Millimeter Wave Near-Field Imagery With Micrometer Spatial Resolution

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***Abstract*—A 60 GHz high spatial resolution millimeter near-field scanning microwave microscope (NFSMM) system is developed with aim of non-destructive testing of material and circuits. Like SNOM, it involves a modulation of the probe-to-sample distance. We derive an analytical model of the probe detection versus the standoff distance and the harmonic order used for lock-in detection. Both the model and experiments exhibit the filtering of the high spatial frequencies with greater efficiency obtained at highest harmonics. When combined with a specially designed bow-tie probe and an optimized detection setup operating on the third harmonic it yields a resolution of $\approx 2\,\mu$m (*i.e.* $\lambda/2500$).**

I. Introduction and Background

NEAR-FIELD scanning microwave microscope (NFSMM) are helpful tools to characterize surface and material properties [1]. A first class of experiments uses vectorial network analyzers (VNA) to measure with high accuracy any impedance modification brought in the near-field of a tip by a sample, eventually including a resonant probe or an interferometric compensation of the very high reflectivity of the near-field probe [2]. Since VNAs are very expensive in the THz, more affordable solutions derived from near-field optical microscopy (SNOM) [3]–[5] are preferred.

For SNOM experiments the modulation of the distance to sample d is a necessary process to reject perturbations brought by probe emissions not belonging to near-field, especially for apertureless probes. The detection process is thus part of the image formation [6]. We recently developed a NFSMM experiment operating at 60 GHz similar to SNOM with a bow-tie near-field probe that interact mostly by a tangential electric field [7] instead of the longitudinal field of more classical tips. In this communication we construct a probe-sample model and improve the detection process to achieve a $\lambda/2500$ resolution.

II. Results

Our 60 GHz NFSMM is a very low-cost system built using a reflectometry setup with a Gunn source, a dual-directional coupler and Schottky detectors. Near-field sensing is obtained with a home-made bow-tie probe fabricated by attaching two metal triangles to the open end of a WR15 waveguide [7]. Various probe metals and geometry (gap g between triangles tips) were studied. The sample is placed on a piezo actuator that provides the d-modulation at frequency f. Probes were characterized by touchdown experiments ($d \in [0, 1000]\,\mu$m) using a lock-in detection at f, $2f$ and $3f$. We then derive a coupling model of the probe-to-sample interaction starting from the dipole emission [8] that was shown in perfect agreement with experiments.

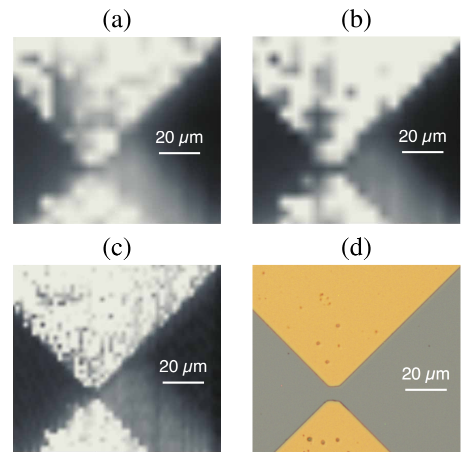

Fig. 1. 60 GHz near-field images of the center part of a bow-tie antenna built on a Si wafer as a function of the detection harmonic at lock-in. (a) fondamental, (a) second harmonic, (c) third harmonic, (d) optical image.

Probes were subsequently used to image a gold bow-tie antenna fabricated on a Si wafer with lock-in detection at f, $2f$ and $3f$ (Fig. 1). As expected [6], a higher harmonics rank allows a better spatial resolution by rejecting more efficiently the lower spatial frequencies. As a result, a resolution of $\approx 2\,\mu$m is obtained @ $3f$ in Fig. 1d instead of only $\lambda/130$ previously [7].

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