Automated Contacting of On-Wafer Devices for RF Testing

F. Mubarak[1, 2], C. D. Martino[2], R. Toskovic[1], G. Rietveld[1], and M. Spirito[2]
[1]VSL, Dutch Metrology Institute, The Netherlands (e-mail: fmubarak@vsl.nl)
[2]Delft University of Technology, The Netherlands

***Abstract*—A method is presented for automated probing of on-wafer devices for measurements at millimetre-wave frequencies. The proposed method automatically detects the contact between the measurement probe and on-wafer device, based on the evaluation of variation in the input reflection coefficient. It is shown that, using this automated technique, about five times better measurement repeatability is achieved in millimetre-wave device characterisation.**

***Index Terms*—On-wafer probing, on-wafer contacting, microwave measurements, measurement techniques, measurement uncertainty, precision measurements, uncertainty.**

I. INTRODUCTION

The rapid advancement of on-wafer device characterisation capability of a vector network analyser (VNA) has exceeded the 1 THz threshold [1]. The continuous progress in operational frequency has directly affected the measurement complexity and thus the achievable accuracy, as increasingly more uncertainty sources become predominant. One of these sources is the ability to realise a reproducible electrical contact between the measurement probe and the device under test (DUT). This contact error is considered small or negligible for measurements up to a few GHz but becomes dominant when measuring above 110 GHz [1]. The conventional method of probing relies on the detection of the transversal movement of the probe tips as a result of the probe-substrate contact [2]-[4]. The operator evaluates images from a top-view microscope and decides on detection of transversal probe displacement as sufficient for a reliable subsequent microwave measurement. The quality of on-wafer DUT characterisation based on this technique is highly user-dependent. Given the complexity of on-wafer probing, non-contact measurement techniques have received new interest [5]. However, these solutions necessitate a drastic overhaul of the measurement system, wafer design techniques and the measurement procedure, resulting in an even more complex measurement process as compared to conventional contact methods. Recent works [2]-[4] have explored the development of automated on-wafer contacting techniques to improve measurement repeatability. In [3], continuous evaluation of variations in the input reflection coefficient (Γ) measurements during the downward translation of the measurement probe allowed accurate detection of the contact. However, a detailed assessment of the correlation between the probe-sample interaction and the measurement parameters remained missing. In this paper, we present an automated probing method using continuous Γ measurements during the downward translation of the probe, including a thorough experimental evaluation of the correlation between probe-sample distance and Γ measurement parameter.

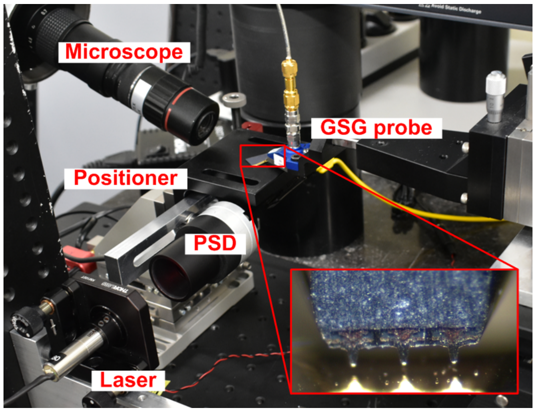

Fig. 1. Test-bench developed for investigation of correlations between probe-substrate distance and Γ measurements.

II. CONTACT DETECTION

Fig. 1 shows the experimental setup designed for investigating the correlation between probe-substrate distance and Γ measurement. In the measurements, a ground-signal-ground (GSG) probe is centred above a coplanar waveguide (CPW) short-device on an impedance standard substrate (ISS) calibration wafer, with a typical starting probe-substrate distance of 100 μm. The substrate is placed on an XYZ-translation stage and moved towards the probe with upward translation. Combination of a photo sensitive detector (PSD) and a laser unit enable height adjustment with a resolution of 0.5 μm. First, start and stop positions of the translation stage are determined using a side-view microscope for determining the probe-substrate contact. Subsequently, the translation stage automatically replicates a contact event by introducing a controlled step-wise translation between the initially established start and stop positions. The experiment starts with a 10 μm step size until the probe-substrate distance reduces to less than 10 μm, at which height the substrate moves with a 2 μm step size until realising a contact. Following each translation step, measurement software automatically acquires 100 points of Γ values at each of the four measurement frequencies ranging from 10 MHz up to 30 GHz. Ten probe-substrate contact experiments provide sufficient Γ measurements for evaluation, with Fig. 2 depicting the polar components of Γ values as a function of probe height. From these results, it is evident that

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[0] The authors wish to acknowledge funding within the research project 18SIB09 TEMMT (Traceability for electrical measurement at millimeter-wave and terahertz frequencies for communications and electronics technologies). This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

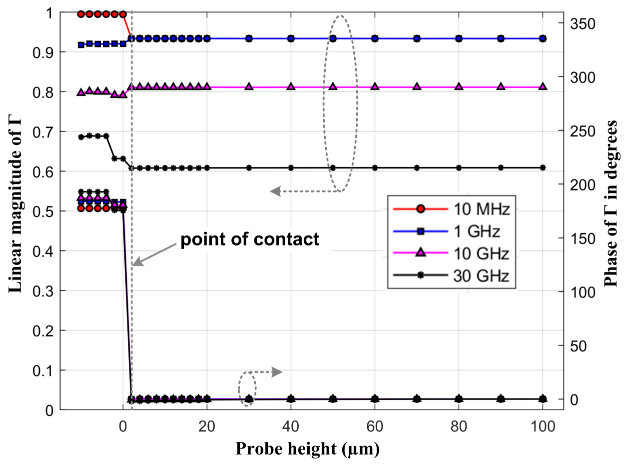

Fig. 2. Γ measurement versus probe-substrate distance. The top and (overlapping) bottom 4 curves are magnitude and phase, respectively.

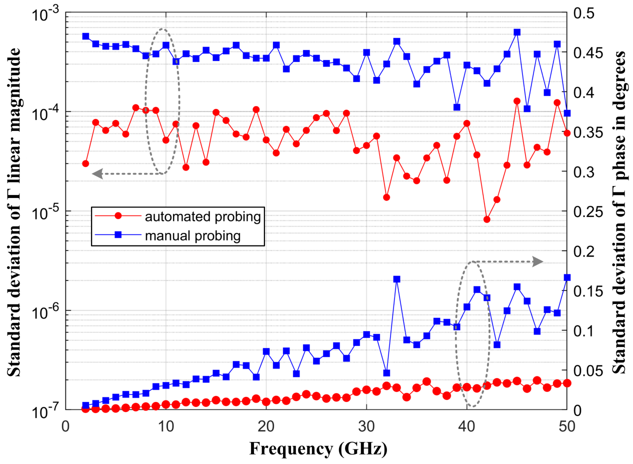

Fig. 4. Repeatability of CPW short-device measurements realised with automated and manual probing techniques.

the probe-substrate contact event initiates an abrupt transition in the Γ value. The following expression allows automatic detection of such transition events:

$$\Delta\Gamma_{n,n-1} = \frac{|\Gamma_n - \Gamma_{n-1}|}{\sqrt{std(\Gamma_n)^2 + std(\Gamma_{n-1})^2}}. \qquad (1)$$

Here, the identification of probe contact requires the difference between measurement values acquired at two successive positions, denoted with *n* and *n–1*, to significantly exceed the corresponding noise values. A threshold value of 1000 for the $\Delta\Gamma_{n,n-1} >> 1$ condition is used by the software. To demonstrate the effectiveness of the algorithm, phase component of Γ measurement results depicted in Fig. 2 are analysed using (1) and shown in Fig. 3 for two measurement frequencies.

III. AUTOMATED CONTACTING

This section outlines an experiment designed for validation of proposed automatic probe contact detection technique. Here, a 150 μm pitch-size GSG probe is positioned above a CPW short-device on an ISS calibration substrate. The substrate is then moved with 5 μm steps upwards and, after each movement, the software collects 100 Γ measurements from the VNA operating at 1 GHz. Following the detection of a contact event, the software collects broadband reflection coefficient measurements from 100 MHz up to 50 GHz. We repeat ten broadband measurements to determine the corresponding repeatability. Furthermore, we also perform ten broadband measurements with the manual probing technique for benchmarking purposes Fig. 4 details the probe contact repeatability results concerning both experiments. The proposed automated probing leads to about five times smaller standard deviation in RF measurements on a CPW short-device.

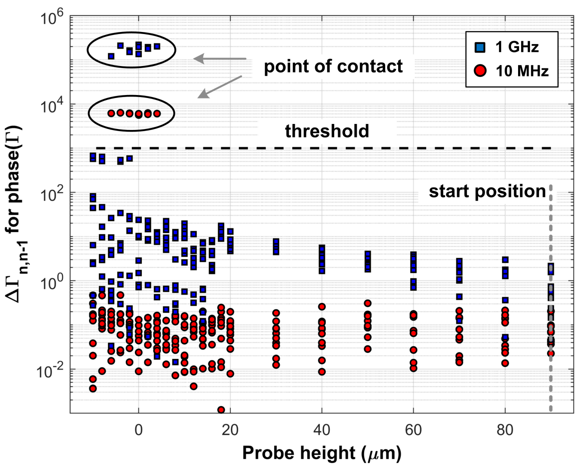

Fig. 3. Γ phase measurement results of Fig. 2 analyzed using (1).

IV. CONCLUSION

An investigation is performed on the correlation between probe-substrate distance and Γ parameter in on-wafer measurements. The measurement results led to a better understanding of the interaction between various parameters involved in on-wafer probing and to the development of an automated contact event detection algorithm. A series of broadband measurements collected with the proposed method and conventional manual probing showed about five times improved repeatability using the automated contacting technique.

ACKNOWLEDGMENT

This work is part of the TEMMT (18SIB09) project that has received funding from the EMPIR programme co-financed by the Participating States and the European Union's Horizon 2020 research and innovation programme. Additional funding was received from the Dutch Ministry of Economic Affairs and Climate.

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