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Building a near-field scanning millimeter-wave microscope integrated in a scanning electron microscope

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Abstract — A near-field scanning millimeter-wave frequency microscope built inside a scanning electron microscope is described. The proposed instrumentation can provide simultaneous atomic force and millimeter-wave images together with the scanning electron microscopy image of the probe / sample interaction. In contrast with conventional scanning microwave microscopy tools, the instrumentation proposed opens the way to achieve traceable measurements by tackling issues encountered in traditional near-field scanning microwave microscopy tools. First, water meniscus in the vicinity of the probe tip is eliminated to reduce parasitic capacitance. Secondly, targeted frequency up to 110 GHz results in confined electric fields in the vicinity of the probe tip to enhance the lateral resolution. Finally, visualization of the tip / sample interaction offers unique possibility to support the measured millimeter-wave signals by fine FEM modeling.

Keywords — Near-field scanning microwave microscopy (NSMM), scanning electron microscope (SEM), evanescent waves, millimeter-wave.

I. INTRODUCTION

The introduction of near-field scanning microwave microscopy (NSMM) tools have pioneered many applications, notably including mapping and quantitative measurement of the electrical properties of materials and devices at micro and nano scale [1]-[7]. Basically, the scanning microwave microscope (SMM) consists of an atomic or scanning tunneling microscope combined with a vector network analyzer (VNA) [8]-[9]. The tip scans across the sample, emitting a microwave signal scattered by the material, altering its amplitude or/and phase properties.

Most of the reported NSMM tools operate in the microwave frequency range, i.e. 300MHz-30GHz. Consequently, there is a natural mismatch between the probe tip size (tens of nm) compared to the wavelength of operation in the order of the cm. When the tip of the probe is held close to the surface of a sample, at a distance separation much smaller than the wavelength of operation, the evanescent electric fields are highly confined in space. In contrast with traditional methods based on propagating waves, microscopy techniques result in high lateral and depth resolutions governed by the tip size [10]-[13]

There is an urgent need to extend the frequency capabilities of microwave microscopy tools to achieve sub-50nm spatial resolution combined with sub-aF electrical resolution. In this effort, a new NSMM is developed with broadband

capabilities up to 110 GHz. Consequently, the new instrumentation offers the possibilities to adapt the lateral and depth resolutions by proper choice of the frequency of interest in the range 1-110 GHz. In addition, the instrumentation has been designed to operate inside a scanning electron microscope for environment control and water meniscus elimination [14]-[15]. Finally, SEM image of the tip / sample interaction offers the opportunity to achieve fine FEM modeling [16]-[17]. In Section II, the design, fabrication and validation of the probing structure is presented with a preliminary targeted frequency of 40 GHz. In Section III, the system integration that requires specific design considerations is discussed.

II. MICROSTRIP PROBING STRUCTURE

The NSMM-cantilever consists of a modified 12Pt400B microwave probe from Rocky Mountain Nanotechnology® (RMN) to achieve 40 GHz frequency operation. This probe consists initially in an ultra-sharp solid platinum probe tapered down to 50 nm and attached to a ceramic substrate. The probe is modified to support a TEM propagation mode through a microstrip structure. To that end, a conductive gold line of 200 μm is placed under the platinum, and continues to the back of the chip as the transmission line (Fig. 1). The back side is then completely covered with gold over an adhesive layer. This NSMM-Cantilever is embedded into a waveguide structure (both coplanar and microstrip structures have been realized for further comparisons) which can be exchanged in case of destroyed tips by using a solder-less PCB mount connector of Rosenberger Corp. with a clamping and screwing mechanism (Fig. 2).

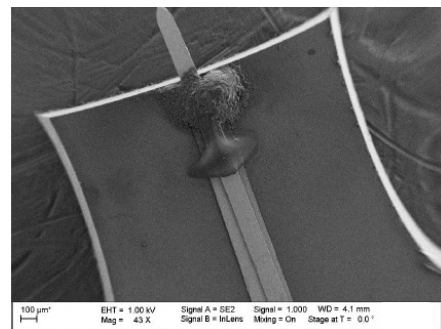


Fig. 1. Scanning electron image of the NSMM-cantilever manufactured by RMN®.

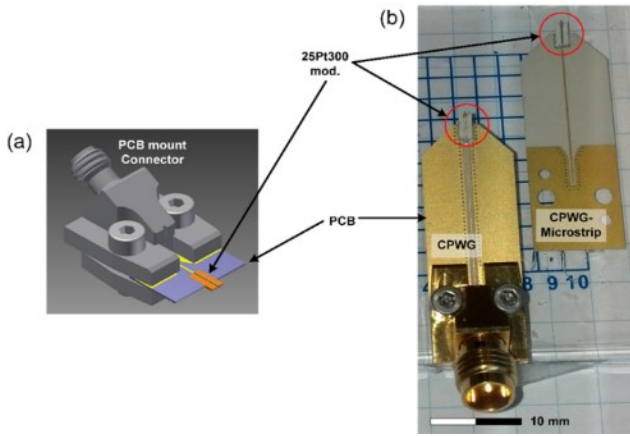


Fig. 2. NSMM-cantilever integration in a dedicated PCB board.

The NSMM-probe has been assembled and millimeter-wave characterization has been performed using a vector network analyzer to measure the return loss (Fig. 3).

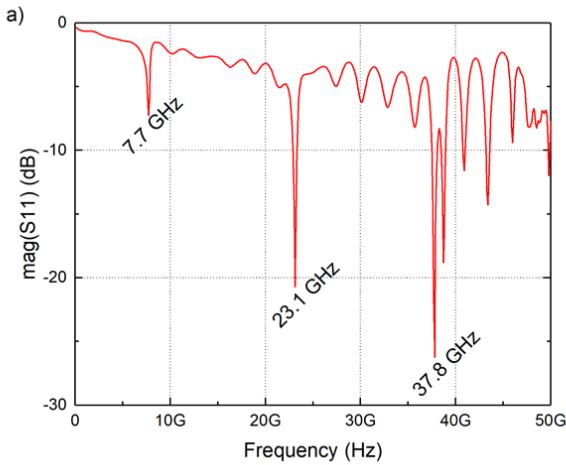


Fig. 3. Return loss mag(S11) of the modified NSMM-probe.

From the experimental results, Fig.3 shows magnitude of the reflection coefficient better than -10 dB up to 40 GHz in accordance with simulated data (not shown here). It has to be noticed that that three resonances occur in the measured response. A time-domain analysis has been used to identify the origins of the resonances at 7.7GHz: transition connector-substrate, 23.1 GHz: Cantilever beam and 37.8 GHz: transition substrate-cantilever. Although the impact of the resonances is minor, optimization of the transitions is under investigation to limit resonance effects.

III. SYSTEM INTEGRATION

The block diagram of the system is described in Figure 4. The hemisphere above the sample is mainly occupied by the electron column and leaves only a very small gap accessible

for the SMM to achieve a working distance of 20 mm. The system presented here has been designed to be as compact as possible. The SMM stage is mounted on the chamber vertically to the electron beam of the SEM. The SMM consists of two main components, a sample scanning stage and a probing unit (Fig. 4). The sample scanning stage is composed of an AFM scanner positioned onto a coarse positioning stage. The positioning stage consists of three piezo driven linear actuators manufactured by Smaract GmbH with scanning ranges of 26 mm in X and Y directions and 11 mm in Z direction. The actuators enable closed-loop operation with less than 10 nm resolution and 25 nm repeatability in any direction. The AFM scanner ANSxyz100/Std from AttocubeTM operates in open-loop on scanning ranges of $50 \times 50 \times 24 \mu\text{m}^3$ with sub-nm positioning resolution and 0.1% scan repeatability (Fig. 5).

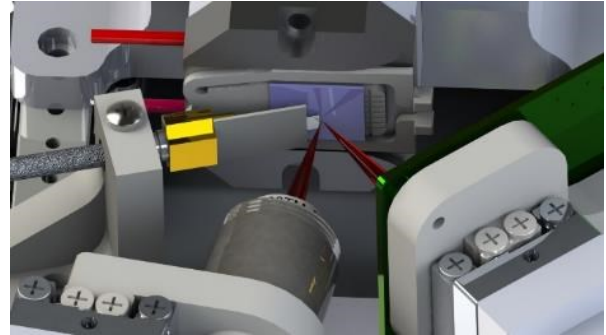


Fig. 4. Sketch of the proposed millimeter-wave NSMM.

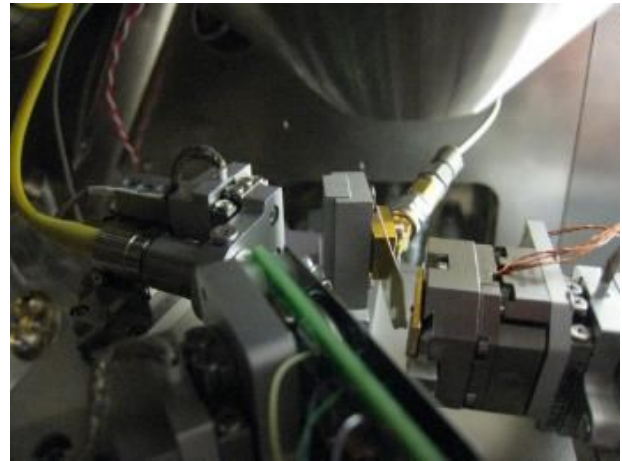


Fig. 5. Photography of the millimeter-wave NSMM integrated inside a Tescan Mira XMU SEM.

The measuring equipment, i.e. SMM integrated into SEM, has been developed and is operational. Fig. 6 gives a picture of the equipment.



Fig. 6. Millimeter-wave NSMM integrated into a SEM.

The preliminary experimental demonstration considers the capacitance reference kit developed by MC2 Technologies® and uses a modified probe from Rocky Mountain Nanotechnologies® [Fig7(a)]. The topography, amplitude and phase images are simultaneously scanned over $30 \times 30 \mu\text{m}^2$ at the scan rate of $5.8 \mu\text{m/s}$ (0.19 line/s in a single direction) with 512×512 pixels resolution. Fig. 7(b) demonstrates 2D AFM image of the reference kit of the device under test.

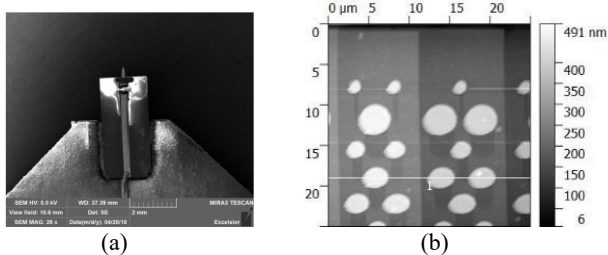


Fig. 7. (a) 25Pt300D modified Rocky Mountain Nanotechnologies® [spring constant = 18 N/m ($\pm 40\%$)]. (b) 2D $30 \times 30 \mu\text{m}^2$ image on reference sample (Capacitance reference kit from MC2 Technologies®).

IV. CONCLUSION

This study was focused on design, fabrication and measurement of new NSMM-cantilevers connected to microstrip based PCBs. These NSMM-cantilevers have been integrated into a SEM. The new instrument has been fully automated using nano-positioning to provide simultaneous atomic force and millimeter-wave images of the sample under investigation.

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