a junction temperature estimation method;
Figure 10 shows the system for estimating the junction temperature;
and
Figure 11 is a graph used to explain a simplified way to mode the temperature dependency of an LED output wavelength.

[0031] The invention relates to apparatus and methods for controlling LED light clusters. In one aspect, the invention relates to colour LED clusters. The control of colour and the control of brightness of the LED cluster are implemented independently. The colour of the LED cluster is controlled by changing the amplitudes of the currents fed to the LEDs, whereas the brightness of the LED cluster is controlled by changing the width of the current pulses fed to the LEDs. In another aspect, the invention relates to single colour LED clusters. The static brightness (i.e. keeping brightness constant despite temperature changes) of the LED cluster is controlled by changing the amplitudes of the currents fed to the LEDs, whereas the dynamic brightness (i.e. implementing deliberate changes in brightness) of the LED cluster is controlled by changing the width of the current pulses fed to the LEDs.

[0032] Figure 3 is a graphical presentation of one current pulse sent to an LED with the proposed control method of the colour implementation of the invention.

[0033] As shown, a periodic signal is used, which steps between an operational current (I_{high}) and a measurement current (I_{low}). The significance of the measurement current is explained further below.

[0034] The operational current level 10 is determined by a colour point control unit and the pulse width 12 (i.e. the duty cycle in the case of a fixed frequency of operation) is controlled by a brightness control unit.

[0035] By splitting the control into two independent tasks, lower complexity circuitry can be used to gain a high control resolution both in colour and brightness of the LED cluster.

[0036] Two different control models for colour point control and brightness control are needed. However, due to the disentanglement between colour point and brightness, simple control models can be used. This also offers greater flexibility to adapt the models to accommodate different LED combinations. The flexibility to use LEDs of larger differences enables a substantial cost saving for LED fixture manufacturers.

[0037] Figure 4 is a block diagram showing the control system (and method) of the colour implementation of the invention.

[0038] The control system is for controlling a lighting system which comprises a cluster 20 of different colour LEDs 22a,22b,22c. A first control unit 24 is for generating amplitude values 26a,26b,26c for the different LEDs of the cluster to provide a desired colour point.

[0039] A second control unit 28 is for controlling the pulse width values for the different LEDs to provide a desired brightness. This pulse width control can be implemented as a single scaling factor 30. Current sources 32 are provided for individually driving the LEDs of the cluster 20.

[0040] The amplitude values generated by the first control unit 24 can provide the desired colour point at a predetermined brightness which is constant for all colour points. This enables the second control unit to generate scaling values for the LEDs, and these can in one example be implemented as a single scaling value 30. However, different scaling values for different LEDs can enable additional freedom in the colour mixing process with compensation for the colour shift due to temperature. No live communication between the brightness control unit and the colour control unit is needed in this arrangement.

[0041] However, an alternative is for the first control unit 24 to provide brightness information 32 concerning the generated amplitude values to the second control unit 28. In this case, the brightness control unit 28 block calculates the right pulse width to produce the desired amount of light output.

[0042] The amplitude values 26a,26b,26c take account of the LED colour shift due to current and temperature at its junction. The junction temperature is determined by unit 34, explained below.

[0043] There are a number of ways to implement the colour point control unit. One possible approach is discussed below, using a circuit for extracting control model parameters.

[0044] Figure 5 is a block diagram of a colour output characteristic determination system 50 for determining the colour output characteristics of the LED cluster. A heater 52 is provided for heating the LED cluster 20, and a colour sensor and brightness sensor 54 provides optical feedback. This enables a relationship to be derived for each LED between the drive current required and the temperature to provide a given colour point output.

[0045] The heater is used to generate real life temperature conditions. By changing the current amplitudes and their combinations while monitoring the colour and flux of the resulting light, a correct current combination for each junction temperature can be determined that will produce the correct colour point and flux of the light.

[0046] As shown in Figure 5, the sensor determines if the desired colour point is achieved. If not (N), the colour control unit 24 varies the amplitudes. If the desired colour point is reached (Y), the parameters (temperature from the temperature sensor 34 and amplitudes) are stored in memory 56.

[0047] The derived relationship for each LED between the drive current required and the temperature for a given colour point is shown in Figure 6.

[0048] Samples 60 are for the red LED, and the curve is a quadratic approximation, samples 64 are for the green LED, and the curve 66 is a quadratic approximation, and samples 68 are for the blue LED, and the curve 70 is a quadratic approximation.

[0049] The quadratic approximation is shown in the top of the figure.

[0050] The three curves describe the current as a function of the LEDs junction temperatures. It has been experimentally proven that each function can be accurately described using a quadratic polynomial equation, thereby requiring only three fitting parameters. Consequently a model for constant colour point and flux of a typical RGB LED combination contain only 9 parameters as shown in equation 1.

$$\begin{bmatrix} I_{RED} \\ I_{GREEN} \\ I_{BLUE} \end{bmatrix} = \begin{bmatrix} A_R & B_R & C_R \\ A_G & B_G & C_G \\ A_B & B_B & C_B \end{bmatrix} \times \begin{bmatrix} T_j^2 \\ T_j \\ 1 \end{bmatrix} \qquad \text{(eq. 1)}$$

[0051] Tj is the junction temperature, and A, B, and C are the quadratic equation coefficients.

[0052] Because LEDs of the same type often have some differences in their properties due to manufacturing process variations, the colour point control model can be customized by having correction coefficients for each LED component as shown in equation 2.

$$\begin{bmatrix} I_{RED} \\ I_{GREEN} \\ I_{BLUE} \end{bmatrix} = \begin{bmatrix} Corr.Coeff.RED \\ Corr.Coeff.GREEN \\ Corr.Coeff.BLUE \end{bmatrix} \bullet \left(\begin{bmatrix} A_R & B_R & C_R \\ A_G & B_G & C_G \\ A_B & B_B & C_B \end{bmatrix} \times \begin{bmatrix} T_j^2 \\ T_j \\ 1 \end{bmatrix} \right) \qquad \text{(eq.2)}$$

[0053] The model parameters in equation 1 are determined for a typical combination of LEDs in the laboratory. At the point of use, only the three correction coefficients (eq. 2) need to be determined. This offers easy of use and flexibility to the control model to be adaptable to a larger population of LEDs of similar type, which is very important to lower the cost of lighting fixtures using LEDs.

[0054] The control system has been tested to determine the control accuracy while controlling RGB LED clusters of the same type but from different bins (i.e. small variation in lighting properties exists between LEDs of the same type). The results were obtained by only adjusting the correction matrix as shown in equation 2 for LEDs of the same type. The robustness of the control method has been confirmed for a wide variety of LEDs. Thus, accurate colour and brightness control for virtually any LED combination is achieved with minimised adjustment of model parameters.

[0055] For brightness control, the widths of the current pulses sent to the LEDs are simply scaled linearly with the desired output brightness. This simplicity is possible due to the constant colour point and luminous intensity offered by the colour point control unit.

[0056] The simplicity of the control model can enables accuracy to be maintained in real time. For example. implementation of the control method in a TV backlight requires accuracies in both colour and brightness at video frame rate.

[0057] The example above relates to colour control. However, the inventive concept of splitting amplitude and pulse width modulation can also be applied to a single colour system, in accordance with a second aspect of the invention.

[0058] For a LED fixture that contains one or more LEDs of the same colour (e.g. white LEDs), the most important aspect of the control is to produce a correct brightness. Conventionally, this is done by modulating the width of the current pulses fed to the LEDs. The pulse width is determined based on the LED condition (e.g. the temperature at the LED junction) and the desired brightness. This combination is found to be inconvenient as at different junction temperature there will be different pulse width needed to produce one value of brightness.

Figure 7 shows a system for an LED fixture 70 containing one or more LEDs 72 of the same colour. The amplitude of the current pulse is determined by a static control unit 74 used for brightness maintenance of the LED. The pulse width modulation is determined by a dynamic control unit 76 used for brightness control.

Figure 8 shows the way the drive pulse is controlled, with the static control as 80 and the dynamic control as 82.

[0059] In this way, brightness maintenance in accordance with the LED condition (Tj) is disentangled from brightness control resulting in a very simple and yet accurate way of control light from a LED fixture. To build the brightness maintenance model, the procedure is similar to that of building colour point control model outlined above.

[0060] The first control unit (in both examples above) has a temperature feedback signal. This can be taken from a conventional temperature sensor, but a more accurate approach is described below.

[0061] The approach measures the junction temperature of a LED with good accuracy by using square wave current pulses, in which the high level (I_{high}) is an operational current of the LED and the low level is a measurement current. By monitoring the forward voltage (Vf) of the LED over time, two dominant values will be found (if the operational current is constant over the monitoring period), one of which is representative of the real temperature at the LED junction during operation. A histogram of the forward voltage drops can be used for the data analysis.

Figures 9A to 9D are graphs will schematically represent the method.

Figure 9A shows the drive current applied to the LED. A pulsed current source is used to drive the LED. The pulses drive a forward bias current through the diode, and the current is in the form of a square wave which toggles between high and low current values.

[0062] The low current value is a measuring current, preferably smaller or equal to 1 mA. It may be in the region of 5μA.

[0063] A low measurement current is desired for two main reasons. Firstly, if a LED is driven at large current, the self-heating effect starts, which means a less accurate measurement is obtained. The self-heating effect has been found by the applicant to be significant above currents of 1 mA. The self-heating effect depends on the thermal design of the LED package, and is therefore different for different LED designs.

[0064] Secondly, the larger the current, the brighter the LED. In an application such as 2D dimming TV, the minimum light level emitted from the backlight should not be more than 1% of the maximum illumination level. This 2D dimming system is a backlight control method in which only parts of the backlight are illuminated so that improved contrast between bright and dark areas of an image can be obtained.

[0065] The desire for low light output for the measurement phase means that the lowest possible current is required, but the current needs to be sufficient for the LED to be forward biased so that the voltage can be measured.

[0066] These considerations will all be taken into account when selecting the measurement current, and the value will depend on the intended use of the LED, the thermal properties of the packaging, and the LED characteristics.

[0067] Figure 9B shows the resulting forward bias voltage drop Vf across the diode.

[0068] The forward bias voltage drop is sampled at regular intervals, and the sampling instants are shown as filled circles in the plot of Figure 9B.

[0069] At each sampling instant, the voltage is measured, and a histogram counter monitors this LED voltage Vf, and determines the dominant value of voltage drop.

[0070] This is achieved by creating the histogram as shown in Figure 9C. As shown, there are two peaks in the count number. The peak in the count number corresponding to the higher voltage drop derives from the drive current (as this has been shown as constant in Figure 9A). The peak in the count number corresponding to the lower voltage drop derives from the measurement current, and this peak represents the forward bias voltage drop at the low current measurement value.

[0071] The LED junction temperature can be determined by relating the dominant forward bias voltage drop corresponding to the measurement current with a calibrated curve or an analytical model of the relationship between forward bias voltage Vf and temperature T. This relationship is shown schematically in Figure 9D.

[0072] An analytical function is used to define the relationship shown in Figure 9D, giving very low memory requirement. The output flux of the LED is controlled by the high current value of the current drive sequence, as well as the pulse frequency and the duty cycle. However, the measurement current value is unchanged throughout the operation.

[0073] This approach provides a constant measurement current so that a model of the relationship between the corresponding forward bias voltage drop and temperature can be easily derived and stored, avoiding the need for look up tables, which introduce unwanted discretisation.

[0074] Figure 10 shows the system for estimating the junction temperature of a light emitting diode.

[0075] A current source circuit 100 is used for driving a forward bias current through the diode 101, and this current comprises the square wave described above. Any suitable current source circuit can be used for this purpose.

[0076] The forward bias voltage drop is sampled by a voltage measurement circuit 102, and the samples are provided to a processor 104. The processor 104 stores the analytical function representing the voltage-temperature characteristics, and determines the forward bias voltage drop at the measurement current based on the histogram analysis described above. The processor derives the temperature from the determined forward bias voltage drop using the function.

[0077] For lighting purposes, the current frequency has to be high enough so that human eye can not see the flickering. This minimum frequency is around 24 Hz, but in practice the pulsing frequency will typically be between 300Hz and 1,5 kHz, but it can be even higher. For TV backlight applications, the most common frame rate now is 120Hz. and this sets the minimum frequency for the LED pulsing.

[0078] An LED module can have any number of LEDs, not only three as in the example above.

[0079] It is clear from the above, that there is a multi-colour implementation and a single-colour implementation of the invention. In general, the invention provides a control system for controlling a lighting system which comprises one or more LEDs. The control system comprises a first control unit for generating amplitude values for the LEDs for controlling a first aspect of the light output characteristic, and a second control unit for controlling pulse width values for the different LEDs to control a first aspect of the light output characteristic. Current sources drive the LEDs. Thus, the first characteristic can be the colour point or maintenance of a constant brightness, whereas the second characteristic is control of brightness or changing brightness.

[0080] The examples above show the use of sensors to characterise the dependency of the light output characteristics on temperature. However, the required sensor measurements can be reduced by using mathematical modelling.

[0081] The emission of a photon in an LED is related to an electron-hole pair recombining in an active structure. Modern LEDs are typically multi-quantum-well structures (MQW) made of several different materials. Many factors influence the wavelength of a real device, and those factors heavily depend on the material, the material quality and the design of the structure. The stress in the structure causes band bending and a gap change. To predict the temperature effects on the structure stress, a complete modelling of each structure would be required. InGaN based LEDs (green and blue LEDs) compositions are not known precisely, as the alloy tends to segregate, leading to very efficient recombination centres, with unknown wavelength. InGaN alloys are piezoelectric materials, with internal fields in the 10MV/cm range, which impact the wavelength of the emitted photons.

[0082] For these reasons, building a wavelength estimation model is not possible, but a *variational* model can be built which can lead to a real time estimation of wavelength, without needing real time sensing of the output light, during operation.

[0083] To estimate the wavelength change with temperature, the effect can be considered to come fully from a change in the gap of the active part.

$$\frac{hc}{\lambda(T)} = Eg*(T) = Eg*(0K) - \frac{\alpha.T^2}{\Theta + T} \qquad \text{(Eq. 3)}$$

[0084] Equation 3 above describes the shift in gap (wavelength) due to temperature effects. It requires a measurement at 0K which is unrealistic, and does not involve gap shifts due to stress or actual packaging of the LED.

[0085] To overcome this difficulty, the wavelength can be measured at a certain single temperature Tcal and given current Id, and an *effective* gap at 0K at this current can be calculated:

$$Eg^*(0K, Id) = Eg^*(T_{cal}, Id) + \frac{\alpha . T_{cal}^{\ 2}}{\Theta + T_{cal}} \qquad \text{(Eq. 4)}$$

[0086] The main advantage of this approach is to completely separate the variation of the wavelength with driving current and the variation with temperature, also to calculate the wavelength with a *single temperature* calibration step.

[0087] This formula relies on two parameters, α and Θ, respectively the Varshni parameter and the Debye temperature.

[0088] Those parameters can be found per material system in a wide range of publications. For example, examples of suitable LEDs have the following values:

	Red	Green	Blue
α	$6.1 \,.\, 10^{-4}$ eV/K	5.10^{-4} eV/K	5.10^{-4} eV/K
Θ	360K	630K	630K

To calibrate the model, it is necessary to have the following number:

α, Θ, Tcal, imid, ihigh, id, T, λmid , λhigh.

[0089] At a given temperature Tcal (in K), the peak wavelength is measured at a given current (if possible at a current as low as possible, where it is still possible to see light). The driving current at this current is the variable imid, wavelength in nm is λmid.

[0090] The same measurement is carried out at a higher current (as high as possible around but above the operational range of the LED). This gives ihigh and λhigh.

[0091] These single temperature calibrations are shown in Figure 11.

[0092] During operation, the quantities the user needs to know are T and id. The temperature can be sensed using the method above, and id is known by the driving current source. The model will output the peak wavelength at a current of id and a temperature of T.

[0093] The overall shift between the modelling and experiment is summarized in the table below for two different LED types in each of the three primary colours (Red, Green, Blue):

LED type	Maximal λ shift
Reds: ES-SAHR814	2.3 nm
Reds : ES-SAHR822	2.5 nm
Greens : ES-CEGHV24A-M	2.2 nm
Greens : ES-CEGHV30A-M	3.5 nm
Blues : ES-CEBHV15A-M	2.1 nm
Blues : ES-CEBHV24A-M	2.2 nm

[0094] The parameters can be adjusted to give more accurate values for all kinds of LEDs.

[0095] The content of the active part of the well, being unknown, still has to be in a narrow range of compositions. Even if the stress in the structure and geometry of the well impact the wavelength, the range of composition to provide the correct wavelength has to be around a certain value.

[0096] On curves of temperature dependency at the given current, the slope of the temperature dependency is either overestimated or underestimated. Thus, adjustments can be made to the model.

[0097] It has been demonstrated that with adjusted Varshni parameters and Debye temperature, the model can be used to accurately describe different families of LEDs. Without adjusted Varshni parameters and Debye temperature, this method is still valid, although more work has to be done to select a value for green LED material. From a single temperature measurement, it is possible using this approach to calculate the entire set of wavelengths at all temperatures and currents, using a physical model (for temperature) with an empirical dependency of wavelength with current. Those parameters can be adjusted and fed into the controllers above.

[0098] Even with one single temperature, each LED has to be calibrated in wavelength at two different currents. This can be done in parallel by measuring the wavelength of several LEDs at two different currents, at a given temperature (room temperature).

[0099] Thus, it is possible to know the wavelength of an LED at any temperature and current with a very fast calibration step. This can be used in the system above. However, more conventional light output sensing can also be carried out.

[0100] The invention can be used in driving circuits of LED fixtures to ensure that the light colour and brightness are accurately managed. This is especially of importance for LED lighting fixtures that require a dynamic changing of light colour and brightness such as entertainment (stage) lighting, atmosphere creation interior lighting, architecture lighting, large panel display, and as the backlight for LCD panel. Automotive lighting (head light, rear light and dashboard/interior lighting) can also use this control system.

[0101] Various modifications will be apparent to those skilled in the art.

Claims

1. A control system for controlling a lighting system (20) which comprises a cluster of different colour LEDs (22a,22b, 22c), wherein the control system comprises:

   a first control unit (24) for generating amplitude values for the different LEDs of the cluster to provide a desired colour point;
   a second control unit (38) for controlling pulse width values for the different LEDs to provide a desired brightness; and
   current sources (32) for individually driving the LEDs of the cluster (20).

2. A control system as claimed in claim 1, wherein the amplitude values generated by the first control unit (24) provide the desired colour point at a predetermined brightness which is constant for all colour points.

3. A control system as claimed in claim 2, wherein the second control unit (38) generates a scaling value or values (30) for the LEDs.

4. A control system as claimed in claim 1, wherein the first control unit (24) provides brightness information concerning the generated amplitude values to the second control unit (38).

5. A system as claimed in any preceding claim, further comprising a temperature sensing arrangement (34), providing a temperature feedback value to the first control unit (24).

6. A control system for controlling a lighting system which comprises a cluster (72) of one or more same colour LEDs, wherein the control system comprises:

   a temperature sensing arrangement (34), providing a temperature feedback value;
   a first control unit (74) for generating amplitude values for the different LEDs of the cluster to maintain a desired output brightness which takes account of the temperature feedback value;
   a second control unit (76) for controlling pulse width values for the different LEDs to provide a desired brightness in response to a desired change in brightness; and
   current sources (32) for individually driving the LEDs of the cluster.

7. A system as claimed in claim 5 or 6, wherein the temperature sensing arrangement (34) is for estimating the junction temperature of each LED, wherein the current source (32) is for driving a forward bias current through the diode, the current comprising a square wave which toggles between high and low current values, the high current value (I_{high}) comprising the LED operation current, and the low current (I_{low}) comprising a non-zero measurement current, wherein the temperature sensing arrangement comprises:

   means for sampling the forward bias voltage drop, and determining the forward bias voltage drop at the measurement current; and
   means for deriving the temperature from the determined forward bias voltage drop.

8. A system as claimed in claim 7, wherein the means for sampling comprises means for analysing the samples to find a forward bias voltage drop which corresponds to a peak in the number of occurrences of that voltage drop.

9. A lighting system comprising a control system as claimed in any preceding claim and the LED cluster (20;72).

10. A lighting system comprising a control system as claimed in any one of claims 1 to 5 and a colour output characteristic determination system (50) for determining the colour output characteristics of the LED cluster.

11. A system as claimed in claim 10, wherein the colour output characteristic determination system (50) comprises a heater (52) for heating the LED cluster (20), and a colour sensor and brightness sensor (54), thereby enabling a relationship to be derived for each LED between the drive current required and the temperature to provide a given colour point output.

12. A method of controlling a lighting system which comprises a cluster of different colour LEDs (22a,22b,22c), wherein the method comprises:

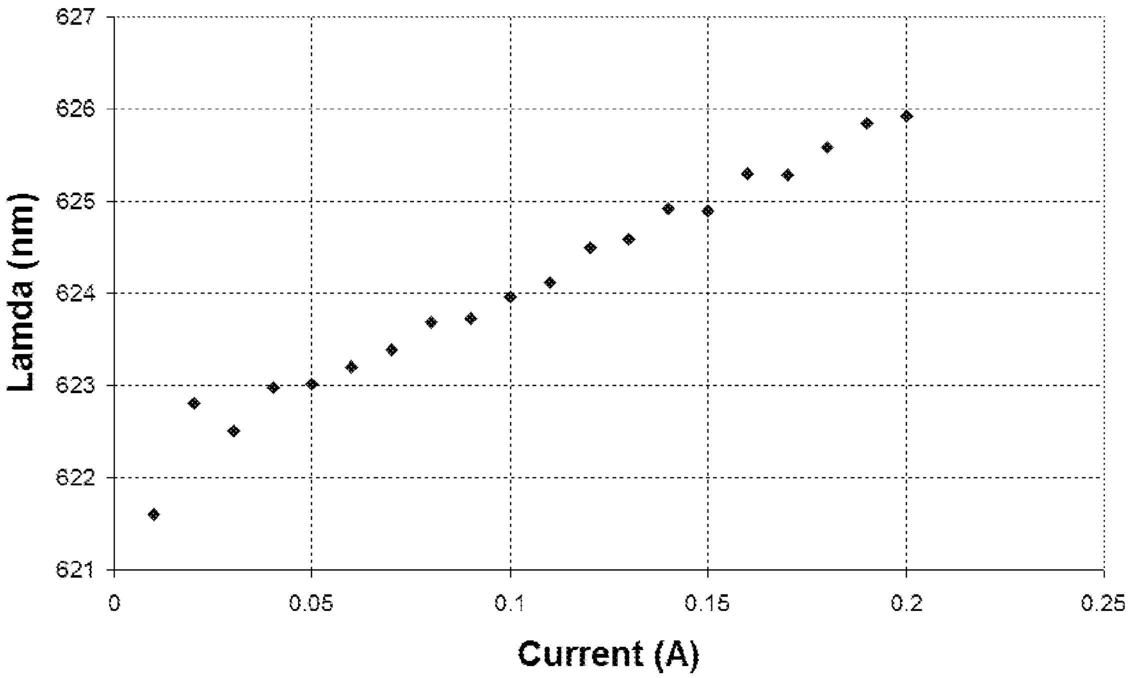
generating amplitude values for the different LEDs of the cluster to provide a desired colour point;
controlling pulse width values for the different LEDs to provide a desired brightness; and
using the amplitude and pulse width values to drive current sources for individually driving the LEDs of the cluster.

13. A method as claimed in claim 12, wherein the amplitude values generated provide the desired colour point at a predetermined brightness which is constant for all colour points and wherein the pulse width values are generated using a scaling value or values (30) for the LEDs.

14. A method as claimed in claim 12 or 13, further comprising providing a temperature feedback value, and using the temperature feedback value in generating the amplitude values.

15. A method of controlling a lighting system which comprises a cluster (72) of same colour LEDs, wherein the method comprises:

providing a temperature feedback value;
generating amplitude values for the different LEDs of the cluster to maintain a desired output brightness which takes account of the temperature feedback value;
controlling pulse width values for the different LEDs to provide a desired brightness in response to a desired change in brightness; and
using the amplitude and pulse width values to drive current sources for individually driving the LEDs of the cluster.



627
626
625
624
623
622
621
Lamda (nm)
0
0.05
0.1
0.15
0.2
0.25
Current (A)

Figure 1

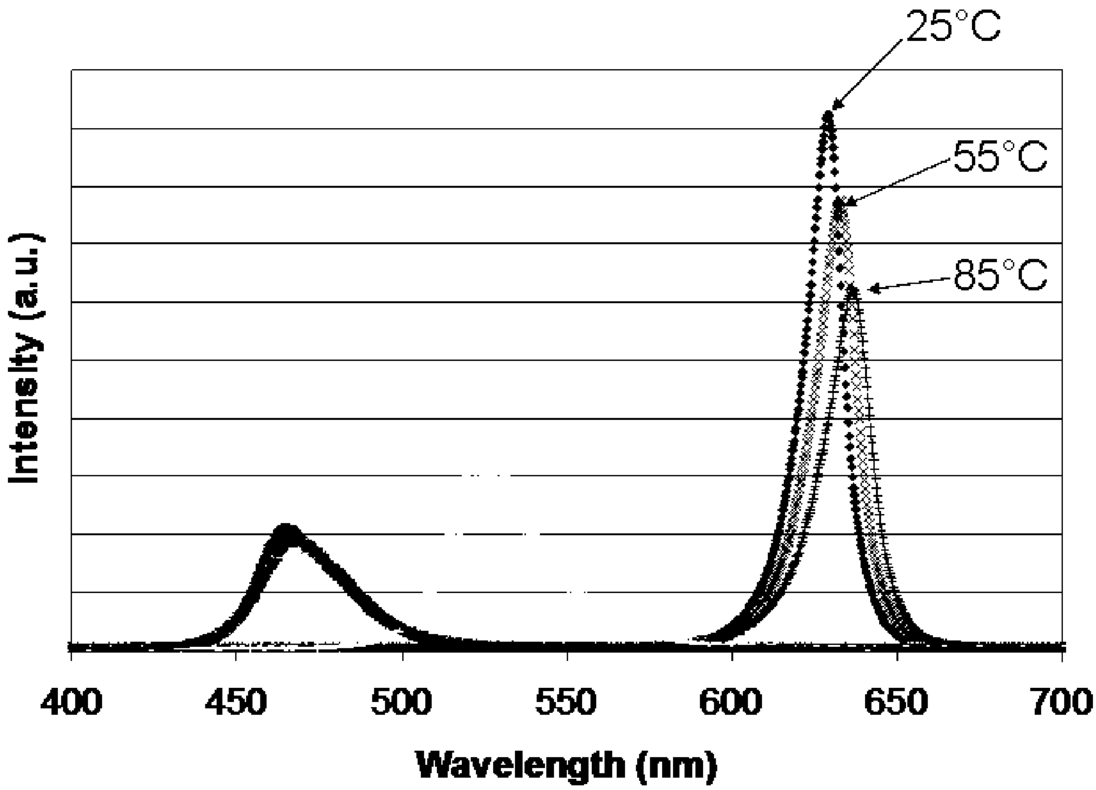

25°C
55°C
85°C
Intensity (a.u.)
400
450
500
550
600
650
700
Wavelength (nm)

Figure 2

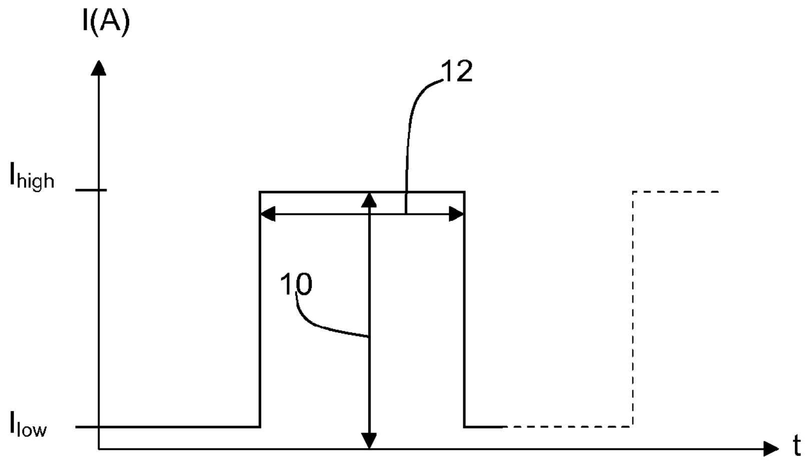


Figure 3

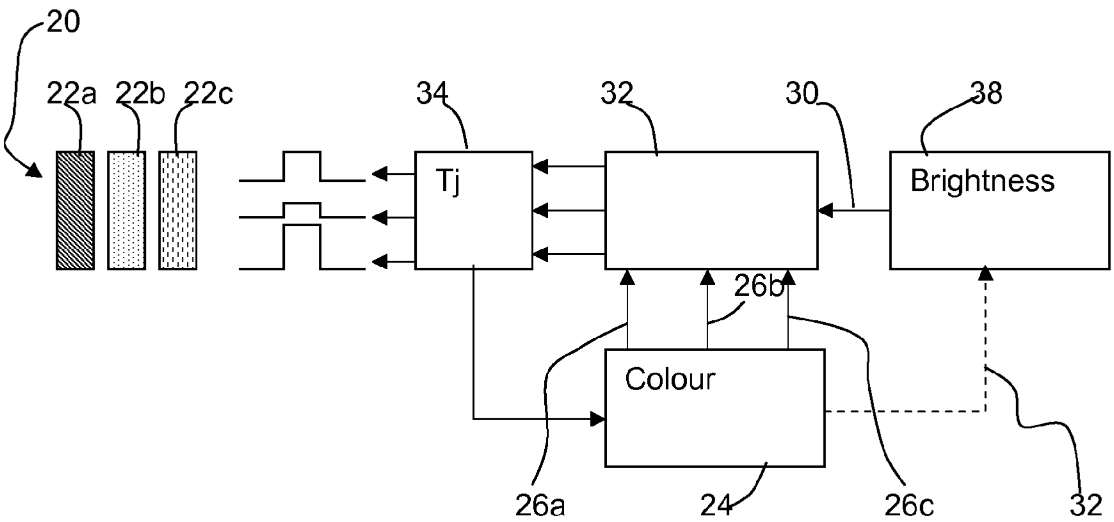


Figure 4

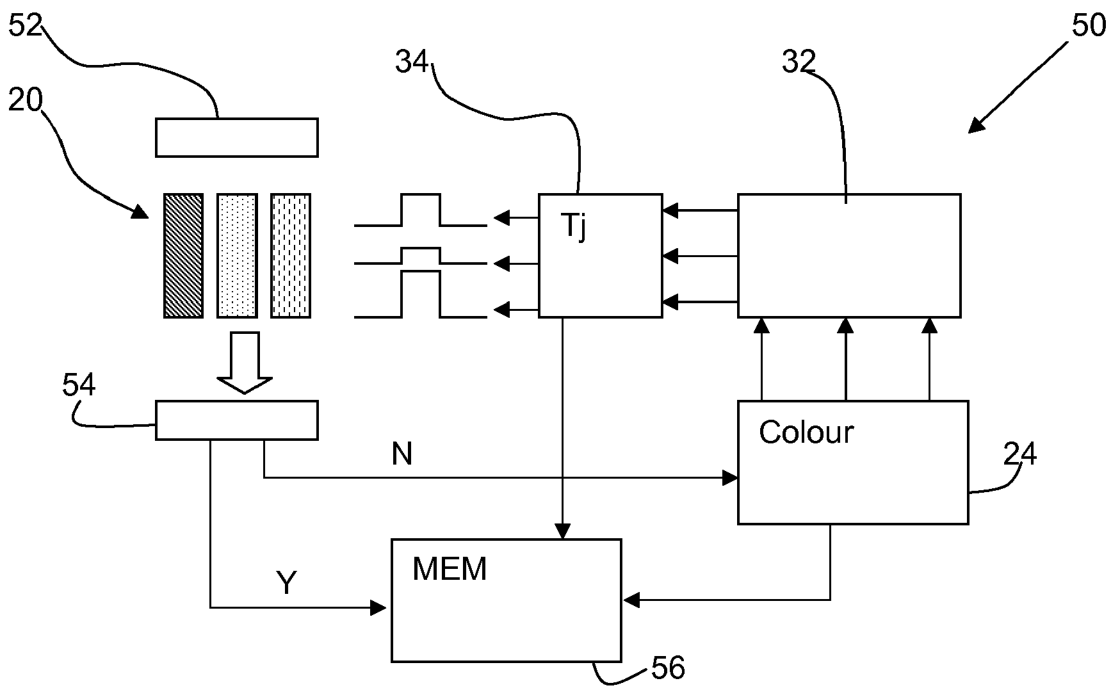


Figure 5

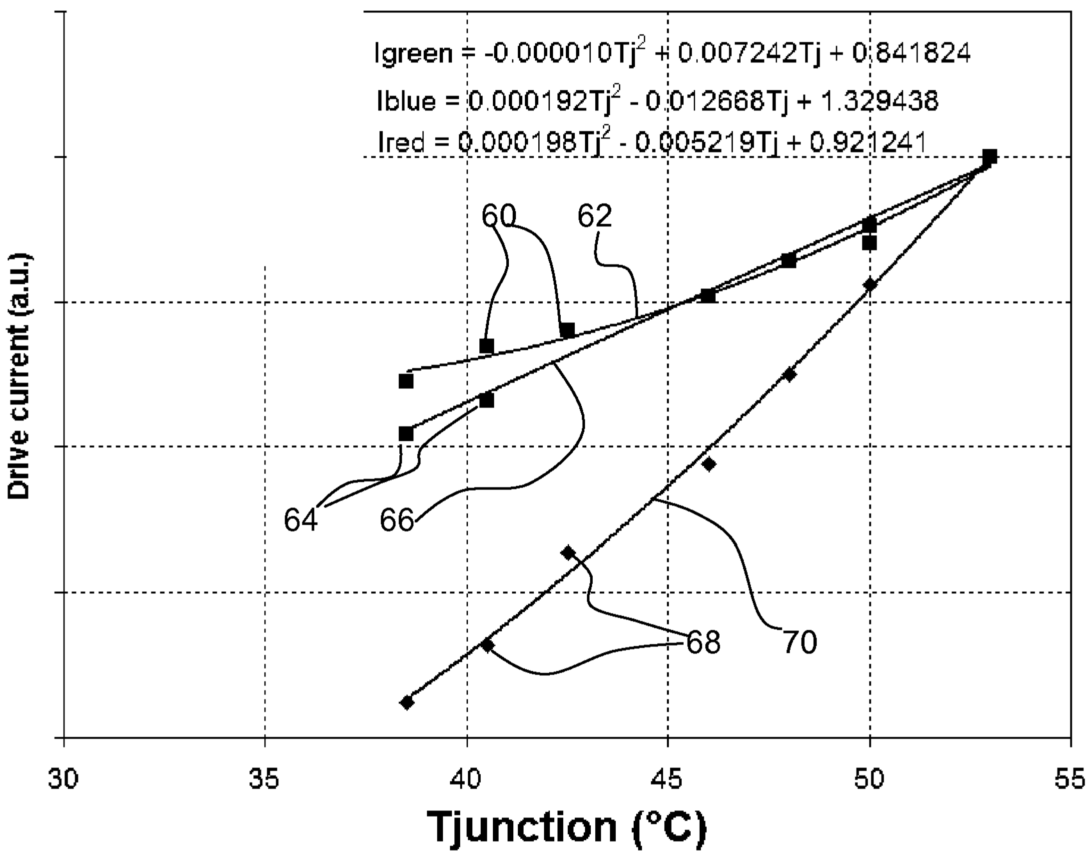

Igreen = -0.000010Tj^2 + 0.007242Tj + 0.841824
Iblue = 0.000192Tj^2 - 0.012668Tj + 1.329438
Ired = 0.000198Tj^2 - 0.005219Tj + 0.921241
60
62
64
66
68
70
Drive current (a.u.)
30
35
40
45
50
55
Tjunction (°C)

Figure 6

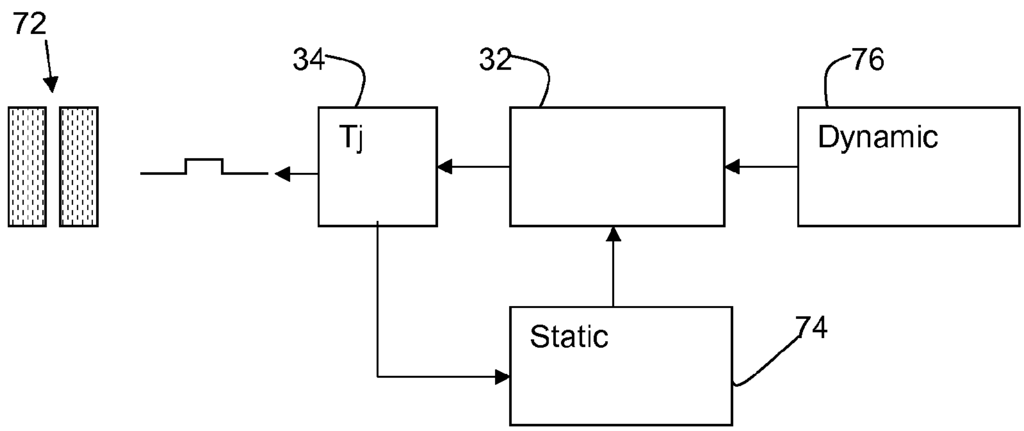


Figure 7

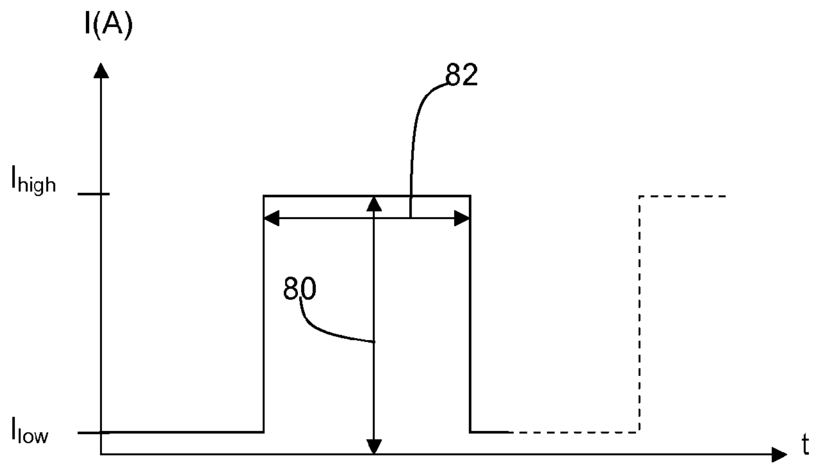


Figure 8

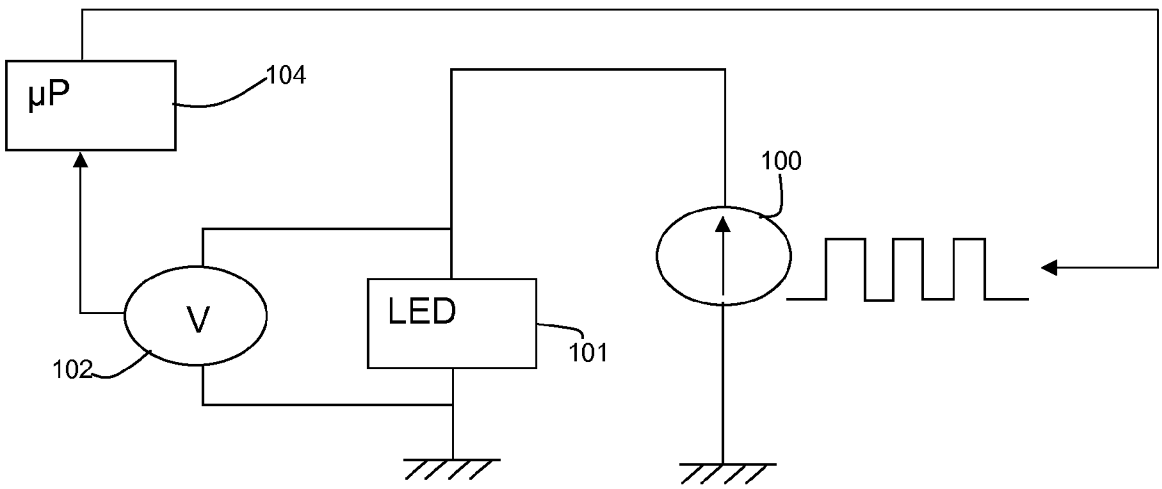


Figure 10

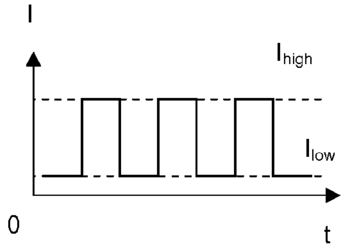


FIG 9A

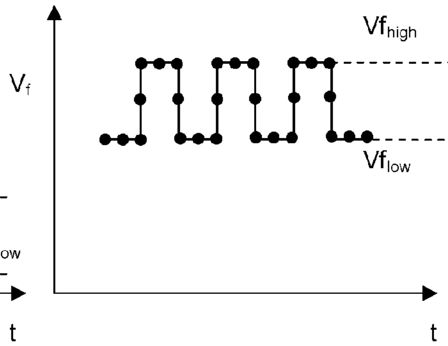


FIG 9B

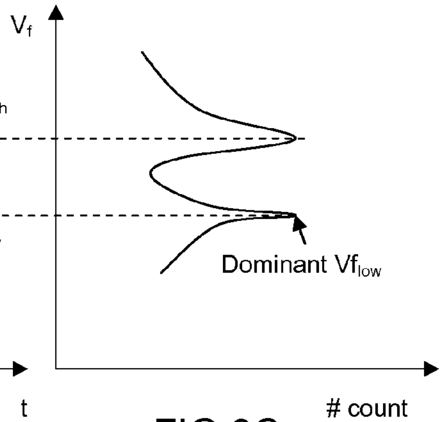


FIG 9C

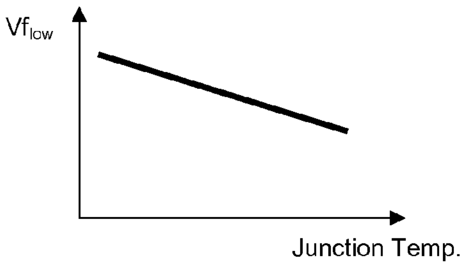
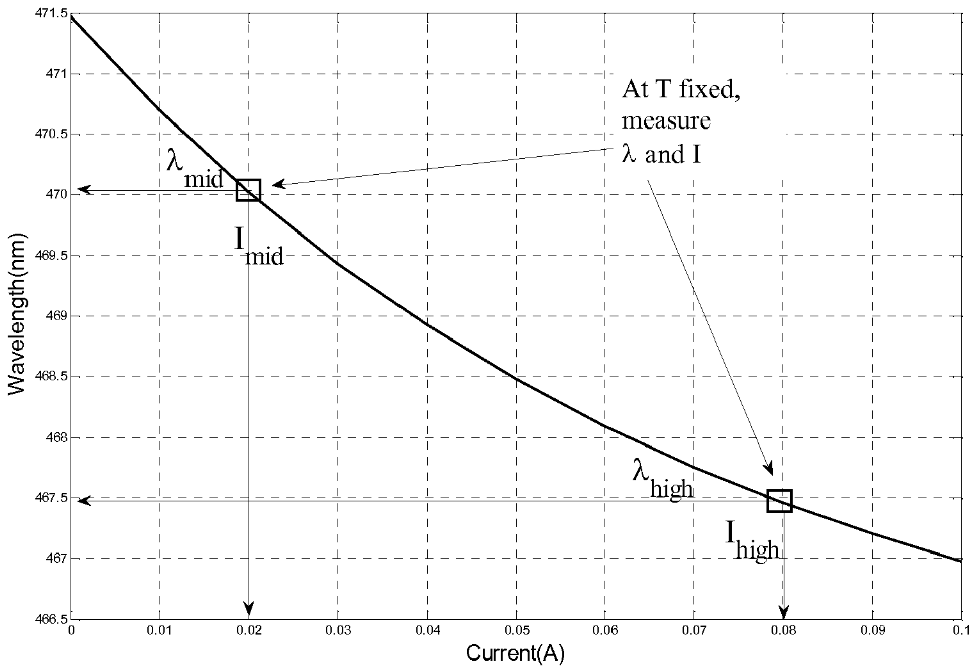


FIG 9D



471.5
471
470.5
470
469.5
469
468.5
468
467.5
467
466.5
Wavelength(nm)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Current(A)
At T fixed,
measure
λ and I
λ_{mid}
I_{mid}
λ_{high}
I_{high}

FIG 11