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Wideband cryogenic on-wafer measurements at 20 – 295 K and 50-110 GHz

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Abstract — **A measurement system has been developed for cryogenic on-wafer characterization at 50–110 GHz. The measurement system allows on-wafer S-parameter measurements of active and passive devices at this frequency range. The S-parameters of active devices can be measured as function of frequency, temperature, and bias conditions. As an example of cryogenic on-wafer measurements, measured S-parameters of InP HEMTs are presented at temperatures of 20, 80, 160, and 295 K and in the frequency range of 50 –110 GHz.**

I. Introduction

S-parameter measurement is a basic tool in any linear microwave (3-30 GHz) and millimeter wave (30-300 GHz) circuit characterization. Impedance, VSWR, gain, and other similar quantities can be derived from the S-parameter data of a device under test (DUT). Reliable S-parameter measurements are also an important part of noise figure, available gain and noise parameter measurements [1-3]. Especially at millimeter waves and low temperatures, where simulations tools and models for components are not always accurate, the on-wafer measurements are an important part of the design chain from a prototype to a real product. For example, the design of low noise amplifiers (LNA) and high temperature superconductor (HTS) devices are greatly dependent on on-wafer measurements. Cryogenic on-wafer measurement systems have been developed mostly for frequency ranges below 50 GHz [2-4]. We have earlier presented a measurement system that allows cryogenic on-wafer S-parameter measurements at 50-75 GHz (V-band) and 20-295 K [5-6]. Here, we present a measurement set-up, which extends the cryogenic on-wafer measurements to include W-band.

II. Measurement system

The developed cryogenic measurement station is based on a commercial cryogenic on-wafer system by Nagase Co. originally designed for measurements below 50 GHz. The Nagase system consists of a stainless steel vacuum chamber, vacuum pump, closet cycle Helium cryo cooler, cold plate (chuck) for the test devices, and a temperature controller. All the installations necessary for waveguide based V- and W-bands measurements have been designed and built in-house. A schematic view of the V- and W-bands measurement system is shown in Fig. 1 and a photograph of the W-band system in Fig. 2. Inside the vacuum chamber, special in-house built spiral-shape waveguides are used for connecting the two feed throughs to the RF probes. V- and W-bands have different waveguide setups.

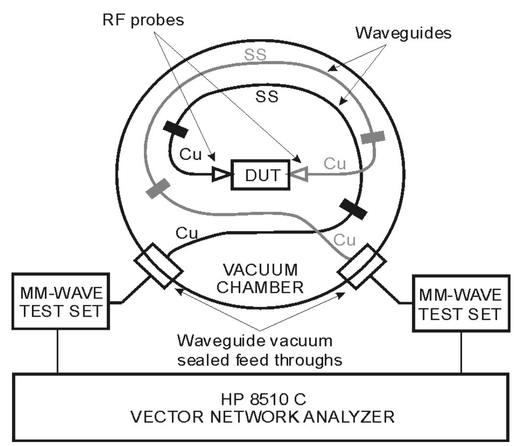


Fig. 1. Schematic view of cryogenic V- and W-bands on-wafer measurement set-ups.

Each of the waveguides is about 450 mm long and consists of three sections. Two of the sections are gold-plated copper, and the third one is gold-plated stainless steel. The steel section is about 200 mm long, and it provids a thermal isolation as well as mechanical flexibility. The feed throughs are in room temperature, whereas a device under test (DUT) can have a temperature as low as 15 K. The steel sections reduce heat flow to the DUT helping to maintain the wanted testing temperature. S-parameter measurements are carried out using a HP8510 C vector network analyzer (VNA) with V- and W-band extension units.

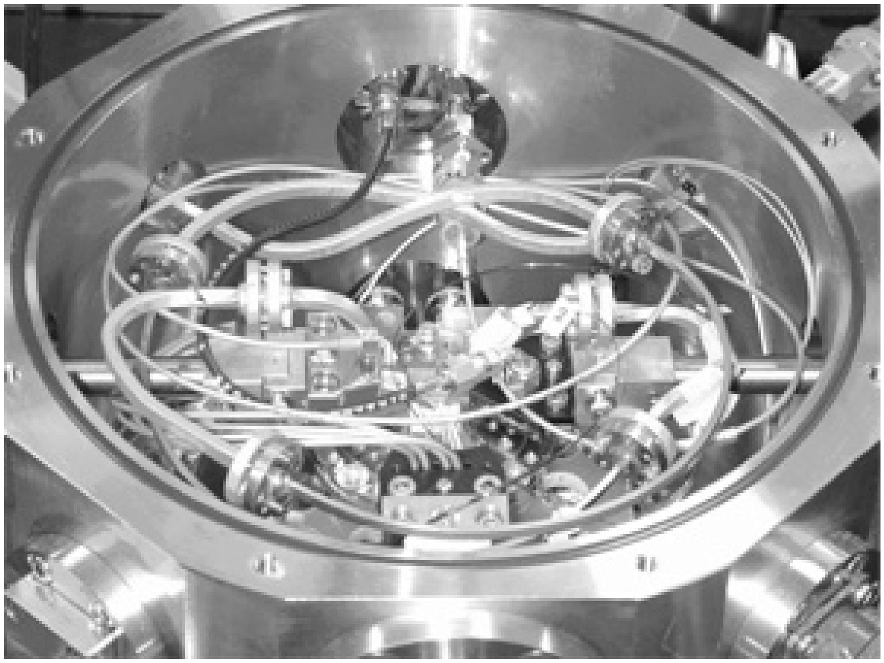


Fig. 2. A photograph showing the RF and bias probes with W-band waveguide installations inside the vacuum chamber.

III. MEASUREMENTS

As an example of cryogenic on-wafer measurements at W-band, the S-parameters of a DaimlerChrysler InP HEMT are presented. The HEMT had a 0.18 μm gate length and 2 x 40 μm gate width. Measurements were carried out at 20, 80, 160 and 295 K (Figs. 3-6). Operating point was V_{ds} = 1 V and I_{ds} = 10 mA in these measurements. The vector network analyzer was calibrated with LRRM or SOLT on-wafer calibrations. Also, wideband measurements (50-110 GHz) at 20 K, 80 K, 160 K, and 295 K were carried out. Two different waveguide set-ups were used with the results combined. Here, an HRL InP HEMT was used as the DUT. The HRL InP HEMT had a 0.1 μm gate length and 2 x 25 μm gate width. The operating point was V_{ds}=1.0 V and I_{ds}=6.25 mA. The measured S-parameters of the HRL HEMT are shown in Figs. 7 - 8. In the cases of both HEMTs, the gain improves about 1 dB when temperature is lowered from 295 K to 20 K. The biggest change occurs from 295 K to 160 K, after which the effect of cooling is smaller.

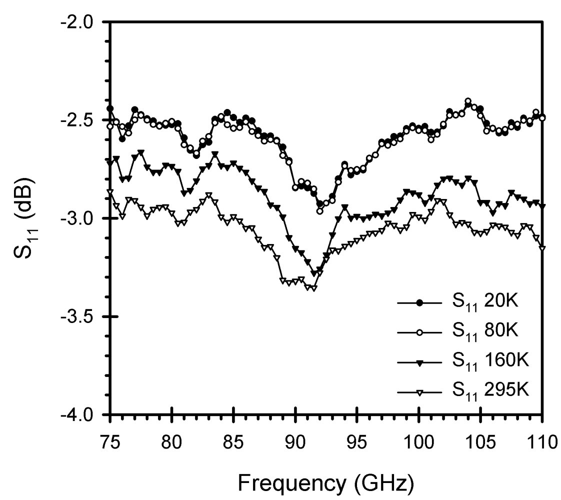


Fig. 3. Measured W-band S_{11} of a DaimlerChrysler InP HEMT at different temperatures.

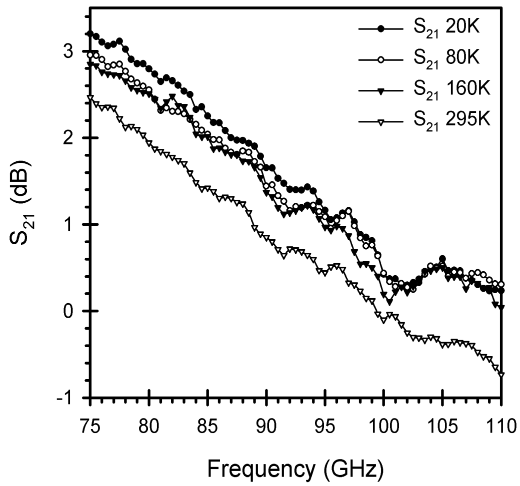


Fig. 4. Measured W-band S_{21} of a DaimlerChrysler InP HEMT at different temperatures.

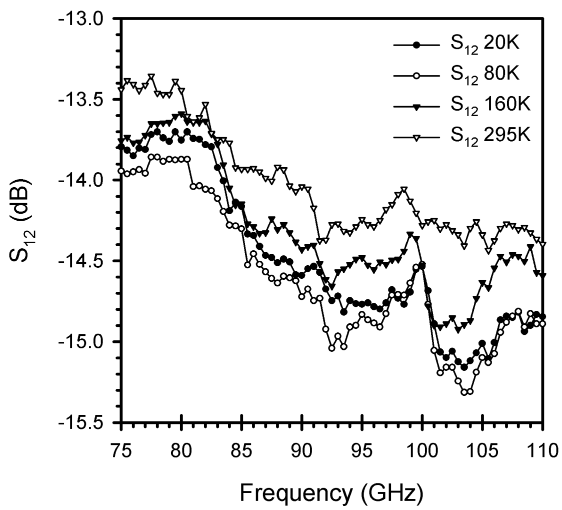


Fig. 5. Measured W-band S_{12} of a DaimlerChrysler InP HEMT at different temperatures..

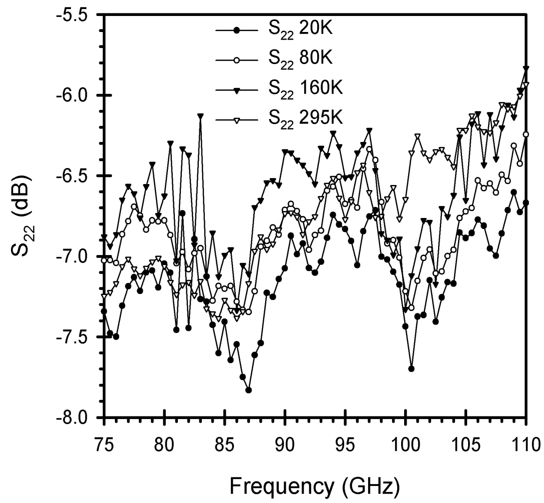


Fig. 6. Measured W-band S_{22} of a DaimlerChrysler InP HEMT at different temperatures..

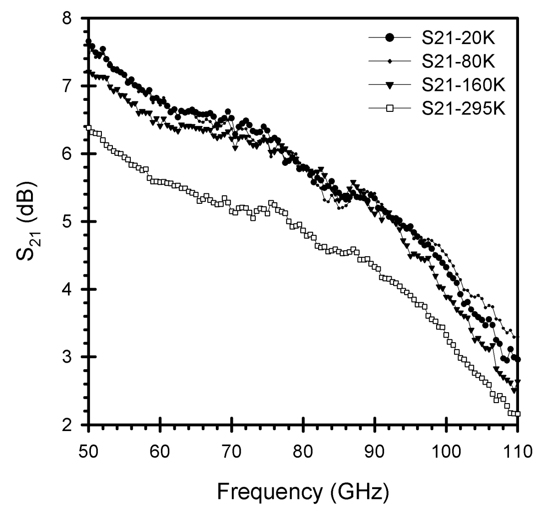
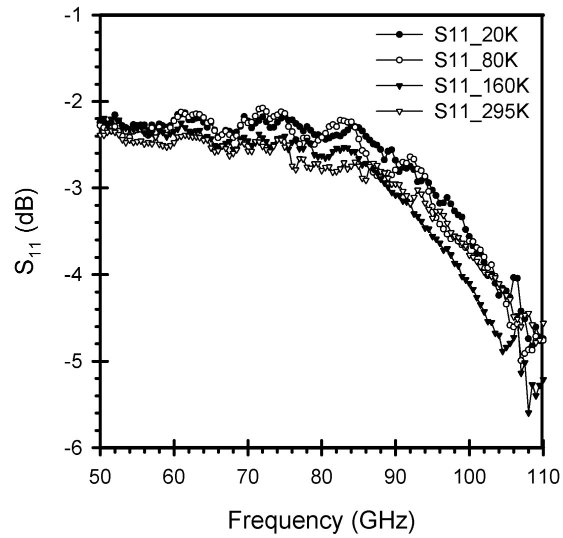
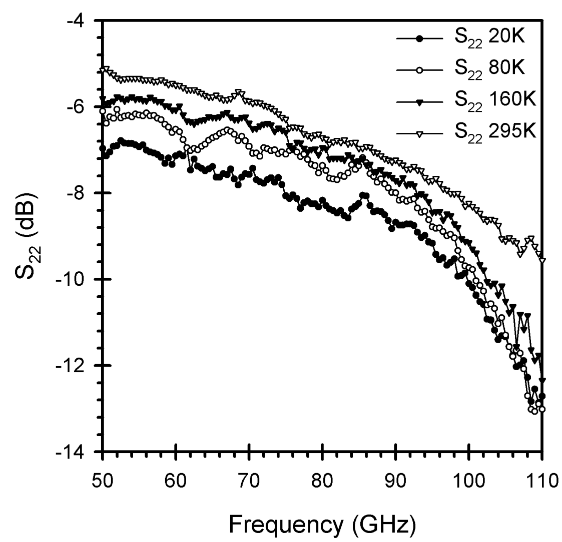


Fig. 7. Measured wideband S_{21} of a HRL InP HEMT at various temperatures.



(a)



(b)

Fig. 8. Measured wideband (a) S_{11} and (b) S_{22} of a HRL InP HEMT at various temperatures.

V. Conclusions

A cryogenic on-wafer system has been demonstrated for measurements at 50-110 GHz and 20-295 K. Measured results have been presented for a DaimlerChrysler InP HEMT at W-band and for a HRL InP HEMT at 50-110 GHz with temperatures of 20, 80, 160, and 295 K. For both HEMTs, the gain improved about 1 dB when cooled from 295 K to 20 K.

Acknowledgement

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