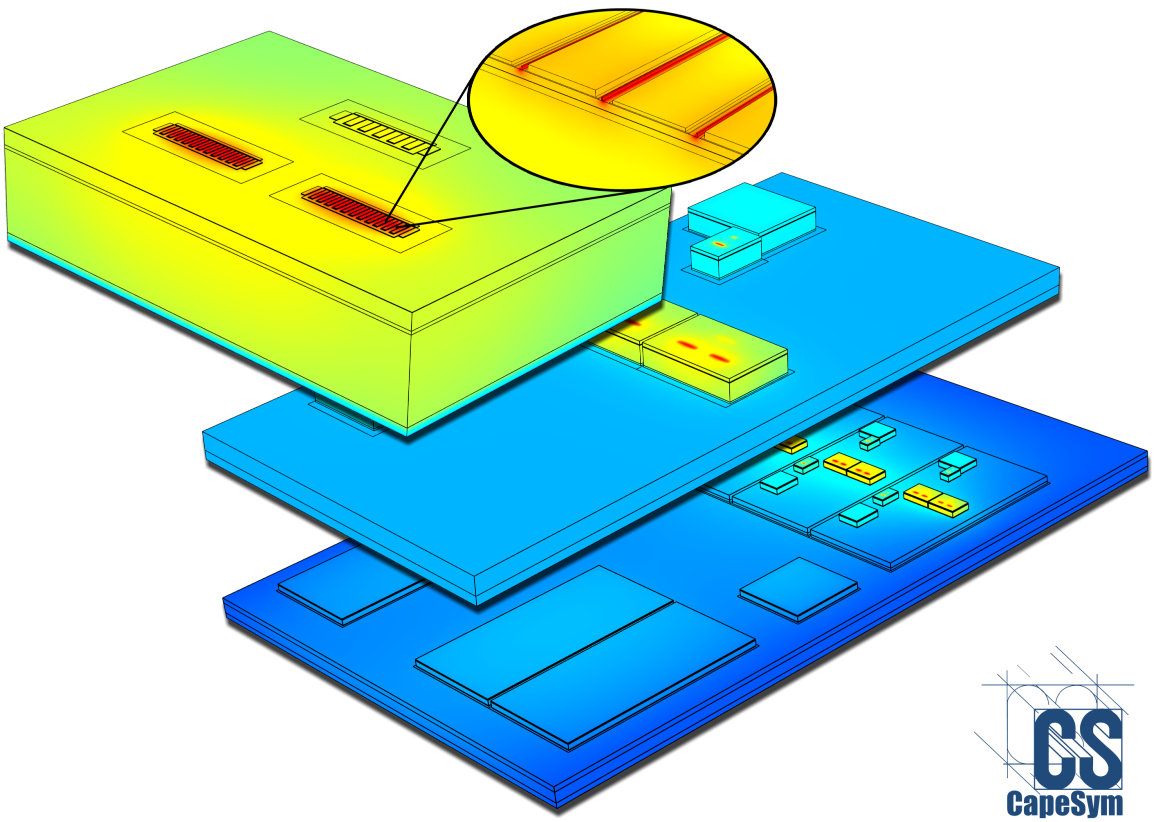
SYMMIC™ Application Note:

Simulations Versus μRaman Spectroscopy



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Simulations Versus µRaman Spectroscopy

Spectroscopy based on Raman scattering of laser light by phonons can be used to measure temperatures in semiconductors with better resolution than infrared instruments [1-2]. Temperature changes are assessed by looking at the shift in the Raman spectrum of the powered device relative to the spectrum from the unpowered state. Many semiconductors are transparent to visible light and have distinct spectral modes, facilitating assessment of temperatures within a layer of a particular material. The use of confocal microscopy for eliminating scattered light outside the focal point results in µm resolution measurements. As a particular example, this note will compare the µRaman measurements of Sarua et al. [2] to simulations obtained with SYMMIC.

The device investigated by Sarua et al. [2] was an AlGaN/GaN transistor on a 400µm thick SiC substrate. The GaN epi-layer was 1.3µm, topped with 0.03µm of $Al_{(28\%)}Ga_{(72\%)}N$. The device had two gates, each 1.2×50×0.5µm, but only one of the gates was powered. The total applied power was 1W and this was assumed to be dissipated in a volume 0.5×50×0.03µm embedded in the top of the GaN layer just outside of the drain-side edge of the gate. The 3mm-wide die of SiC was mounted on a heat sink with a hole in the middle so that µRaman measurements could be made from below, through the transparent substrate. The temperature measured at the edge of the die during the experiment was about 42°C.

To model the single-gate device, a template was constructed that consisted of 5 layers: 400µm substrate, 1.27µm epi-layer, 0.03µm epi-layer (heater layer), 0.03µm epi-layer, and 0.5µm gate metal. The substrate and epi-layers were 3mm×3mm in the x- and y-directions. The gate was placed in the center of this slab, and the heater was located at the gate edge (Figure 1). It was not necessary to model the rest of the source/drain metalization, as this had relatively little effect on temperatures around the gate.

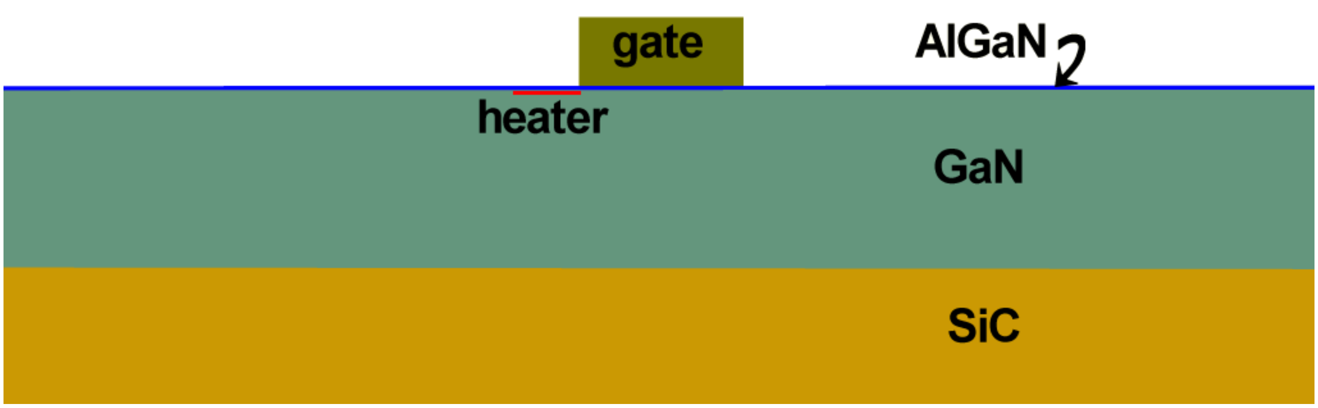

Figure 1: Components of a template modeling the experiment of Sarua et al. [2].

The orthotropic thermal conductivities of SiC were taken from the data of Cree [3], with the temperature dependence correlation ($T^{-1.5}$) of Ayalew[4], as described in the appendix of the SYMMIC Users Manual. The material properties for the epi-layers were taken from Liu and Balandin [5]. GaN was given a room temperature thermal conductivity of 125 W/m-K, and temperature dependence proportional to $T^{-0.67}$. According to the data of Lui and Balandin, the thermal conductivity of AlGaN alloy films does not decrease with increasing temperature. A constant value of 50 W/m-K was used for $Al_{(28\%)}Ga_{(72\%)}N$. Gate metal properties were assumed to be those of pure gold.

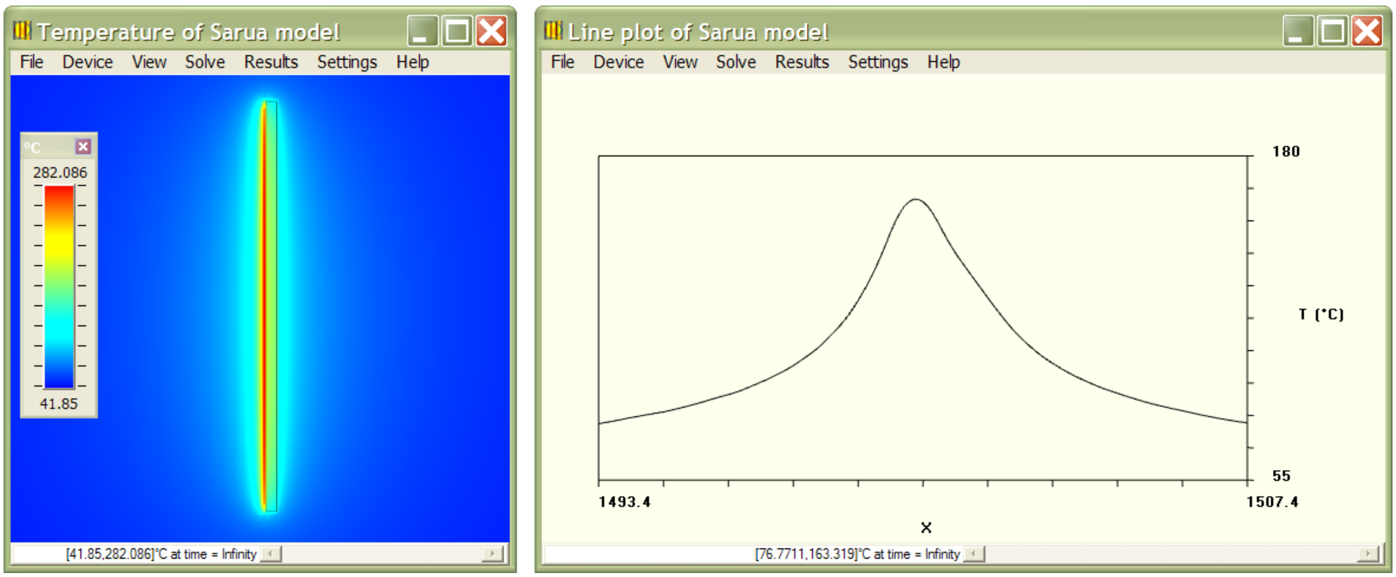

Figure 2: (*Left image*) Temperature distribution around the gate on the top surface. (*Right image*) The temperature of the GaN layer across the middle of the gate, averaged over volumes of 1x1x1.3µm.

Figure 2 shows the solution of the template model in SYMMIC. The line plot shows the temperature in the GaN layer along a line through the middle of the gate width. Values along the line were calculated by averaging GaN temperatures over a volume that matched the resolution of pixels in the µRaman instrument. The average temperature in the GaN layer attains a peak of about 163°C, but the peak temperature at the top of the GaN layer in the solution is actually 282°C. This demonstrates that µRaman spectroscopy has insufficient resolution to fully capture peak temperatures in a FET device. Peak temperatures are only obtainable at present through detailed simulation, as was also noted by Sarua et al. [2].

Figure 3 shows the overlay of the line plot from Figure 2 on the µRaman data of Sarua et al. There is excellent correspondence between data and simulation, with the possible exception of somewhat higher temperatures measured near the edge of the drain metal. This may be an indication that some of the power is dissipated at the drain edge, as has also been suggested by electric field distributions calculated by 2D Monte Carlo simulations [6]. The effect of shifting a fraction of the dissipated power to a second heater located in the GaN layer beneath drain metal would be to lower the main peak of the temperature plot slightly and raise a smaller, secondary peak to the left of the drain edge.

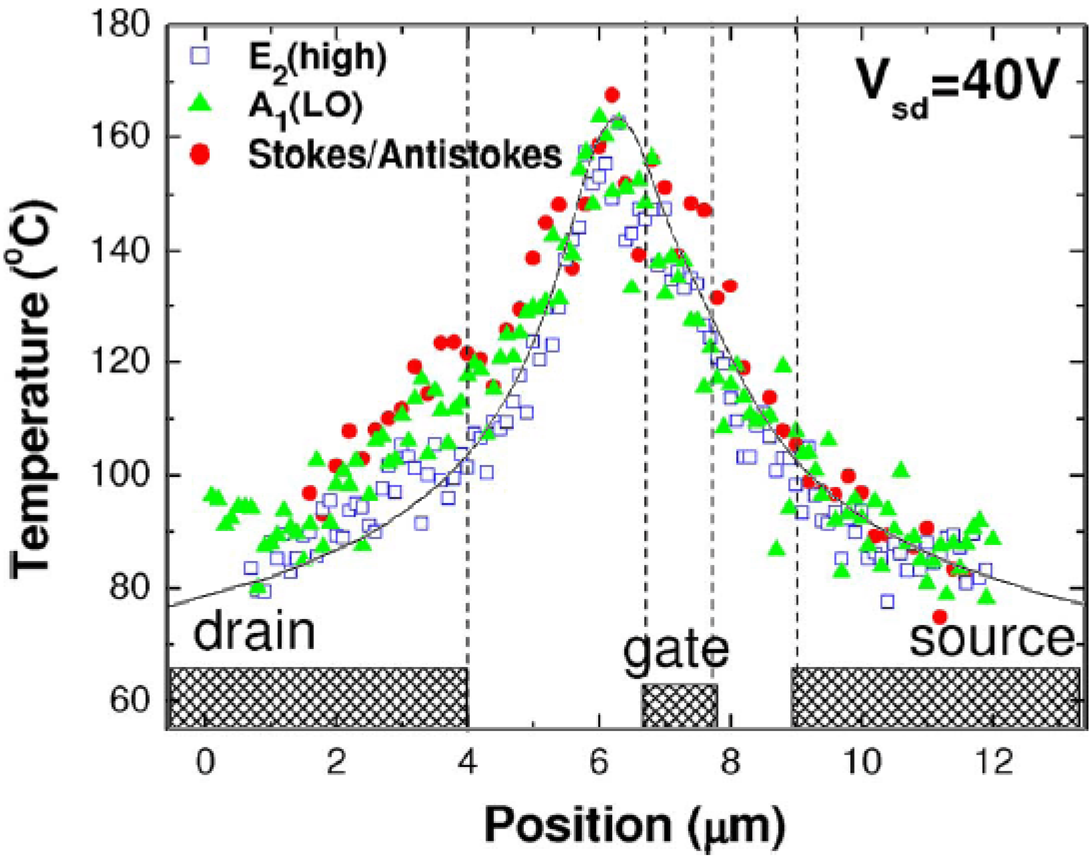

Figure 3: Data points show temperature measurements of GaN for 3 different phonon modes in the Raman spectrum [2]. The matching line plot was calculated by SYMMIC as in Figure 2.

Model Compactness

One advantage of SYMMIC is that a template can provide a very compact, readable model of a thermal analysis problem. The template that produces the results of Figure 2 consists of only 75 lines of ASCII text, a total of 3 kilobytes. (See the figure below for the entire template model.) By comparison, the TAS model that Sarua et al. used to analyze the same problem was 78 megabytes when put in ASCII readable form. The main reason for the compactness of the SYMMIC model is that it is geometric rather than mesh-based. The dynamic meshing approach used by SYMMIC has the added advantage of allowing mesh generation to be parameterized by geometrical dimensions. A single template can represent an entire class of geometric models rather just one case, and multiple cases can be analyzed much more quickly. As a consequence, SYMMIC facilitates thermal analysis as part of the design process rather than as a post-design operation.

```
<?xml version="1.0"?>                                    <!-- This is an XML Document with a defined format -->
<!DOCTYPE Template SYSTEM "template_format.dtd">
<Template title="Sarua et al. Model">

<Points>                                                 <!-- These are the geometric features in x -->
 <RefX delta="1500" refn="26" bias="1/1.32"/>
 <RefX delta="0.5" refn="4" bias="1"/>
 <RefX delta="1.2" refn="4" bias="1"/>
 <RefX delta="1500" refn="26" bias="1.32"/>
                                                         <!-- These are the geometric features in y -->
 <RefY delta="1475" refn="24" bias="1/1.32"/>
 <RefY delta="25" refn="13" bias="-1.32"/>
 <RefY delta="25" refn="13" bias="-1.32"/>
 <RefY delta="1475" refn="24" bias="1.32"/>
</Points>
                                                         <!-- These are the geometric features in z -->
<ZLayers>
 <Layer id="layer01" begin="0" end="400" refn="24" bias="0.8"/>
 <Layer id="layer02" begin="400" end="400+1.3-0.03" refn="8" bias="0.8"/>
 <Layer id="layer03" begin="400+1.3-0.03" end="400+1.3" refn="6" bias="1"/>
 <Layer id="layer04" begin="400+1.3" end="400+1.33" refn="2" bias="1"/>
 <Layer id="layer05" begin="400+1.33" end="400+1.83" refn="2" bias="1"/>
</ZLayers>
                                                         <!-- This section defines the material properties -->
<Materials>
 <AMaterial id="Au" description="Pure Gold" color="120 120 0"
  conductivity="0.0003 300" />

 <AMaterial id="AlGaN" description="Aluminum (28%) Gallium (72%) Nitride" color="0 0 255"
  conductivity="5e-005 300" />

 <AMaterial id="GaN" description="Gallium Nitride" color="100 150 125"
  conductivity="0.000123038 300, 0.000116614 325, 0.000110965 350, 0.000105952 375,
                0.000101468 400, 9.74296e-005 425, 9.37689e-005 450, 9.04329e-005 475,
                8.73779e-005 500, 8.45677e-005 525, 8.19725e-005 550, 7.95672e-005 575,
                7.73304e-005 600" />

 <AMaterial id="SiC" description="Silicon Carbide" color="203 153 3" isotropic="false"
  conductivity="0.000863 0.000863 0.00068 200,  0.00047 0.00047 0.00037 300,
                0.000417 0.000417 0.000328 325, 0.000373 0.000373 0.000294 350,
                0.000336 0.000336 0.000265 375, 0.000305 0.000305 0.00024 400,
                0.000256 0.000256 0.000201 450, 0.000218 0.000218 0.000172 500,
                0.000166 0.000166 0.000131 600, 0.000132 0.000132 0.000104 700,
                0.000108 0.000108 8.5e-005 800"
  capacity="0.00067 300" density="3.2e-009 300" />
</Materials>
                                          <!-- Geometric parts defined using above features and materials -->
<Device>
 <Component name="Substrate" material="SiC" layer="layer01" >
  <Blocks x="1-4" y="1-4" />
 </Component>
 <Component name="Epilayer 1" material="GaN" layer="layer02" >
  <Blocks x="1-4" y="1-4" />
 </Component>
 <Component name="Epilayer 2" material="GaN" layer="layer03" >
  <Blocks x="1-4" y="1-4" />
 </Component>
 <Component name="Epilayer 3" material="AlGaN" layer="layer04" >
  <Blocks x="1-4" y="1-4" />
 </Component>
 <Component name="Gate" material="Au" layer="layer05" >
  <Blocks x="3-3" y="2-3" />
 </Component>
```

Figure 4: The SYMMIC device template used to generate the result shown in Figure 2.

```
</Device>
                                                     <!-- Power fluxes and other boundary conditions -->
<BoundaryConditions>
 <Constant temperature="315" face="bottom" layer="layer01" >
  <Blocks x="1-4" y="1-4" />
 </Constant>
 <BFlux flux="1/(50*0.5*0.03)" layer="layer03" >
  <Blocks x="2-2" y="2-3" />
 </BFlux>
</BoundaryConditions>
                                                     <!-- Template element is closed to end the model -->
</Template>
```

Figure 4 (cont.): The SYMMIC device template used to generate the result shown in Figure 2.

References

[1] T. E. Beechem III, *Metrology of GaN Electronics Using Micro-Raman Spectroscopy*, Doctoral Thesis, Georgia Institute of Technology, 2008.

[2] A. Sarua, H. Ji, M. Kuball, M. J. Uren, T. Martin, K. P. Hilton, R. S. Balmer, "Integrated Micro-Raman/Infrared Thermography Probe for Monitoring of Self-Heating in AlGaN/GaN Transistor Structures," *IEEE Trans. Electron Devices* **53**(10), October 2006. pp. 2438-2447.

[3] Cree, Inc., 4600 Silicon Dr., Durham, NC 27703; data from www.cree.com in April 2008

[4] T. Ayalew, *SiC Semiconductor Devices Technology, Modeling, and Simulation*, Ph.D. Thesis, Technische Universitat Wien, January 2004; www.iue.tuwien.ac.at/phd/ayalew.

[5] W. Liu, A. A. Balandin, "Thermal conduction in $Al_xGa_{1-x}N$ alloys and thin films," *J Applied Physics* **97**, 073710 (2005).

[6] S. Rajasingam, J. W. Pomeroy, M. Kuball, M. J. Uren, T. Martin, D. C. Herbert, K. P. Hilton, R. S. Balmer, "Micro-Raman Temperature Measurements for Electric Field Assessment in Active AlGaN–GaN HFETs," IEEE Electron Device Letters 25, 7, July 2004. pp. 456-458.

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