A 1.1 THz Micromachined On-Wafer Probe

Matthew F. Bauwens¹,², Naser Alijabbari³, Arthur W. Lichtenberger²,¹, N. Scott Barker²,¹, and Robert M. Weikle, II¹

¹Dominion MicroProbes, Inc., Charlottesville, VA, USA
²Charles L. Brown Department of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA, USA

Abstract — This paper presents a micromachined probe for on-wafer measurements of circuits in the WR-1.0 waveguide band (0.75 – 1.1 THz). The probe shows a measured insertion loss of less than 7 dB and return loss of greater than 15 dB over most of the band. These are the first reported on-wafer measurements above 1 THz.

Index Terms — Micromachining, probes, submillimeter wave integrated circuits, submillimeter wave measurements.

I. INTRODUCTION

Recently, advances in the development of terahertz monolithic integrated circuits (TMICs) have resulted in the demonstration of amplification at frequencies greater than 600 GHz [1]-[3]. On-wafer probing will further this progress by providing accurate models and reducing characterization time and cost relative to fixture testing. The University of Virginia developed WR-1.5 micromachined probes, which for the first time, enabled on-wafer testing from 500 – 750 GHz [4], [5]. Shortly thereafter, initial results of a prototype micromachined WR-1.2 probe were reported in [6]. While wafer probes are now commercially available up to 750 GHz [7], there is no on-wafer measurement infrastructure at higher frequencies. To aid in the development of TMICs in the 0.75 – 1.1 THz frequency range, a WR-1.0 micromachined on-wafer probe has been developed and is presented here.

II. PROBE DESIGN

Fig. 1 illustrates the micromachined probe concept. A thin silicon chip is installed between the halves of an E-plane split-block waveguide housing. The waveguide transition, coaxial transmission line, GSG contacts, and DC bias-T are all integrated onto this single, lithographically defined chip. The probe chip is fabricated on a 15 µm thick high-resistivity silicon substrate (>10 kΩ-cm) using a silicon-on-insulator fabrication process described in [8] and [9]. Recesses are milled into the waveguide block that self-align the chip to the waveguide and allow it to be clamped in place. The probe chip emerges from the housing at a 30-degree angle, allowing the GSG tips to contact the wafer. The rectangular waveguide channel carries the RF signal from the tip to the back face of the probe housing, which features a precision UG-387 waveguide interface.

The probe design process consists of optimizing two transitions: full-height rectangular waveguide to rectangular coaxial transmission line, and rectangular coaxial to on-wafer 50 Ω coplanar waveguide (CPW). These optimizations are performed through finite-element simulation using ANSYS HFSS, where all conductors are assumed to be gold having a conductivity of 3.2x10⁷ Siemens/meter. The waveguide to coaxial transition utilizes a substrate-supported radial stub with waveguide capacitive step [10] and incorporates a bias-T on the opposing side of the waveguide [11]. This transition is optimized to maximize the coaxial and waveguide return loss while maintaining isolation at the bias-T. The rectangular coax is converted to CPW at the edge of the waveguide block and tapers down to the 50 Ω GSG tips with 25 µm pitch. Radiation boundary conditions are applied around the tip to account for any radiation losses.

For verification, the full probe is simulated from waveguide to on-wafer CPW, as shown in Fig. 2. Shown in the inset of Fig. 2 is a simulation model of a 30-degree H-plane waveguide junction in which one of the ports is de-embedded by 0.8 inch. This simulation captures the mismatch at the probe’s waveguide interface as well as the waveguide loss between the interface and the probe tip. The S-parameters from this simulation are combined with that of the probe model to produce the expected probe S-parameters, shown in Fig. 3. The simulated insertion loss is less than 6.1 dB and return loss is greater than 14.5 dB across the full waveguide band. Not shown is the bias port isolation, which is simulated to be greater than 40 dB across the band.
III. PROBE CHARACTERIZATION

The one-port S-parameter measurement setup consists of a Virginia Diodes (VDI) WR-1.0 vector network analyzer extension module (WR1.0-VNAX TxRx) connected to an Agilent PNA-X (N5245A) network analyzer. The frequency extension module is mounted to a Cascade Microtech PA200 semi-automatic probe station. To properly align the waveguide interface of the probe with that of the extender, a split-block 90 degree waveguide twist is used. The measurement setup is shown in Fig. 4.

To determine the full two-port S-parameters of the probe, a one-port, two-tier calibration process is performed. The first tier calibration is performed at the waveguide port using a waveguide short, quarter-wave delay short, and load from a VDI WR-1.0 waveguide calibration kit. The second tier calibration is performed on-wafer using a CPW short and 4 CPW delay shorts through a least-squares fit. The calibration wafer is a 325 μm thick, high resistivity (>10 kΩ-cm) silicon substrate with 1 μm of electroplated gold metallization. The on-wafer CPW center conductor width is 4.2 μm and the gap width is 4.0 μm. Shown in Fig. 5, the contact pads have a center width of 13 μm and a gap width of 11 μm to accommodate the probe tip center-to-center pitch of 25 μm. Each CPW delay short is 13.5 μm longer than the previous, representing approximately 35 degrees of electrical length at 925 GHz. Fig. 6 shows an example probe station view of the probe tip contacting an on-wafer CPW calibration standard. For this second-tier calibration, the error terms represent the probe, and by noting that the probe is a reciprocal device, its full two-port S-parameters are obtained and are shown in Fig. 7. The measured insertion loss is less than 7 dB across nearly the entire band, which agrees well with simulation. The measured return loss is several dB less than simulation, which is expected due to the tolerances associated with machining of the waveguide housing, mounting of the probe chip into the
waveguide housing, and alignment of the waveguide interfaces.

As a validation of the on-wafer calibration, Fig. 8 shows error-corrected re-measurements of the CPW short and 4 delay shorts, which agree well with the ideal response. All data are taken at 10 Hz IF bandwidth without averaging. For clarity, the Smith chart traces are shown from 760 GHz to 1060 GHz due to reduced dynamic range of the test set near the band edges.

IV. CONCLUSION

A WR-1.0 micromachined probe has been designed to facilitate the development of TMICs in the 750 GHz to 1.1 THz frequency range. Test results show a measured insertion loss of less than 7 dB and return loss of greater than 15 dB over most of the waveguide band and error-corrected measurements of the calibration standards agree well with the ideal responses. These results are the first on-wafer measurements reported over 1 THz.

ACKNOWLEDGMENT

The authors would like to thank Dr. Dev Palmer of DARPA, Dr. Alfred Hung of ARL, and Dr. Bill Deal of Northrop Grumman. This work was supported by the U.S. Army National Ground Intelligence Center (NGIC) under contract W911W5-11-C-0013 and the DARPA THz Electronics Program and Army Research Laboratory under DARPA Contract no. HR0011-09-C-0062 under a subcontract from Northrop Grumman. The views, opinions, and/or findings contained in this article are those of the authors and should not be interpreted as representing the official views or policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the Department of Defense. Approved for Public Release, Distribution Unlimited.
REFERENCES


