

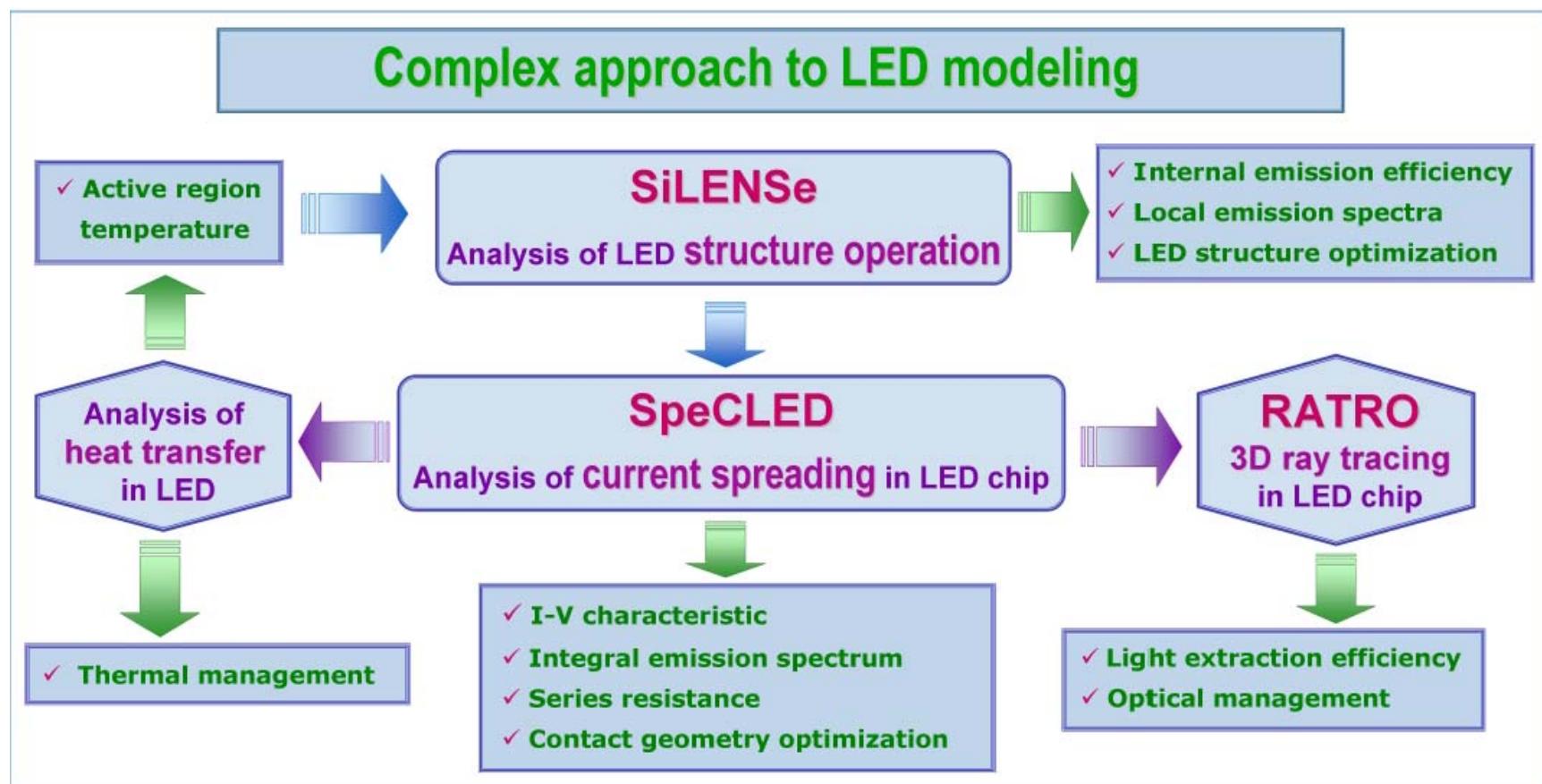
SimuLED

LED epi-chip Simulation Software
(SiLENSe/SpeCLED/RATRO)

SimuLED 구성

- **1. SiLENSe**(LED heterostructure 최적화)
 - Material properties editor (SiLENSe 기본 물성 편집)
 - project input file(".sls"), output file(".sls")
- **2. SpeCLED**(ITO,BL,electrode 구조 최적화)
 - project input file(".dpx"), output file("~_(40).cgs")
~_(40).cgs: 칩에 40mA 전류가 흐를 때 결과값
 -  Planar2ITO
 -  Planar2ITO(40)
- **3. RATRO**(Chip level 광추출 효율/ 광분포 최적화)
 - project input file(".dpx"). Output file("(40)_rtr.cgs")
 -  Planar2ITO(40)_rtr

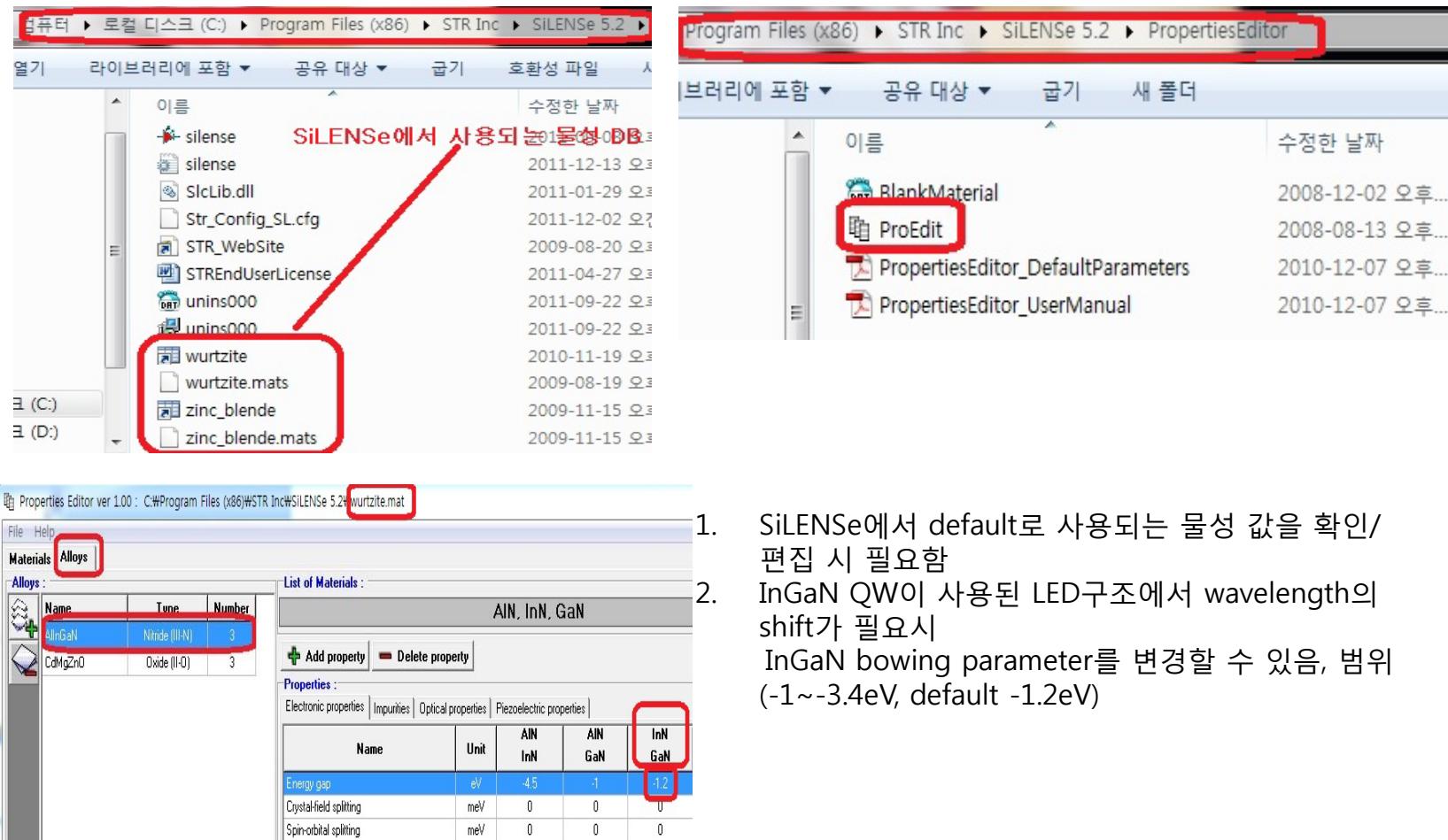
SimuLED 개념도



1. SiLENSe

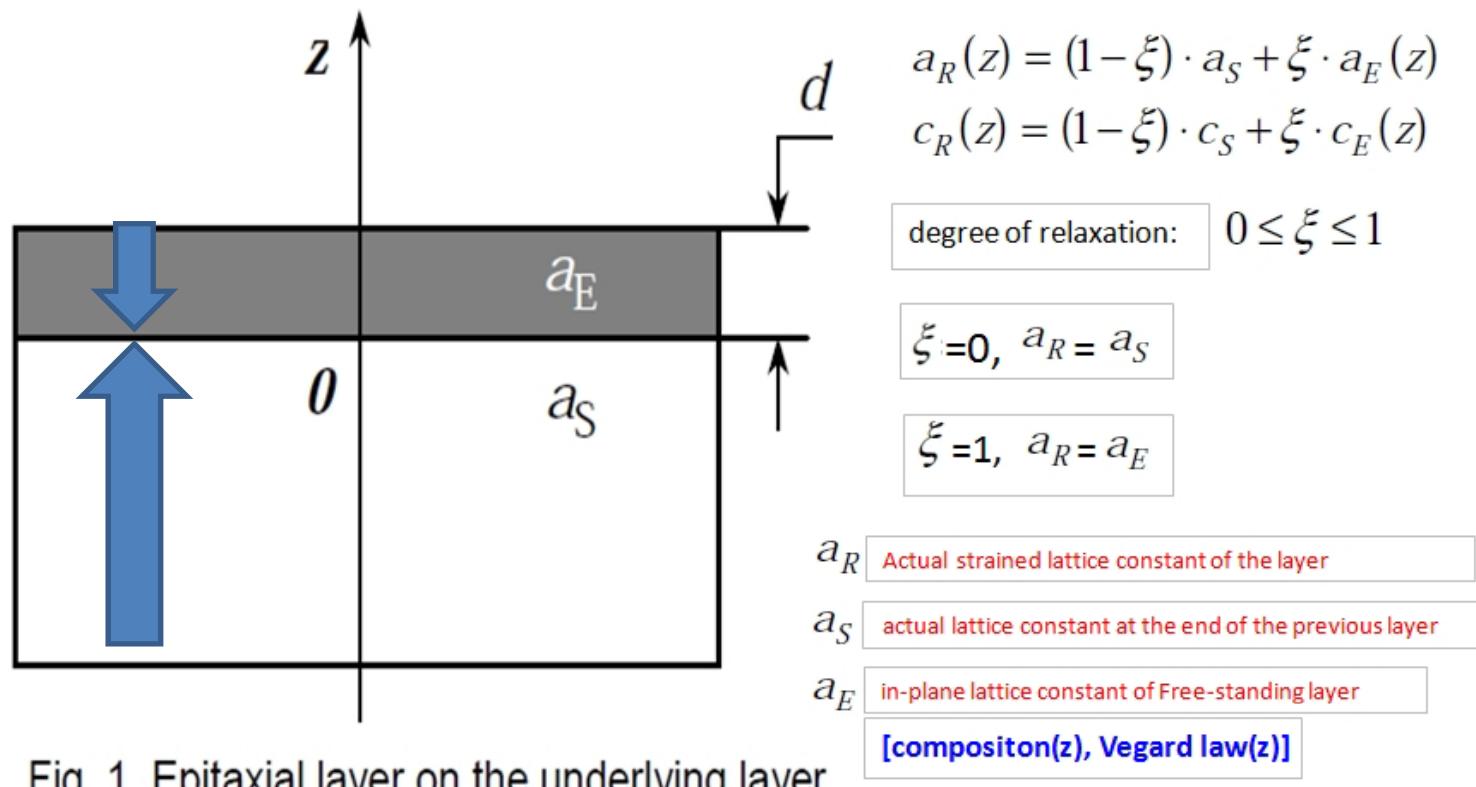
- 0. Material Properties(ProEdit)
 - SiLENSe에서 사용되는 물성 정보의 확인 및 편집기
 - SiLENSe 시작하기 전 Default parameter 물성 확인
- 1. Input parameters
 - 1-1 degree of relaxation
 - 1-2 layer profile
 - 1-3 global parameter
- 2. Output results
 - 2-1 current band diagram
 - 2-2 I-V curve and wavelength
- 3. Export Data into SpeCLED
 - 3-1 to load "J(bias), IQE(J), Spectra(bias)" on the active region of SpeCLED

O. Material properties



1. SiLENSe에서 default로 사용되는 물성 값을 확인/편집 시 필요함
2. InGaN QW이 사용된 LED구조에서 wavelength의 shift가 필요시
InGaN bowing parameter를 변경할 수 있음, 범위 (-1~ -3.4eV, default -1.2eV)

1-1. Degree of relaxation



1-2. Layer profile

Layers :			
N	Name	Thickness, nm	Type
1	n-GaN	500	AlInGaN
2X2	InGaN-QW	3	AlInGaN
3X2	n-GaN-barrier	12	AlInGaN
4	InGaN-QW	3	AlInGaN
5	n-GaN-barrier	12	AlInGaN
6	InGaN-QW	3	AlInGaN
7	p-AlGaN	60	AlInGaN
8	p-GaN	500	AlInGaN

Left(각 layer시점)/middle(각 layer 중점)/right(각 layer끝점)

각 layer 물성 정의 시 grade 줄 수 있음
 -composition
 -dopant
 -mobility

Composition :			
Fraction	Left point	Right point	Middle point
AlN	0		
InN	0.13		
GaN	0.87		

Dopant concentration :			
Type	Left point	Right point	Middle point
Donors (cm^{-3})	0		
Acceptors (cm^{-3})	$1.000\text{E}+18$	$1.000\text{E}+19$	

Mobility :			
Type	Left point	Right point	Middle point
Electrons ($\text{cm}^2/\text{V}\cdot\text{s}$)	100		
Holes ($\text{cm}^2/\text{V}\cdot\text{s}$)	10		

Structure visualization

Doping | Mobility | Relaxation | Dislocation density | Lifetimes | DOS tails

Donors ($1/\text{cm}^3$)
 Acceptors ($1/\text{cm}^3$)

1-3. Global parameter

The screenshot shows a software interface for managing global parameters in a heterostructure simulation. The menu bar includes File, Heterostructure, Material properties, Run, Export, Tools, Window, and Help. The toolbar contains various icons for file operations and simulation control.

The main window has tabs: Heterostructure, Global parameters (selected), Materials properties, Results, Spectrum, Laser parameters, and Waveguide. Below the tabs, a section titled "Physical and Solver parameters" is visible.

Physical parameters:

Physical parameters	
Temperature (K)	310
Quantum Potential Model	Yes
Electron Quantum Potential Correction Factor	0.7
Hole Quantum Potential Correction Factor	1
Temperature Factor for B	-1.5
Temperature Factor for Cn	0
Temperature Factor for Cp	0

A red box highlights the "Layer" section, and a red arrow points to the "Electron Quantum Potential Correction Factor" table entry, which is annotated with the text "[0, 10], 2~3, default: 0.7/1".

Main solver parameters:

Main solver parameters	
Intervals per layer	100
Maximum number of iterations	2000

Spectrum solver parameters:

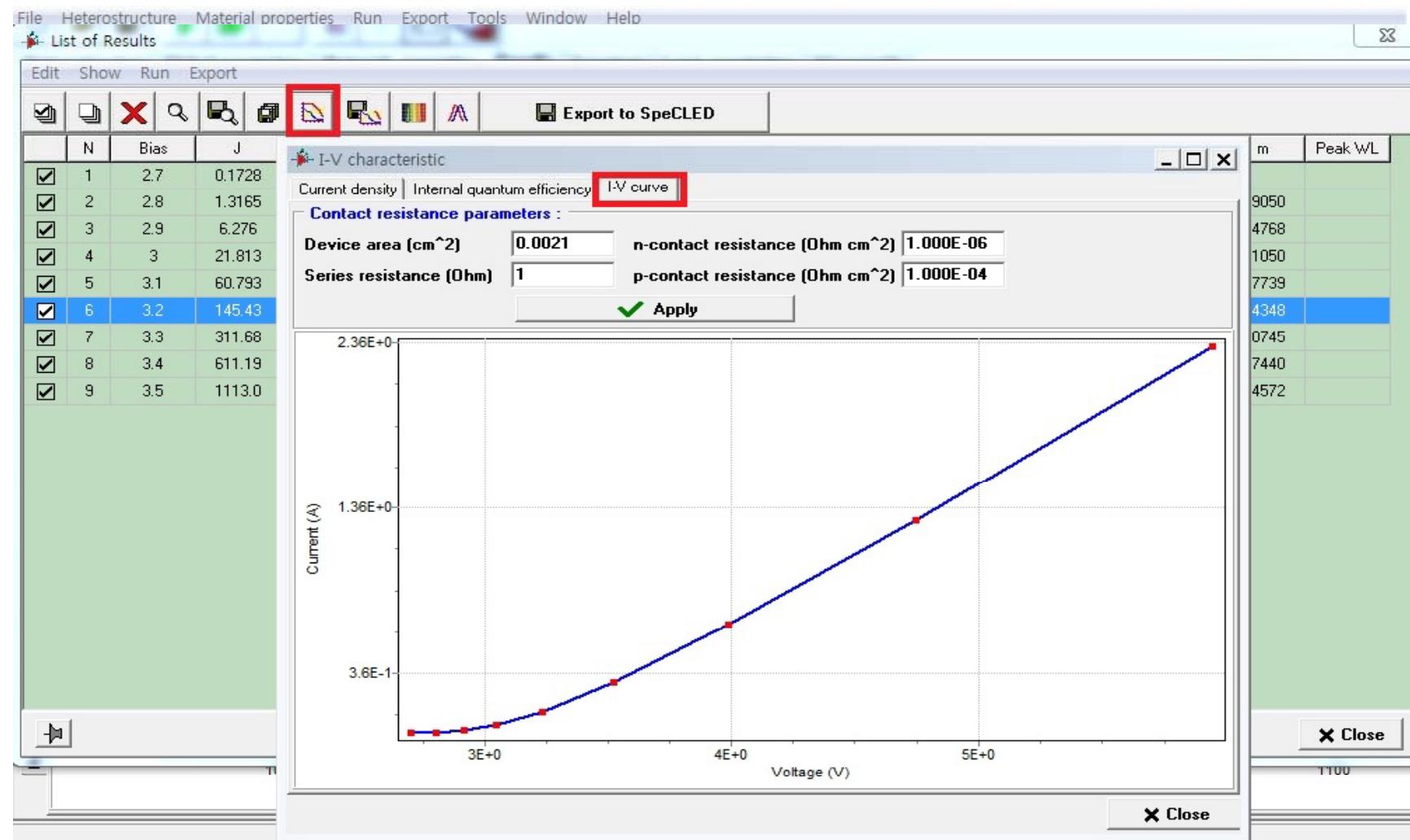
Spectrum solver parameters	
Mesh step (nm)	0.05
Wavefunction damping in a barrier	100
Maximum number of levels in a QW	100
Minimum energy level (eV)	0.02
Spectrum broadening (eV)	0.02

2-1. Current band diagram

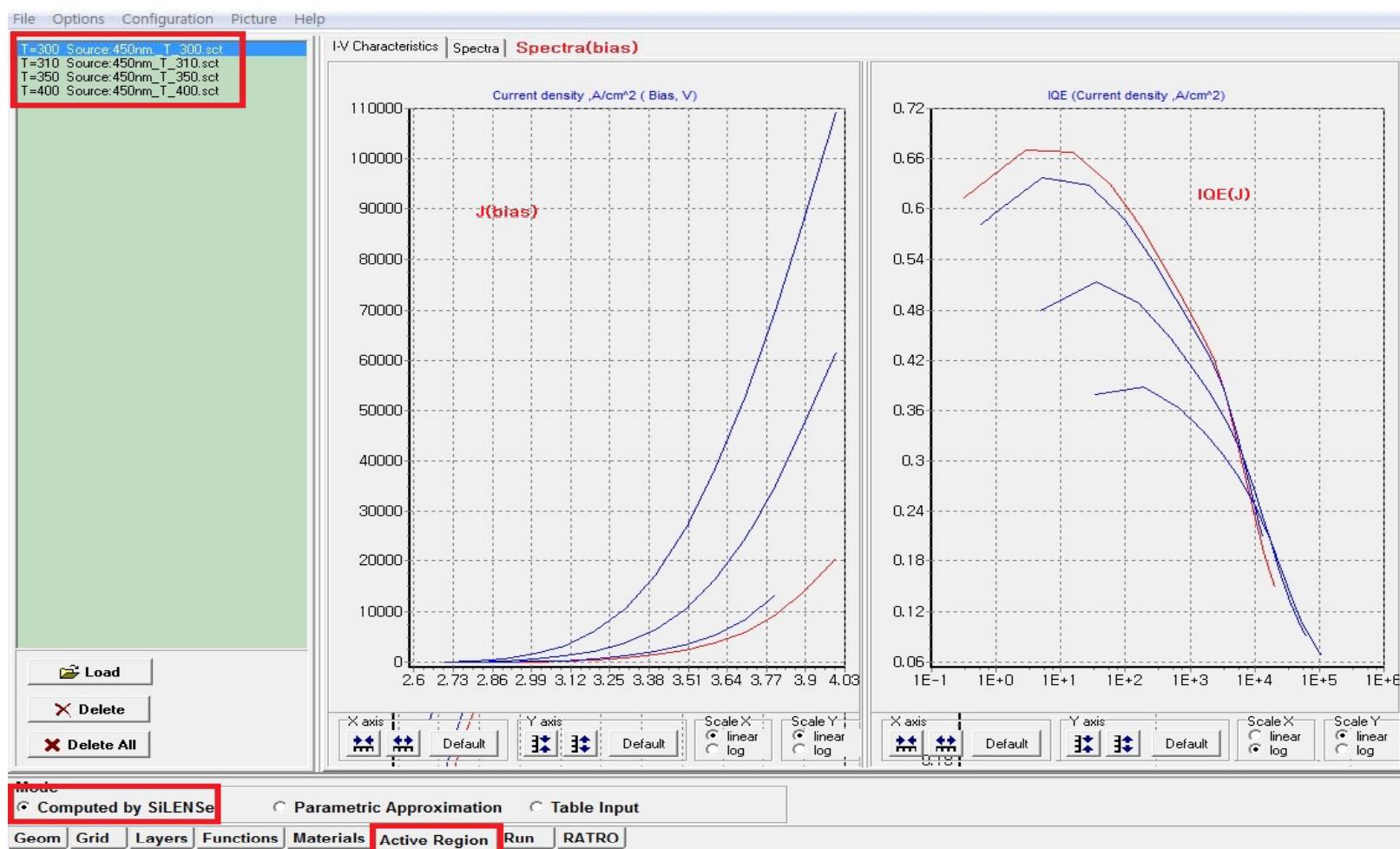
The screenshot shows a software application window titled "List of Results". The menu bar includes File, Heterostructure, Material properties, Run, Export, Tools, Window, and Help. The toolbar contains various icons for file operations like Open, Save, Print, and Run. Below the toolbar is a toolbar with icons for Edit, Show, Run, and Export, followed by an "Export to SpeCLED" button.

	N	Bias	J	J rad	J nrad	J SRH	J Auger	J n	J p	Jn right	Jp left	IQE	IQE QW	Inj eff	m	Peak WL
<input checked="" type="checkbox"/>	1	2.7	0.1728	0.1219	0.0510	0.0478	0.0031	0.1728	0.1728	6.006E-07	1.105E-09	0.7051	0.7051	0.9944		
<input checked="" type="checkbox"/>	2	2.8	1.3165	0.9801	0.3364	0.2831	0.0532	1.3165	1.3165	8.550E-06	1.243E-08	0.7445	0.7445	0.9938	1.9050	
<input checked="" type="checkbox"/>	3	2.9	6.276	4.6579	1.618	1.1188	0.4992	6.276	6.2759	8.195E-05	8.274E-08	0.7422	0.7422	0.9909	2.4768	
<input checked="" type="checkbox"/>	4	3	21.813	15.473	6.339	3.4409	2.8981	21.813	21.812	0.0006	4.403E-07	0.7094	0.7093	0.9868	3.1050	
<input checked="" type="checkbox"/>	5	3.1	60.793	40.297	20.493	8.7514	11.7388	60.793	60.79	0.0037	2.104E-06	0.6629	0.6627	0.9849	3.7739	
<input checked="" type="checkbox"/>	6	3.2	145.43	89.213	56.196	19.2191	36.9774	145.43	145.41	0.0217	9.998E-06	0.6134	0.6134	0.9858	4.4348	
<input checked="" type="checkbox"/>	7	3.3	311.68	176.35	135.19	37.9064	97.2885	311.68	311.55	0.1300	5.108E-05	0.5658	0.5657	0.9870	5.0745	
<input checked="" type="checkbox"/>	8	3.4	611.19	318.86	291.48	68.3222	223.1653	611.19	610.35	0.8431	0.0003	0.5217	0.5214	0.9873	5.7440	
<input checked="" type="checkbox"/>	9	3.5	1113.0	535.76	571.08	114.0107	457.0461	1113.0	1107.0	5.7713	0.0015	0.4815	0.4811	0.9836	6.4572	

2-2. I-V curve and Wavelength



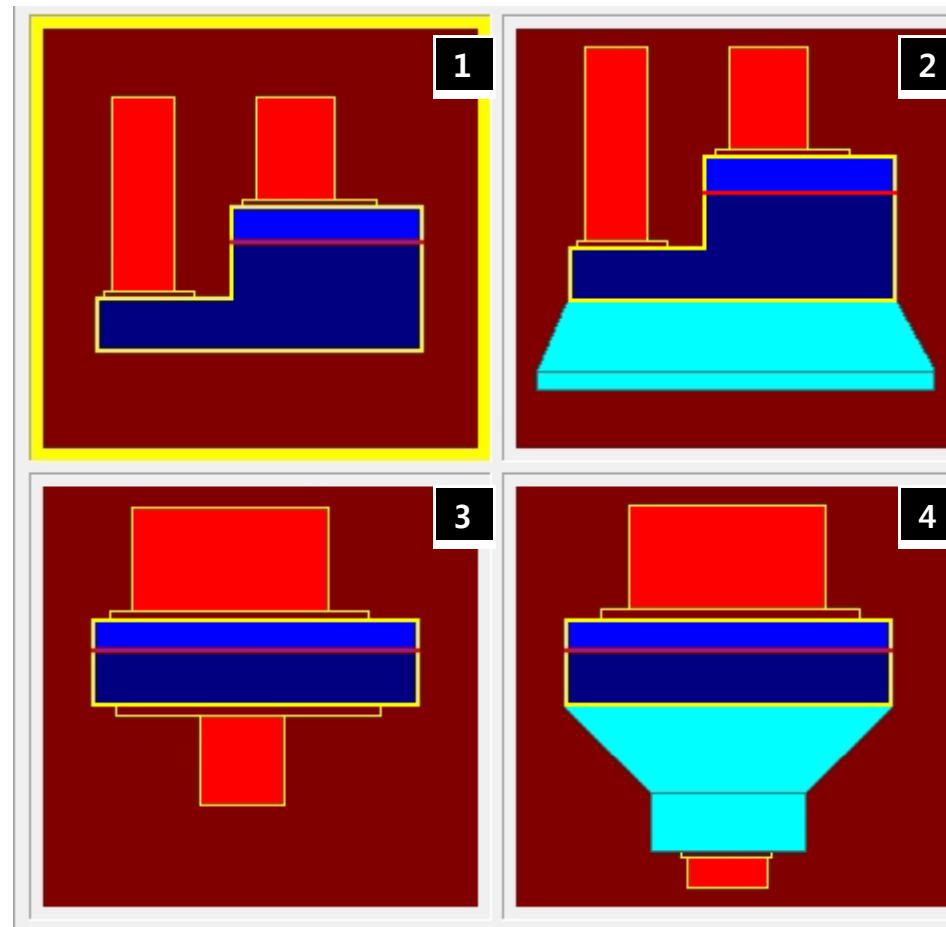
3. Export to SpeCLED



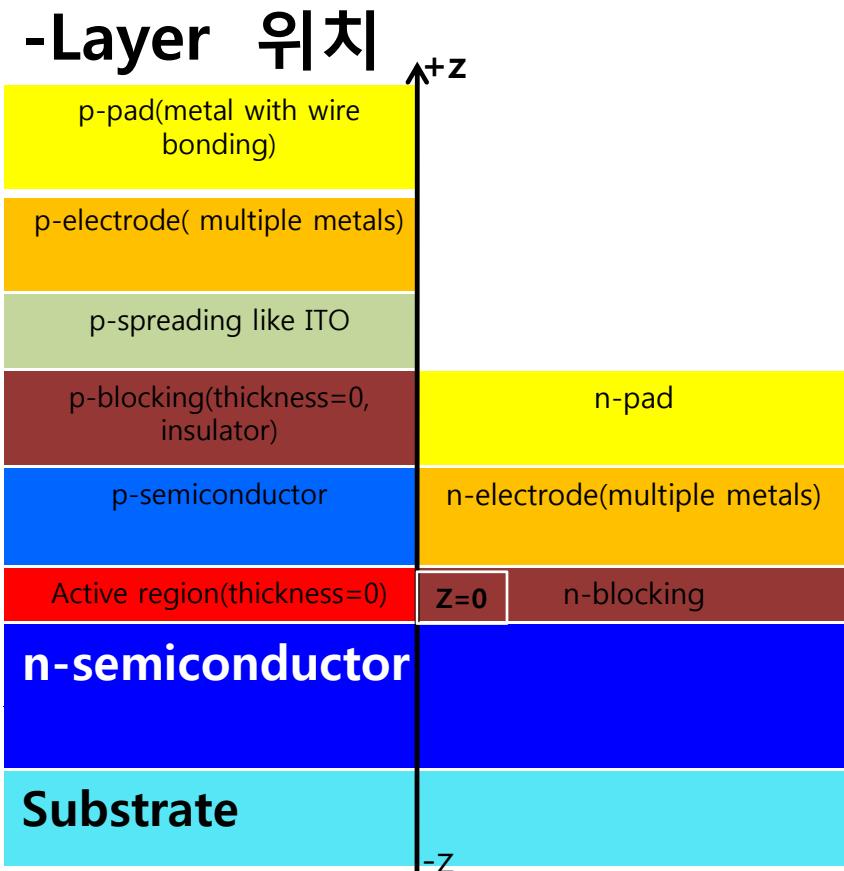
2. SpeCLED

- 2-1. Chip structures available
- 2-2. Layer 위치와 종류
- 2-3. Layer Properties Profile
- 2-4. Computation Vertical mesh
- 2-5. Chip computation mode

2-1. Chip Structures



2-2. layer 위치와 종류



-Layer 물성 정의

Layer	물 성
Semiconductor	Mobility, 열전도도, 전기전도도, 도핑 DOS, Ei, g-factor
Conductor	열전도도 / 전기전도도
Spreading	전기전도도 from sheet R
Insulator	열전도도
Substrate	열전도도/전기전도도
Active region(z=0)	J(bias), IQE(J), spectra(bias)

2-3. Layer Properties profile

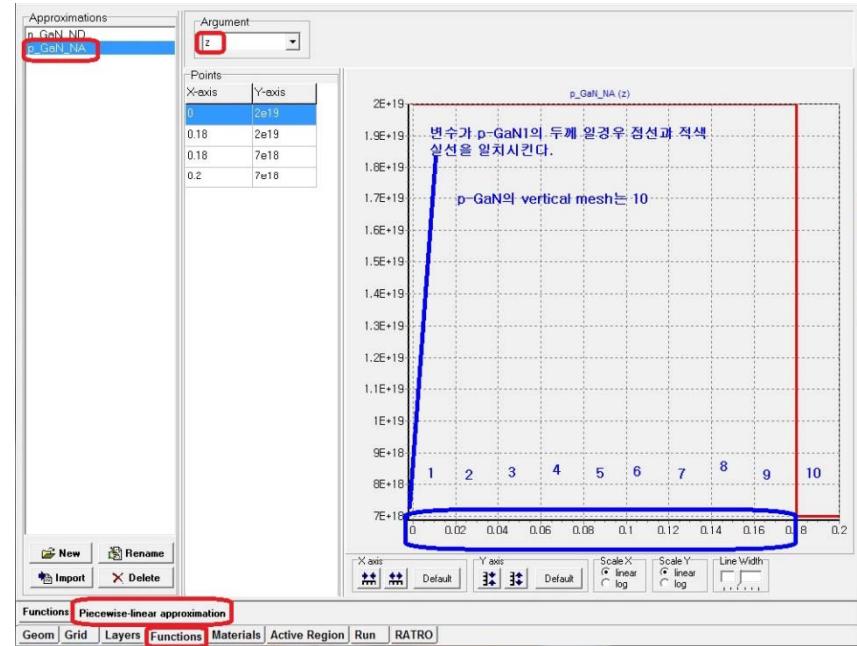
- 2-3-1. p-GaN mobility & doping profile
- 2-3-2. n-GaN mobility & doping profile
- 2-3-3. Vertical mesh
- 2-3-4. Layer contact resistance
- 2-3-5. Heat transfer coefficient

2-3-1. mobility&doping

p-GaN profile

Thickness(+z)	h_Mobility(z,T)	Doping(z)
p-GaN2=0.02um	$M=10*(300/T)$	5e18
p-GaN1=0.18um	$M=8*(300/T)$	1e19
z=0		

Piecewise tab in doping(z)



Function tab in mobility(z,T)

If ($z>0$) and ($z<0.18$) then
 $h_{mob}=8*(300/T);$

If ($z>0.18\mu m$) then
 $h_{mob}=10*(300/T);$

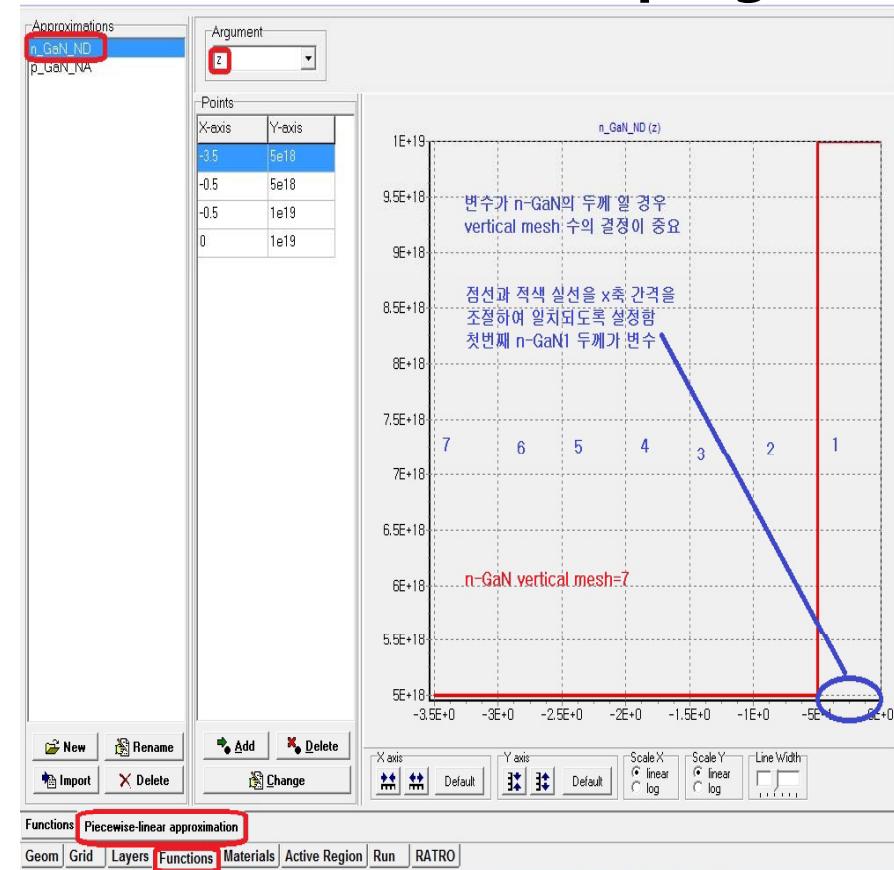
Result= $h_{mob};$

2-3-2. mobility&doping

n-GaN profile

Thickness(-z)	E_Mobility(z,T)	Doping(z)
Z=0		
n-GaN1=0.5um	Mob=100*(300/T)	1e19
n-GaN2=3.0um	Mob=120*(300/T)	5e18

Piecewise tab in doping(z)



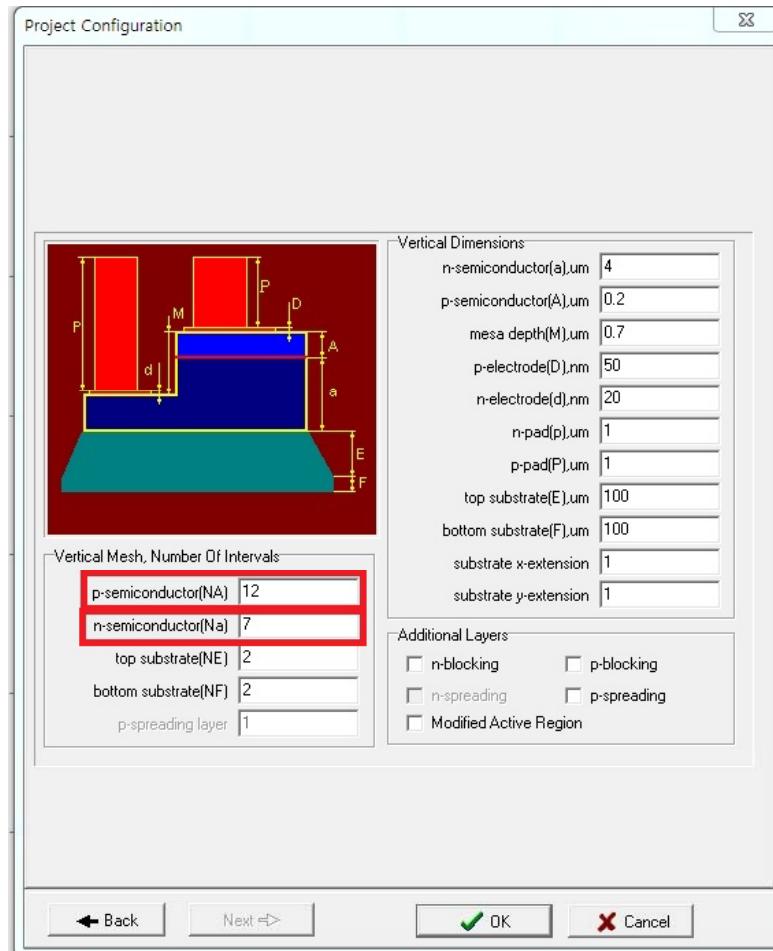
Function tab in mobility(z,T)

If $(z < 0)$ and $(z > -0.5)$ then
 $e_mob = 100 * (300/T);$

If $(z < -0.5\text{um})$ then
 $e_mob = 120 * (300/T);$

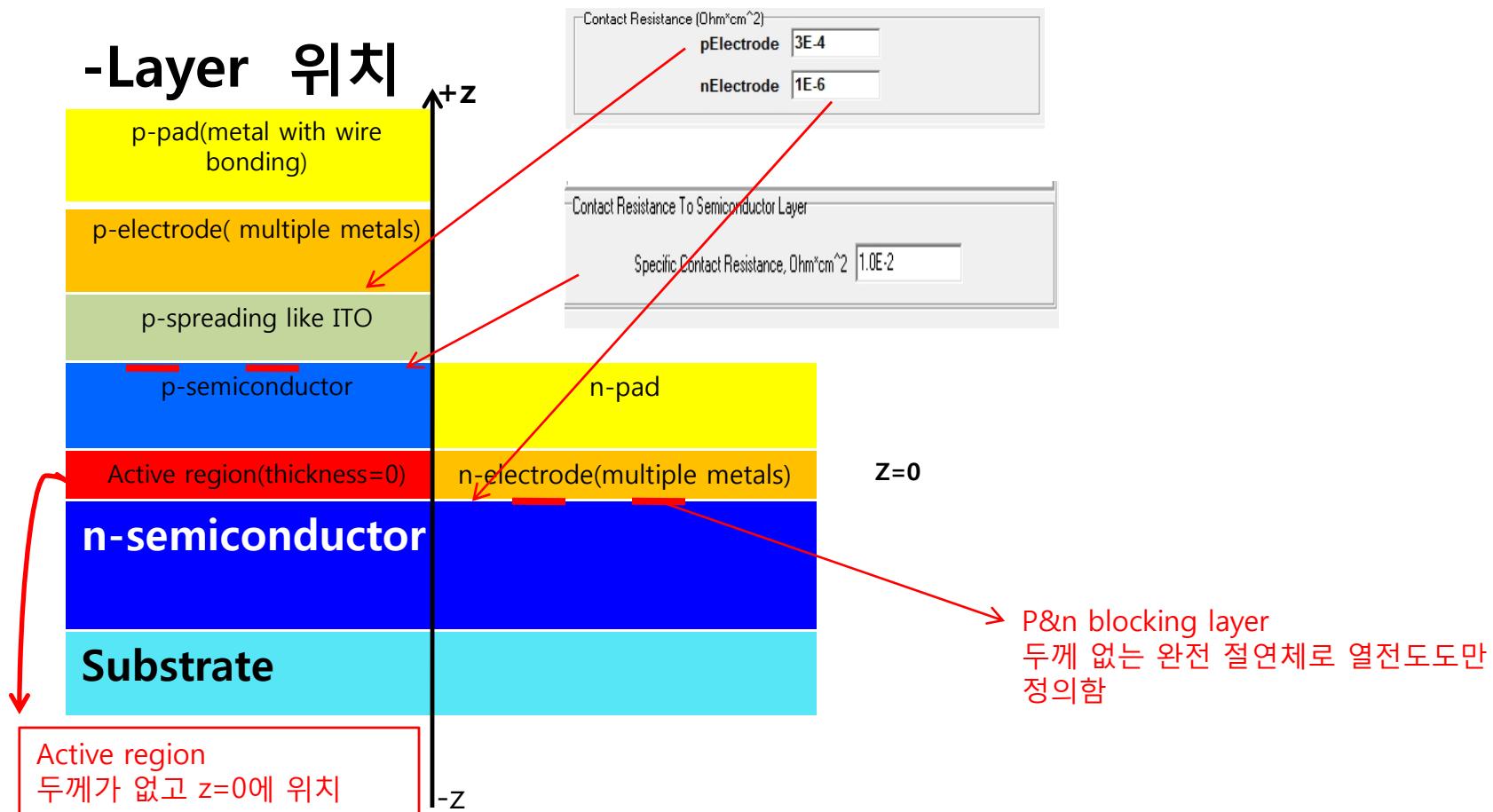
Result = e_mob;

2-3-3. Vertical Mesh



- Computation=Planar grids X vertical mesh
- Vertical mesh 수의 증가는 막대한 계산시간이 필요함으로 vertical mesh의 증가가 계산 결과에 영향을 미치는 경우에만 사용을 권장
- 시뮬레이션 변수가 p-GaN 또는 n-GaN의 두께가 아닐 경우 p-GaN(3) and n-GaN(5)를 권장함

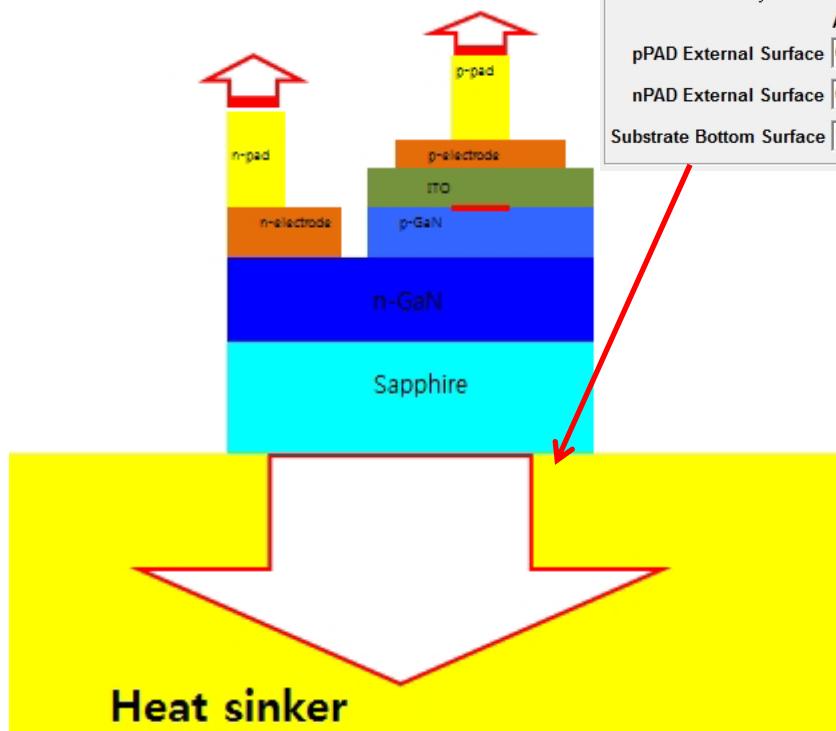
2-3-4. p&n 접촉 저항



2-3-5. 열 전달 계수

수평형 일반칩

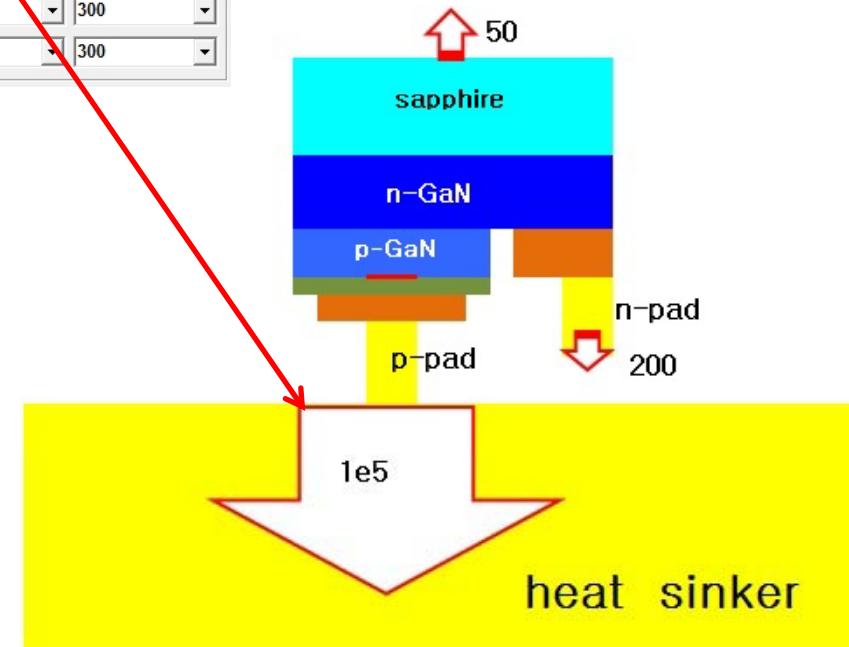
열전달 계수 200
Au와 대기



수평형 플립칩

열전달 계수 200
Au와 대기

Heat Transfer Boundary Conditions		
Alpha, W/m ² /K	T _a , K	
pPAD External Surface 0	300	
nPAD External Surface 0	300	
Substrate Bottom Surface 1e5	300	



2-4. Computation mode

Series calculation

Current Solver Settings Output

Computation Mode

- Single Calculation
- Series Calculation
- Series Calculation for SimuLAMP

V1=3.2v-->I1=350mA
V2=3.1v-->I2=150mA
V3=3.0v-->I3=10mA
V=3.005v-->I=30mA
V2=3.01-->I2=50mA.....

Total Current Range

Min	10	mA
Max	350	mA

Voltage

Initial Voltage, V	3.2
Voltage Fitting Step, V	0.1
Voltage Variation Step, V	0.05

min. I=10mA full 3D 계산..
I2=30mA -->active region only
I3=50mA-->active region only~

Run Solver

Solver setting

Current Solver Settings Output

Convergence Limits

ΔJ , mA:	1E-3
U Residual Preliminary:	1E-6
U Residual Final:	1E-8

Active Region Parameters

I-V Linearization Method

- Tangent planar
- Secant vertical

Relaxation 0.5

OK Relaxation<1
0:more slow and stable

BCGS Solver Parameters

U-Number of Iterations:	200
U-Residual Limit:	1E-2
U-Inertion:	1E-5
U-Relax:	0.9

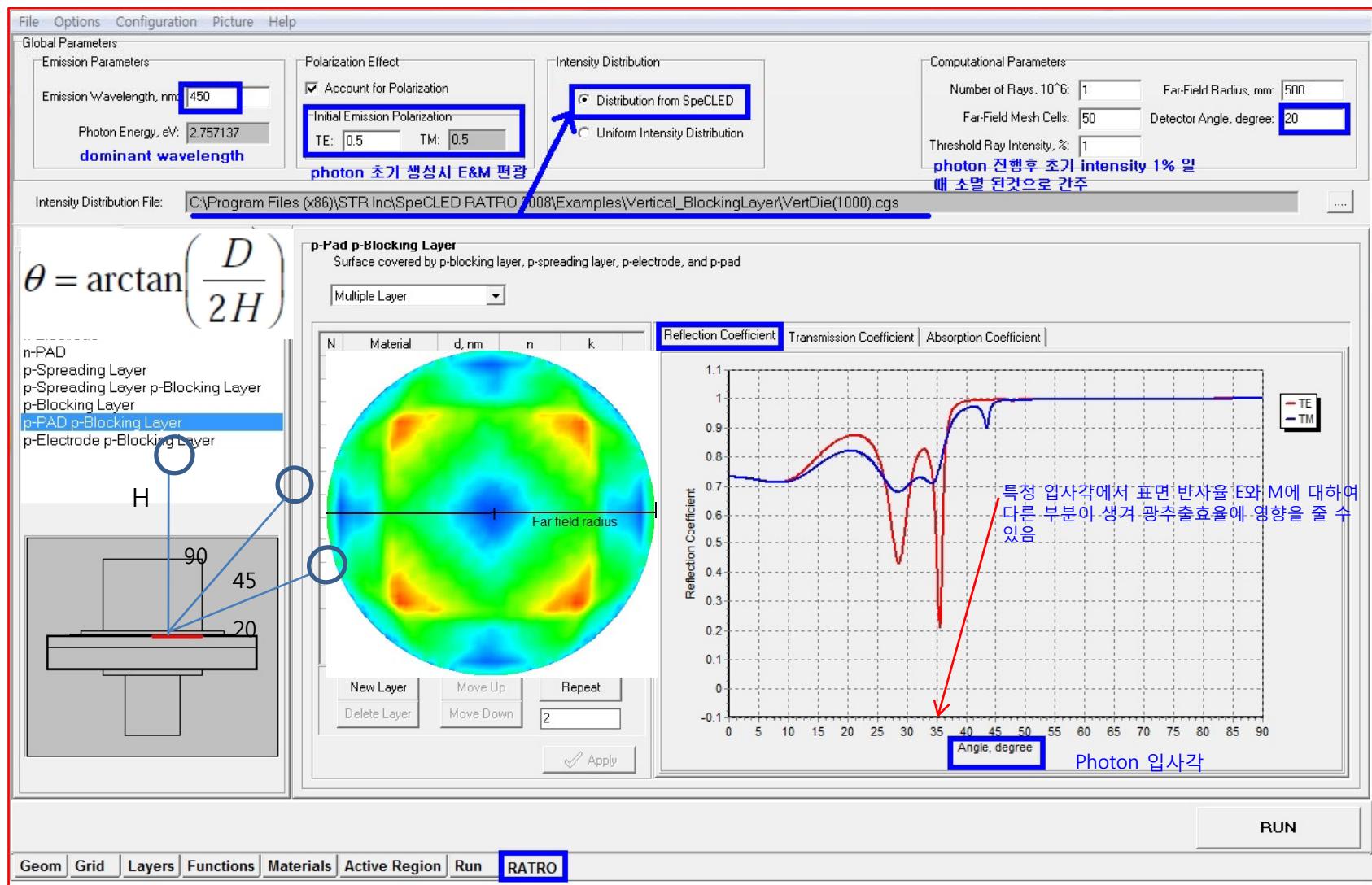
Run Solver

Current Spreading Heat Transfer Coupling

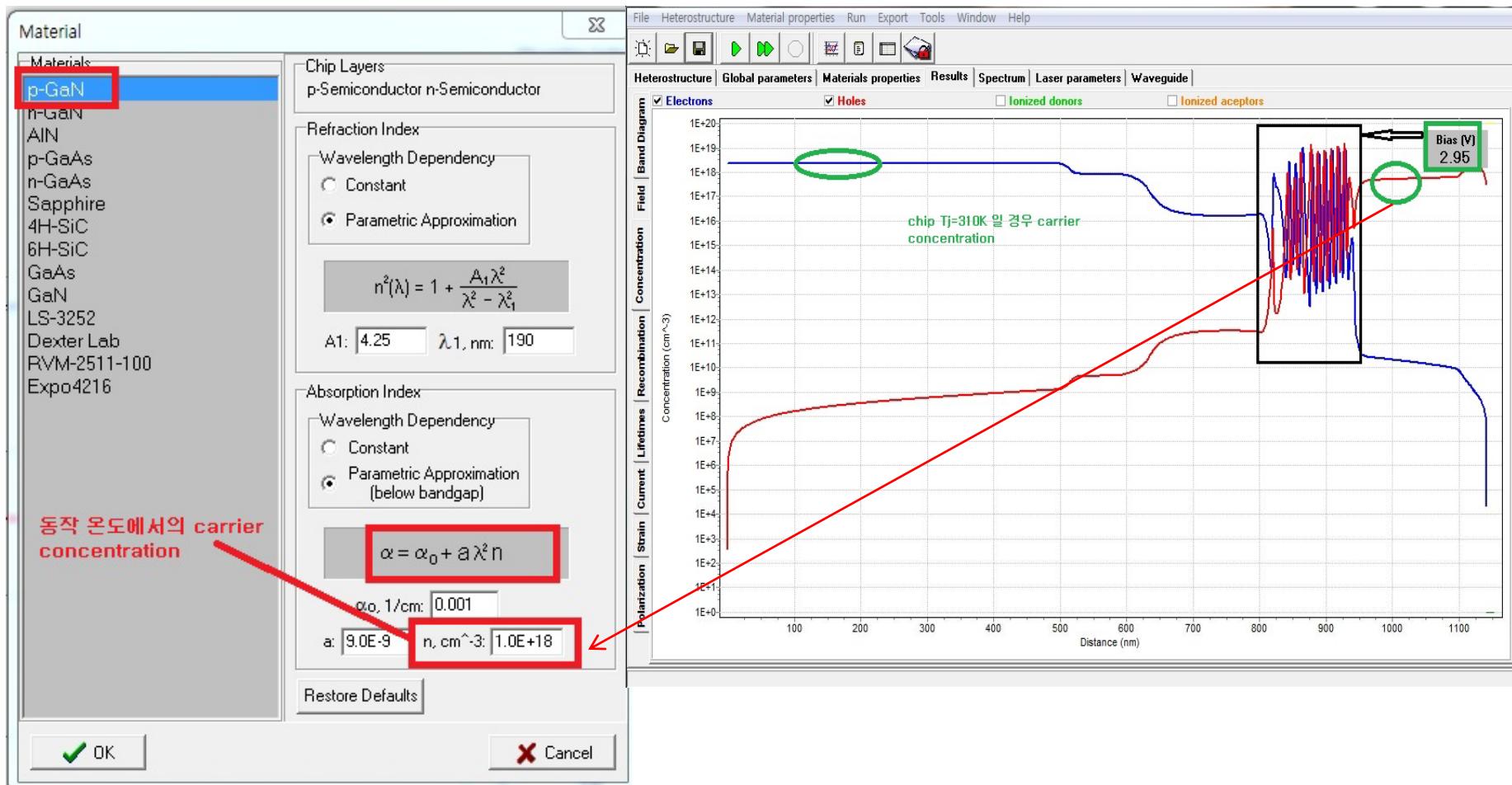
3. RATRO

- 3-1. Global parameters
- 3-2. Bulk Properties 정의
- 3-3. Surface Properties 정의

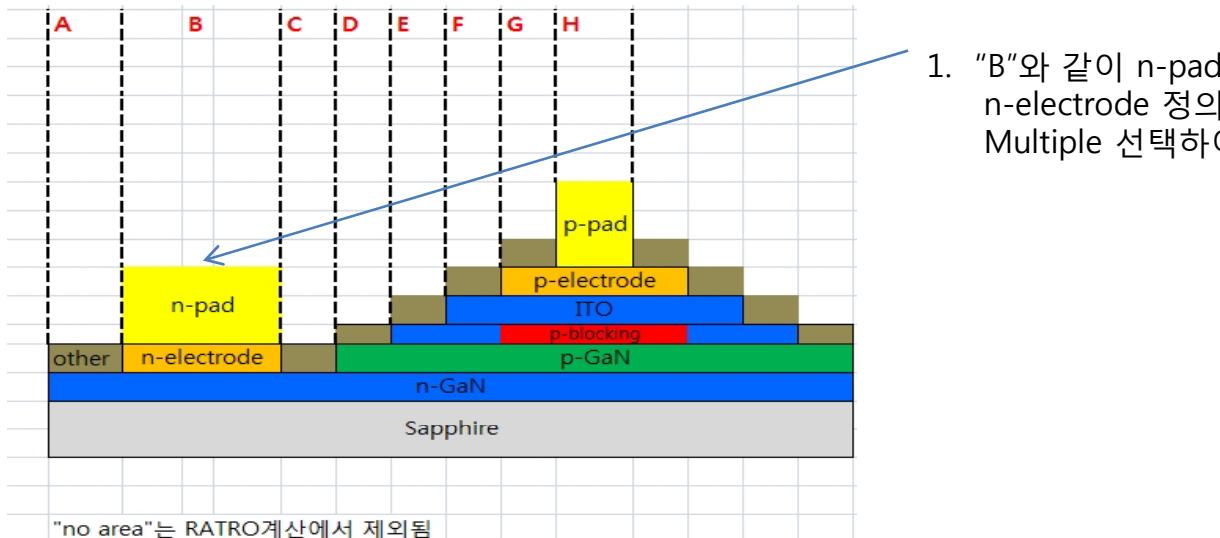
3-1 Global parameters



3-2 Bulk properties



3.3 Surface properties



1. "B"와 같이 n-pad=n-elec. 영역이 같은 경우 n-electrode 정의할 필요 없고, n-pad를 Multiple 선택하여 n-electrode 함께 묘사함

"no area"는 RATRO계산에서 제외됨

	Surface properties	Explanation
D	p-semiconductor	Free surface of p-semiconductor
G	p-electrode	Surface covered by p-spreading layer and p-electrode
no area	p-pad	Surface covered by p-spreading layer and p-electrode and pad
A	n-semiconductor	Free surface of n-semiconductor
no area	n-electrode	Surface covered by n-electrode only
B	n-pad	Surface covered by n-electrode and n-pad
	substrate bottom surface	
	hetero-structure/substate interface	
	substrate sidewall1	
	substrate sidewall2	
F	p-spreading layer	Surface covered by p-spreading layer only
F	p-spreading-p-blocking layer	Surface covered by p-blocking layer and p-spreading layer and not covered by p-electrode or pad
E	p-blocking layer	Surface covered by p-blocking layer only
H	p-pad p-blocking layer	Surface covered by p-blocking layer, p-spreading layer, p-electrode, and p-pad
G	p-electrode p-blocking layer	Surface covered by p-blocking layer, p-spreading layer, and p-electrode, not covered by p-pad

-시뮬레이션 순서-

- 1. SiLENSe:
 - 입력: "Heterostructure", "Global parameter",
 - 계산 모드: Series calculation for SpeCLED
 - 생성 결과 파일: => "~T_300.sct", "~T_320.sct", "~T_350.sct"
- 2. SpeCLED: 칩구조 입력
"Active region" 탭에서 1번 결과 생성파일 ".sct" 파일 온도 별로 로드
- 3. RATRO
"Global parameter(Uniformity intensity 선택)"->"Bulk properties"→"Surface properties"→Run
결과: LEE 계산
- 4. SpeCLED "Run" 탭에 LEE(user input에 3번 결과 입력) 계산
결과: ~(mA).cgs 파일
- 5. RATRO "intensity distribution from SpeCLED" 모드 선택→4번 .cgs 파일 선택
"Run" 실행→최종 RATRO 결과 ~(mA)_rtr.cgs 생성