Thermal CAE Recipe

2017-09-18, 김동호

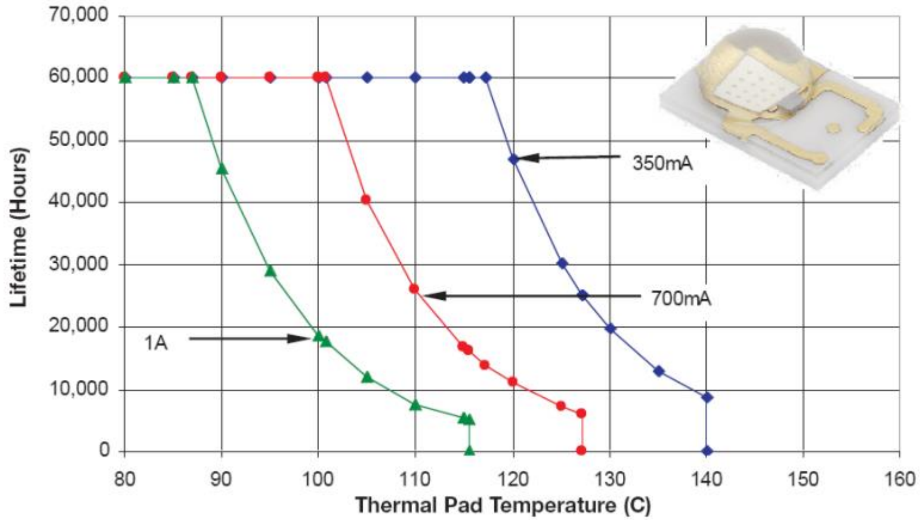
기초데이타

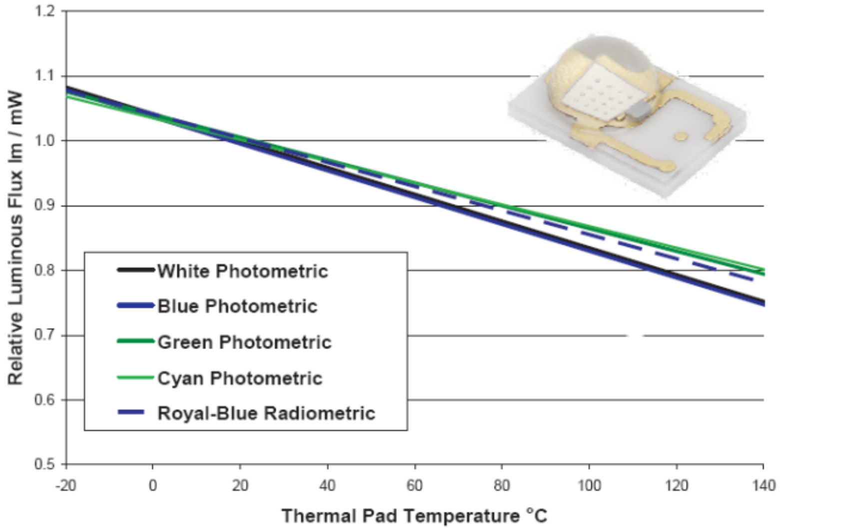
Min Seok Ha, THERMAL ANALYSIS OF HIGH POWER LED ARRAYS, 2009
https://smartech.gatech.edu/bitstream/handle/1853/31803/ha_minseok_200912_mast.pdf

광원	형태	발광 능률 (Luminous efficacy) [lm/W]	발광 효율 (Luminous efficiency) [%]	일반적인 보증 수명 [Hours]	백색광의 파워 변환 비율 [%]
백열등 (Incandescent)	40W 텅스텐 백열등 (120V)	12.6	1.9	750-2000	가시광선 8 IR 73 UV 0 발열 19
	100W 텅스텐 백열등	17.5	2.6		
	석영 할로겐 (12-24V)	24	3.5	3000-4000	
형광등 (Fluorescent)	9-16W 소형 형광등	57-72	8-11	8000-10000	가시광선 21 IR 37 UV 0 발열 42
	T8 튜브 자석 밸러스트	80-100	12-15	20000-30000	
HID (High-intensity discharge)	메탈 할라이드 (Metal Halide)	65-115	9.5-16.8	7500-20000	가시광선 27 IR 17 UV 19 발열 37
LED	고출력 백색 LED	-115	-16.8	35000-50000	가시광선 15-25 IR 0 UV 0 발열 75-85

LED는 발광효율과 수명이 가장 좋지만, 발열이 상당히 많다는 특징이 있다.
발열 문제를 해결하는 것이 핵심.
T_J가 높아지면, 광도가 저하되고 수명이 단축된다. 보통 보증 T_J는 130~185도씨로 설정되고, 이를 넘어서면 즉각 파괴된다.

기초 데이타





T_J에 따른 기대수명의 단축 양상 사례

이 사례에서는 T_J를 85도씨 이하로 관리해야 함을 알 수 있다.

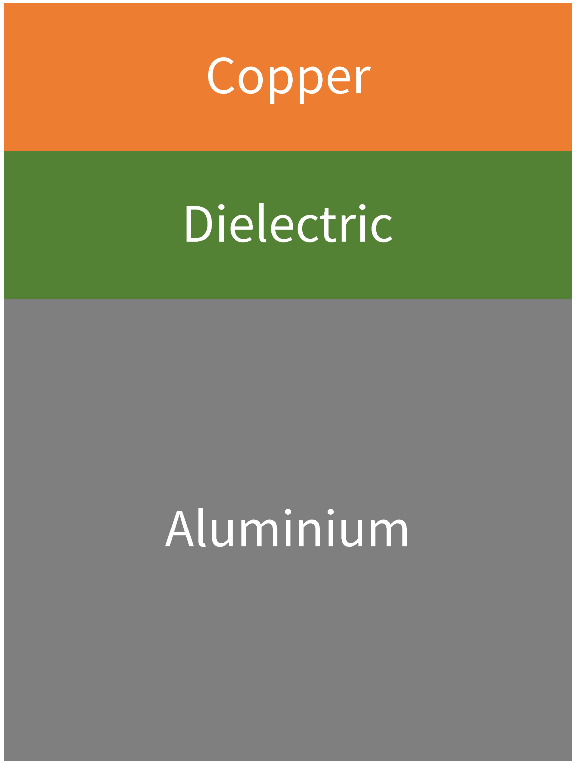
T_J에 따른 광도 저하의 양상 사례

이 사례에서는, 온도에 따라 광도가 선형적으로 저하되고 있으므로, 기대수명에서 설정한 T_J 관리온도 85도씨일 때의 광도를 보증 광도로 잡아야 할 것이다.

단순화모델

MCPCB

IMS
(Insulated Metal Substrate)



Dielectric의 소재

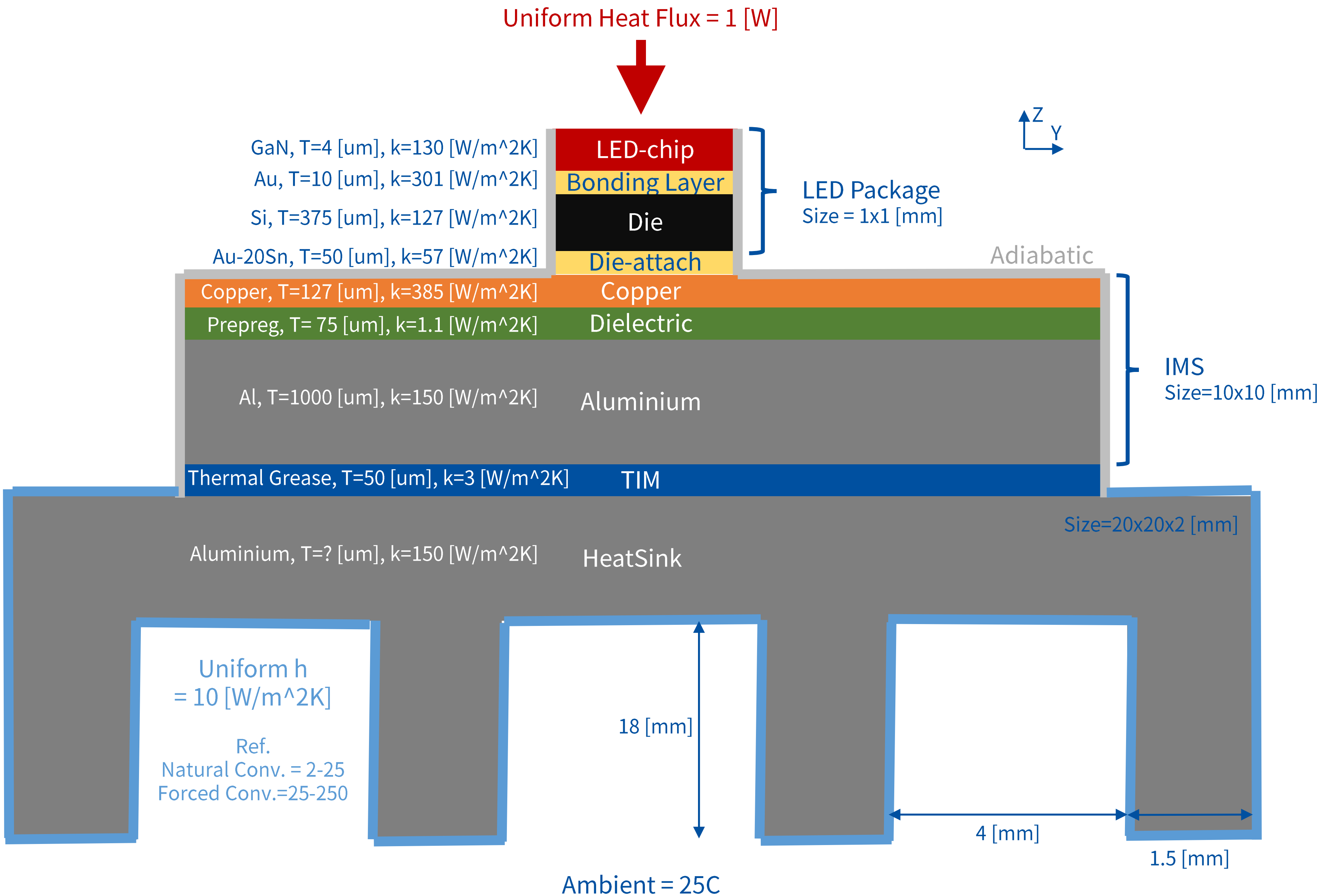
1. FR4 : k=0.35 [W/mK]
2. Prepreg (Preimpregnated Material, 강화섬유)
3. Bergquist사 HT-04503 : k=2.2[W/mK], 76um

DBC
(Direct Bonded Copper)

Ceramic 소재

1. AlN(Aluminium Nitride) : k = 180 [W/mK]
2. Alumina(Al2O3) : k = 35 [W/mK]
3. Beryllium Oxide(BeO) : 분말상태에서의 독성으로 인해 잘 사용되지 않음

Simplified Model of LED Thermal System



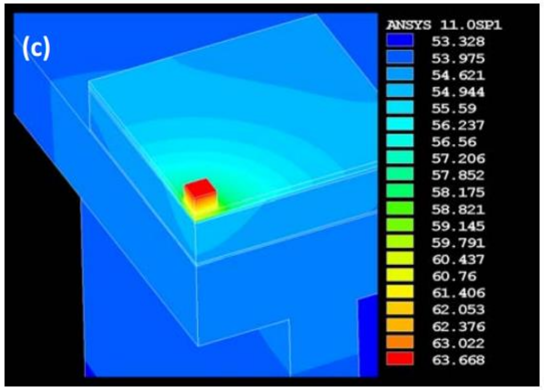
Materials


```xml
<material name="GaN (LED)" >
   <parameter name="Density" >6100.0</parameter>
   <parameter name="Youngs modulus" >1.8456863E10</parameter>
   <parameter name="Poisson ratio" >0.352</parameter>
   <parameter name="Tensile strength" >19374608</parameter>
   <parameter name="Heat expansion coeff." >6.66e-06</parameter>
   <parameter name="Heat capacity" >930.37</parameter>
   <parameter name="Heat conductivity" >130</parameter>
 </material>

<material name="Au, Gold (LED)" >
   <parameter name="Density" >19300.0</parameter>
   <parameter name="Youngs modulus" >7.9537865E+09</parameter>
   <parameter name="Poisson ratio" >0.44</parameter>
   <parameter name="Tensile strength" >8.0047723E+09</parameter>
   <parameter name="Heat expansion coeff." >14.1e-6</parameter>
   <parameter name="Heat capacity" >129.0</parameter>
   <parameter name="Heat conductivity" >318.0</parameter>
 </material>

<material name="Si (LED)" >
   <parameter name="Density" >2330.0</parameter>
   <parameter name="Youngs modulus" >185.0e9</parameter>
   <parameter name="Poisson ratio" >0.28</parameter>
   <parameter name="Tensile strength" >7.1380135E+08</parameter>
   <parameter name="Heat expansion coeff." >4.68e-6</parameter>
   <parameter name="Heat capacity" >555.8</parameter>
   <parameter name="Heat conductivity" >127.0</parameter>
 </material>

<material name="Au-20Sn (LED)" >
   <parameter name="Density" >14510.0</parameter>
   <parameter name="Youngs modulus" >6.9340702E+09</parameter>
   <parameter name="Poisson ratio" >0.136</parameter>
   <parameter name="Tensile strength" >28042196</parameter>
   <parameter name="Heat expansion coeff." >16.1e-6</parameter>
   <parameter name="Heat capacity" >388.0</parameter>
   <parameter name="Heat conductivity" >57.0</parameter>
 </material>

<material name="Prepreg, GlassFiber (MCPCB)" >
   <parameter name="Density" >1850.0</parameter>
   <parameter name="Youngs modulus" >2.5492905E+09</parameter>
   <parameter name="Poisson ratio" >0.2</parameter>
   <parameter name="Tensile strength" >4.4867513E+10</parameter>
   <parameter name="Heat expansion coeff." >11.6e-6</parameter>
   <parameter name="Heat capacity" >1000.0</parameter>
   <parameter name="Heat conductivity" >1.1</parameter>
 </material>

<material name="Thermal Grease (MCPCB)" >
   <parameter name="Density" >1000.0</parameter>
   <parameter name="Youngs modulus" >1000.0</parameter>
   <parameter name="Poisson ratio" >0.3</parameter>
   <parameter name="Tensile strength" >1.0e3</parameter>
   <parameter name="Heat expansion coeff." >1.0e-6</parameter>
   <parameter name="Heat capacity" >300.0</parameter>
   <parameter name="Heat conductivity" >3.0</parameter>
 </material>
```


Red Characters : Not proper values yet

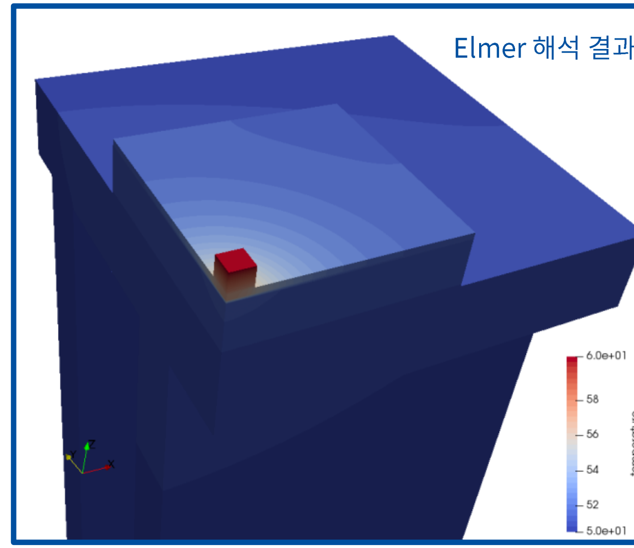
테스트해석

원래 논문과의 결과 비교



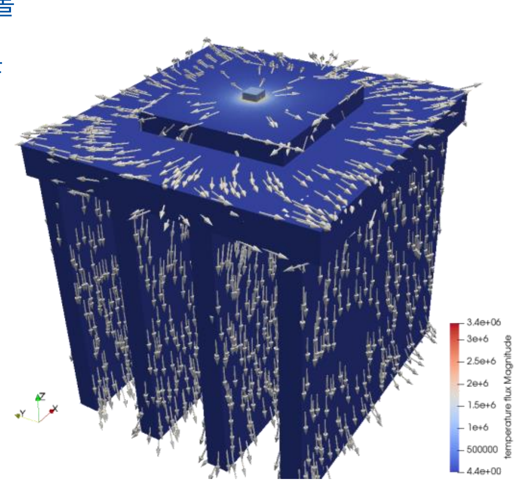
Die (Si)
375µm, k=127W/mK
Die-attach (Au-20Sn)
50µm, k=57W/mK
Substrate (IMS)
Cu 127µm, k=385W/mK
Dielectric 75µm, k=1.1W/mK
Al 1000µm, k=150W/mK
TIM
50 µm, k=3W/mK
1W Heat Flux
h=10 W/m²K, T_∞=25 °C

원래 논문의 결과

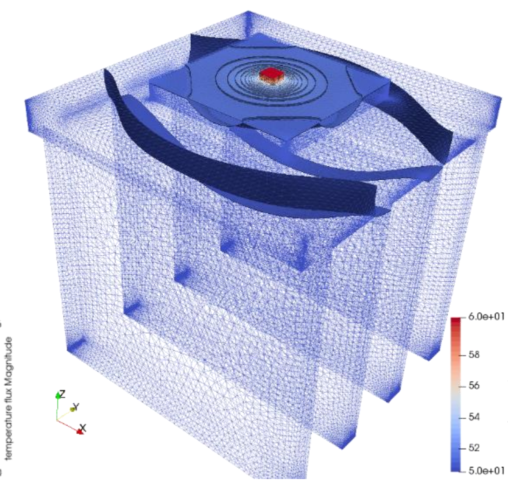


원래 논문과 Elmer 해석 결과는 3C 가량의 차이가 나는 것을 확인하였다. 오차의 원인은, 일부 물성치가 다르게 들어갔거나 매쉬 분할 상태의 차이가 있을 수 있고, 사용된 해석자의 차이도 생각해 볼 수 있다.
물성치의 차이는, 원래 논문에 모든 물성치가 공개되어 있지는 않기 때문에 보정하기가 어렵다.
대신 온도 분포의 형태는 거의 동일하게 나타난다.

	원래 논문	Elmer	오차
최고온도	63.688	60.437	3.251
최저온도	53.328	50.4997	2.8283



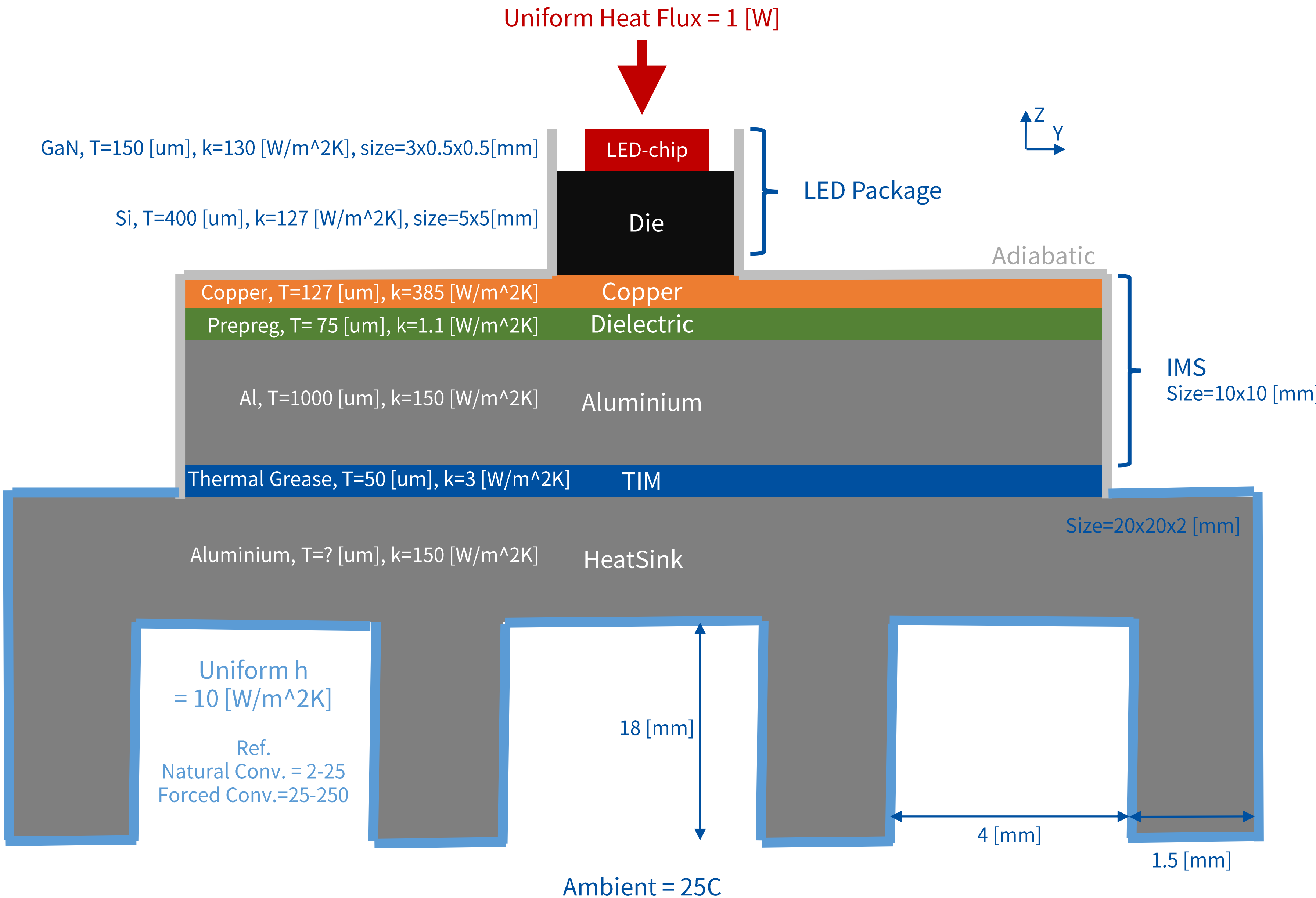
Temperature Flux



Temperature Contour

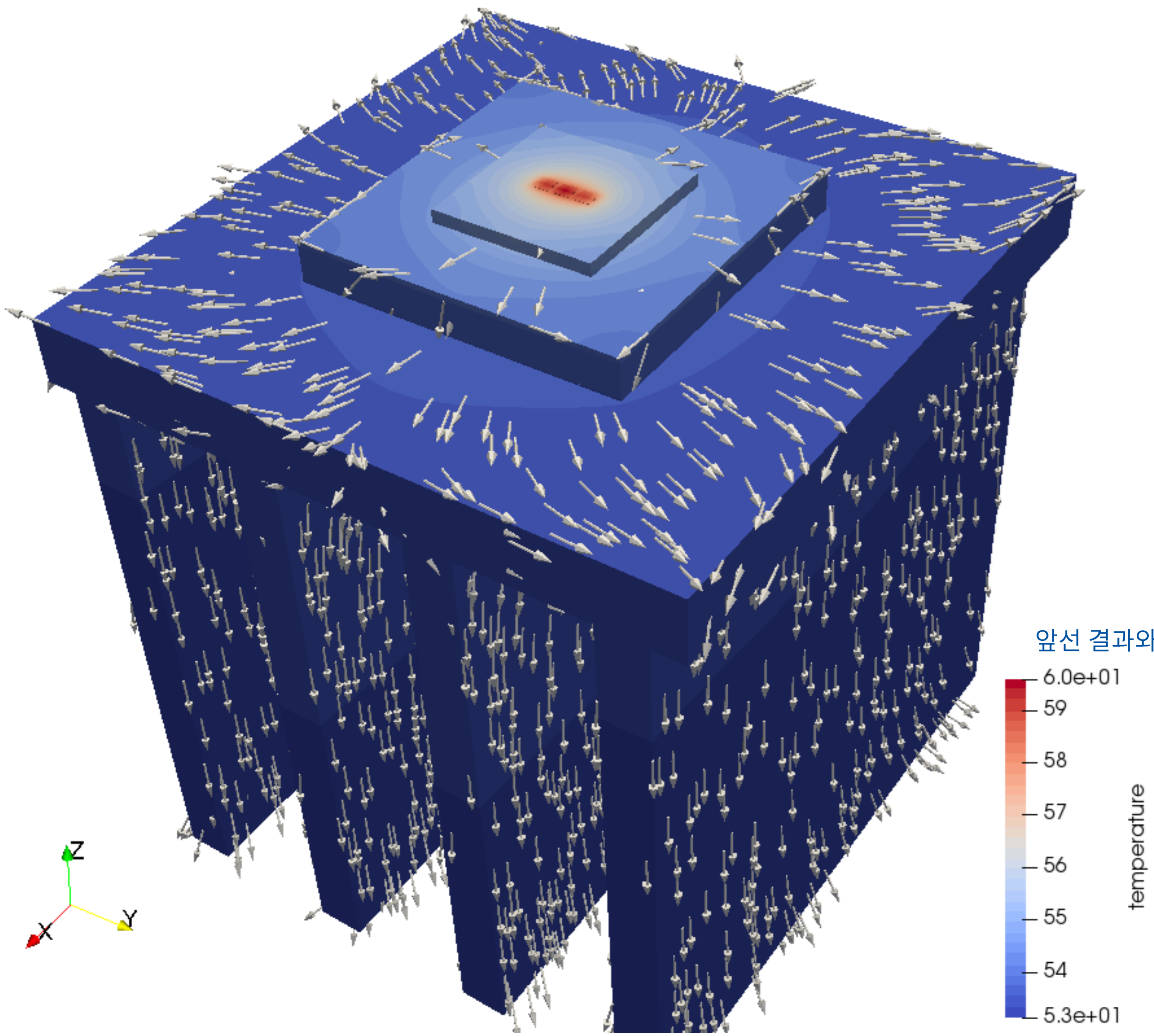
단순화모델 2

Simplified Model 2 of LED Thermal System



```
Header
  CHECK KEYWORDS Warn
  Mesh DB "." "."
  Include Path ""
  Results Directory "case01"
End

Simulation
  Max Output Level = 5
  Coordinate System = Cartesian
  Coordinate Mapping(3) = 1 2 3
  Simulation Type = Steady state
  Steady State Max Iterations = 1
  Output Intervals = 1
  Timestepping Method = BDF
  BDF Order = 1
  Solver Input File = case01.sif
  Post File = case01.vtu
End

Constants
  Gravity(4) = 0 -1 0 9.82
  Stefan Boltzmann = 5.67e-08
  Permittivity of Vacuum = 8.8542e-12
  Boltzmann Constant = 1.3807e-23
  Unit Charge = 1.602e-19
End

Body 1
  Target Bodies(1) = 1
  Name = "LED1"
  Equation = 1
  Material = 1
End

Body 2
  Target Bodies(1) = 2
  Name = "HEATSINK"
  Equation = 1
  Material = 5
End

Body 3
  Target Bodies(1) = 3
  Name = "TIM"
  Equation = 1
  Material = 4
End

Body 4
  Target Bodies(1) = 4
  Name = "ALUMINIUM"
  Equation = 1
  Material = 5
End

Body 5
  Target Bodies(1) = 5
  Name = "DIELECTRIC"
  Equation = 1
  Material = 3
End

Body 6
  Target Bodies(1) = 6
  Name = "COPPER"
  Equation = 1
  Material = 6
End

Body 7
  Target Bodies(1) = 7
  Name = "SLUG"
  Equation = 1
  Material = 2
End

Body 8
  Target Bodies(1) = 8
  Name = "LED2"
  Equation = 1
  Material = 1
End

Body 9
  Target Bodies(1) = 9
  Name = "LED3"
  Equation = 1
End

Solver 1
  Equation = Heat Equation
  Procedure = "HeatSolve" "HeatSolver"
  Variable = Temperature
  Exec Solver = Always
  Stabilize = True
  Bubbles = False
  Lumped Mass Matrix = False
  Optimize Bandwidth = True
  Steady State Convergence Tolerance = 1.0e-5
  Nonlinear System Convergence Tolerance = 1.0e-7
  Nonlinear System Max Iterations = 20
  Nonlinear System Newton After Iterations = 3
  Nonlinear System Newton After Tolerance = 1.0e-3
  Nonlinear System Relaxation Factor = 1
  Linear System Solver = Iterative
  Linear System Iterative Method = BiCGStab
  Linear System Max Iterations = 500
  Linear System Convergence Tolerance = 1.0e-10
  BiCGstabl polynomial degree = 2
  Linear System Preconditioning = Diagonal
  Linear System ILUT Tolerance = 1.0e-3
  Linear System Abort Not Converged = False
  Linear System Residual Output = 1
  Linear System Precondition Recompute = 1
End

Solver 2
  Equation = Flux and Gradient
  Calculate Flux = True
  Flux Coefficient = "Heat Conductivity"
  Calculate Grad = True
  Target Variable = Temperature
  Procedure = "FluxSolver" "FluxSolver"
  Exec Solver = After Simulation
  Stabilize = True
  Bubbles = False
  Lumped Mass Matrix = False
  Optimize Bandwidth = True
  Steady State Convergence Tolerance = 1.0e-5
  Nonlinear System Convergence Tolerance = 1.0e-7
  Nonlinear System Max Iterations = 20
  Nonlinear System Newton After Iterations = 3
  Nonlinear System Newton After Tolerance = 1.0e-3
  Nonlinear System Relaxation Factor = 1
  Linear System Solver = Iterative
  Linear System Iterative Method = BiCGStab
  Linear System Max Iterations = 500
  Linear System Convergence Tolerance = 1.0e-10
  BiCGstabl polynomial degree = 2
  Linear System Preconditioning = Diagonal
  Linear System ILUT Tolerance = 1.0e-3
  Linear System Abort Not Converged = False
  Linear System Residual Output = 1
  Linear System Precondition Recompute = 1
End

Equation 1
  Name = "Equation 1"
  Active Solvers(2) = 1 2
End

Material 1
  Name = "(LED) GaN"
  Youngs modulus = 1.8456863E10
  Heat Conductivity = 130
  Poisson ratio = 0.352
  Youngs modulus = 1.8456863E10
  Heat Capacity = 930.37
  Youngs modulus = 1.8456863E10
  Poisson ratio = 0.352
  Heat expansion Coefficient = 6.66e-06
  Poisson ratio = 0.352
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.352
  Density = 6100.0
End

Material 2
  Name = "(LED) Si"
  Youngs modulus = 185.0e9
  Heat Conductivity = 127.0
  Poisson ratio = 0.28
  Youngs modulus = 185.0e9
  Heat Capacity = 555.8
  Youngs modulus = 185.0e9
  Poisson ratio = 0.28
  Heat expansion Coefficient = 4.68e-6
  Poisson ratio = 0.28
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.28
  Density = 2330.0
End

Material 3
  Name = "(MCPCB) Prepreg, GlassFiber"
  Youngs modulus = 2.5492905E+09
  Heat Conductivity = 1.1
  Poisson ratio = 0.2
  Youngs modulus = 2.5492905E+09
  Heat Capacity = 1000.0
  Youngs modulus = 2.5492905E+09
  Poisson ratio = 0.2
  Heat expansion Coefficient = 11.6e-6
  Poisson ratio = 0.2
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.2
  Density = 1850.0
End

Material 4
  Name = "(MCPCB) Thermal Grease"
  Youngs modulus = 1000.0
  Heat Conductivity = 3.0
  Poisson ratio = 0.3
  Youngs modulus = 1000.0
  Heat Capacity = 300.0
  Youngs modulus = 1000.0
  Poisson ratio = 0.3
  Heat expansion Coefficient = 1.0e-6
  Poisson ratio = 0.3
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.3
  Density = 1000.0
End

Material 5
  Name = "Aluminium (generic)"
  Electric Conductivity = 37.73e6
  Relative Permeability = 1.000022
  Youngs modulus = 70.0e9
  Heat Conductivity = 237.0
  Electric Conductivity = 37.73e6
  Electric Conductivity = 37.73e6
  Poisson ratio = 0.35
  Youngs modulus = 70.0e9
  Heat Capacity = 897.0
  Youngs modulus = 70.0e9
  Relative Permeability = 1.000022
  Sound speed = 5000.0
  Poisson ratio = 0.35
  Heat expansion Coefficient = 23.1e-6
  Poisson ratio = 0.35
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.35
  Electric Conductivity = 37.73e6
  Density = 2700.0
  Relative Permeability = 1.000022
End

Material 6
  Name = "Copper (generic)"
  Electric Conductivity = 59.59e6
  Relative Permeability = 0.999994
  Youngs modulus = 115.0e9
  Heat Conductivity = 401.0
  Electric Conductivity = 59.59e6
  Electric Conductivity = 59.59e6
  Poisson ratio = 0.34
  Youngs modulus = 115.0e9
  Heat Capacity = 385.0
  Youngs modulus = 115.0e9
  Relative Permeability = 0.999994
  Sound speed = 3810.0
  Poisson ratio = 0.34
  Heat expansion Coefficient = 16.5e-6
  Poisson ratio = 0.34
  Porosity Model = Always saturated
  Mesh Poisson ratio = 0.34
  Electric Conductivity = 59.59e6
  Density = 8960.0
  Relative Permeability = 0.999994
End

Boundary Condition 1
  Target Boundaries(3) = 34 35 27
  Name = "HeatSource"
  Heat Flux = $(1.0/(3.0*0.0005*0.0005))  ! [W/m^3]
End

Boundary Condition 2
  Target Boundaries(1) = 28
  Name = "HeatSink"
  Heat Transfer Coefficient = 10
  External Temperature = 25
End
```

결과



앞선 결과와 큰 차이가 나지 않는다.

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