Analysis of the extraction efficiency in GaN-on-sapphire Light emitting diodes

2006.09.11

Samsung electro-mechanics R&D Institute

Jin-Bock LEE

Contents

- ✓ Motivation and purpose
- ✓ Modelling of LED structure
- ✓ Simulation results
  - Flat LED vs PSS (patterned sapphire substrate) LEDs
  - Flat LED vs PSS LED vs Flip-chip LED
    with a reflection layer on the bottom face
  - Comparison of three different type of LEDs
    with reflectance on bottom face
- ✓ Conclusion

Motivation

- The efficiency of LEDs has an important factor on such application and the property such as the energy efficiency of current GaN based LEDs is not yet sufficient to satisfy consumer demand.
  For conventional LEDs, the extraction efficiency is very low compared to internal efficiency.
- The role of the patterned sapphire substrate on the extraction efficiency was not reported clearly.
- The extraction efficiency of LEDs is not analyzed quantitatively though simulation and modeling approach of LED structure by optical ray tracing method require rather extensive efforts

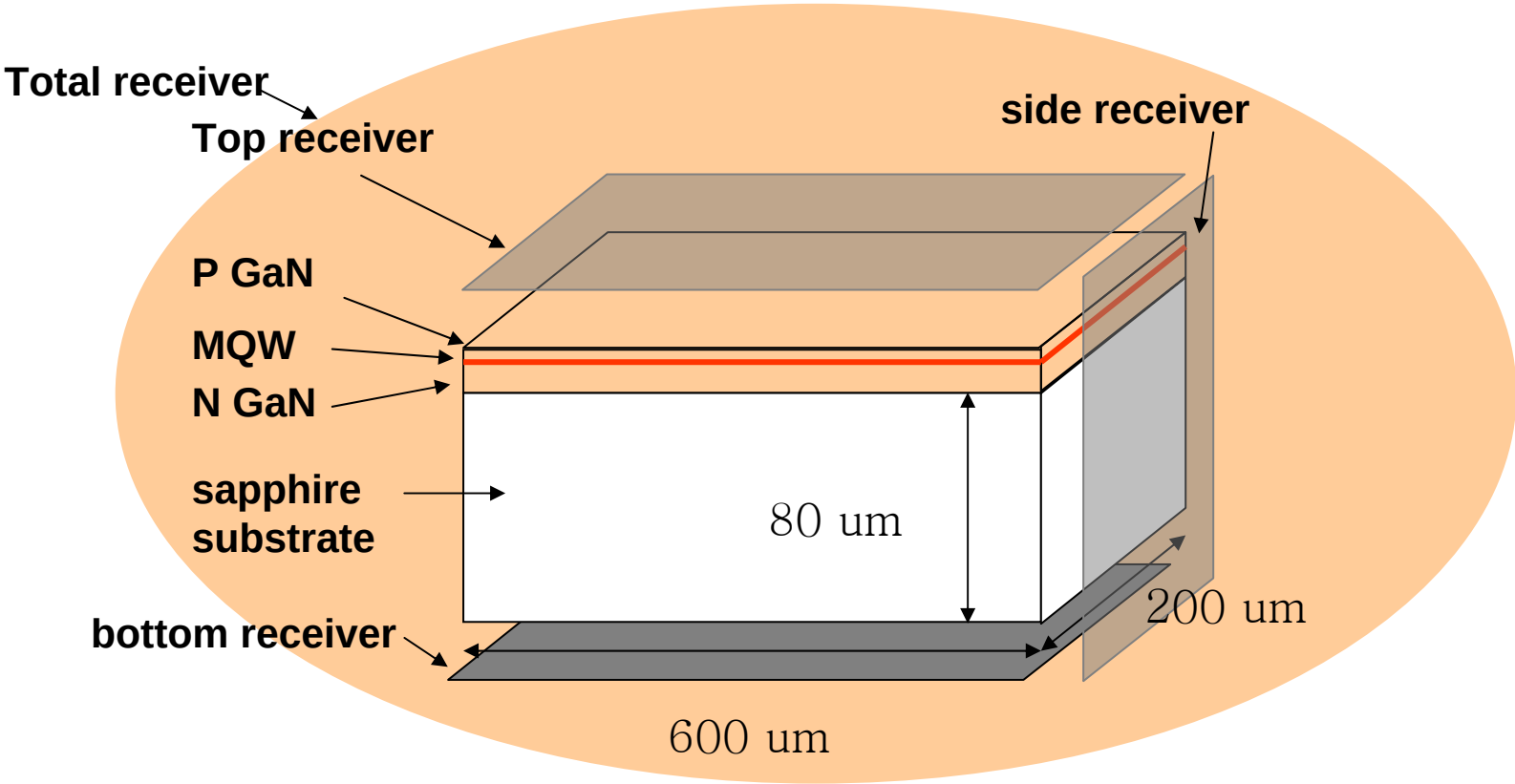
Purpose

- Analysis and discusstion on the role of the patterned sapphire substrate in GaN-on-Sapphire LEDs
- Elucidation of the effects of reflectance on three different types of LED
- Fundamental research for the design of high brightness GaN LEDs.

Modeling of LED structure (I)

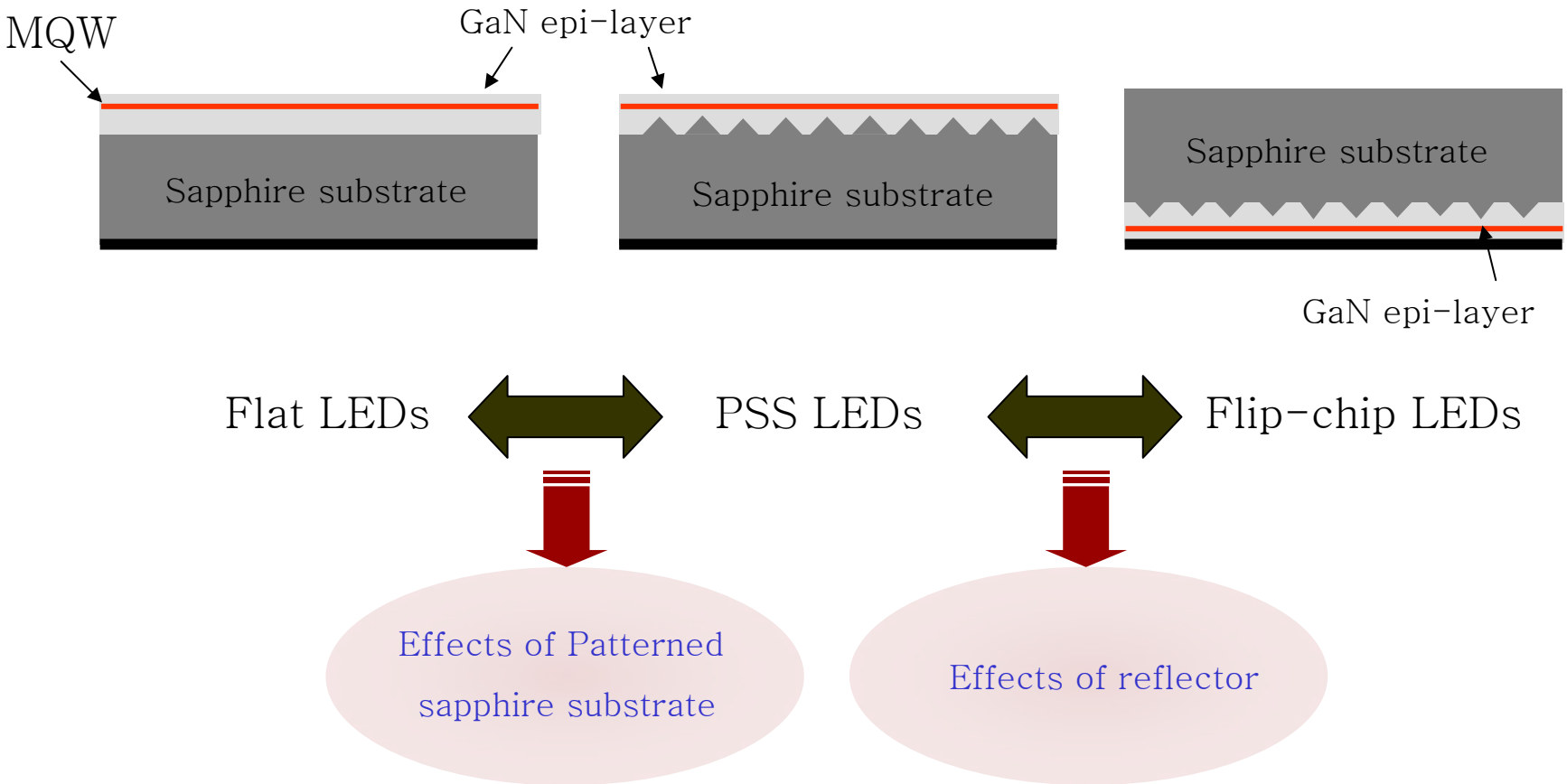
Schematic diagram of LEDS for simulation

Use of a Monte-Carlo ray tracing simulation to obtain the light distribution across the whole volume of the chip



Modeling of LED structure (II)

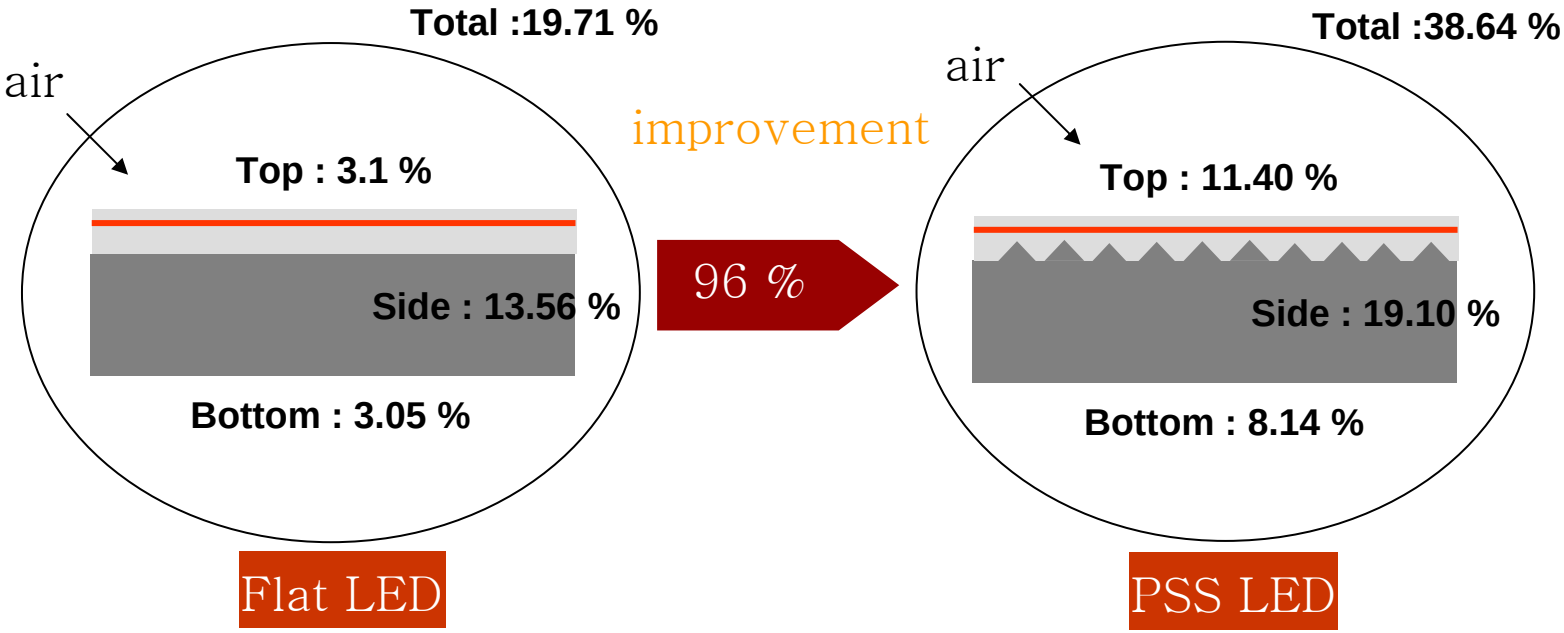
- Three different types of LED structure



Results (I)

- The extraction efficiency with two different types of LEDs (In air atmosphere)

The extraction efficiency of PSS LEDs compared to flat LEDs increase dramatically



Top emission is similar to bottom emission and most of total emission is emitted to the side.

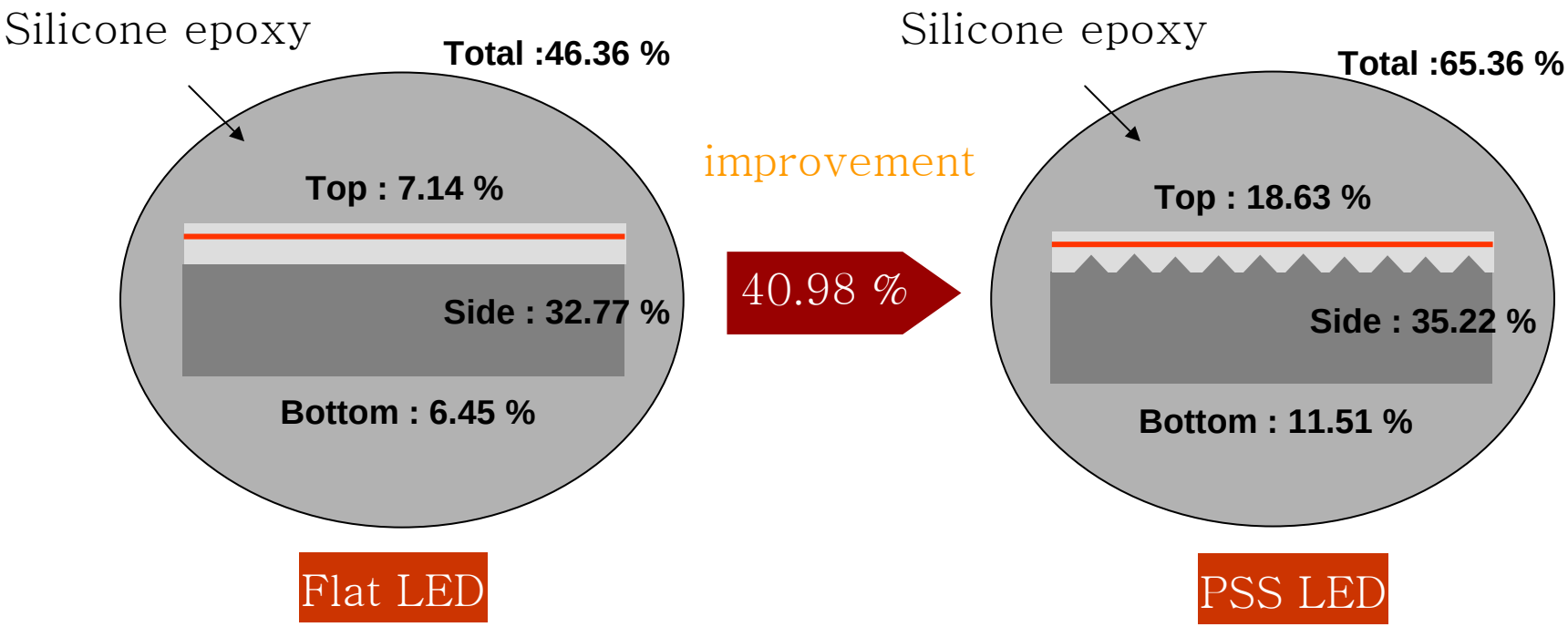
Top and bottom emission increase relatively rather than side emission. And the top emission is larger than bottom emission.

Results (II)

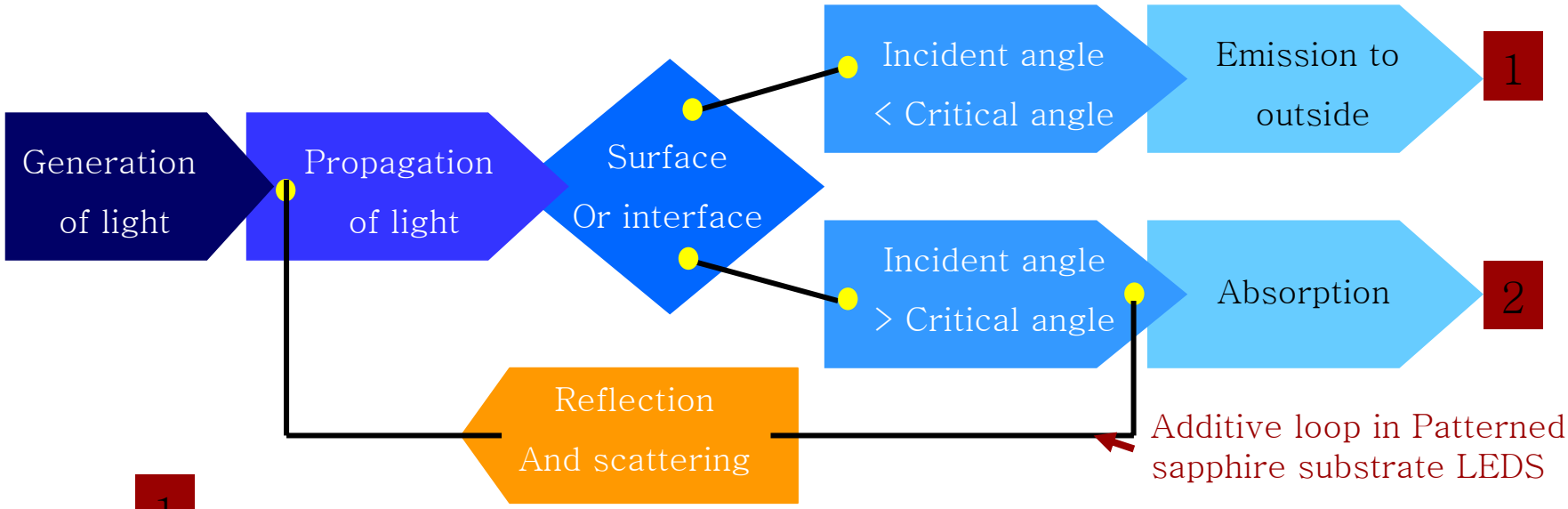
- The extraction efficiency with two different types of LEDs

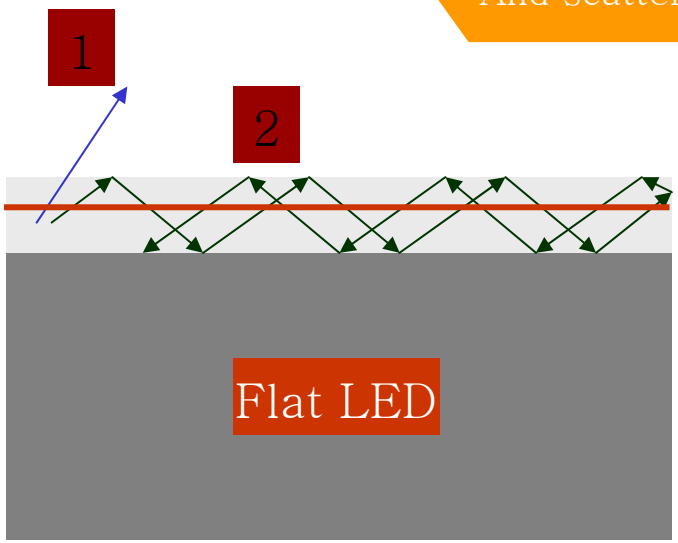
  (In silicone epoxy atmosphere)

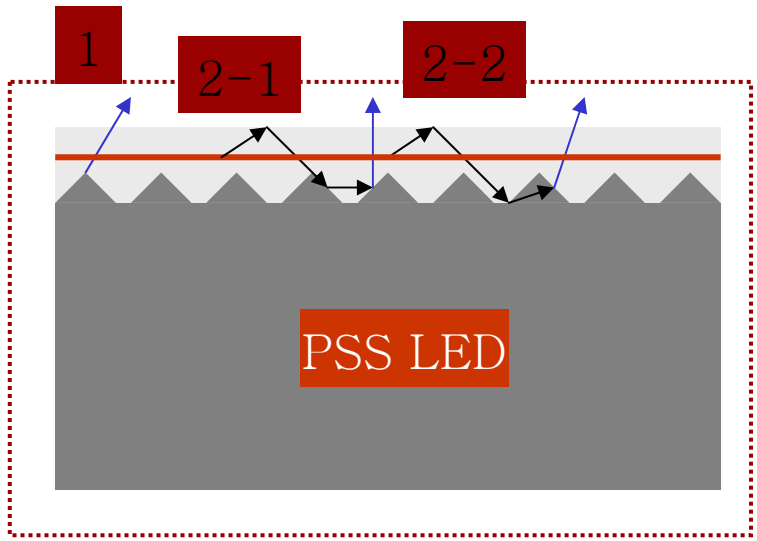
  It is also important to investigate the extraction efficiency of LEDs in silicone epoxy atmosphere because a yellow phosphor is mixed with silicone epoxy for the white LEDs.



Results (III)

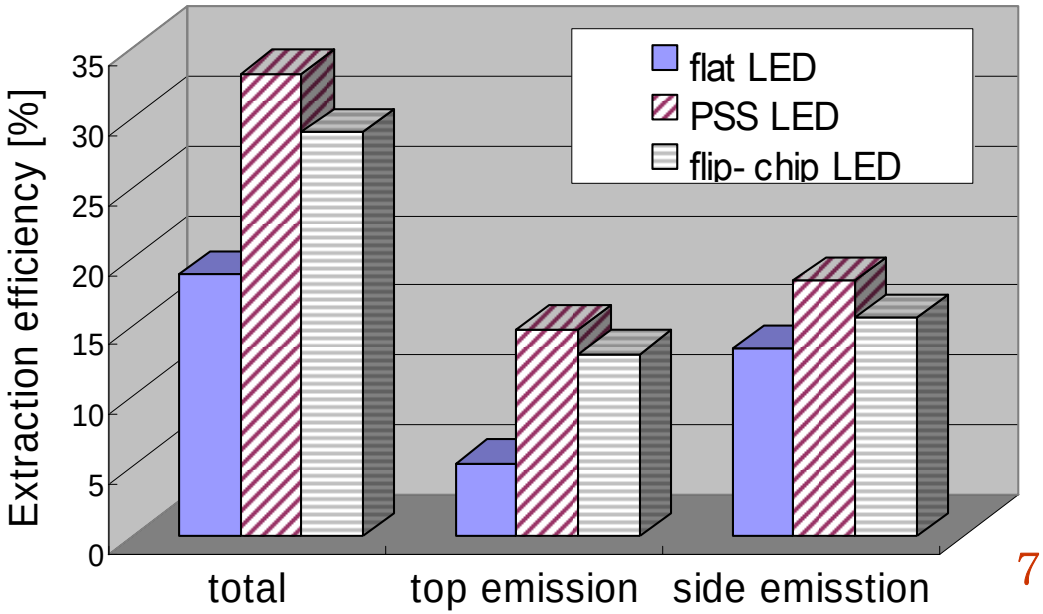

Generation of light
Propagation of light
Surface Or interface
Incident angle < Critical angle
Emission to outside
1
Incident angle > Critical angle
Absorption
2
Reflection And scattering
Additive loop in Patterned sapphire substrate LEDS


1
2
Flat LED

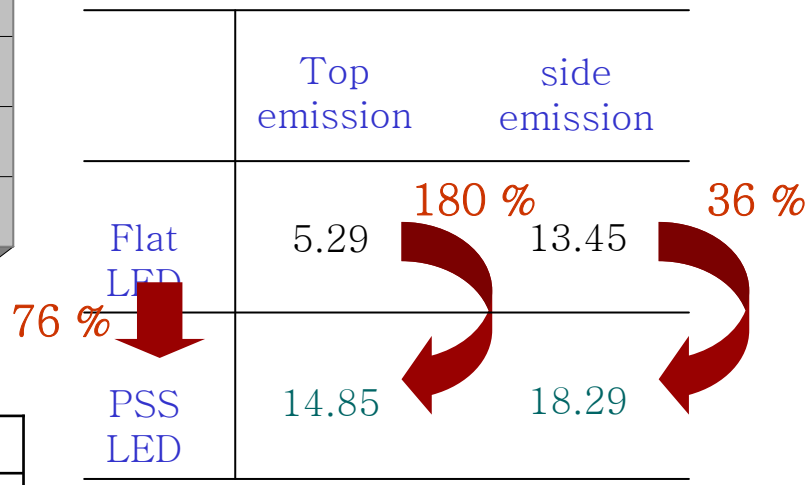

1
2-1
2-2
PSS LED

Results (IV)

- The extraction efficiency for three different types of LEDs with a reflection layer on the bottom face (In air atmosphere)

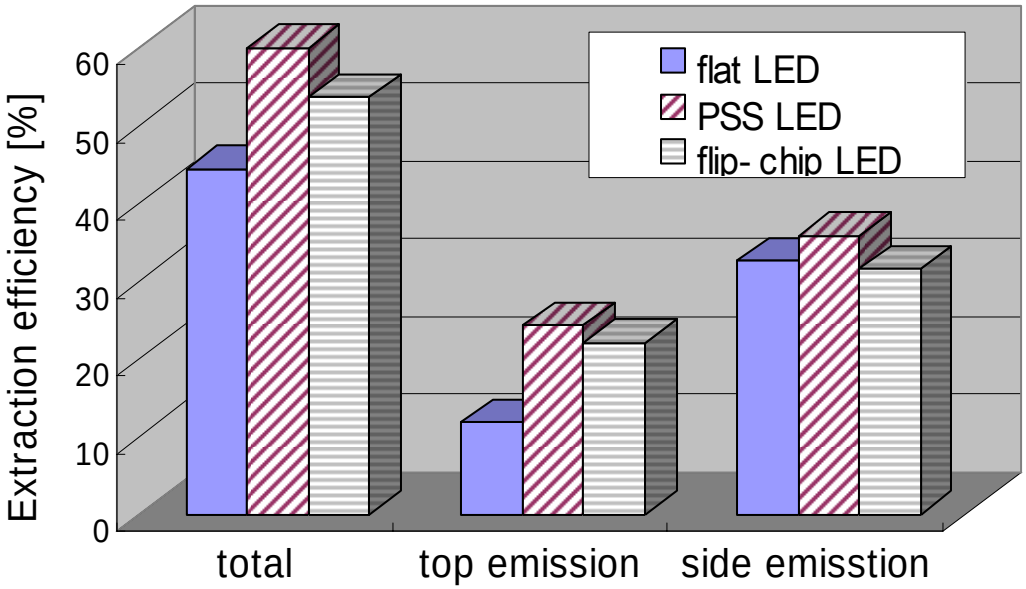


	total	top emission	side emission
flat LED	18.74	5.29	13.45
PSS LED	33.14	14.85	18.29
flip-chip LED	28.96	13.08	15.68

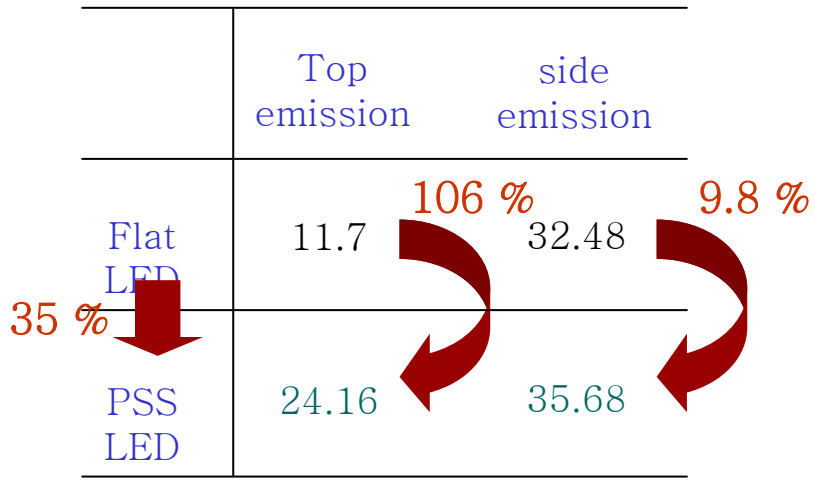


Results (V)

- The extraction efficiency for three different types of LEDs with a reflection layer on the bottom face (In silicone epoxy atmosphere)



	total	top emission	side emission
flat LED	44.18	11.7	32.48
PSS LED	59.84	24.16	35.68
flip-chip LED	53.48	22.04	31.44

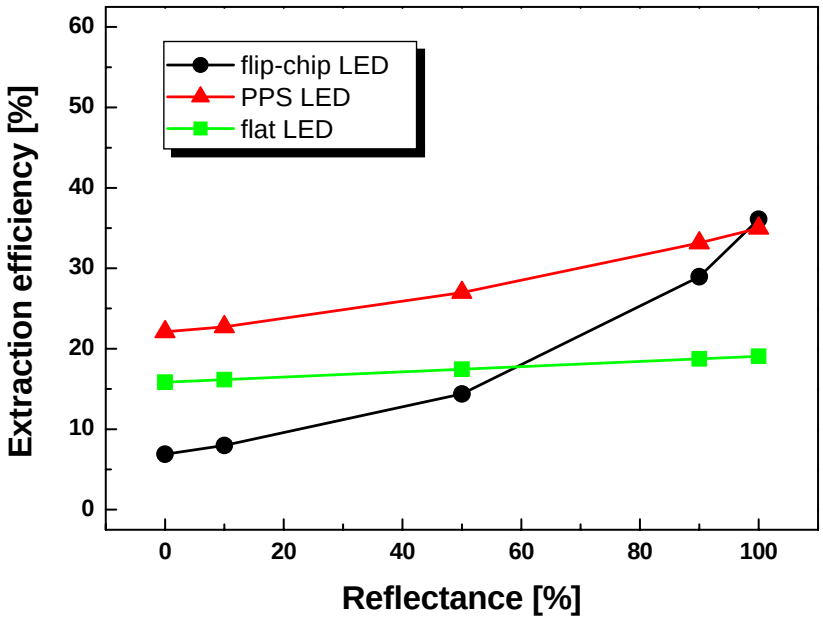


The patterned sapphire substrate leads most light to escape from top surface rather than side surfaces.

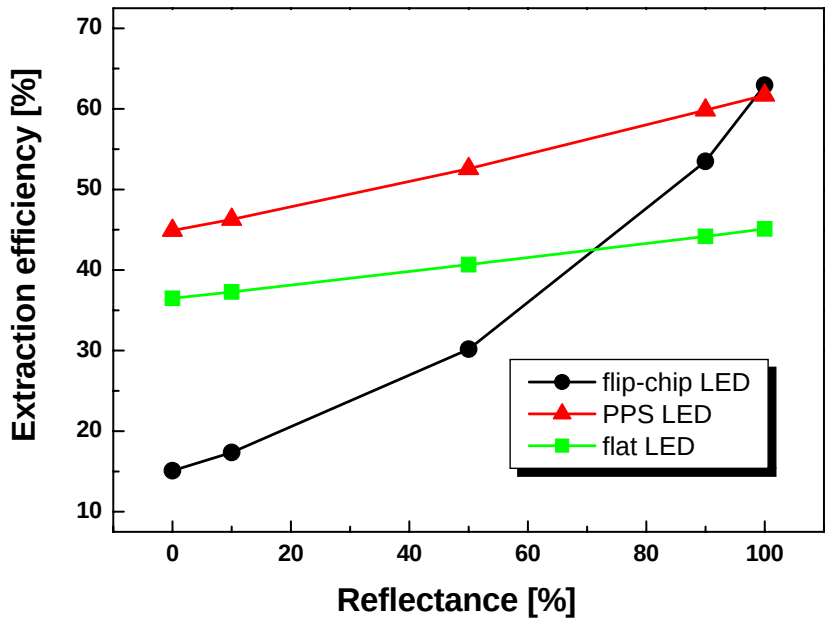
Results (VI)

- The extraction efficiency of three different types of LEDs with reflectance on bottom face

Air



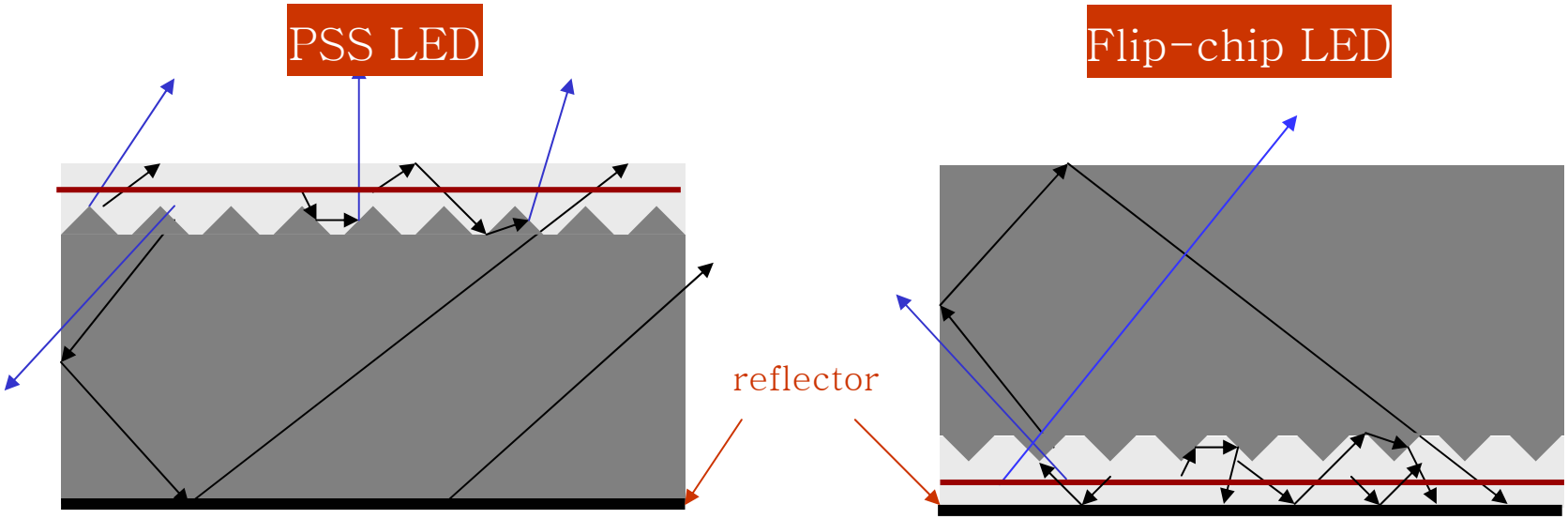
Silicone epoxy



It should be noted that the extraction efficiency at flip-chip LEDs is more sensitive to the reflector of bottom face than that of flat and PSS LEDs.

Results (VII)

The refractive index of nitride films is higher than that of the sapphire substrate. Therefore, most of the emission light from the active layer propagates through the nitride film.



Light of Only 27 % arrived at reflector

Most of light arrived at reflector

Conclusion

- The extraction efficiency can be greatly improved by patterned sapphire substrate.

  It is attributed to continuously change incidence angle, which is resulted from scattering by pattern sapphire substrate.

- The extraction efficiency at flip-chip LEDs is more sensitive to the reflector of bottom face than that of flat and PSS LEDs.

  The reason is that most of light emitted from MQW is influenced by reflector in flip-chip LEDs.

- It is important to reduce the effects of reflectance in flip-chip LEDs. In future work, we will propose novel structures for enhancement of the extraction efficiency in flip-chip LEDs.