AGENDA of presentation "SimuLED – engineering tool for LED and laser diode design and optimization"

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We will present the SimuLED package (http://www.str-soft.com/products/SimuLED/) aimed at design and optimization of advanced light emitting diodes (LEDs) and laser diodes (LDs) made of III-nitride and II-oxide compounds. These new semiconductor materials possess a number of extraordinary properties, like spontaneous electric polarization, strong piezoeffect, a low activation efficiency of p-type impurities, etc., which hamper intuitive development of these devices based on analogies with conventional III-V and II-VI compounds.

The SimuLED package consists of three modules, SiLENSe, SpeCLED, and RATRO, that may be used in combination with each other or in stand-alone manner.

SiLENSe is a 1D simulator providing comprehensive understanding of operation of LED or LD heterostructures. It models the electron and hole transport, carrier injection in the active region, and their radiative and non-radiative recombination. All important recombination mechanisms are accounted for, i. e. (i) radiative recombination of electrons and holes, (ii) their non-radiative recombination at threading dislocations (within an original model) and point defects, and (iii) Auger recombination that has been recently demonstrated to control the internal quantum efficiency (IQE) of blue and green LEDs. The simulator predicts also the IQE dependence on various factors and heterostructure design, computes the light emission spectra and provides necessary data for other module – SpeCLED. Internal editable database of the materials properties is supplied along with the package. The SiLENSe simulator is found by many customers to be helpful not only for device engineers but also for people growing LED and LD heterostructures and interested in their operative assessment.

SiLENSe-Laser Edition simulator has additional options – 1D analysis of waveguide formed in the LD heterostructure and calculation of specific laser parameters and characteristics like optical confinement factor for TE- and TM-modes, threshold current density, free-carrier losses, optical gain, etc. The waveguide simulation considers rigorously the birefringence in wurtzite III-nitride and II-oxide semiconductors and the effect of metallic electrodes on the waveguide mode intensity distributions.

SpeCLED package provides coupled 3D modeling of current spreading and heat transfer in planar and vertical LED dice. These two processes are interrelated, so that the chip design and optimization require accounting for both of them. The SpeCLED simulator generates valuable information on the influence of the electrode geometry and contact layer parameters, like dopant concentration and thickness, on the current spreading and local active region overheating. The internal model of anisotropic electrical conductivity of the contact layers enables accounting for superlattice effects on the current spreading in an LED die. The characteristics of the LED, i. e. total current through the diode at a certain forward voltage, output optical power, external and wall-plug emission efficiency, differential resistance, etc. can be obtained by user from the simulations by SpeCLED. The package may either use the results of modeling a particular LED structure by SiLENSe or operate in stand-alone manner, utilizing the parametric input of a number of heterostructure characteristics. Internal visualization tool helps to analyze the computed distributions of the current density, temperature, emission wavelength and efficiency in the dice. The SpeCLED simulator is especially helpful for the people designing visible and ultraviolet LED chips. The package provides also the necessary information for the ray-tracing analysis of light propagation in and extraction from the LED.

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RATRO module serves for the 3D ray-tracing analysis. It takes into account the non-uniform light emission intensity in the LED active region and considers various shapes of the substrate. RATRO computes the light extraction efficiency, which is used in the SpeCLED simulator to calculate the output optical power of an LED and its emission efficiency. The RATRO module considers wavelength dependence of refraction and absorption indices of the semiconductor, substrate and epoxy materials, accounts for the light absorption in the bulk of the device heterostructure and effects of light interference occurring in thin metallic layers, including multiple layers of a complicated structure. The advanced approach is used for simulation of light interaction with the textured surface allowing analyze the effect of surface patterning on light extraction. Simulator allows operation with polarization light predicting polarization degree in the far field.

The main advantages of the presented software include:

- easy to learn and to use (the software is specially adopted to using by device and crystal growth engineers; experience in numerical simulations is not required)
- fast operation and getting valuable results (the software is optimized to solution of particular engineering problems, so that it is free of typical drawbacks of general-purpose packages)
- continuous incorporation of important physical models (as soon as some factor is recognized to be important, the respective model is developed and implemented in the respective software)

A large number of application cases will be discussed during presentation in order to demonstrate the capabilities of the STR's simulators and their level of predictability. The comparison with available data will be presented for III-nitride LEDs and LDs.

Within the presentation several advanced approaches used now by leading manufactures in production of HBLEDs will be discussed and analyzed with the SimuLED software:

- Analysis of Thin-Film LED operation
- Use of ITO spreading layer for improvement of LED performance
- Analysis of Inderdigitated Multi-Pixel LED array proposed by UCSB group

Future directions of the software development will be highlighted. New software package **SimuLAMP** for Optical and Thermal Management of LED Lamps developed now by STR will be presented.