Possibility of Bandwidth-Widening with Luminescent Layer in LED Structures

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Abstract— **LEDs are the most innovative light sources in lighting technics as well as industrial application. LEDs compared to incandescent bulbs have lots of advantages, but important disadvantage of their application are temperature sensitivity and relative narrow spectrum.**

To widening bandwidth there are several known solutions, e.g. application of phosphor, but these structures have many disadvantages, e.g. different ageing, loosing of good focusability, etc. One of the possible solutions is application of multiple layers of different composition, and realizes several radiation peaks with luminescence.

The method we use for wavelength broadening is growing luminescent layer. It means application of multiple layers of different composition, where the light originated from active layer exits the LED unchanged only partially, meanwhile remainder radiation excites additional layer(s), and realizes several radiation peaks with luminescence.

Wavelength converter achievable with two luminescent layer also, results three wavelength photon emission.

Index Terms—**GaInAsP; LED; luminescence; multi-wavelength.**

INTRODUCTION

The white light emitting LED light source has become dominant in the advanced lighting technology in recent years. Despite the fact that LEDs replace varied light sources with very different properties, most of these LEDs have blue light – yellow phosphor structure.

Because of LED has narrow bandwidth, the broadening is necessary in lighting applications, and there are several well-known methods exist. One of the possible ways is multi-color LED, mostly red-green-blue (RGB) LED which means three chips in one package or three independent LED structure grown on common substrate. The wide spread solution is the blue LED completed with yellow phosphor. Other ways are the blue LED with yellow + red phosphor or yellow + green phosphor. Solutions of combination of two above well-known also, e.g. blue and red LEDs in common package completed with yellow phosphor.

The phosphor and the substrate of phosphor cause considerable losses. The point wise of LED decreases several orders of magnitude, (though most lighting applications still point-like). The phosphor has thermal contact with the LED and higher temperature affects ageing phosphor also.

The RGB LED operates with additive mixing of three basic color light, which is causing a sense of white. It has much worse color rendering than LEDs with phosphor, because the radiation ranges of individual diodes are very narrow and these covers very small parts of the wide visible range (380-780 nm).

Operation of the three diode problematic because of working points should be adjusted individually and must be continuously corrected as different ageing happened.

These problems have incurred in visible range, are even greater in the case of LEDs for measurement purposes. The following InP-based GaInAsP LEDs operating in the near infrared range, and these are can be light sources of spectrophotometric measures in handheld instruments. The energy source of handheld devices is limited, so tempering is not possible. The LED suitable for measurement in handheld devices has to be almost temperature independent operating ranges without tempering as well. The only-one LED is not a sufficient for spectrophotometric measurements because radiated narrow range. The customized widening of radiation bandwidth is necessary for specific wavelengths or wavelength ranges Meanwhile it is important to keep LED point wise, remember, we have to make 3-5 orders of magnitude smaller point-like light source than usual in lighting applications.

It can be seen that requirements above are strict, neither phosphor solution nor multichip solution can satisfied. Different solutions exist for bandwidth widening also, e.g. tandem-LED, quantum-LED. In our experiment we performed luminescent layer for band widening. The results, if partially, will hopefully be useful for researches in visible range as well.

EXPERIMENTAL

E. Requirements of LEDs in NIR hand-held spectroscopy

Near infrared (NIR) spectroscopy is suitable to detect -OH, -NH, -CH functional groups in organic materials, with absorbing resonant wavelength of stretching vibrations typical of these bonds. The presence of organic materials and their concentration can be inferred from the detection of material-specific functional groups. The bond vibration wavelengths are λ=3-4μm in these functional groups, however, in practice, in orders of magnitude smaller signals can be effectively measured in the range of 1st-3rd harmonics (λ=1000-1800 nm) due to better signal to noise ratio of shorter wavelength detectors. Another advantage is that the short wavelength radiation penetrates deeper into the material, this way the volume composition of samples can be measured.

The incandescent lamp was the typical traditional light source of NIR spectroscopy earlier. The maximum radiation of incandescent lamps is in this range 1000-1200 nm (depending on temperature of filament), but the wavelength range necessary for the measurement is narrow within the wide range of radiation. The useful radiation power compared to the power consumption of incandescent lamp is very small, the efficiency is poor. The LED as radiation source of NIR spectroscopy compared with the incandescent lamp has a lot of advantages [1]. The LED wavelength range is narrow and can be planned. The advantages of LEDs are their short response time (x*10-9 s), good focusability, high efficiency, low power consumption, and multiple expected lifetime compared to incandescent lamps [2]. The latter features of LED make it especially suitable for use in hand-held devices, allowing faster and less expensive measurement than before.

Typical application areas are for example biological samples, human health diagnostics, measurements of agricultural crops, measurements in oil industry, environmental and plastics industry measurements.

The disadvantage of LEDs comes from one of their advantageous features: the narrow range of radiation allows a specific wavelength measurement only. To detect or determine the concentration of a specific organic material measurements have to be taken at several (at least two) wavelengths, because they should be distinguished from other present substances in the environment (this usually means water or other organic materials). To achieve this, the operation of several (typically three) different wavelength LEDs is mostly common in current practice. The drawback of the solution is that the radiation source is not entirely focusable, and the temperature dependence and aging parameters of various wavelength emitting LEDs are different. The ideal source of radiation is a single semiconductor structure that emits a wide band range while it has minimum temperature dependence.

F. Selection of suitable materials

The wavelength range of compound semiconductor LED has to be tunable by changing the composition of the active layer, and it should be in λ=1000-1800 nm range. As it shown in Fig. 1., the GaInAsP compound semiconductor is suitable as an efficient NIR radiation source.

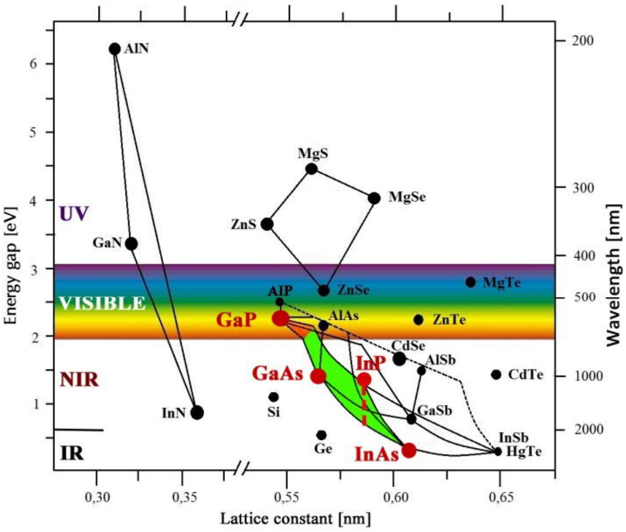


Fig. 1. Lattice constant – band gap relationship in some important semiconductor materials [5]. Along the vertical dashed line tunable wavelength NIR semiconductors lattice-matched to InP are made possible. [3]

In order to tune the wavelength of the radiation the composition of the active layer has to be changed, however, the lattice constant usually changes along with it. The errors caused by lattice-mismatch reduce the efficiency of the LED. The wavelength is tunable in the GaInAsP/InP material system meanwhile the lattice-constant remains unchanged. GaInAsP lattice-matched to InP LED structure can be prepared in the 960-1670 nm wavelength range where the substrate absorption is negligible [3, 4]. The dashed line through InP shows the actual compounds lattice-matched to InP in Fig. 1.

Liquid phase epitaxy (LPE) is an ideal method for growing thin layers, where thicknesses and composition must be tuned up accurately, and because it is relatively cheap and easy.

G. *Broadening with luminescent layer*

The measurement range in handheld spectroscopy of organic materials are generally wider than the bandwidth of a single LED therefore a wider wavelength range of operation is preferred.

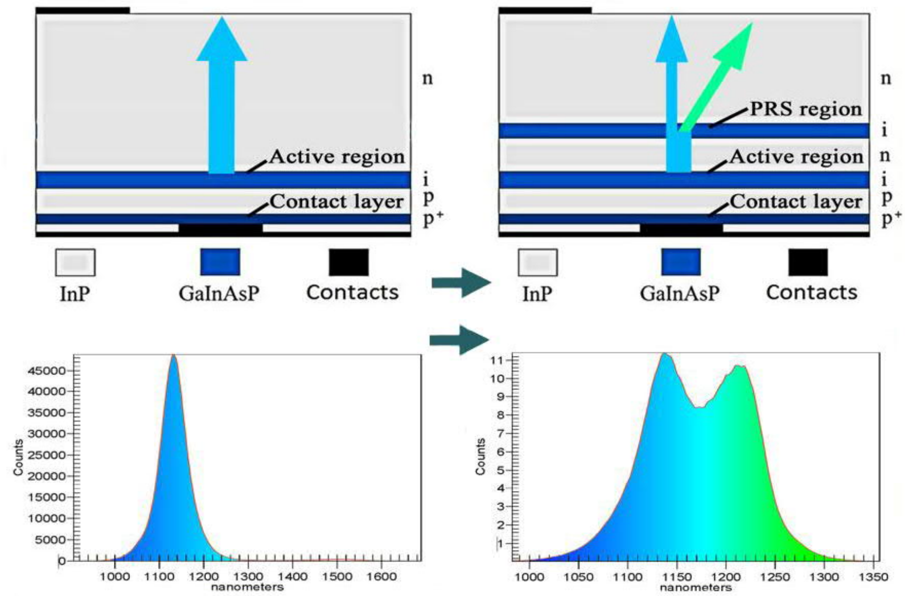
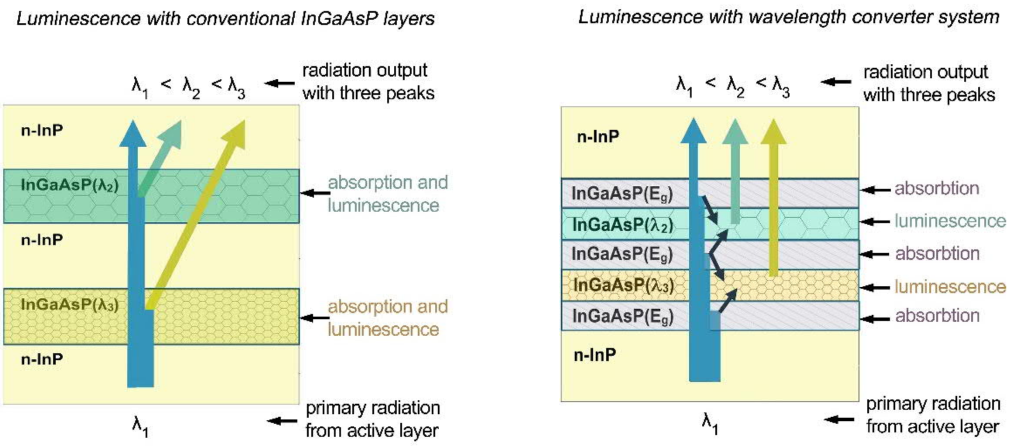


Fig. 2. Ordinary layer stucture and spectra of InGaAsP/InP LED (left) and layer structure including a luminescent layer with widened spectra (right).

The method we use for wavelength broadening is growing luminescent layer. We were grown LEDs by liquid phase epitaxy (LPE) because it is an ideal method for growing thin layers, where thicknesses and composition must be tuned up accurately. On the other hand it is relatively cheap and easy, material-saving, relatively quick and typically fit to research purpose production.

To grow luminescent layer means application of multiple layers of different composition, where the light originated from active layer exits the LED unchanged only partially, meanwhile remainder radiation excites additional layer(s), and realizes several radiation peaks with luminescence [6, 7]. Fig. 2. shows usual layer structure compared with luminescent structure.

A single chip luminescent LEDs are capable of emitting light in wide wavelength range, so they can find application as light sources for modern detector diode array spectrometers. To grow efficiency of LEDs and to make more sophisticated spectra we deigned a new structure.


Luminescence with conventional InGaAsP layers

Luminescence with wavelength converter system

Fig. 3. Schematic luminescent layer structures of GaInAsP/InP NIR LED for radiating three wavelength peaks: luminescence with conventional InGaAsP layers (left), luminescence with wavelength converter system (right).

Fig. 3. shows a completely new structure we built on the right side opposite the earlier on the left side. The difference compared to the previous structure is the separation absorption and emission, into separate layers. The emission layers are embedded in absorption layer. The built in narrow band gap GaInAsP layers serve as potential well enhancing the direct recombination of the optically excited charge carriers. The emission layers have lower band gap than the active layer and the first absorption layer. The free charge carriers diffuse to neighboring (lower band gap) emission layer, within free path distance and radiating at higher wavelengths. The λ3 radiation passes through the λ2 luminescent layer unchanged, because its highest wavelength, as well as absorption layers are transparent for λ2 and λ3 luminescent radiations also. Light emitting layers are close to each other.

RESULTS

The intensity of LED emission at different part of the spectrum may vary in opposite direction due to changing the operation temperature. This could result in measurement errors which is difficult to correct. [8, 9] The shift of the emission spectrum of multi wavelength LEDs is a sum the change of the emission spectra of its components. Temperature dependence of the spectrum can be design in two ways. Important sections for a given measurement points can have the same temperature coefficients, or can have near zero between the two adjacent peeks of the LED. Owing to this, another possible area of use is application to meet the needs of small temperature-dependent use, especially in handheld instrumental measurements, where complex circuit correction cannot be realized because of simplicity, or temperature correction because of low power consumption.

We were grown various LEDs, and measured LED characteristics as a function of driving current and temperature. As temperature increases, the peak of the emission spectrum shifts towards higher wavelengths, while the efficiency is decreasing. The peak wavelength shows a slight blue shift at high current, but this does not compensate the heat-induced red shift, only reduces it at real operating conditions [5]. Therefore, the measured temperature dependence is important in practice. Radiation peaks of active layer and luminescent layer can be near and far. In both cases, nearly temperature independent sections are formed. 1120-1230 nm LED has relatively near peak points. Based on measurements in accordance with the theoretical calculations nearly temperature-independent linear section formed between two radiation peaks (Fig. 4.). Changes in the relative intensity in 1150-1200 nm range are within 1%

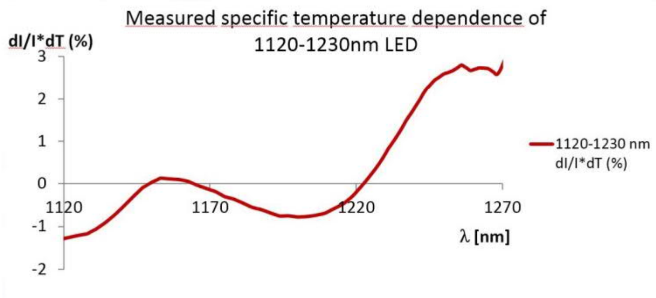


Fig. 4. The luminescent LED with near peak points has nearly temperature independent section between two peak points

In other case with far peak points, temperature dependence of 1200-1400 nm LED were measured. It can be corrected linearly at peak wavelengths. Temperature independent sections are created above peak wavelengths of 20-50 nm (Fig. 5.). These sections are particularly suitable for measuring if there is proper amplitude and detector sensitivity. To do so, the wavelengths of LED should be tuned so that these wavelength values will set to be on sections of measurement.

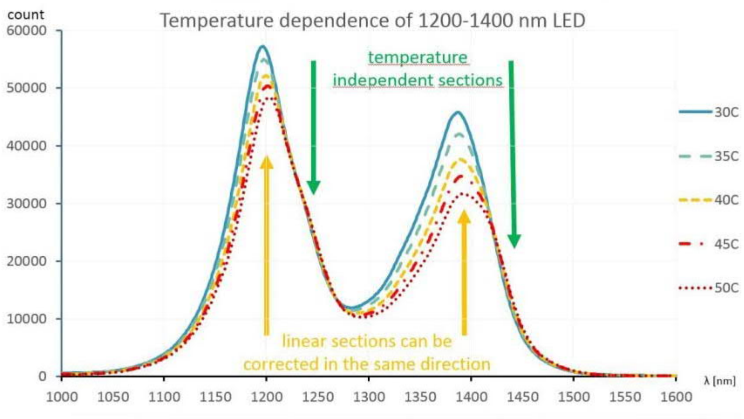


Fig. 5. The luminescent LED with far peak points has temperature independent sections above peak pionts

Fig. 6. compares temperature dependences of a luminescent LED and a common LED with active layer only. The grey line show reference values at 25°C for both LEDs. Continuous colour lines show changing radiation intensity of

luminescent LED at different temperatures, scattered lines show the same in case of LED without luminescent layer. Radiation intensities decrease below peak wavelengths by increasing temperature, in both cases. Intensities increase by increasing temperature above peak wavelengths and setting to nearly constant values. Maximum intensities shift to longer wavelengths. Low temperature dependence section formed between two peak wavelengths of luminescent LED thanks to the opposite effects.

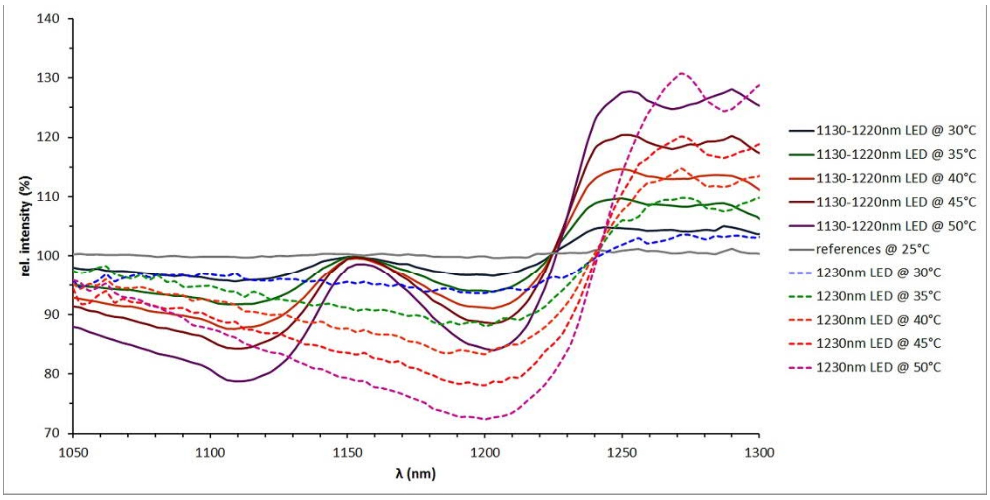


Fig. 6. Temperature dependences of a LED with luminescent layer 1130-1220nm peaks and without it 1230nm peak radiation

Our new layer structure shown on Fig. 3. has further advantages. The efficiency of this layer structure is more than ninety percent. Intensities can be adjusted by the thicknesses of each layer, similarly, as the above-mentioned structure, but considering the absorption of the intermediate layers as well is developing a complex system of layers, wherein the interaction between layers is very important. We made it by Liquid Phase Epitaxy and absorption layers serve as anti meltback layers also, therefore it performs two function at the same time. This type of structure works similarly than phosphor conversion white LED structure, but it is more compact and stable, because all layers are lattice matched to the substrate.

CONCLUSION

GaInAsP/InP LEDs with spatially and spectrally stabile broad emission spectrum can be prepared in a single semiconductor structure. The LED structure contains an electrically pumped active layer at p-n junction as a primary light source, and a wavelength converter region required for broadening the spectrum of the device by luminescence. The wavelength of the active and luminescent layer(s) and their intensity is tunable with material composition, and the layer thicknesses. This allows to grow LEDs which are efficient, precisely tuned to the desired wavelength in wide range, narrow beam and almost independent of temperature. Two-wavelength LED in several wavelength range was developed and characterized. The device structure has closely spaced emitting layers and small emitting area. The emission of the LEDs broadened in a new way keeps the focusability, it is almost independent of temperature, can be accurately tuned to a desired wavelength range and the spectral intensity is adjustable. The LED is suitable for the specified purpose as a light source of NIR handheld spectrometer, it has high efficiency and almost temperature independent.

Our results can be used in the visible range, but still need to improve a lot. The operating principle can be used in other material systems as well as in visible range, but only partial results can be expected with 2-3 luminescent layer because wider visible range and larger lattice constant differences. The EU had set a goal for 2020 that the luminous efficiency of commercial white LED reach 242 lm/W. We do not know how to increase the efficiency of LEDs over it, but it is a possible way to the future.

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