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Characterization of Nepali Solid-state Lamps

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Introduction

Solid-state lighting technology based on injection electroluminescence devices, light-emitting diodes (LEDs), already found numerous applications in traffic lights, automotive signage, full-colour video displays, liquid-crystal display backlighting, optical measurements, phototherapy, and other niche applications [1,2]. The development of white LEDs based on partial or complete conversion of short-wavelength radiation in phosphors and phosphor blends and recent progress in compound semiconductor and phosphor materials quality and photonic design of the chips resulted in that LEDs are also considered as promising candidates in general lighting. General lighting based on solid-state lamps has a high potential in energy saving, offers vast environmental benefits, and features unsurpassed longevity, reduced maintenance, and functionality [2,3].

In industrialized countries where electrical lighting is very common, solid-state lighting meets high competition from conventional sources of light, such as incandescent, fluorescent, high-pressure sodium, and metal-halide lamps. Meanwhile in developing countries, especially in rural area, LEDs encroach on the lighting market occupied by fuel-based sources, such as firewood and kerosene lamps. Owing to high efficiency, compatibility with off-network and rechargeable-battery-based d. c. sources of electrical power, such as photovoltaic, hydro, wind, and pedal generators, LEDs are the most appropriate sources for such substitution with huge benefits in energy consumption, cost, as well as in resolving education and health issues [4,5]. In particular, fuel-based sources have luminous efficiency below 0.1 lm/W comparing to 15–80 lm/W of present commercial LEDs [4,5] with a potential of attaining 200-lm/W efficiency in the nearest future [6,7]. To this end, penetration of solid-state lighting technology to general lighting might be even faster in developing countries than in industrialized ones, especially with international support taken into account [8].

Solid-state lamps are a novel source for general lighting with no well-established standards developed so far. However because of cost pressure, fabrication of solid-sate lamps for developing countries is drawn to local manufacturing facilities, which lack instrumental characterization. Meanwhile the conditions of exploitation of lighting devices in developing countries are much harsher than in industrialized ones and involve wide ranges of temperature and humidity, variation in driving voltage, and smoking from organic-fuel based stoves. This draws a need in international cooperation on characterization of solid-state lamps manufactured in developing countries.

The present work aimed at the temperature, directional, and chromatic characterization of solid-state lamps manufactured for Rural Integrated Development Services-Nepal (RIDS-Nepal) village illumination programs.

Experimental setup

Two kinds of lamps produced by Pico Power Nepal were investigated. The lamps were designed for the 12.6-V input voltage that is the rated voltage of the deep-cycle lead-acid batteries typically used in combination with solar photovoltaic charging systems. The luminaries contained LEDs, driving circuitry, and flat aluminium reflector assembled within identical stainless steel cases with a sealed glass lid. The luminaries were designed for almost similar luminous flux (11–13 lm) and differed in the model and number of LEDs and driving electronics used. When mounted on the ceiling of a room, such luminaries provide with an illuminance of about 5 lx sufficient for performing simple visual tasks. Meanwhile at a shorter distance, the illuminance can amount 100 lx in magnitude that is sufficient for common tasks, such as reading [5].

The lamp of first kind was based on nine low-power white phosphor-conversion LEDs (*Nichia* model NSPW510BS [9]) with the rated viewing angle of about 50°. The LEDs were connected in three parallel strings each consisting of three LEDs. Each string had a resistive ballast (100 Ω) connected in series for current regulation. Of nine LEDs, eight ones were arranged in a ring (with a slight outside bending in order to provide a wider viewing angle of the lamp) and the ninth one was placed in the centre of the reflector. The rated input power of the lamp was 0.88 W. Here we designate this lamp as low-power LED (LPLED) based lamp. The lamp of the second kind was based on a single white phosphor-conversion high-power LED (*Philips Lumileds Lighting* model LXHL-MW1D [10]) with the rated viewing angle of 110° ("batwing" radiation pattern). The LED was placed in the centre of the reflector and driven by a switching converter based on step-down voltage regulator IC (*National Semiconductor* LM2575). The converter was controlled by a current regulator based on a measurement resistor and an operational amplifier (½LM358N). The lamp was also equipped with a comparator (½LM358N) for power cut-off at low input voltage in order to prevent battery overdrain. The rated input power of the lamp was 1 W. Here we designate this lamp as high-power LED (HPLED) based lamp.

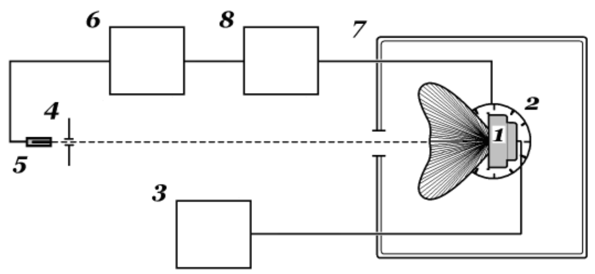

Fig. 1. Schematic view of the experimental setup. (*1*) solid-state lamp; (*2*) rotating stage; (*3*) power supply; (*4*) pinhole; (*5*) optical fibre probe; (*6*) spectrometer; (*7*) climatic chamber; (8) computer

The experimental setup used for the characterization of the lamps is shown in Fig. 1. A lamp (*1*) was mounted on a computer-controlled rotation stage (*2*) (*Standa* 8MR151 driven by a controller *Standa* 8SMC1-USBh). The lamp was driven using a power supply with regulated voltage (*3*) (*Keithley* 2430 *SourceMeter*), which is equipped with digital voltmeter and ammeter. The emission of the lamp was passed through a pinhole (*4*) with the aperture diameter of 2.5 mm and directed to the optical fibre probe (*5*) of a spectrometer (*6*) (*Hamamatsu* model C7473). The pinhole was located at a distance of 20*D* from the lamp, where *D* is the diameter of the lamp front window (77 mm). The lamp and rotation stage were placed within a climatic chamber (*7*) (*ILKA* model *Feutron* 3001-01). The temperature within the chamber was regulated with an accuracy of 2 ºC. A desktop computer (*8*) was used for the control of the experimental setup. The CIE 1931chromaticity coordinates and the correlated colour temperature (CCT) were derived from the recorded spectra using spectrometer software.

Results and discussion

The emission spectra of the lamps at two ambient temperatures are depicted in Fig. 2. The spectra were taken in the front view (along the axis of the lamps) at the input voltage of 12 V. These spectra are typical of standard cool-white phosphor-conversion LEDs. The narrow peak on the short-wavelength side of the spectra (at about 460 nm) is due to electroluminescence of the InGaN chip of the LEDs. The broader long-wavelength band is due to the photoluminescence of the Ce^{3+}-doped yttrium-aluminium-garnet-based phosphor converter. The mixture of blue light emitted by the semiconductor chip and yellow light emitted by the phosphor is perceived as white light.

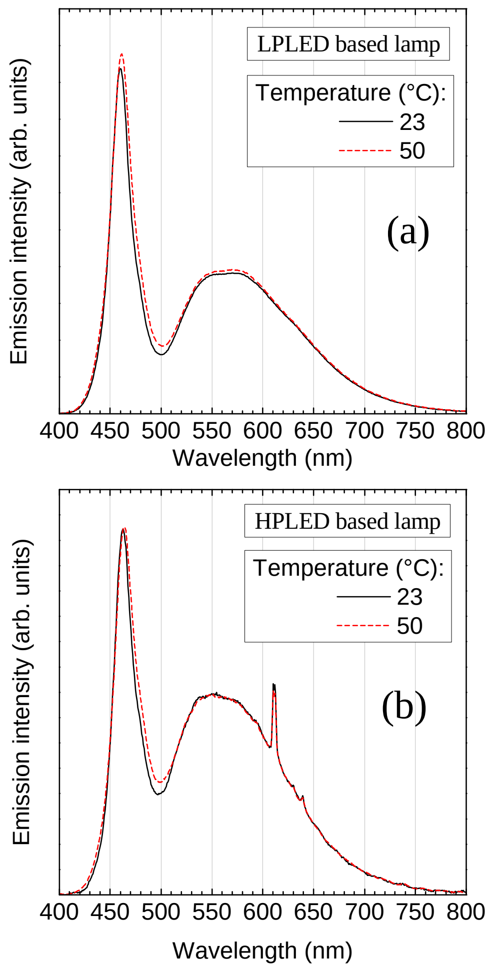

Fig. 2. Emission spectra of solid-state lamps at front view at two ambient temperatures. (a) LPLED based lamp; (b) HPLED based lamp

When ambient temperature is increased from 23 °C to 50 °C, both spectra exhibit some broadening and long-wavelength shift of the blue line typical of near-band-gap emission from semiconductors, whereas the yellow line due to phosphor maintains almost constant shape and spectral position. Note that the overall emitted flux increases with temperature, although LEDs have negative temperature coefficients of output due to thermally activated nonradiative recombination. Therefore the observed increase of output with temperature must be attributed to the peculiarities of the driving circuits, which provide LEDs with a higher electrical power at elevated temperatures as discussed below.

Fig. 3 depicts the dependence of driving current on temperature for the lamps investigated at the input voltage of 12 V. The LPLED based lamp exhibits an increase of current with temperature (circles in Fig. 3). Such an increase is duo to resistive ballast used and can be understood in terms of a negative temperature coefficient of the LEDs forward voltage, which has typical values of about −2 mV/°C. For three LEDs connected in a string, this results in a decrease of the voltage drop over the string of about 160 mV, when temperature is increased from 23 °C to 50 °C. A corresponding increase of the voltage drop over the ballast resistor results in an increase of the driving current and in a small increase of the flux generated (Fig. 2a) despite the negative temperature coefficient of the LED output.

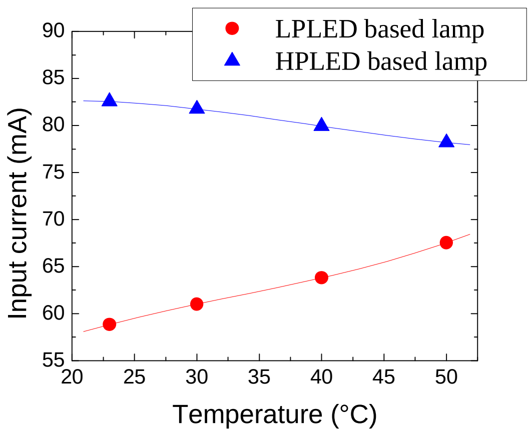

Fig. 3. Input current vs. ambient temperature dependence for two types of solid-state lamps. The input voltage is maintained at 12 V

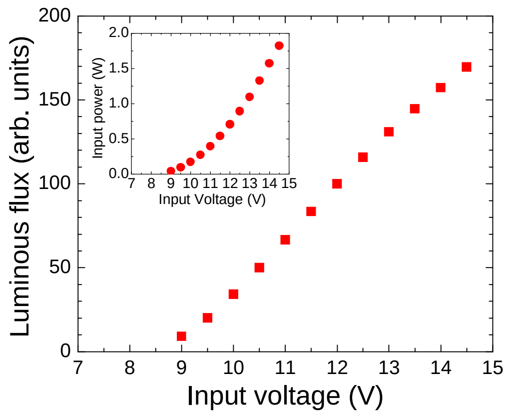

Fig. 4. Luminous flux vs. input voltage dependence for the LPLED based lamp. The inset shows the electrical power vs. input voltage dependence

Although the resistive ballast used in the LPLED based lamp is sufficient for almost temperature-coefficients of the LED forward voltage and output, such a driving circuitry is unable to ensure stability of the lamp against the variation of the input voltage. Fig. 4 shows luminous flux as a function of input voltage for theLPLED based lamp with resistive ballast. The flux is seen to almost linearly increase with input voltage with a coefficient of 30 %/V at the rated input voltage of 12 V. The reason is a steep dependence of electrical power vs. input voltage (inset in Fig. 3) that is due to the resistive ballast based driving circuit. Such a variation of the flux independent output due to the interplay of the temperature with input voltage aggravates the use of standard lead-acid deep-cycle batteries that are very common in rural lighting installations. With a typical variation of the deep-cycle battery voltage from ~11 V (uncharged) to 14.4 V (fully charged), the output of such a lamp varies by about 250%.

Triangles in Fig. 3 show the dependence of input current on temperature for the HPLED based lamp that is driven by the electronic ballast. The input current is seen to decrease with temperature. Since the electronic ballast has a circuitry for the regulation of the LED driving current (this results in almost temperature-independent output of the lamp), the observed decrease of the input current with temperature can be attributed to an increased efficiency of the ballast at elevated temperatures.

However, the main advantage of the electronic ballast used in the HPLED based lamp is a high stability of the output flux against input voltage (Fig. 5). For the input voltage ranging from 11.75 V (start-up voltage of the built-in battery overdrain protection circuit) to 17 V, the output flux varies by less than 2%. This is due to a small variation of the input power (inset in Fig. 5) provided by the electronic ballast. Since the corresponding variation in illuminance is almost indistinguishable by human vision, the electronically ballasted HPLED based lamp is much more appropriate for using it in deep-cycle battery based lighting installations.

The measured angular distribution of the spectrally integrated luminous intensity for both the two solid-state lamps is depicted in Fig. 6. Solid and dashed lines present data obtained at 23 °C and 50 °C, respectively. The LPLED based lamp (Fig. 6a) has a narrow viewing angle.

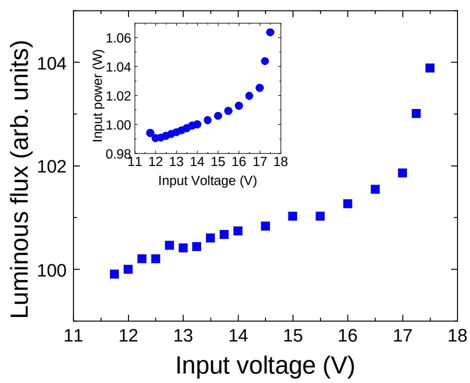

Fig. 5. Luminous flux vs. input voltage dependence for the HPLED based lamp. The inset shows the electrical power vs. input voltage dependence

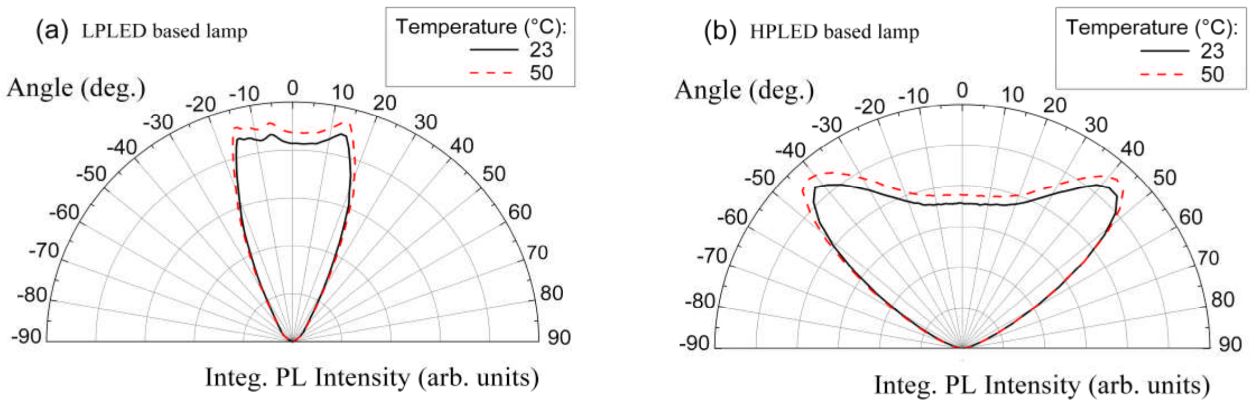

Fig. 6. Angular distribution of integrated PL intensity for solid-state lamps based on LPLEDs (a) and HPLEDs (b). Solid lines and dashed lines correspond to 23 °C and 50 °C ambient temperatures, respectively

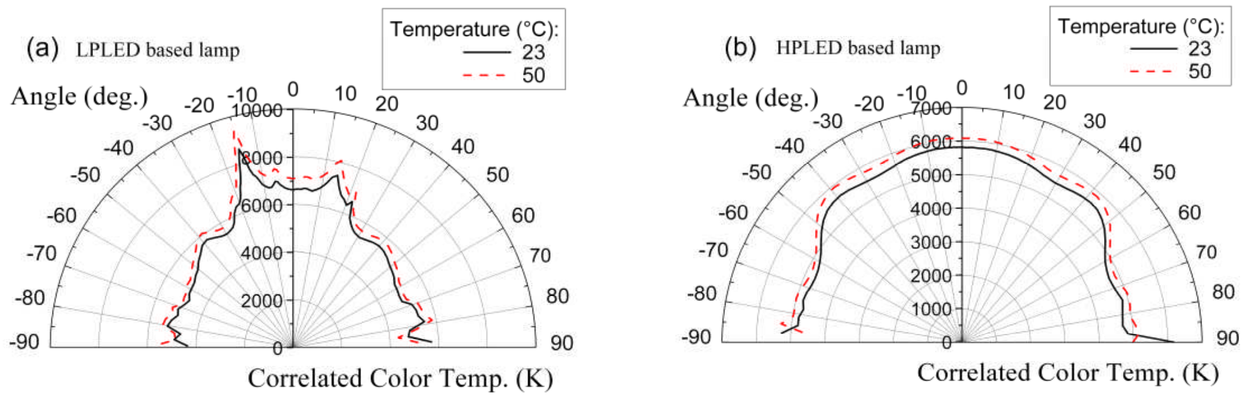

Fig. 7. Angular distribution of correlated colour temperature CCT for the solid-state lamps based on LPLEDs (a) and HPLEDs (b). Solid lines and dashed lines correspond to 23 °C and 50 °C ambient temperatures, respectively

of about 50 degrees, whereas the HPLED based lamp (Fig. 6b) exhibits a "batwing" angular distribution with the viewing angle of 113 degrees and two peaks at about 42 degrees in both directions from the front view. A small asymmetry can be traced in the angular distribution of the LPLED based lamp, probably, due to the deviations in the arrangement of the nine LEDs. Basically, since the measured viewing angles are in line with the rated viewing angles of the LEDs, one can conclude that the reflector and the front glass lid play a minor role in the formation of the angular distribution of intensity.

With increasing ambient temperature, both lamps are seen to exhibit a small increase in luminous intensity, while the angular distribution of luminous intensity remains almost unchanged.

The angular distribution of correlated colour temperature (CCT) is shown in Fig. 7. At 23 °C, the LPLED based lamp has CCT of about 6610 K in the front view and a noticeable variation of CCT from about 5700 K to about 8600 K within the viewing angle of 50 degrees. Such variation can be tolerated in performing simple visual tasks, such as orientation. However in can cause inconvenience in performing common visual tasks, such as reading. Differently, the HPLED based lamp has CCT of about 5800 K in the front view with a less important drop to about 5000 K at the boundaries of the viewing angle.

With ambient temperature increased to 50 °C, the shape of the angular distributions remains almost unchanged. However, an increase in CCT by up to 10% is observed in all directions. Such variations in CCT are almost indistinguishable by human vision and can be tolerated in most visual tasks.

More details of the chromatic behaviour of the investigated lamps are shown in Figs. 8 and 9 that depict a portion of the CIE 1931 diagram with the Planckian locus, which contains chromaticity points of blackbody radiators at different temperatures. Figure 8 shows the chromaticity coordinates of the two lamps as functions of the angular displacement from the in-axis position. One can see in Fig. 8 that with increasing angular displacement, the coordinates are shifting towards upper right corner of the diagram, what corresponds to the aforementioned drop in CCT (Fig. 6). These angular distributions of CCT are due to peculiarities of the LED design, in particular due to the position of the phosphor layer in respect of the semiconductor chip. At high angular displacements the blue light passes a larger distance through the phosphor layer in comparison with that along the in-axis direction. This results in that a larger portion of the blue light is absorbed in the phosphor layer and the blue to yellow intensity ratio decreases. In terms of the chromaticity diagram, such a decrease means a shift outwards from the "blue" (lower left) corner of the diagram. Note that with approaching the "blue" corner, the colour discrimination

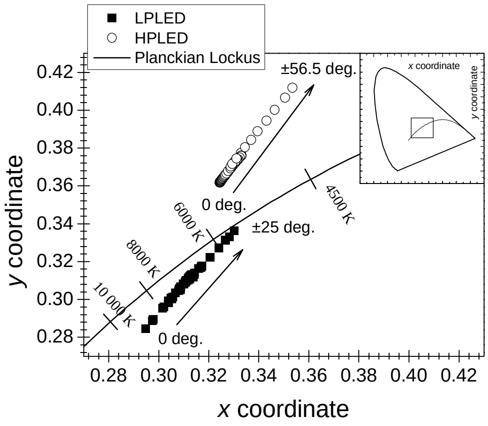

Fig. 8. Location of the chromaticity points on a segment of the CIE 1931 diagram as a function of angular displacement within the viewing angle for LPLED and HPLED based lamps. The inset shows the position of the segment in the diagram

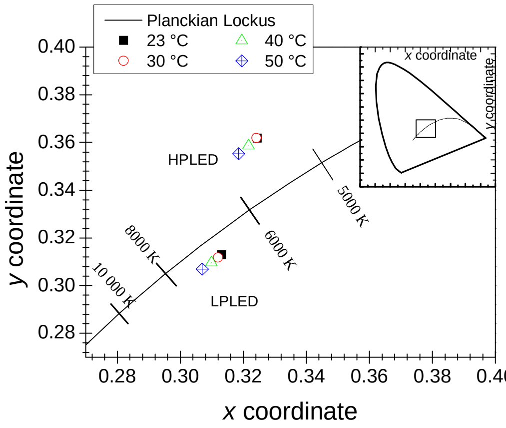

Fig. 9. Location of the chromaticity points on a segment of the CIE 1931 diagram as a function of ambient temperature for front-viewed LPLED and HPLED based lamps. The inset shows the position of the segment in the diagram

ability of human vision increases. Therefore, the chromaticity shift of the LPLED lamp and the corresponding drop in correlated temperature are more visually noticeable than those of the HPLED lamp.

Fig. 9 shows the chromaticity coordinates of the two lamps as functions of ambient temperature for front view. With increasing ambient temperature the chromaticity points are seen to shift towards the "blue" corner of the diagram, what corresponds to the aforementioned increase in CCT (Fig. 7). Such chromatic behaviour can be attributed to thermal quenching of the phosphor emission that results in an increase of the blue to yellow intensity ratio (such an increase can be implied in Fig. 2, where an increase of the spectrally integrated blue emission in respect of the yellow one can be traced). In terms of the chromaticity diagram, an increase in the blue to yellow ratio means a shift toward the "blue" corner of the diagram.

Conclusions

Solid-state lamps manufactured in Nepal for village illumination programs were characterized by measuring the input current, optical output, radiation pattern, and chromaticity characteristics as functions of temperature. Also, the variation of the output flux with input voltage was examined. The lamps exhibited stability of output flux and chromaticity against temperature variation irrespectively of the driving circuit and model of white LEDs used. However, the LPLED based lamp with resistive ballast was found to feature a high sensitivity of output flux to input voltage in comparison with the electronically ballasted HPLED based lamp. This implies that electronic ballasts are preferred in deep-cycle battery driven lighting installations based on LEDs. (At the time of publishing of this paper, Pico Power Nepal has already upgraded LPLED based lamps by the introduction of a switching regulator and battery-overdrain protection circuit.) Also, some models of LEDs were found to have a large variation of CCT within the viewing angle what might cause visual inconvenience in performing some common tasks, such as reading.

Acknowledgment

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Two in-door solid-state lamps produced in Nepal for village illumination programs were investigated. The lamps, which are based on white phosphor-conversion LEDs and have different driving circuits (resistive ballast or switching converter), where characterized by measuring the input current, optical output, radiation pattern and chromaticity characteristics as functions of temperature. The variation of the output flux with input voltage was examined. The generated flux, chromaticity, and radiation pattern exhibited stability against temperature variation irrespectively of the driving circuit. The lamp based on the resistive ballast showed a high sensitivity of the output flux to input voltage. Also, for some models of the LEDs used, a noticeable variation of the correlated colour temperature within the viewing angel was observed. Ill. 9, bibl. 10 (in English; summaries in English, Russian and Lithuanian).

М. Каралюнас, П. Витта, А. Жукаускас, А. Цанд, Д. Биста, Б .Б. Чхетри, М. Р. Упдхяя. Характеризация светодиодных ламп, изгатовленых в Непале // Электроника и электротехника. – Каунас: Технология, 2009. – № 1(89). – С. 29–34.

Исследованы две твердотельные лампы для внутреннего освещения, изготовленные в Непале по программе сельского освещения. Лампы основаны на белых конверсионных фосфорных светодиодах и имеют разные цепи питания (резистивный балласт или импульсный преобразователь). Они характеризованы путём измерения входного тока и характеристик оптического выхода, направленности и цветности в зависимости от температуры. Так же измерялась зависимость выходного потока от входного напряжения. Выходной поток, цветность и диаграмма направленности обладают температурной стабильностью вне зависимости от цепи питания. Выходной поток лампы с резистивным балластом сильно зависит от входного напряжения. Для некоторых типов применяемых светодиодов обнаружено заметное изменение коррелированной цветовой температуры в пределах угла видимости. Ил. 9, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

M. Karaliūnas, P. Vitta, A. Žukauskas, A. Zahnd, D. Bista, B. B. Chhetri, M. R. Updhyaya. Nepale pagamintų kietakūnių šviestuvų charakterizavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 29–34.

Ištirti du vidaus apšvietimui skirti kietakūniai šviestuvai, pagaminti Nepale pagal kaimo apšvietimo programas. Jie pagrįsti baltais konversijos fosfore šviestukais (šviesos diodais) ir turi skirtingas maitinimo grandines (varžinį balastą arba jungiklinį keitiklį). Įtaisai charakterizuojami matuojant įėjimo srovės, optinio išėjimo, kryptingumo ir spalvio charakteristikų priklausomybę nuo temperatūros. Taip pat tirtas išėjimo srauto kitimas sulig įėjimo įtampa. Parodyta, kad generuojamas srautas, spalvis ir kryptinė diagrama pasižymi temperatūriniu stabilumu nepriklausomai nuo maitinimo grandinės. Tuo tarpu šviestuvo su varžiniu balastu išėjimo srautas stipriai priklauso nuo įėjimo įtampos. Taip pat naudojant kai kurių modelių šviestukus, aptiktas pastebimas koreliuotosios spalvinės temperatūros kitimas matymo kampo ribose. Il. 9, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).