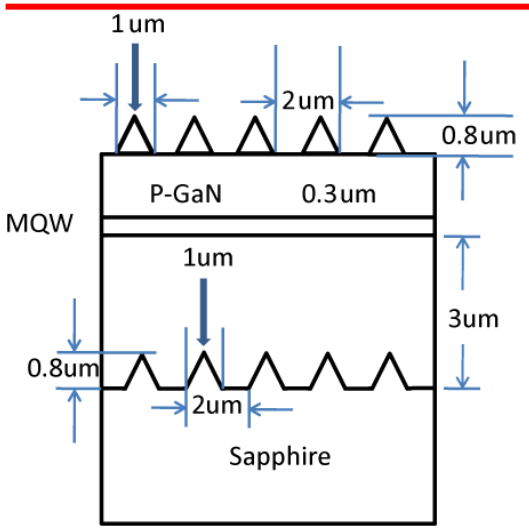
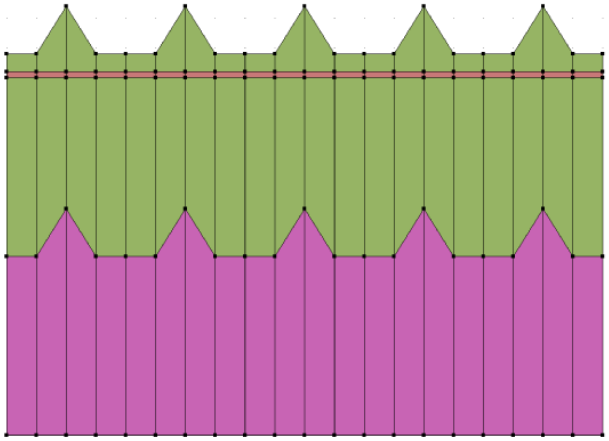
Simulation of Patterned Saphire Substrate LED by FDTD

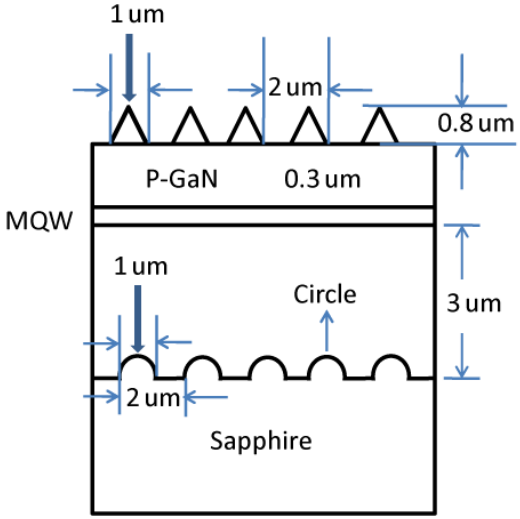
Schematic of Two Different Textured Structures



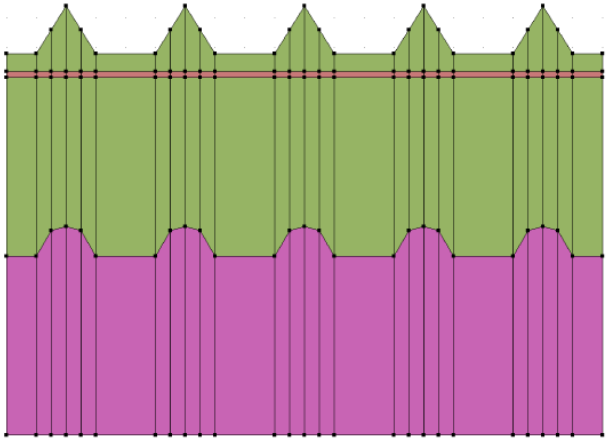
Modeled by GeoEditor



Triangle shape texture on GaN/Sapphire interface



Modeled by GeoEditor



Circle shape texture on GaN/Sapphire interface

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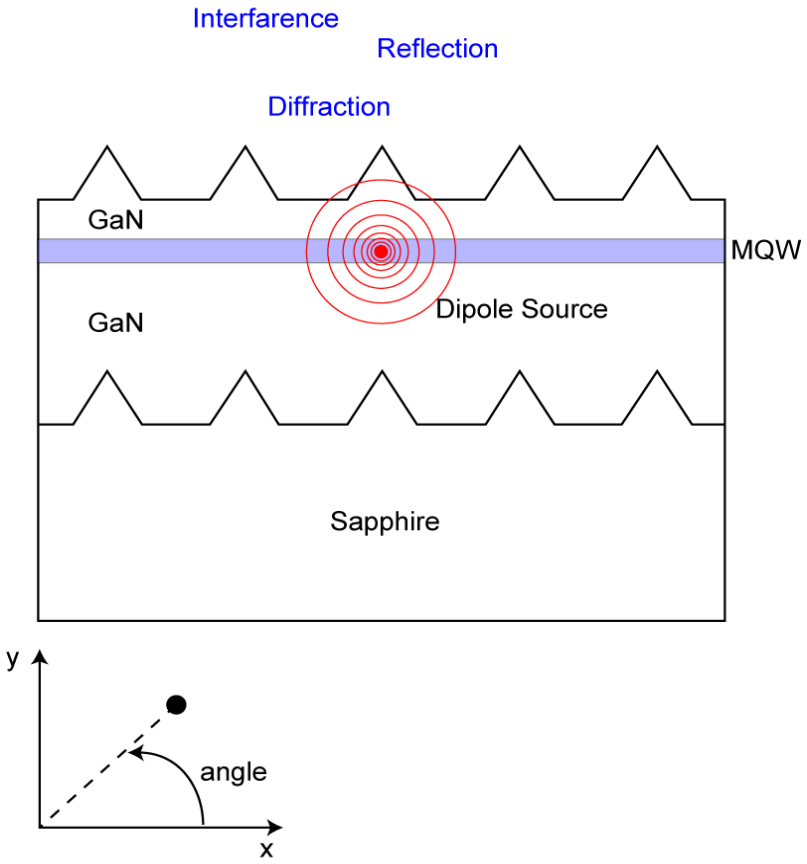
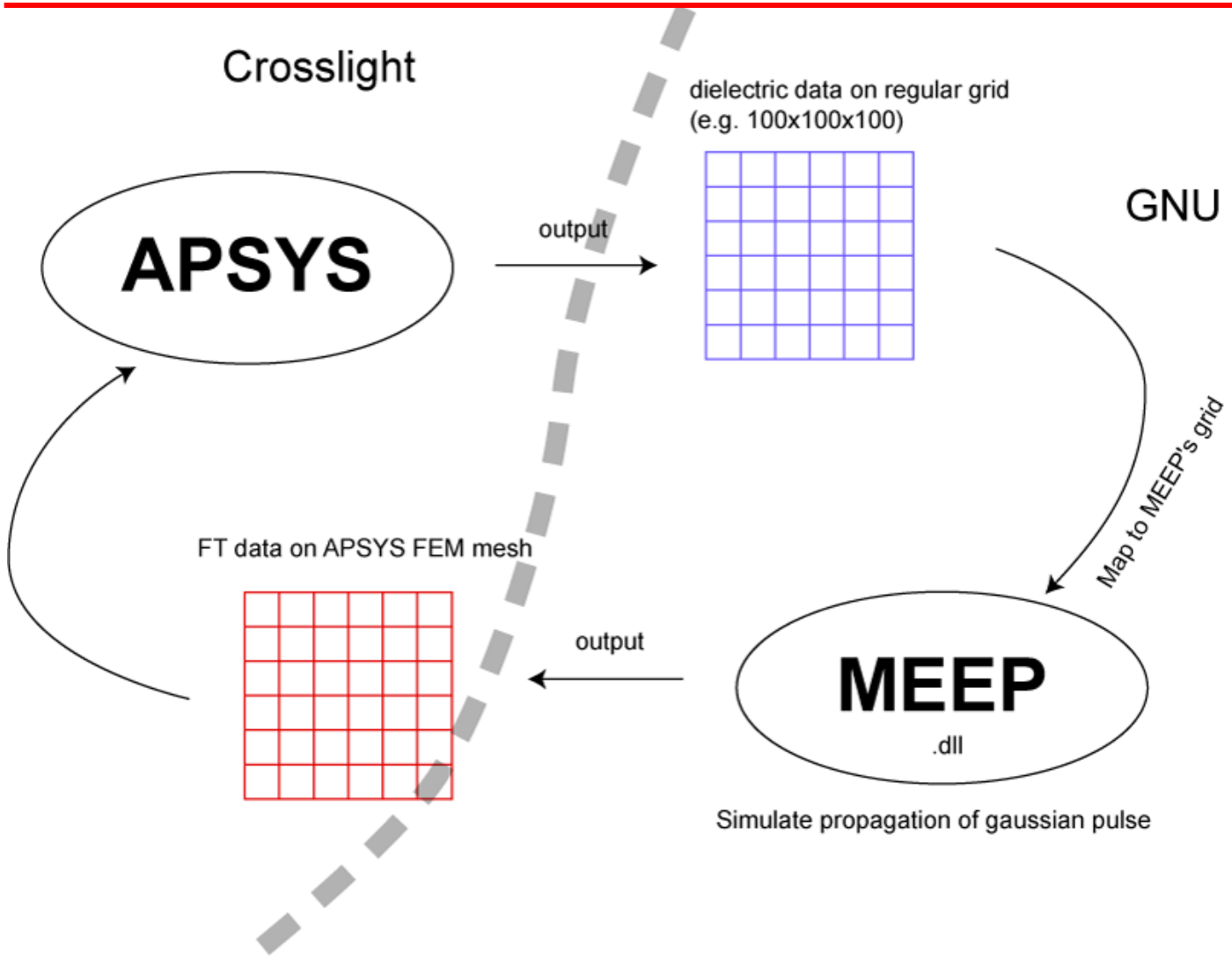
Theoretical Approach



- FDTD simulation yields time evolution of electromagnetic fields by solving time dependent Maxwell's equations.
- Point dipole source is a model of spontaneous emission center of LED. Statistical averaging over different dipole orientations and locations is required to obtain incoherent result.
- Fourier transformed electromagnetic field, i.e. far-field pattern, gives angular distribution of radiation intensity.

Interface between APSYS and FDTD



Available FDTD solvers

- MEEP: Free software developed at MIT
  http://ab-initio.mit.edu/wiki/index.php/Meep

- Acceleware: Commercial FDTD solver with support for GPU-accelerated calculations. Strongly recommended for large 3D problems.
  http://acceleware.com/fdtd-solvers

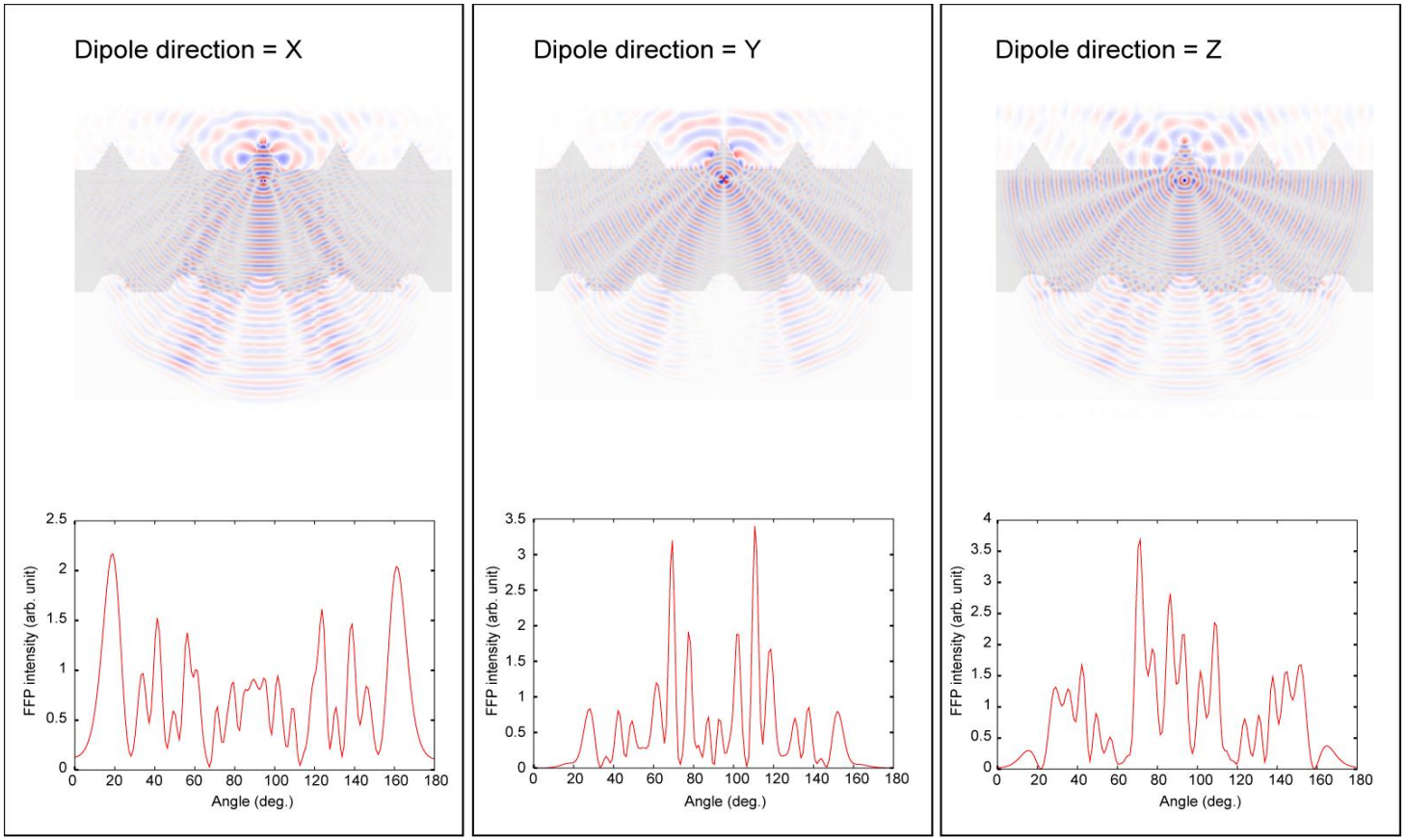
Advanced features of APSYS/FDTD simulation model

- 2D/3D structure is seamlessly exported from APSYS to FDTD simulation.
- Far-field radiation pattern calculation and utility programs for visualization using FDTD results.
- Optical FDTD solution incorporated into electronic part of APSYS simulation.

Effect of dipole orientation

Snapshot of electric field →

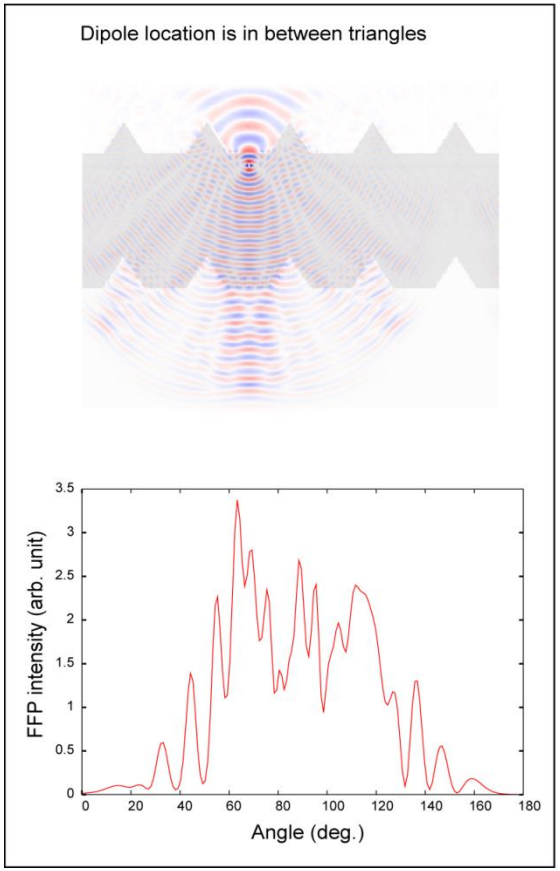
Radiation intensity normalized by source power →

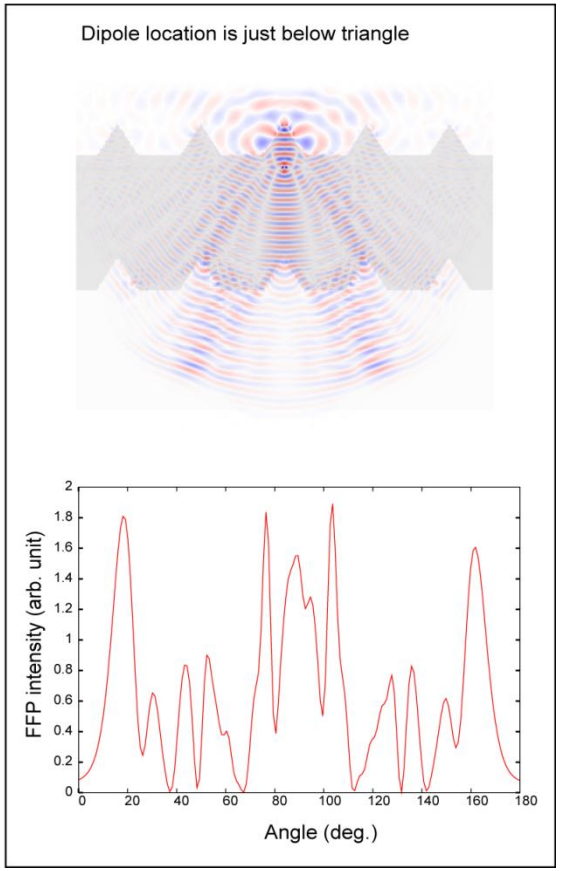


Effect of dipole location

Snapshot of electric field →

Radiation intensity normalized by source power →





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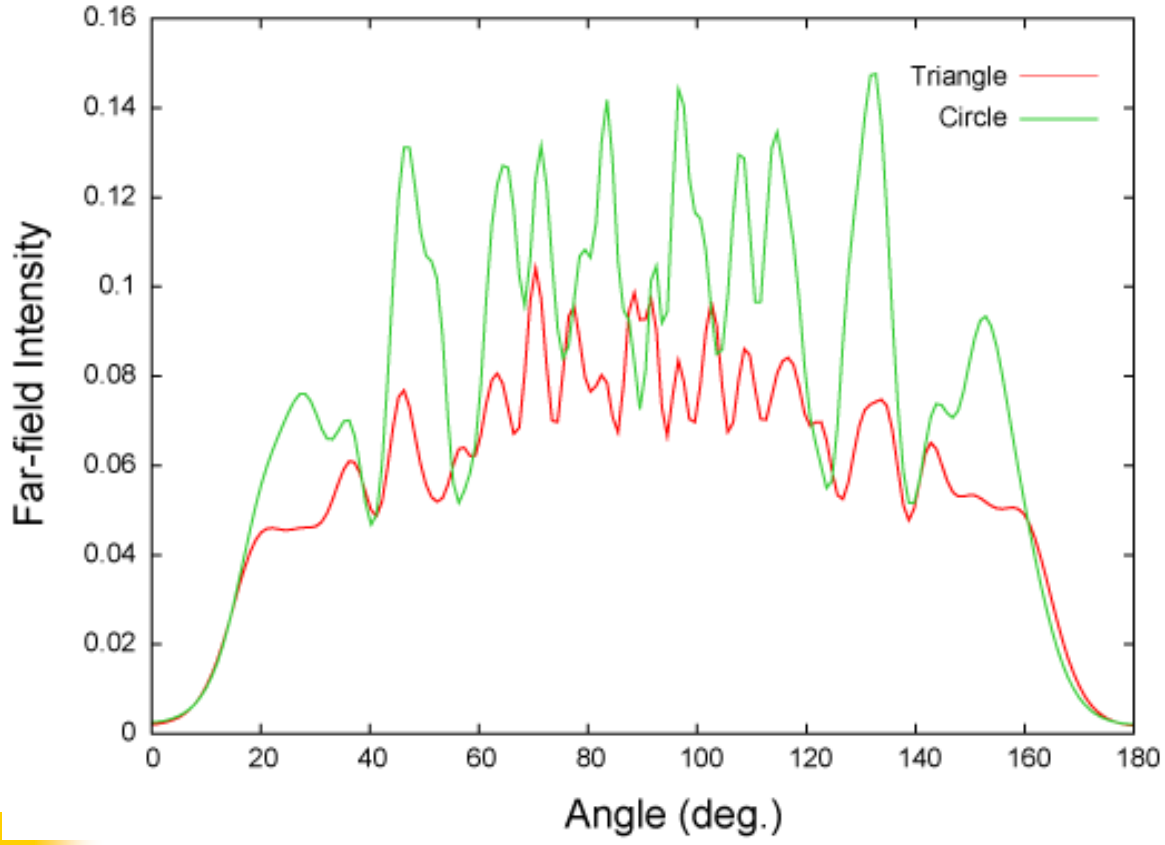
Angular distribution of radiation intensity



Statistical average operation was done by summing FFP data obtained from simulation of X, Y, Z dipole orientations and five different locations of dipole source, i.e. 15 different FDTD simulations.

Statistical averating is required to obtain incoherent and unpolarized result from FDTD simulations.

Far-field data in this plot were normalized by source power, so the integration of each curve gives extraction efficiency of upward radiation.

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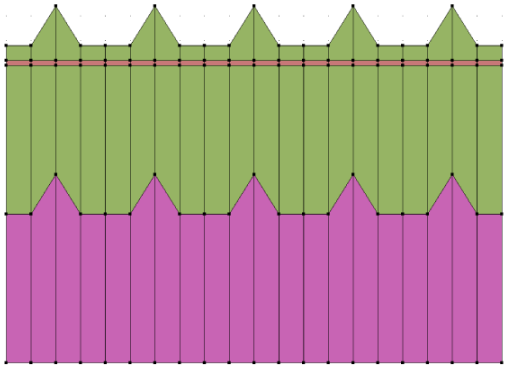
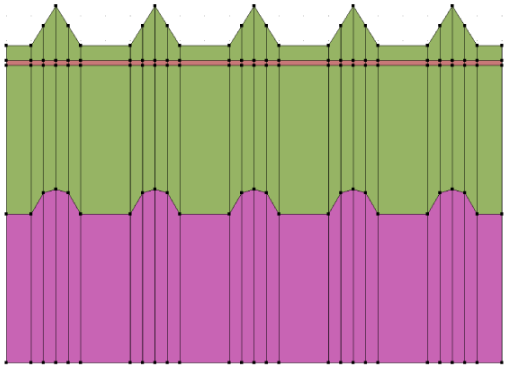
Comparison of LED power extraction efficiency



Triangle shape texture on GaN/Sapphire interface

$$\eta_{ext} = \int S(\theta,\varphi)d\theta d\varphi / P_0$$

ηext for triangle shape=17.6 percent



Circle shape texture on GaN/Sapphire interface

ηext for circle shape=20.8 percent

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CPU timing and size of simulation

- Each FDTD run took 5 minutes on Intel Core2 Duo E6600 processor.
- Statistical averaging needed to obtain results for incoherent LED light emission requires 15 FDTD runs. So, entire simulations for one device structure took around 75 minutes.
- Number of FDTD cells used is 139 200.

Summary

- Two LED device structures with different texture shape were simulated by APSYS/FDTD, and angular distribution of radiation intensity was obtained.
- Difference of texture shape is reflected in radiation intensity.
- FDTD simulation for 3-D structure is feasible in the same way as 2-D.