W-Band MMIC Characterization in an Isothermal Environment

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***Abstract*— A W-band pulsed network analyzer has been developed to emulate an isothermal environment for on-wafer characterization of MMIC's. Testing results of a W-band monolithic power amplifier with a dc power consumption of 728 mW show an increase of 0.9 dB for small signal gain at 94 GHz in the isothermal environment. The measurement system and the MMIC testing are described in this letter. To our knowledge, this is the first demonstration of the on-wafer isothermal MMIC measurement at this frequency.**

I. Introduction

IT IS WELL KNOWN that both dc and RF performance of GaAs FET devices will be affected by the channel temperatures of the devices. This phenomenon has been observed especially for on-wafer probing devices where the GaAs substrates do not have good heat sink capability. The problem is aggravated with increasing gate periphery of power devices. The pulsed-bias measurement systems were therefore proposed to emulate an isothermal environment for on-wafer probing of devices. Platzker *et al.* has investigated the dc-IV characteristics of the GaAs FET devices and in a pulsed IV measurement system [1]. A pulsed S-parameter measurement setup was demonstrated up to 20 GHz for nonlinear characterization of FET's and bipolar power transistors [2]. Recently, Scott and Sayed *et al.* reported pulsed-bias/pulsed-RF device measurement system requirements and demonstrated a GaAs MMIC traveling wave amplifier (TWA) gain performance up to 50 GHz [3], where significant gain variations were observed between pulsed and nonpulsed bias conditions.

This letter presents a W-band (75–110 GHz) pulsed millimeter-wave (MM) network analyzer developed to emulate an isothermal environment for on-wafer S-parameters measurement. Testing results of a W-band monolithic power amplifier with a dc power consumption of 782 mW show an increase of 0.9 dB for small signal gain at 94 GHz in the isothermal environment. To our knowledge, this is the first demonstration of the on-wafer isothermal MMIC measurement at this frequency.

II. Isothermal Measurement Test System

Fig. 1, shown at the top of the next page, shows the block diagram of the isothermal measurement test system. It consists of four unique subsystems: 1) the W-band pulsed MM vector network analyzer, 2) the pulse bias, 3) probe station, and 4) overall system integration and synchronization. The subsystems are described as follows.

A. W-Band Pulsed MM Vector Network Analyzer

This is the millimeter wave version of the HP 85108A system. The HP 85105A is used to amplify, filter, and route LO and RF signals to the HP W85104A reflectometer. The harmonic number for the LO signal is 18 and the multiplier number for the RF is 6. The HP 8510C with the wideband (3 MHz) IF option 008 is used. The pulse width and repetition rate can be adjusted separately without affecting the system dynamic range. The output power was adjusted to be zero to +3 dBm [4]. For higher output power a customer-made post amplifier was used to bring the power to +14 dBm across the band of interest. The pulse width was chosen to be 1 μs and repetition rate was 1 kHz (repetion period 1 ms).

B. Pulsed Bias Subsystem

The HP 85120A-K43 pulser is the heart of the subsystem [3]. The HP 8110A is used to turn on and off the pulser. The HP 6629A power supply is used to drive the HP-85120A pulser. The output pulse was routed through a 2-Ω ribbon cable to DUT's drain. The dc voltage to the DUT's gate is routed through the pulser. The pulser is capable of voltages of up to 25 V and current of up to 6 A. The voltage can be adjusted from V_1 to V_2 ($V_2 > V_1 > 0$). The pulse width can be adjusted from 1–100 μs and the repetition rate of 1–10 ms (duty cycle of 0.01% –10%). The HP 54602B oscilloscope is used to display the pulsed voltage and current of the DUT. Careful design consideration was used to minimize the ringing at the beginning of the pulse. A front panel switch on the HP 85120A-K43 was used to choose the device bias mode (dc or pulsed).

C. W-Band Probe Station

A Cascade probe station was used with a W-band probe [5]. A W-band waveguide is used to connect the Cascade Microtech probe to the output of the HP W85104A reflectometer. For discrete devices, the W-band probe with its own bias tee was used and for MMIC, a customer-made bias probe was used. The bandwidth for both probes is more than 100 MHz to allow a pulse width less than 1 μs.

D. System Integration and System Extension

System synchronization is arranged using one channel of the HP 8110A pulse generator. The second channel was used

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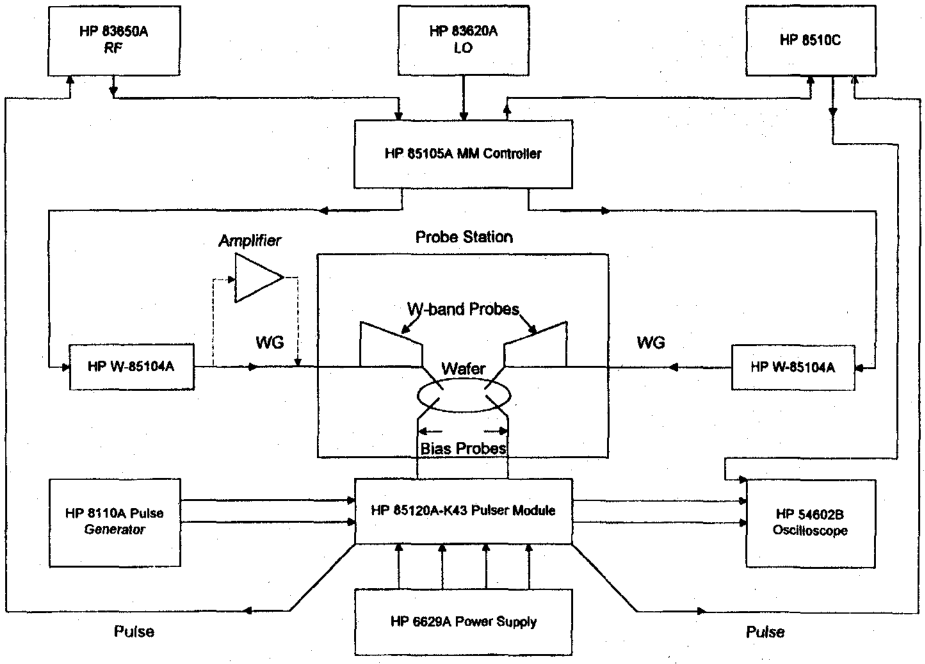

Fig. 1. The block diagram of the W-band isothermal measurement system.

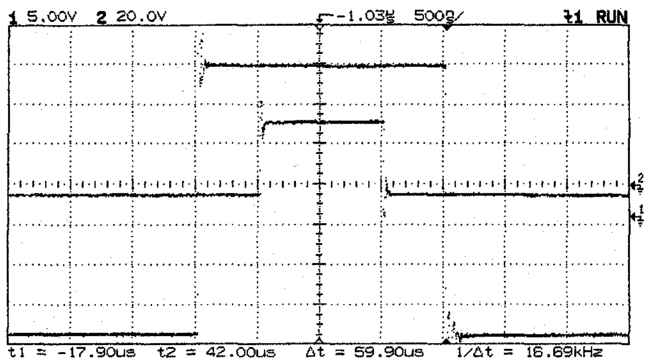

Fig. 2. The dc and RF pulse timing for the emulation of isothermal environment, where channel 1 is the drain pulsed voltage and channel 2 is the MM pulsed envelope.

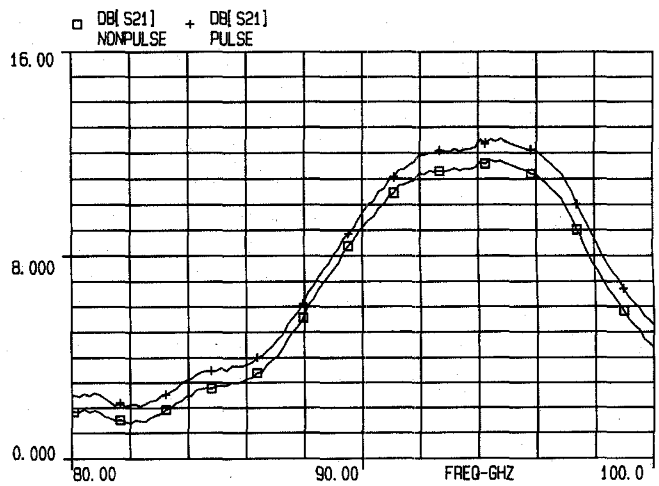

Fig. 3. The small-signal gain from 80–100 GHz of the 94-GHz push-pull MMIC PA measured under the pulsed-bias/pulsed-MM (+) and normal bias (□) conditions.

to pulse the W-band signal. The drain pulse bias is adjusted to be 2 μs and the W-band signal is 1 μs. A time delay of 500 ns is chosen between the pulsed drain and the pulsed MM, as shown in Fig. 2. Pulse profile can be measured by adjusting trigger delay anywhere inside the pulsed MM. The calibration was performed on the W-band wafer using the open, short, load, and through (OSLT) method. Adding the HP 85110A-H50 should enable the system to test MMIC from 45 MHz to 50 GHz using the Cascade air coplanar probe [6]. The advantage of this method is the high input power to the DUT and high dynamic range in both 45 MHz–50 GHz and 75–110 GHz frequency range.

III. Measured Results

A 94-GHz MMIC push-pull two-stage power amplifier is used as the device under test (DUT) for the demonstration of the W-band pulsed network analyzer. This push-pull power amplifier has a similar design as the one reported in [7] with a different peak gain frequency at 94 GHz. On-wafer full two-port S-parameters under both pulsed-bias/pulsed-MM and normal (non-pulse) bias conditions are taken from 75–110 GHz. The pulse timing of the drain bias and the MM signal envelope has been described in Fig. 2, with a repetition rate of 1 kHz (1 ms cycle time) and therefore the duty cycle is 0.2% for dc and 0.1% for RF. Fig. 3 shows the measured small signal gain performance ($|S_{21}|$ in dB) under the two different bias from 80–100 GHz. A gain of 11.6 dB at 94 GHz is observed under the nonpulsed condition with 4-V drain voltage and 182-mA total drain current for both stages, which is a dc power consumption of 728 mW. In the pulsed-bias/pulsed-MM case

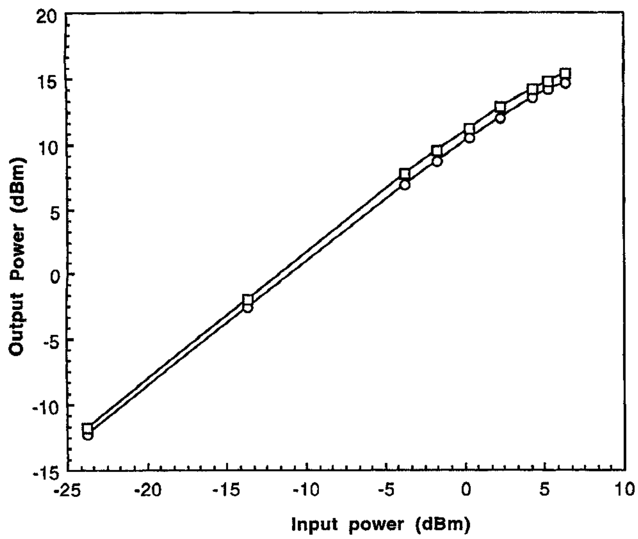

Fig. 4. The output power versus input power at 94 GHz of the push-pull MMIC PA measured under the pulsed-bias/pulsed-MM (□) and normal bias (○) conditions.

or the isothermal environment, the MMIC amplifier exhibits a gain of 12.5 dB at 94 GHz, indicating a gain increase of 0.9 dB. Further reduction of the duty cycle from the pulser results in insignificant gain increase, indicating a good emulation of the isothermal environment by using the pulse timing shown in Fig. 2.

We also performed the P_{out} versus P_{in} measurement at 94 GHz under the same setup. After subtracting the loss from the waveguide components and the probe losses, the maximum input power to the DUT amplifier is 6.3 dBm, which drives the MMIC power amplifier to near 3-dB compression. The output power versus input power curves under both pulsed-bias/pulsed-MM and nonpulse bias conditions are plotted in Fig. 4. An output power of 14.6 dBm is obtained for the nonpulsed bias case while 15.4-dBm is achieved for the isothermal condition at the input power level of 6.3 dBm. The output power difference of 0.8 dB is similar to the small signal gain measurement (0.9 dB).

IV. Summary

We have demonstrated a W-band pulsed network analyzer to emulate an isothermal environment for on-wafer characterization of MMIC's. Both small signal S-parameters and P_{out} versus P_{in} measurement have been performed under pulsed-bias/pulsed-MM and normal bias conditions. An increase of 0.9 dB for small signal gain with a dc power consumption of 728 mW and 0.8 dB for the 3-dB compression gain at 94 GHz were observed in the isothermal environment. To our knowledge, this is the first demonstration of the on-wafer isothermal MMIC measurement at this frequency.

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