GaAs MMIC THERMAL MODELING FOR CALCULATION OF ACCURATE CHANNEL TEMPERATURES

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ABSTRACT

To accurately determine GaAs MMIC channel temperatures, an automated model generation program has been developed. The results were correlated with IR Scanning techniques to verify the Finite Element Model. This model was used to generate a unique temperature profile for each device, which is used for higher level models, saving time while maintaining accuracy.

INTRODUCTION

The thermal characteristics of GaAs MMIC devices must be defined to accurately predict reliability and device performance. The reliability of a GaAs device is determined mainly by its channel temperature; the more accurate the temperature, the better the prediction. Due to the small size (0.25 - 0.50 microns) of GaAs MMIC devices, present temperature measuring equipment lacks the required fine feature resolution to allow for the direct measurement of device channel temperatures.

By utilizing a Thermal Math Model (TMM), which is a series of finite element models and submodels, it has been shown that accurate channel temperatures can in fact be derived for a GaAs MMIC device. The thermal resistance of the device is characterized over temperature using the TMM to generate a unique temperature profile (or thermal footprint). Higher level thermal models can then be derived to determine the junction temperature of the device in its operating environment.

While other methods of determining MMIC channel temperatures are typically conservative estimates, as in Cooke's Equation[1], this method is both accurate and efficient. It generates a precise representation of the device over temperature and saves time in the analysis of higher level Thermal Math Models.

SUMMARY

Temperature Measurement Technique:

Several temperature measurement techniques were considered to correlate the GaAs MMIC channel temperatures. The most viable measurement technique was found to be the IR Scan, offering the correlation required to corroborate our TMM results. An IR scan resolution of 38.0 µm was used for comparison with the TMM chip level results, correlating within an average variance of 2°C. Various temperature measurement techniques and their limitations are shown in Table 1.

TH 2C

Temperature Measurement Techniques	Limitations
Fiber Optics	Operator dependent, requires multiple measurements, unable to measure channel temperature directly due to air bridge (metallization).
Liquid Crystal	Operator dependent, requires multiple measurements, contaminates test specimen.
Electrical (SAGE)	Measures average temperature only.
IR Scan	Has a 5-50 µm resolution, unable to measure channel temperature directly due to air bridge (metallization).

Table 1 - Various Temperature Measurement Techniques

While all the temperature measuring equipment has limitations, the IR scanner has the necessary resolution to corroborate the TMM results. The IR scanner also offers a non-contact method that is less prone to operator error.

A total of eighteen devices were IR scanned. The temperature of each device was recorded at three extremes using a Compu Therm™ IR thermal image scanner.

Thermal Math Model:

Software and Hardware tools:

- Pre-processor (geometry input): PDA/PATRAN®
- Finite Element Analyzer: MSC®/NASTRAN®
- Post-processor (color plot, temp.): PDA/PATRAN®
- Sparc 2 and 10 Sun work station (Computer)

Methodology:

The thermal analysis of multilayered structures require accurate evaluation of the "spreading effect". This is more accurately accomplished with the use of finite elements as opposed to lumped nodes in a finite differencing approach. Thus, MSC®/NASTRAN® was used to perform the analysis.

The development of this thermal modeling approach for GaAs MMIC devices was based on previously published work[2]. The approach involved constructing a global model with resolution down to the FET and a local model (a sub-model of the global model), having resolution down to the individual gates and channels. Each model having some designed in flexibility to allow several discrete variations of particular parameters. However, due to the small size of the FETs, considerable mesh transitioning was required to arrive at accurate channel temperatures using only one submodel. This results in elements having potential skew or taper problems, which could yield erroneous results.

From the initial investigation it was determined that although a finite element approach provided a proven method for predicting accurate channel temperatures, more sub-models would be required to eliminate mesh transitioning and ensure accurate results. The drawback to this approach is that the time required to construct a finite element model for one module design containing several MMIC devices becomes quite time consuming. Thus, an automated procedure was necessary to reduce the model generation time.

To automate the MMIC thermal model generation process, Lockheed Sanders, Inc. has written a software program, called MACROMESH, that constructs a finite element mesh with no transitioning, i.e. element sizes are carried through the entire stack-up resulting in a purely rectangular mesh. MACROMESH, written in PATRAN® Command Language, takes a user constructed input file to create geometry directly into the PATRAN® database, then invokes PATRAN's® meshing routines to construct the finite element mesh. The resulting database is then available in PATRAN® to apply boundary conditions, heat loads, or geometry changes. While this method requires more sub-models, it lends itself easily to an automated process and results in elements free of skew or taper problems.

Benefits of using the MACROMESH automated process for thermal modeling of GaAs MMIC devices are:

- Model and submodel generation times are significantly reduced. Models that take months to analyze using finite element methods can be done in weeks.
- The power and flexibility of the finite element method is fully available.
- Resulting models may be used for thermal stress analysis.
- Documentation of geometry and material parameters is neatly presented in the user data file.
- Changes to the model geometry are made fast and easy. A simple geometry change can be incorporated in only a few days, compared to several weeks.

The use of MACROMESH allows for the generation of several complex finite element models quickly and easily. Using the submodels keeps the model size small, allows for accurate modeling of small features, and minimizes execution time. Four levels of models are created per device, as shown in Figure 1 and Table 2.

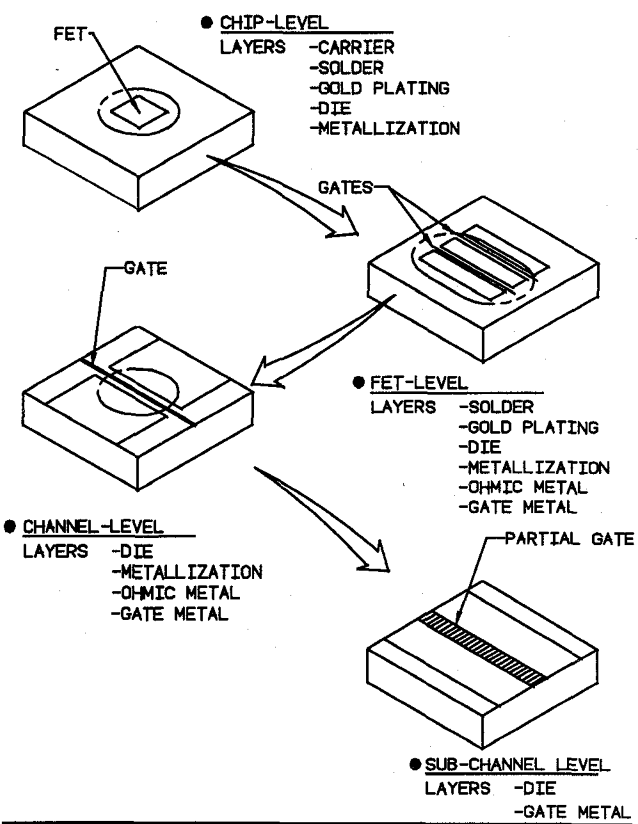

Figure 1 - TMM Model Levels of a typical device

	Level Description	Layers	# of Nodes	# of Elements
1	Chip	Carrier, solder, gold plate, die	3060	2472
2	FET	Solder, gold plate, die, ohmic & gate metal	9118	7296
3	Channel	Die, ohmic & gate metal	17281	14888
4	Sub-channel	Die, gate metal	9765	8228

Table 2 - TMM Model Level Descriptions

Illustrated in Figure 2 is the output of the four models for a typical GaAs MMIC device. Note that with descending levels the area represented by the models is smaller as it is focused toward the hot-spot, while the mesh size is reduced to increase the resolution of the model.

It was established that the smaller the mesh size, the more accurate the temperature of the hot-spot. It was also shown that further reduction in mesh size yielded no greater accuracy, only an increase in the number of nodes in the model. This proved that the mesh sizes at the sub-channel level provided highly accurate temperature predictions.

TMM & IR Scan Correlation:

A total of 54 chip level TMM's were generated to correlate to the IR thermal images. Table 3 compares the results of a Thermal Math Model to the results obtained from each of the thermal IR scans for that device. Figures 3A-3B compare the TMM thermal image of a typical device to its corresponding IR Scan, showing correlation within a few degrees.

Three samples of each device were chosen and their sub-level TMM's created to predict and characterize the device channel temperature. Figures 2A-2D show the FEM output of each of the four levels for a typical device.

The validity of the results was checked by comparing the temperature of the second layer of the TMM to the IR Scan. This check is valid because the second layer metallization is the layer that was "seen" by the IR Scan. The "T-Max" temperature is the local maximum temperature of the second metallization layer.

The resulting output of the Thermal Math Model, correlated to the IR scan, is a "thermal footprint" of the device. Carrier temperature versus the thermal resistance of the device is shown in Figure 4. Since the thermal resistance (θ_{jc}) of the FET is dependent upon the properties of its carrier, the thermal resistance (θ_{jc}) includes the GaAs MMIC, MMIC die attach (in this case solder), and its carrier.

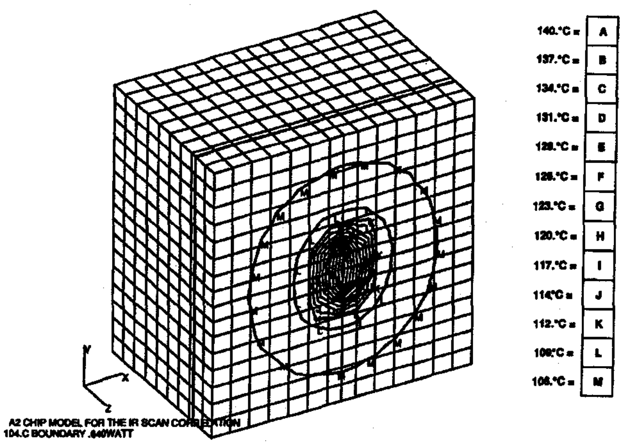

Figure 2A - Chip Level (1)

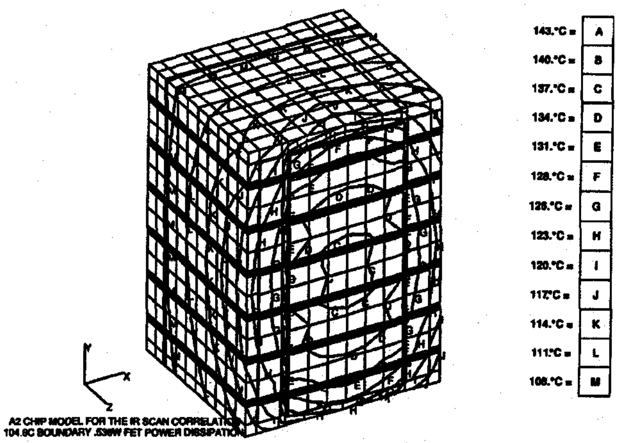

Figure 2B - FET Level (2)

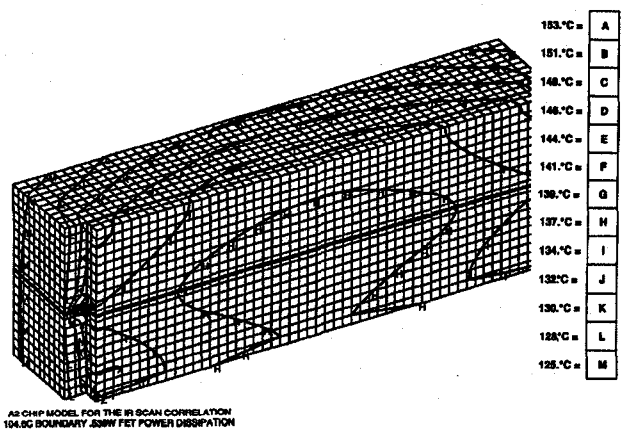

Figure 2C - Channel Level (3)

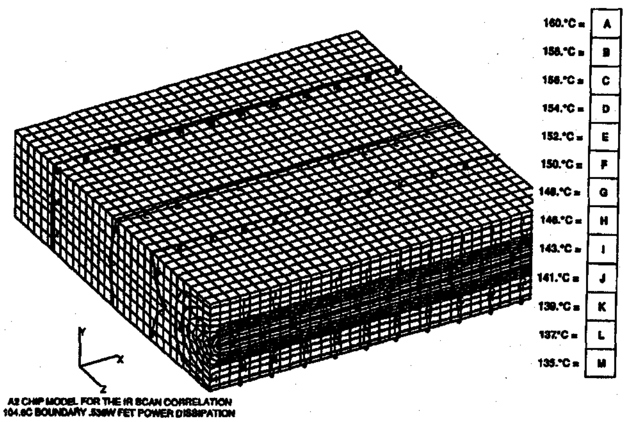

Figure 2D - Subchannel Level (4)

TST SAM	TOTAL PWR (mW)	PWR PER FET (mW)	IR SCAN RESULTS T-MIN (Carrier) (°C)	T-MAX (°C)	CALCULATED RESULTS T-MAX (°C)	Tch (°C)	FET θ_{jc} (°C/W)
NOM	240	120.00	N/A	N/A			
A	243.2	121.60	45.08	**54.5**	**53.6**		
A	241.4	120.70	81.12	**90.7**	**90.7**		
A	241.1	120.55	101.25	**110.9**	**111.0**	115.0	114.1
B	240.6	120.30	44.15	**50.6**	**52.6**		
B	243.8	121.90	80.98	**87.6**	**90.6**	94.0	106.8
B	241.7	120.85	101.15	**107.7**	**111.0**		
C	240.9	120.45	44.25	**51.6**	**52.7**	56.0	97.6
C	240.0	120.00	80.73	**88.3**	**90.2**		
C	241.7	120.85	100.81	**108.0**	**111.0**		

Table 3 - Correlation of IR Scan and Calculated Results

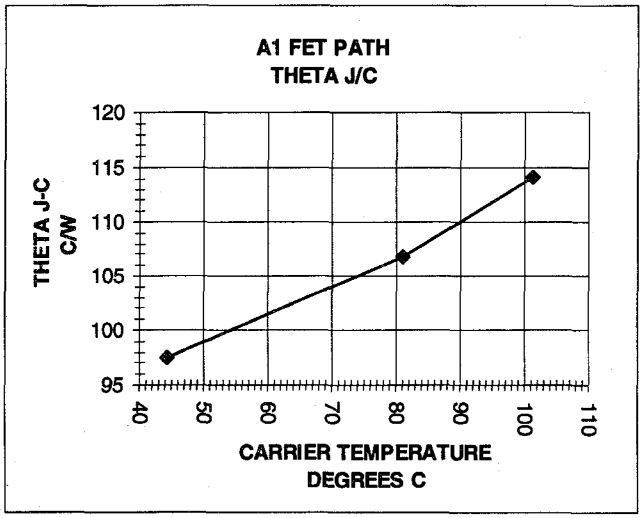

Figure 4 - FET Thermal Profile or "Thermal Footprint"

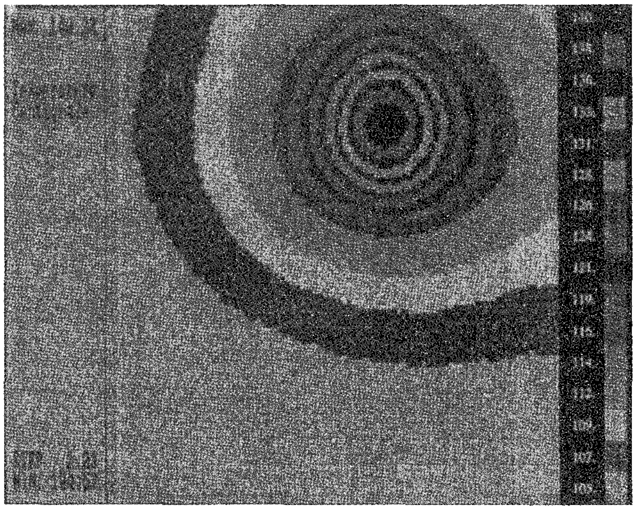

Figure 3A - Thermal IR Scanning Image

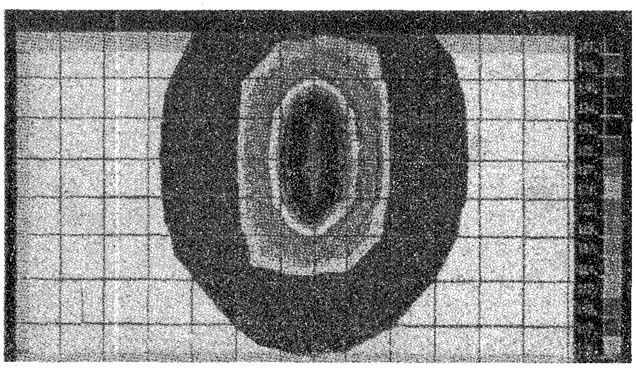

Figure 3B - TMM Output Correlation

CONCLUSION

It has been shown that accurate GaAs MMIC channel temperatures can be achieved by utilizing a combination of analytical models and physical measurement techniques. A unique thermal modeling routine developed by Lockheed Sanders, Inc. reduces analysis time and provides highly accurate results at the chip and module levels. The analytical results from the Thermal Math Model are shown to correlate within a few degrees of the IR scan.

Acknowledgments

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References

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