Simulation of Light Emitting Diodes Using Ray Tracing

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We have developed a new software module to extend the capability of our APSYS simulator [1]. We use geometrical treatment of the TE-, TM- and non- polarized light propagation. Geometrical treatment is appropriate when the dimension of the LED is large compared with the wavelength of light. It is a very useful for the design of the structures with a certain angular distribution of the emitting power. We have tested some complicated structures to reveal interesting near/farfield patterns. The model is also suitable for optimization of a structure to get the most efficient output.

This software module is called LR (Light Ray) and it was built on the principles of the geometric and wave optics with using standard formulas of light refraction[2]. LR is a program designed to simulate emission, absorption, refraction, reflection and transmission of the light rays in arbitrary multi-regions transparent/absorbing medium in two dimensions. LR can be applied to the design and optimization of the different configuration of LED such as resonant cavity LED (RC-LED). Using a special graphic utility one can view the ray moving in arbitrary multi-regions transparent/absorbing medium. Maximum quantity of the adjacent regions is 50 with different optical indexes and absorption coefficients. Each region can be arbitrary polygon with from 3 to 20 angular points. Simulated structure can include metal cladding, DBR- and other substructures. LR computes angle distribution of the transmitted light power. It has possibility to use a few different models of the source of light: the point source, the line source or continuous source from an arbitrary polygon region.

We have tested LR for different cases. One was to compare different simplified structures with similar sizes and different shapes. For comparative analysis we put in the center of the structures point source with relative 100% of the power. For example, it was reported in [3], truncated-inverted-pyramid (TIP) chip geometry provided substantial improvement in light extraction efficiency. We compared cubical and TIP geometry cross-sections. Figure 1 shows results of such simulations. As one can see, there are significant differences in the angular distribution and transmitted power for these structures. We also did simulations for the structures consisting of many material regions with different complex optical indices. Figure 2 shows result for a simple structure. As well we simulated some structures with DBR-substructures such as in an RC-LED. To reduce runtime, LR provided calculation of the DBR-structure separately and used it as a single material region with equivalent transmission parameters. This simulation allowed us to estimate edge effects of the DBR-structure for different incident angles. Figure 3 shows reflectance deviation of some DBR-structure depending on distance from the edge and incident ray summed for all angles.

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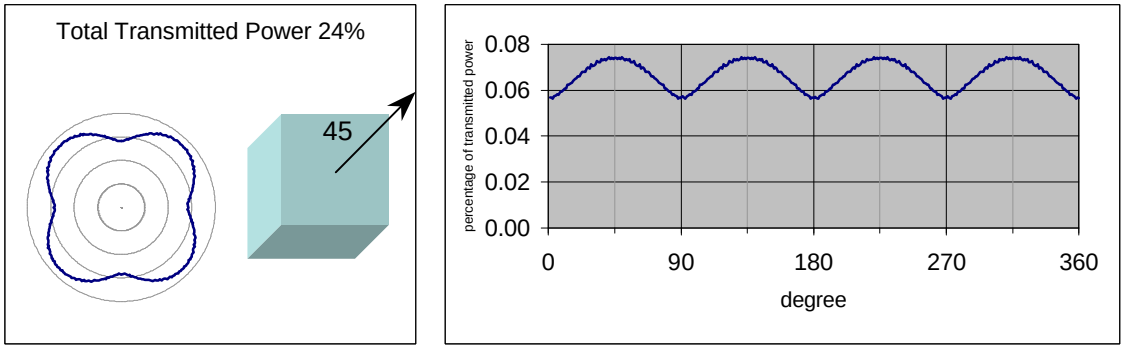
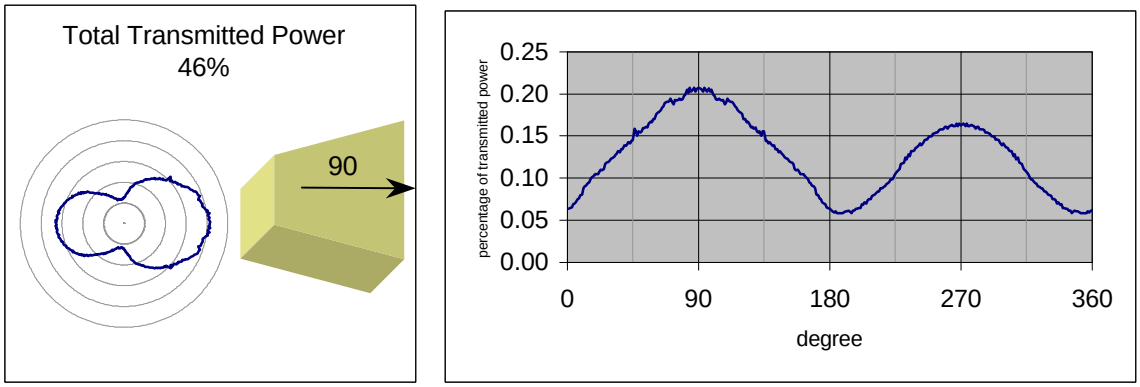
[1] Please see product description in www.crosslight.com
[2] "Thin Film Optical Filters" by H. A. MacLeod, NY, 1989, 2nd ed.
[3] M. R. Krames, M. Ochiai-Holocomb, G. E. Hofler, C. Carter-Coman, E. I. Chen, I.-H. Tan, P. Grillot, N. F. Gardner, H. C. Chul, J.-W. Huang, S. A. Stockman, F. A. Kish, M. G. Craford, T. S. Tan, C. P. Kocot, M. Hueschen, J. Posselt, B. Loh, G. Sasser, D. Collins, Appl. Phys. Lett. **75**, 2365 (1999).



(a)



(b)

FIG.1. Angular distribution of the transmitted power: the cubic (a) and TIP (b) structures.

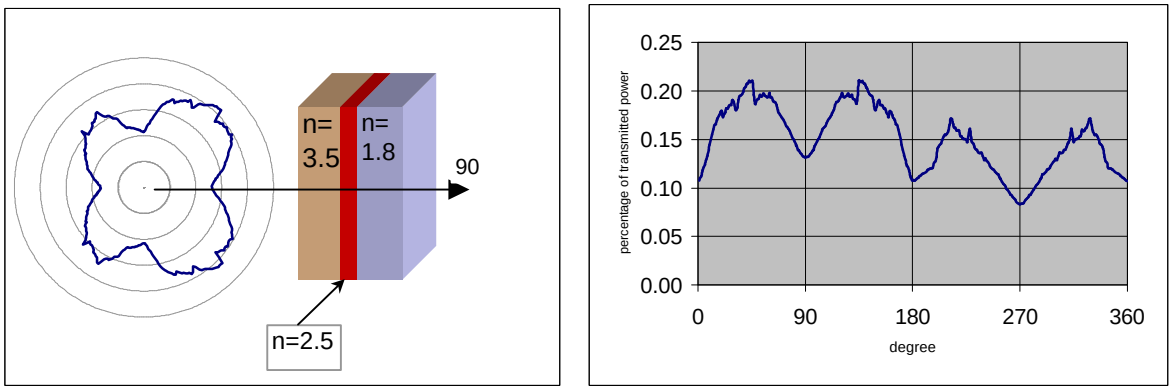


FIG.2. A sample of the simplest structure with three different boxes

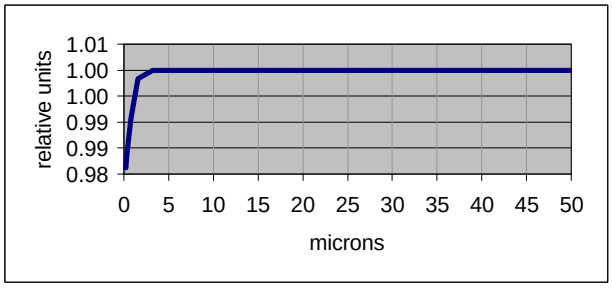


FIG.3. Reflectance deviation of some DBR-structure depending on distance between the edge and incident ray summed for all angles.