Evaluation of Commercially Available SiC MESFETs for Phased Array Radar Applications

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Abstract

Silicon Carbide MESFETs supplied by a commercial vendor were evaluated for their suitability for Phased Array Radar applications. The results showed superior performance over traditional III-V semiconductors in respect of pulse droop, and demonstrated the increasing maturity of these wide bandgap devices.

Introduction

Wide bandgap materials such as Silicon Carbide and Gallium Nitride have been suggested for many years as alternatives to traditional III-V compounds for high power microwave applications [1]. Until recently wide bandgap materials have remained very much “research-only” devices, however SiC MESFETs are now available as commercial samples, and GaN devices will be available in the not too distant future. One application that could benefit from using wide bandgap technology is Phased Array Radar (PAR). The GaAs IC group at Roke Manor Research Ltd. has been investigating the suitability of wide bandgap materials for PAR and other applications for several years, and the following results are taken from our evaluation of commercially available SiC MESFETs.

Advantages of Wide Bandgap Materials For PAR Applications

For PAR applications the transmitter must develop a high output power, with little or no pulse droop (change in output power, gain or phase throughout the length of the transmit pulse). These requirements are most important for the final output stage of the transmitter chain. Additional requirements may include size, weight and DC supply. The advantages of wide band gap materials for PAR applications include a high power density, which results in high power is a limited space, high voltage operation, resulting in low current and a lower overhead for DC supply distribution, simple matching due to high output impedance and in the case of SiC good thermal management due to the high thermal coefficient resulting in high temperature operation and a lower cooling overhead.

Evaluation of SiC MESFET samples

Our work has been based on Cree Inc. CRF-20010-101 SiC MESFETs. Previous results have been published from early samples of this product [2]. These showed that SiC MESFETs were potentially suitable for use in PAR applications, showing superior pulse droop characteristic when compared with traditional III-V devices. However there were several problems with these initial samples including instability and current hysteresis.

In this paper we present results from a new generation of Cree devices. In order to compare devices from the current and the previous generation, a similar set of measurements were undertaken. Additional measurements were also made to investigate current hysteresis and some measurements techniques were improved from our previous work.

Investigation of Current Hysteresis

During the course of our evaluation of the first generation devices, several devices exhibited instability which led to the failure of several devices. These instabilities were noted, but not investigated further. It was suggested that the instabilities might have been due to "trapping," evidence of which is provided by current hysteresis. Current hysteresis is the tendency for the transistor to draw different drain current for the same gate voltage when the voltage is being increased against when it is being decreased. In order to investigate this effect the following measurements was made on samples from the new generation devices.

The gate voltage for each device was set to Pinch-Off (V_{po} was around –14V) and the drain voltage was set to the normal operating point (+48V). The drain current was measured while the gate voltage was increased to the normal operating voltage (-6V) and back to V_{po}. Results for two devices, are shown in figure 1.

The results show that there is still some inconsistency between devices, as some exhibit very little hysteresis while some devices exhibit a high degree of hysteresis. However the majority of the devices exhibited little hysteresis, and device stability was not found to be a significant issue during the remainder of our evaluation demonstrating improvement over the previous generation devices

CW Measurements

Before measurements were made under pulsed conditions, each device was measured under CW conditions to verify the CW data supplied with the devices. All devices exhibited better than 10W output power under CW conditions with the output power of all devices measured within 0.3dBm of each other. This device repeatability was a marked improvement on the previous generation of devices.

Pulsed Measurements

The SiC MESFETs were measured under various pulsed conditions, intended to replicate typical PAR operating conditions. Amplitude (output power and gain) measurements were made using a HP8990A Peak Power Analyzer and phase measurements were made using a Pulsed HP8510C Vector Network Analyzer. For all measurements both the incident RF and the drain supply were pulsed. The evaluation included

1. Measurement of amplitude and phase for pulses of varying length, but constant duty cycle
2. Measurement of amplitude and phase for pulses of constant length, but varying duty cycle
3. Measurement of amplitude for very short, very low duty cycle against increasing baseplate temperature.

Measurement of Devices with Varying Pulse Lengths

The SiC MESFET devices were measured for pulse lengths of between 100µs and 5ms with a constant duty cycle of 30%. The devices were measured with 30dBm (pulsed) input power with a gate voltage of –7V and a drain supply of +48V. Amplitude measurements were made using a power test bench with the input and output power measured using the peak power analyzer. Phase measurements (“large signal” S21 only) were made using the pulsed VNA with the test port power increased to the required level using external amplifiers. For both amplitude and phase measurements the results were captured and stored using HP VEE. Results are shown in figures 2 and 3. The results show good amplitude and phase droop with comparable performance to the previous generation devices.

Measurement of Devices with Varying Duty Cycles

The SiC MESFET devices were measured for duty cycles of between 5% and 50% with a constant pulse length of 500µs, using the same measurement set up and DC and RF conditions as used for the varying pulse length measurements. The results show that as the duty cycle is increased that the “bulk” performance of the devices decreases, but the magnitude of the amplitude and phase droop remains constant.

Measurement of Devices with Varying Baseplate Temperatures

In order to measure that effect of raising the baseplate temperature (and hence the junction temperature) of the device on its amplitude performance, the device was mounted on a temperature controlled hotplate and the output power and gain were measured for baseplate temperatures between room temperature and 100°C. So that the self-heating of the devices during the pulse should not contribute to the junction temperature, the pulse length was kept to 1µs and the duty cycle was maintained at 1%. Results for output power verses baseplate temperature are shown in figure 4

Discussion of Results

The results show favourable performance for both CW and pulsed measurements. The CW results for this generation of devices are slightly improved against the previous generation of devices. The current devices also exhibit greater stability that the previous generation.

The pulsed results for the current generation devices are a power droop of around 0.4dB and phase droop of around 5° for a 5ms pulse at 30% duty cycle. The pulse droop is slightly worse than for the previous generation devices, although this has to be set against a more uniform and higher output power to start with. The results are still significantly better than for a comparable GaAs MESFET. Power degradation under increased baseplate temperature is similar to the previously reported results. The main results are summarized in table 1

Conclusions

SiC MESFETs have demonstrated their suitability for PAR applications by nature of their high power performance and good pulse stability. These latest results confirm their performance and demonstrate improved device stability and therefore process maturity. Cree have recently re-launched their SiC MESFET devices and they are now commercially available.

References

[1] RJ Trew, JB Yan, PM Mock, “The Potential of Diamond and SiC Electronic Devices for Microwave and Millimeter-wave Power Applications” Proc IEEE, May 1991, Vol 79, No. 5, pp598-620

[2] M. Walden, “Pulsed Power Operation of Commercially Available Silicon Carbide MESFETS” Conference Proceedings GAAS 2001, Sept 2001, pp319-322.

Results

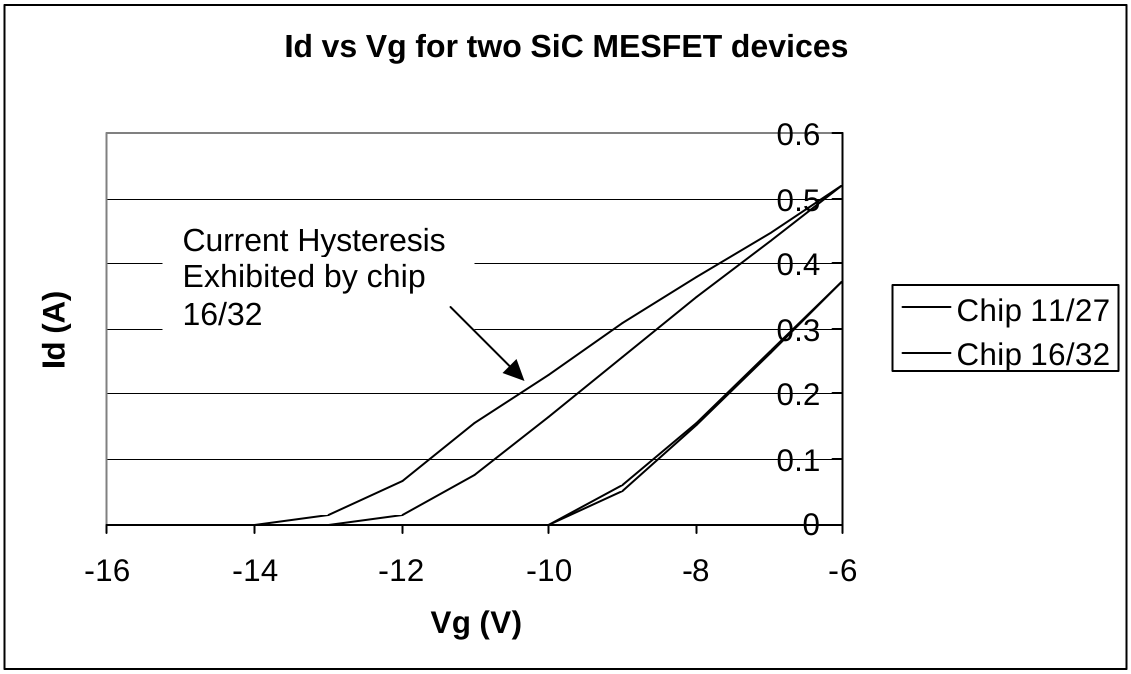

Figure 1: DCIV curves for a good device (11/27) and poor device (16/32) exhibiting significant current hysteresis.

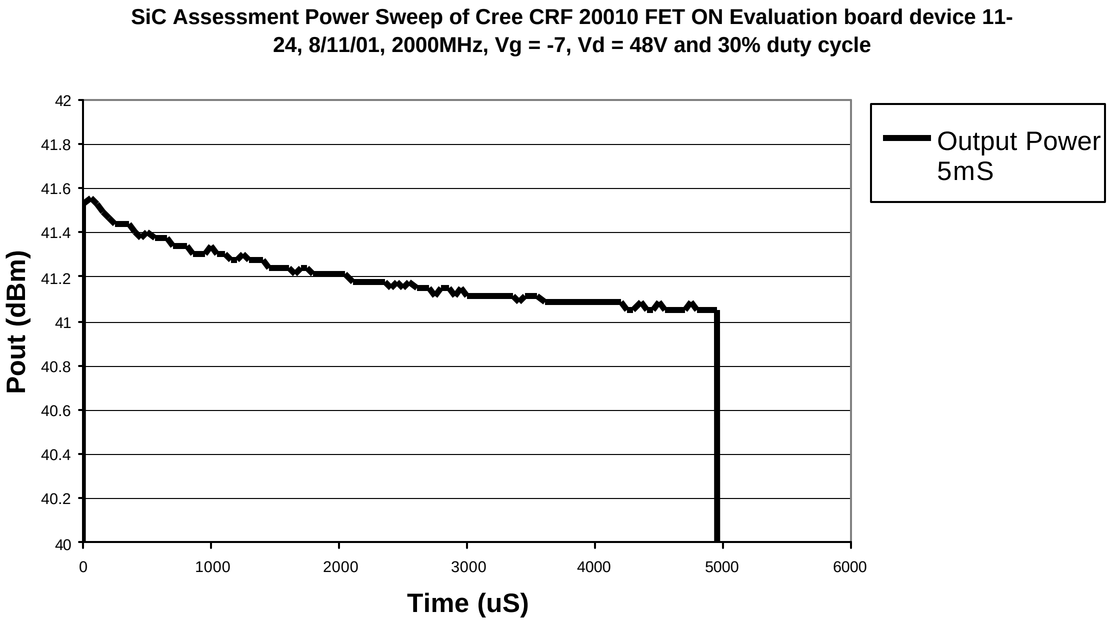

Figure 2: Power droop for a SiC MESFET device for a 5ms pulse length

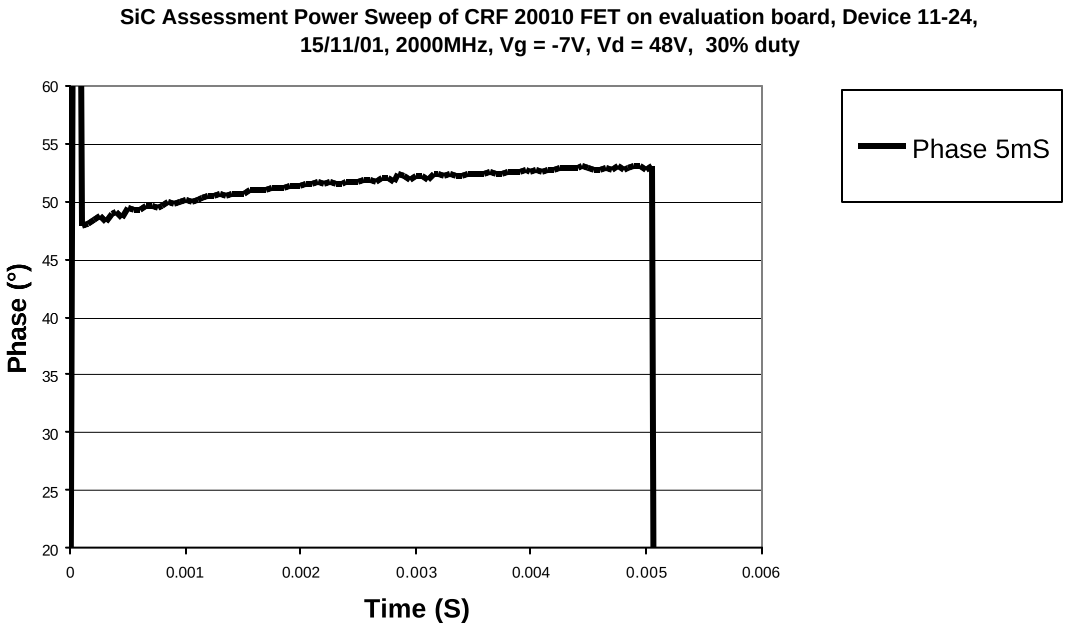

Figure 3: Phase droop for a SiC MESFET device for a 5ms pulse length

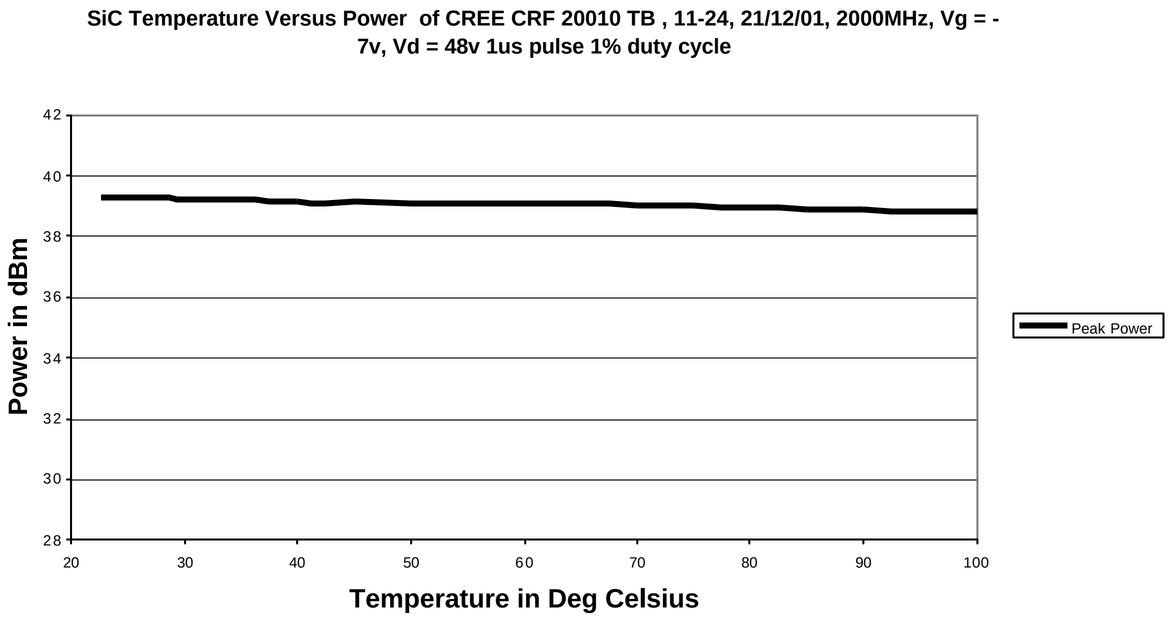

Figure 4: Power vs baseplate temperature for SiC MESFET device

Property	Result for a GaAs MESFET	Result for Previous Generation Cree SiC MESFET	Result for Current Generation Cree SiC MESFET
Power density	Typically 0.5W/mm	Typically 1.4W/mm	Typically 1.4W/mm
Drain current for a 10W device	~3A	0.5A	0.5A
Chip size for a 10W device	~10mm^2	~1mm^2	~1mm^2
Power degradation with temperature	~1.2dB for a 80°C temperature rise	0.7dB for a 80°C temperature rise	0.5-0.6dB for a 80°C temperature rise
Output power droop for a 5ms pulse	~0.5dBm	0.2dBm	0.4dBm
Phase droop for a 5ms pulse	~15°	5°	5°

Table 1: Properties and results for SiC MESFET devices (and a typical GaAs device)

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Mathew Knight graduated from Portsmouth University in 2000 with a MEng in Electrical and Electronic Engineering. He joined Roke Manor in the same year. He is currently in the GaAs IC group where he contributes to a number of projects including advanced semiconductor characterisation, mobile and Satellite communication systems.