HOW TO CHOOSE SIMULATION PARAMETERS TO IMPROVE ACCURACY?

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1. Introduction

Optical design and light propagation modeling would be significantly harder and less precise without simulations. As the LEDs are becoming more and more popular, simulations are also required in order to satisfy their diverse professional applications. In modern light sources, the manufacturer provides the luminous intensity distribution database files for the simulations, in international standard formats or with "Ray Files", which define millions of guided ray vectors (*Fig. 1*). This file contains all photometrical information about the light source. Thus, the software can calculate with these vectors quickly and easily.

However, many questions arise about simulations:

- How may traced rays are required to achieve accurate results?
- What is the relationship between the traced rays and the simulation time?
- What is the effect of complex geometries on the simulation results?
- Can we improve accuracy with implementing a measured spectral power distribution?

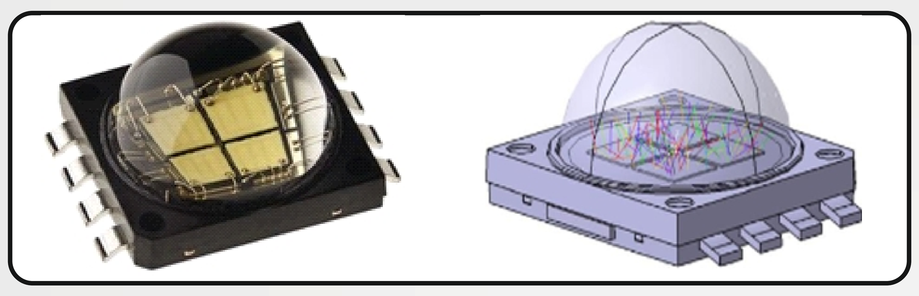


Fig. 1 LED light source with guided ray vectors at chips, and the original LED

Our aim of was to answer these questions using a professional light-modeling and simulation software.

2. Calculation methods of optical simulation software

Modern optical simulation algorithms can be separated into three sub-categories based on their used calculating methods [1]:

1. Finite-difference time-domain (FDTD)

- Mainly used to design micro-optical systems
- Calculates electromagnetic wave propagation with Maxwell equations
- Wave-optical calculations can be obtained with high accuracy

2. Sequential ray tracing

- Substitutes the light source with directed rays
- Guides these rays through the pre-defined optical elements in a determined order
- Capable of simulating a wide variety of optical effects (scattering, dispersion, etc.)
- Boundary conditions specify the optical properties of the optical elements
- Ideal for lens system design

3. Non-sequential ray tracing

- The rays can reach one surface in multiple times and in any order
- Scattering of the rays is allowed
- The order of the ray tracing is arbitrary
- Ideal for complex optical systems, with diffuse surfaces and scattering light

We applied a non-sequentual software (*OPTIS SPEOS*) at BUTE-MOEI for the simulations. The algorithms applied by the software are mainly confidential but based on the *Monte Carlo method*.

3. Simulation inputs

The main steps of creating the simulation environment are the followings:

1. Define geometries

- Import or create CAD geometries

2. Define light sources

- Import ray files or standard light intensity distributions files from manufacturers or implement measurements to achieve better accuracy

3. Define material and surface optical properties

- Set reflectance, transmission, scattering properties etc. to geometries and surfaces

4. Define sensors

- Virtual equivalent of real measurements, detailed output results

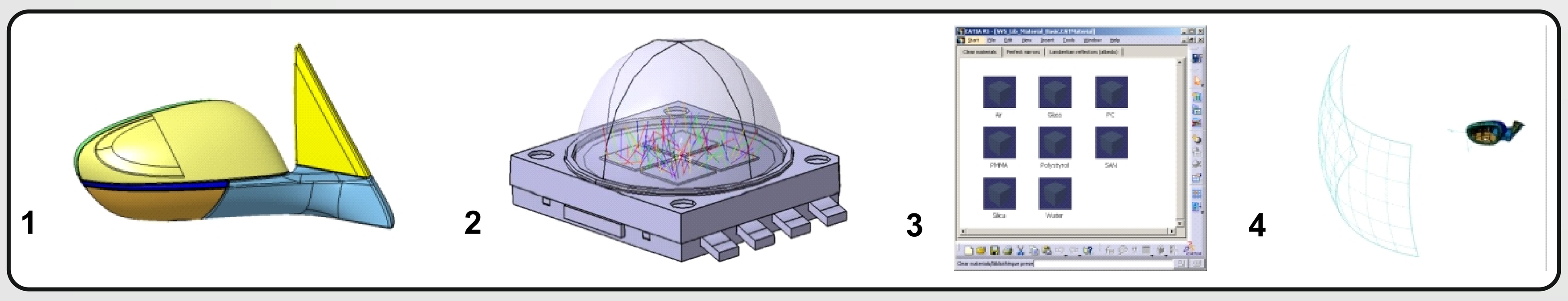


Fig.2 Simulation Inputs

4. Results and evaluation

A. Correlation between traced ray number and simulation time

As expected, with the increase of the number of traced rays the simulation time grows linearly (Fig. 2), and the standard deviation decreases [2]. However, in order to get properly accurate simulation results, the applied ray number should be sufficient.

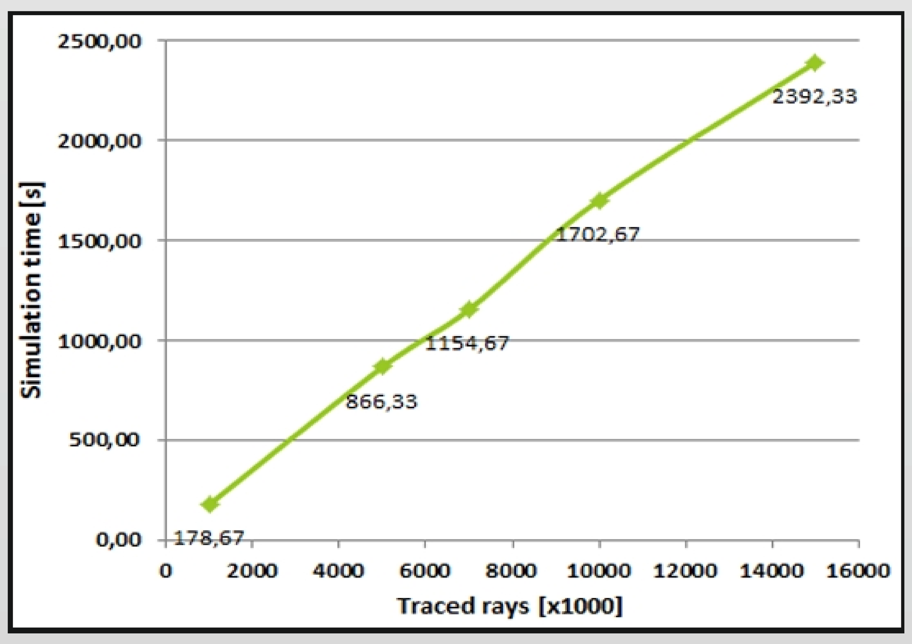


Fig. 3 Correlation between the traced ray number and simulation time

B. Effect of traced ray number on the simulation accuracy - without defined optical geometries

The results show that the number of the traced rays should be always more than 1 million. Above 1 million rays the results were constant, the standard deviation was around zero[2].

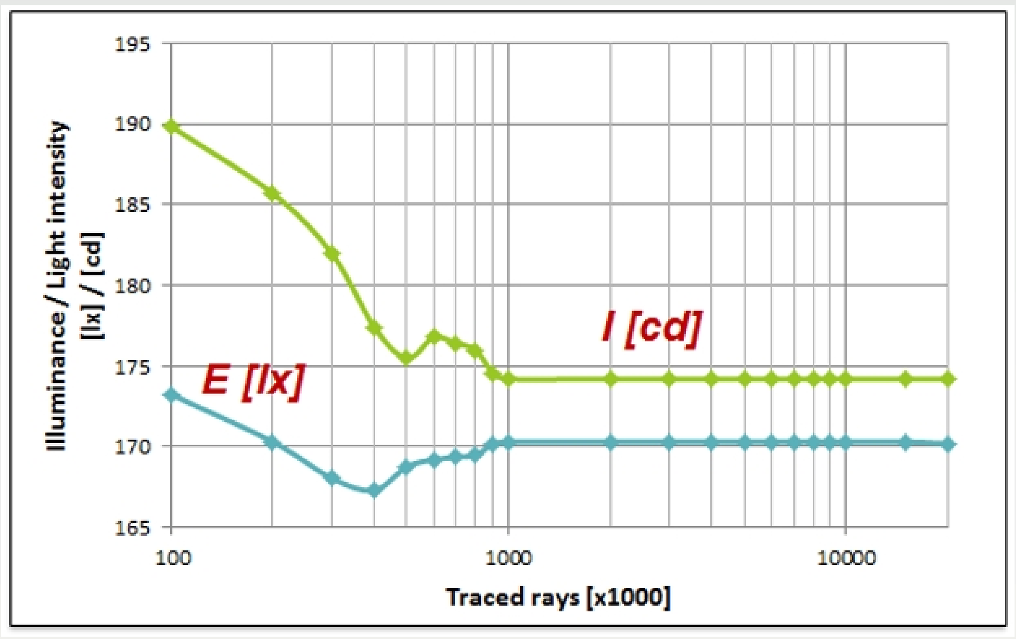
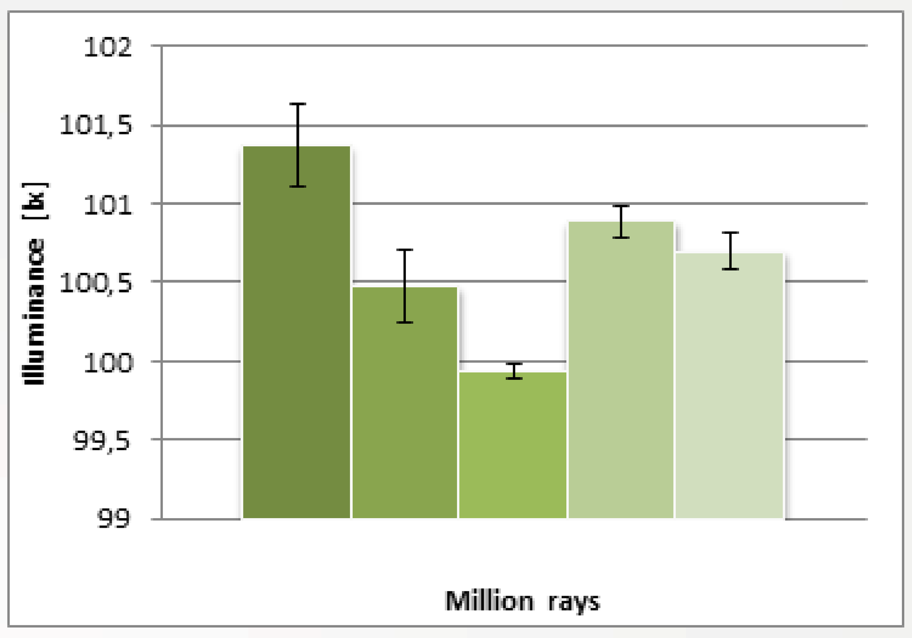


Fig. 4 Simulated illuminance and light intensity results, in function of the traced ray number

C. Effect of complex optical geometries

We applied 10 surfaces with defined optical parameters (reflection, transmission and scattering) between the light source and the illuminance sensor. The simulations have been conducted with 1, 5, 7, 10 and 15 million traced rays (Fig. 5).



- The difference between the results is very small
- The average value is slightly higher at 1 million rays
- The standard deviation is bigger at 1 and 5 million rays
- Complex geometries require above 5 million traced rays

Fig. 5 Simulations with complex geometries

D. Improving simulation accuracy with measured spectral power distribution

The Ray file doesn't contain information about the spectral power distribution of the light source, thus the simulation can be supplemented with the measured spectral power distribution of the LED (Fig. 6).

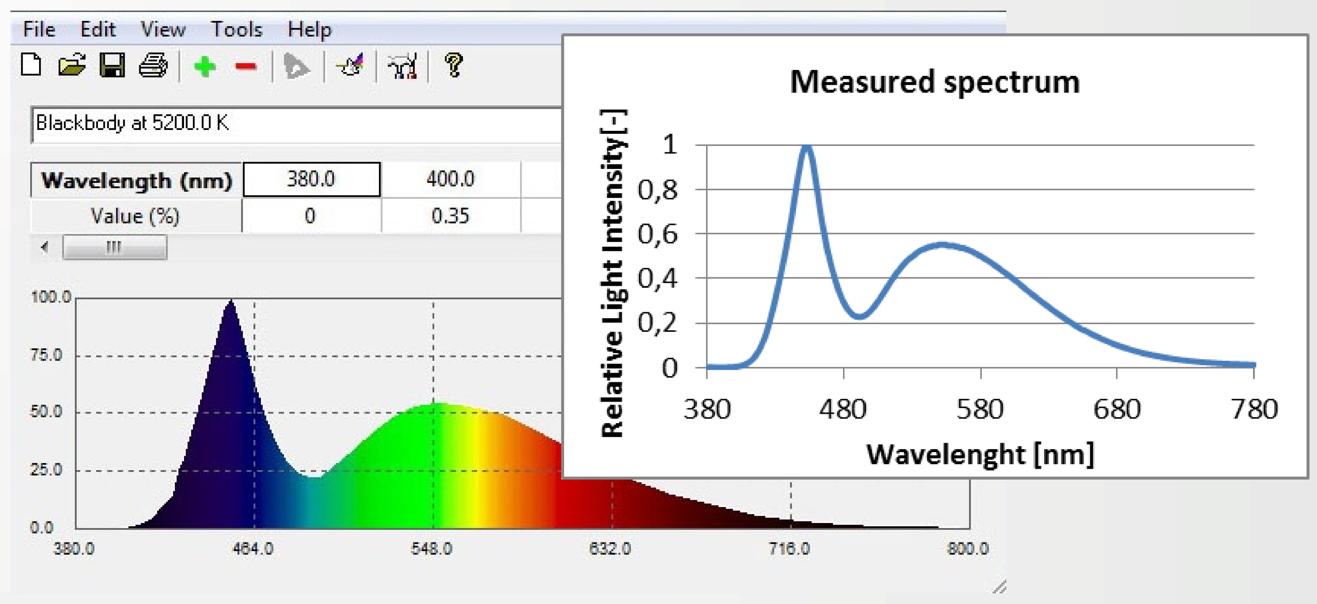


Fig. 6 LED spectrum measured with a spectroradiometer camera

Implementation of the spectral power distribution improved the results by 1-2 %, thus it's effect is significant.

5. Summary

Based on the simulations, we can declare the following conclusions:

- ✓ Simulation time grows nearly linearly with the increase of the traced rays
- ✓ The number of the traced rays should be more than 1 million (with our without defined optical geometries)
- ✓ Complex geometries require above 5 million traced rays
- ✓ Implementation of the spectral power distribution can also improve the results

6. References

[1] BRO - Breault Research Organization. 2006. Optical software: which program is right for me? Stevenson, M. Institute of Physics and IOP Publishing Ltd.
[2] GÉMESI, Sz. 2011. Világító dióda fotometriai paramétereinek mérése és szimulációja. Budapest: In: Diploma thesis
[3] NICODEMUS, F. 1965. Directional reflectance and emissivity of an opaque surface. Applied Optics 4 (7): 767–775.

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