LOCALIZED CIRCUIT PROBING WITH A COMBINED SCHOTTKY DIODE/ SCANNING FORCE MICROSCOPE

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ABSTRACT

We present the first scanned probe Schottky diode used as a detector of microwave power. This technique enables direct sensing of local fields without the use of a high frequency receiver, and it can accommodate simultaneous measurement of sample topography, as well. Applications for this probe range from field mapping on planar filters to failure analysis of MMIC's.

INTRODUCTION

The growing need for measuring local high-frequency electromagnetic fields on both passive (material) and active (device or circuit) samples has spawned a variety of techniques using scanned beams and probes. Optoelectronic means of probing microwave circuits have shown promise on GaAs and other non-centrosymmetric crystalline substrates[1], but for Si MMIC's or amorphous substrates (such as alumina), which are not optoelectronically active, new techniques for sub-micrometer internal node probing at high frequencies are needed.

BACKGROUND

One promising approach to substrate-independent probing of local microwave fields uses a scanning-force microscope (SFM). The first efforts used the SFM cantilever as a mechanical frequency mixer since it exhibits a square-law response to the voltage difference between tip and sample[2-5]. While >100 GHz signals have been measured with this technique[6], it requires coherent signals between tip and sample, and because it injects a signal onto the probe tip, it is more invasive than a passive antenna or detector.

We first addressed this concern by combining a near-field coaxial antenna with a scanning force microscope (SFM) tip to measure picosecond electric field waveforms and ~10 nm topography of a GaAs nonlinear transmission line (NLTL) using a 50 GHz sampling oscilloscope as the receiver[7]. More recently, we designed, fabricated and tested a combined SFM tip/cantilever and loop antenna for simultaneous acquisition of both sample topography and high-frequency magnetic field using a vector network analyzer[8]. Both methods require microwave instrumentation for signal detection since they themselves are only near-field antennas.

NEAR-FIELD DIODE PROBES

Here, in contrast to previous approaches, we report the first integrated Schottky diode/SFM tips for measuring local microwave power directly. Sub-micrometer diode probe tips, either free standing[9] or integrated with cantilevers[10], have already been reported as photodetectors, and used for scanning optical near-zone fields in combination with SPM platforms. Photosensitive probes have also been realized by modifying existing single-crystal Si tip/cantilevers by evaporating Schottky contacts onto them[11].

In this work we have employed both modified commercially available cantilevers and microfabricated diodes, which are then mounted onto cantilevers. For the former, we prepared commercially available single-crystal Si SFM tip/cantilevers with metal contacts at the tip and shielding along the cantilever and probe body. This results in a rectifying junction just at the tip region that can be used for detecting microwave power. For the latter, we used specially fabricated coaxial diode tips[9, 12] mounted onto metal cantilevers. While these proved more sensitive and uniform than the modified commercial tips, they did not have adequate topography sensing capability due to the large mass of the metal cantilevers. We are now developing a fabrication process to integrate these latter diodes onto cantilevers.

TIP MODIFICATION PROCESS

To make the multifunctional tip structure using commercially available cantilevers[12], we perform a 90 °C bakeout of the tip to drive off water, then prepare its surface with HMDS for better adhesion of AZ-5214 photoresist, applied with a brush fiber to the cantilever and body. We follow this by a 120 °C "hard bake" with selective removal of stray photoresist. Then we mount the tip in a Topometrix SFM to gently remove the photoresist at the tip area by making light contact to a gold surface. We then evaporate 200-300Å of Ti and 1000-2000Å of Au to form both the Schottky contact and the shield along the cantilever and body. Using very small coaxial cable, we contact both shield (anode metal) and body (cathode, highly doped N-type Si) using Ag epoxy. Finally, the metal at the tip is thinned again with light contact to achieve a power-sensitive rectifying probe.

After modification, the tip/cantilever assembly retains its ability to perform "non-contact" measurements of sample topography, becoming a useful multifunctional probe tool for sub-micrometer length scales. The drawbacks of this approach are, however, significant variability in the quality of the tip and sensitivity of the detector.

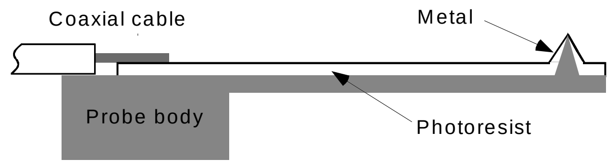

Figure 1. Cross sectional view of modified Schottky diode probe.

We have achieved more uniform results using batch fabricated Schottky diode probe tips (Fig. 2) that we in turn mount onto conducting cantilevers.

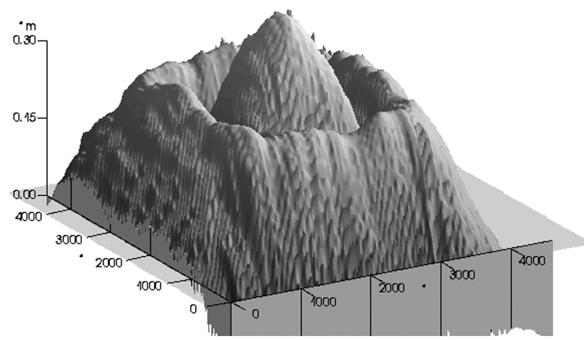

Figure 2. SFM image of batch fabricated Schottky diode probe tip. Center conductor is the anode with a ~10 nm tip radius. Outer shield is a polysilicon cathode.

The confined geometry of the Schottky contact, which is formed just at the 100 nm diameter junction of center and outer conductor (Fig. 2) leads to μA currents in forward bias (Fig. 3).

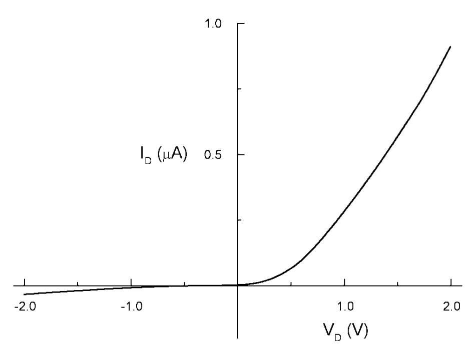

Figure 3. Typical current-voltage characteristics for the diode of Fig. 2.

MEASUREMENTS

To both demonstrate and understand the characteristics of these new probes, we chose simple microwave structures, such as a coplanar waveguide (CPW) and an interdigitated capacitor (IDC). Using a modified Topometrix Accurex SPM platform, which accommodates CPW probes, we excited a variety of samples at frequencies from 1-20 GHz and detected the near-field power directly above the samples. To facilitate detection, we amplitude modulated the microwave source and fed the (unbiased) diode output to a 1 MΩ input resistance lock-in amplifier, whose magnitude and phase output was acquired and plotted by the SPM.

The low current expected from the diode (Fig. 3) meant that its responsivity was also weak, in the range of 200-500 pA/W at the μm scale tip-sample distances we used in this initial characterization (Fig. 4). For these results we used an auxiliary Si probe tip to measure topography since the metal cantilever on which the diode was mounted prevented reliable tip-sample distance feedback. Still, we clearly see the correspondence of microwave power on the gold contact of the IDC sample to that of its topography, while the phase of the rectified signal exhibits significant contrast between metal and the alumina dielectric, as well. We observed the expected dependence of detector output vs. both power on the sample and tip-sample distance.

We measured ~10× larger currents from the modified commercial tips due to their larger junction areas, but because in most cases large fractions of the junctions were shielded by the Schottky metal contacts, their responsivities were usually even lower than the microfabricated diodes. The ability, however, to scan within 1-5 nm of the sample surface using non-contact vibrating cantilever techniques nearly compensated for the much smaller active junction area of these tips.

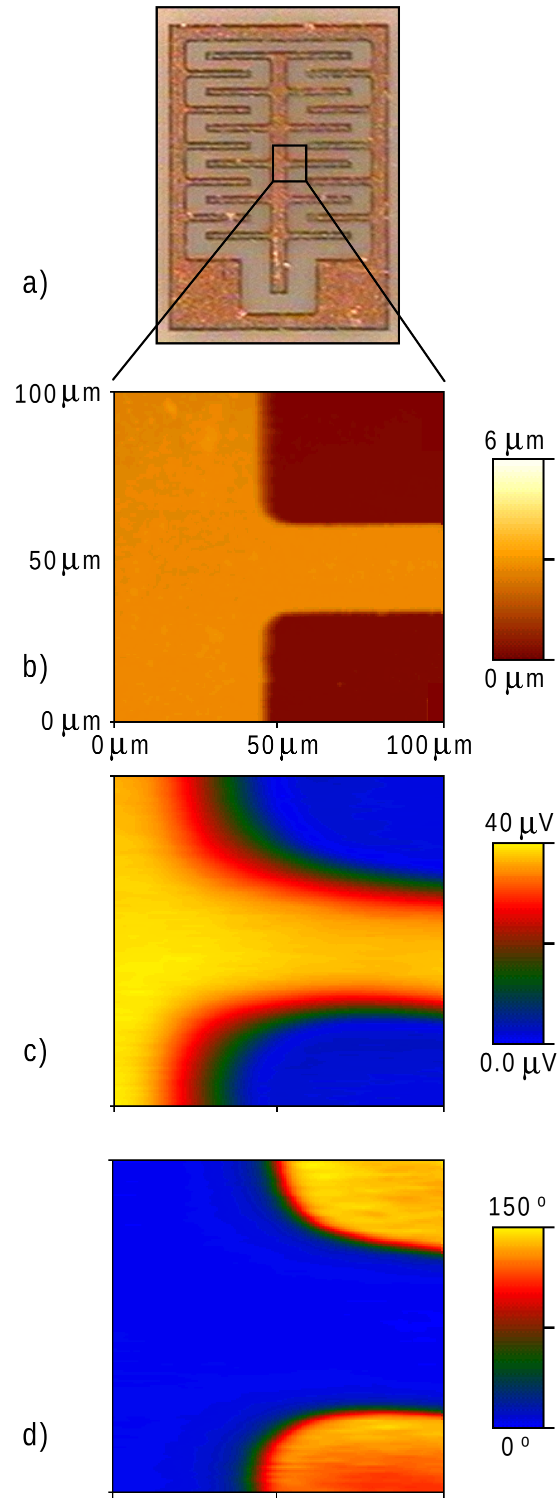

Figure 4. Interdigitated capacitor sample (a); non-contact topography using Si probe tip (b); local power magnitude (c) and phase (d) as detected by scanning diode probe at 2.053 GHz with 226 Hz amplitude modulation.

CONCLUSIONS

We have developed the first near-field scanning diode tips for microwave power detection, using both modified single-crystal Si tip/cantilevers and specially fabricated coaxial Si diodes mounted onto auxiliary cantilevers. These devices can resolve μm level variations in microwave power above a structure or circuit, and they simplify the means for detecting localized fields.

ACKNOWLEDGEMENTS

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REFERENCES

[1] K. J. Weingarten, M. J. W. Rodwell, and D. M. Bloom, "Picosecond optical sampling of GaAs integrated circuits," *IEEE Journal of Quantum Electronics*, vol. 24, pp. 198-220, 1988.

[2] F. Ho, A. S. Hou, and D. M. Bloom, "High-speed integrated circuit probing using a scanning force microscope sampler," *Electronics Letters*, vol. 30, pp. 560-562, 1994.

[3] A. S. Hou, F. Ho, and D. M. Bloom, "Picosecond electrical sampling using a scanning force microscope," *Electronics Letters*, vol. 28, pp. 2302-2303, 1992.

[4] G. E. Bridges, R. A. Said, and D. J. Thompson, "Heterodyne electrostatic force microscopy for high frequency integrated circuit measurement," *Electronics Letters*, vol. 29, pp. 1448-1449, 1993.

[5] C. Böhm, C. Roths, and E. Kubalek, "Scanning-force microscope test system for device internal test with high spatial and temporal resolution," *Microelectronic Engineering*, vol. 24, pp. 91-98, 1994.

[6] A. Leyk, C. Böhm, D. W. van der Weide, and E. Kubalek, "104 GHz signals measured by high frequency scanning force microscope test system," *Electronics Letters*, vol. 31, pp. 1046-1047, 1995.

[7] D. W. van der Weide, "Localized picosecond resolution with a near-field microwave/scanning-force microscope," *Applied Physics Letters (in press)*, 1996.

[8] V. Agrawal, P. Neuzil, and D. W. van der Weide, "A microfabricated tip for simultaneous acquisition of sample topography and high-frequency magnetic field," *Applied Physics Letters*, vol. 71, pp. 2343-45, 1997.

[9] R. C. Davis, C. C. Williams, and P. Neuzil, "Micromachined submicrometer photodiode for scanning probe microscopy," *Applied Physics Letters*, vol. 66, pp. 2309-2311, 1995.

[10] S. Akamine, H. Kuwano, and H. Yamada, "Scanning near-field optical microscope using an atomic force microscope cantilever with integrated photodiode," *Applied Physics Letters*, vol. 68, pp. 579-581, 1996.

[11] H. U. Danzebrink, G. Wilkening, and O. Ohlsson, "Near-field optoelectronic detector probes based on standard scanning force cantilevers," *Applied Physics Letters*, vol. 67, pp. 1981-3, 1995.

[12] D. W. van der Weide and P. Neuzil, "The nanoscilloscope: Combined topography and AC field probing with a micromachined tip," *Journal of Vacuum Science & Technology B*, vol. 14, pp. 4144-7, 1996.