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Live Determination of Health State of GaN FETs

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Abstract

Predicted reliability often differs from observed reliability in semiconductor devices. The predicted estimates sometimes fail particularly when on-board semiconductor devices experience excursion from safe operating conditions. One method to detect such failures is continuous live reliability monitoring. Therefore, we propose a new approach for determining the internal property state by using only externally measurable parameters. Using a device's surface temperature, T and the strength of the magnetic field, B surrounding the device, we develop a model to correlate with latent defects in the device. Preliminary results show that our model indicates promise in distinguishing a GaN FET device which has been stressed and is at risk of latent failure from a normal working device.

Introduction

Sudden failure of semiconductor devices is highly undesirable and yet not uncommon in a range of power devices today. Overvoltage and other electrical stress conditions may occur during device operation and damage the device or significantly alter the life expectancy of such devices.

Setup

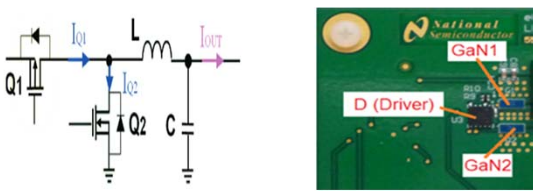


Fig.1. Circuit Diagram (left) and a part of PCB (right) of LM5113 Evaluation Board.

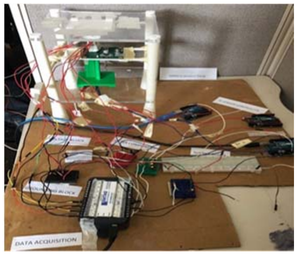
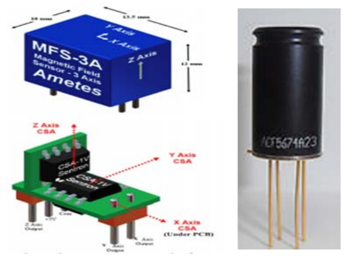


Fig.2. Experimental set-up for GaN Transistor surface temperature and magnetic field measurement

Experiment Procedure



- Performed "scans" cycling through 6 to 7 varying load values
- Every scan maintains its setup, bias and loading condition for 20 minutes for each load level and bias condition
- Observe cooling period lasting up to 15 minutes for the board to return to room temperature

Fig. 3. GMR magnetic field and IR temperature sensors

Preliminary Results

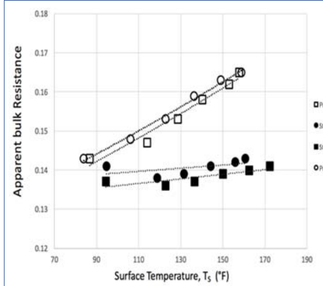


Fig. 4. Apparent bulk resistance vs. surface temperature of GaN FET for pristine and stressed GaNs in two separate set of experiments

Apparent Bulk Resistance, R
The amount of heat needed to raise the temperature of GaN FET as a whole by one degree

$$R(T_S, I_D) = A\,e^{(m-n)T_S} - 0.0056\,e^{0.00127\,ID} \quad \text{s.t} \quad \left\{ \begin{array}{ll} \underline{\text{Pristine}}: & n \le 0 \\ & A \le 0.125 \\ \underline{\text{Stressed}}: & n \ge 0 \\ & A \ge 0.125 \end{array} \right\}$$

Where $m_1 = 2 \times 10^{-3}$

Apparent Heat Capacity, C_A
The amount of heat needed to raise the temperature of GaN FET as a whole by one degree

$$C_A(T_S, B) = \frac{B^2}{\Delta T_S}\left(a\,e^{\frac{-(T_S-b)^2}{c}} \right)$$

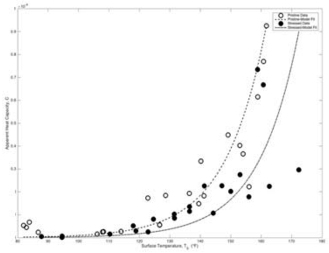


Fig. 5. Apparent heat capacity C_A vs surface temperature, T_S data for pristine and stressed GaN FETs with an exponential fit

Fig. 6. DI-1110 analog to digital converter by DATAQ instruments

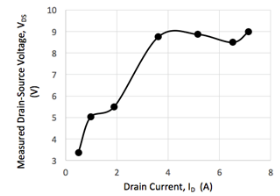


Fig. 7. Measured (dots) points for V_{DS} magnitude for varying I_D

Discussion

- Permeability of the semiconductor material offers the most convincing justification for the pristine vs. stressed macroscopic behavior distinction
- Permeability, specifically magnetizing permeability, may be irreversibly altered when semiconductor materials undergo stress conditions
- Data analysis performed suggests that the apparent bulk resistance for the stressed GaN is less in peak magnitude than the pristine curve. Since the theoretical apparent bulk resistance is computed using an ohmic relationship, this infers a higher magnetic field component, B for the stressed case than the pristine GaN FET.
- We can correlate this with a rise in the material permeability of the GaN FET which results in a greater magnetic field component for the stressed case.

Conclusions

There is sufficient reason to suggest permanent changes within the GaN FET semiconductor material including changes to its material permeability may occur on exposure to stressed, unsafe operating conditions. Surface measurable parameters such as device surface temperature and magnetic field strength emitted by GaN FETs may reflect the permanent internal state changes for the GaN FET.

This research work presents a preliminary model for the apparent bulk resistance and apparent heat capacity of the GaN FET as a means to discriminate the stressed GaN transistors from its pristine counterpart with which a live monitoring and determination of the overall health state of GaN may be achieved.

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