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Probing Local Device Fields Using AC Scanning Force Microscopy

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13. ABSTRACT *(Maximum 200 words)*

Several ground-breaking results were achieved during the past year: The first combined scanning-force/electric-field probes were fabricated, tested and published. These results showed unprecedented spatial and temporal resolution of approximately 100 nm and 10 ps, respectively, when they were used to measure ultrafast electronic circuits. The approach taken was to modify commercial scanning probe microscope (SPM) probe tips with coaxial shields, then connect them directly to a 50 GHz sampling oscilloscope, a considerable simplification over laser-based systems for probing integrated circuits, yet much more flexible than commercial needle probes. This work has generated significant interest in the industry, and tech-transfer activities and discussions are ongoing with a number of companies, since, for the first time, it is possible to simultaneously locate sub-micrometer features (using the SPM feature to see sample topography) and electrically probe these features. Another significant accomplishment was the design, development and publication of the first combined high-frequency magnetic field and topography probe tip. This invention was used to probe a coplanar waveguide sample at 10 GHz, mapping out the normal component of the magnetic field together with sample topography for the first time. This probe could prove especially useful in understanding new superconducting logic elements.

14. SUBJECT TERMS
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Microfabricating a Nanoscilloscope

Executive Summary

Several new results were achieved during the past year: The first combined scanning-force/electric-field probes were fabricated, tested and published. These results showed unprecedented spatial and temporal resolution of 10–100 nm and 10 ps, respectively, when they were used to measure ultrafast electronic circuits. The approach taken was to modify commercial scanning probe microscope (SPM) probe tips with coaxial shields, then connect them directly to a 50 GHz sampling oscilloscope, a considerable simplification over laser-based systems for probing integrated circuits, yet much more flexible than commercial needle probes. This work has generated significant interest in the industry, and tech-transfer activities and discussions are ongoing with Cascade Microtech, two of the largest SPM vendors, and Schlumberger, the leading electron-beam probing manufacturer. Their interest is high since, for the first time, it is possible to simultaneously locate sub-micrometer features (using the SPM feature to see sample topography) and electrically probe these features.

Another significant accomplishment was the design, development and publication of the first combined high-frequency magnetic field and topography probe tip. This invention was used to probe a coplanar waveguide sample at 10 GHz, mapping out the normal component of the magnetic field together with sample topography for the first time. Furthermore, in contrast with the more-familiar superconducting quantum interference device, or SQUID, the present invention serves both as a near-field antenna and a topography probe. As an antenna, its sensitivity is limited by that of the receiver used in the experiment, and at microwave frequencies, this is on par with that of the SQUID, though the SQUID maintains its high sensitivity down to DC, whereas the sensitivity of the antenna/receiver combination scales with frequency. This probe could prove especially useful for understanding new superconducting logic elements.

To support these activities, the University of Delaware and Topometrix, Inc. designed and built a new SPM platform to allow combined wafer probing using both high-speed coplanar waveguide or needle probes and the new SPM probe.

Accomplishments

Combined Electric-Field/Scanning-Force Microscope

The objective of this work has been to develop scanning probe tips for measuring high-frequency electric field and sample topography at the same time. Several new results were published and presented of scans at a variety of length scales and frequencies. The most significant were measurements of a nonlinear transmission line showing 30 ps waveforms with a spatial resolution set by the probe tip radius to be 10–100 nm, depending on the condition of the probe. This represents an important advance in the state of the art, being both the highest combined resolution result and one built on an idea distinct from previous probing attempts.

As shown in Fig. 1, significant progress was made in realizing the fully integrated micromachined version of this probe. While further process development is underway, short-term results were achieved with a modified commercial silicon probe, as desribed above.

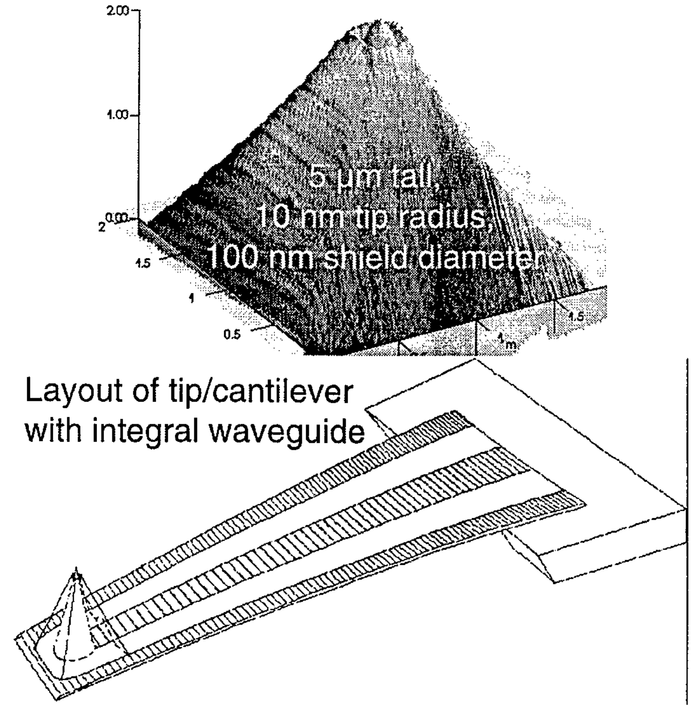
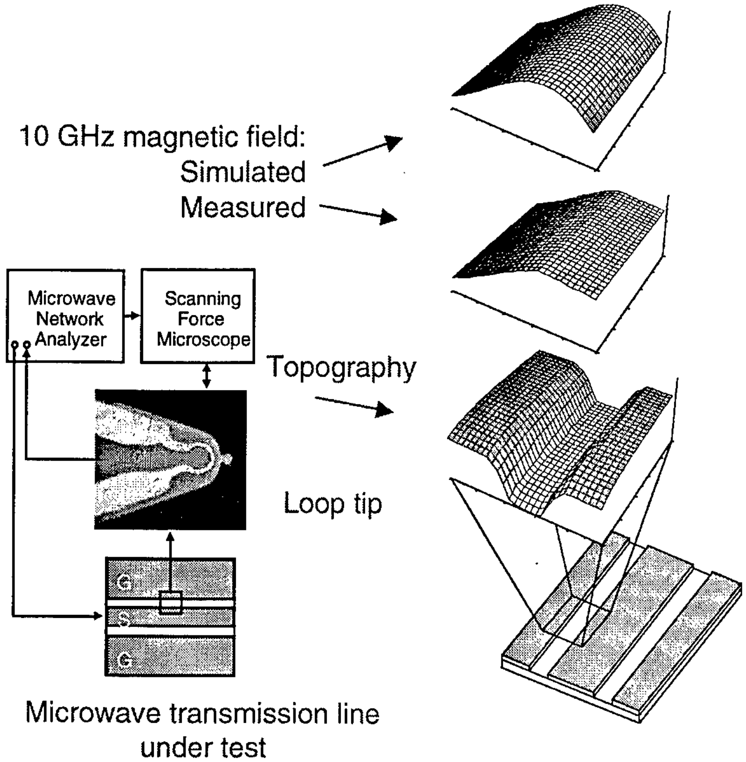


Figure 1. Micromachined silicon coaxial probe tip (above) and conceptual layout for probe on a scanning-force microscope cantilever (below).

Combined Magnetic-Field/Scanning-Force Microscope

The objective of this work is to develop multifunctional scanning probes for simultaneous measurement of sample topography and high-frequency magnetic field. The approach to this objective is to lithographically define near-zone magnetic-field antennas onto silicon nitride scanning-probe microscope cantilevers, as shown in Fig. 2. Various loop diameters were defined, ranging in size from 2 to 6 µm, and these were combined with a topography "finger" probe extending from the plane of the cantilever. These cantilevers were integrated on silicon wafers, which were etched with V-grooves to accommodate small coaxial cables connecting the loop antennas to external instrumentation. The combined probes were mounted into a commercial scanning-probe microscope platform and were used to measure the topography and magnetic field of a simple microwave transmission line, a coplanar waveguide (CPW). The properties of the CPW sample at 10 GHz were computed with a full three-dimensional field solver to get the absolute electric and magnetic field values, which were compared to those of the measurement. Subtracting cable and connector losses, an absolute calibration of the field values was done, comparing values measured with the loop probe using a microwave network analyzer and calculations. Topographical resolution was set by the radius of the finger probe to less than 1 µm, while spatial resolution of the magnetic field at 10 GHz was set by the radius of the 6 µm loop. These represent the first and highest combined field/topography resolutions for microwave probing of magnetic fields.



(Agrawal, Neuzil, and van der Weide, to appear in APL, Oct 1997)

Figure 2. Experimental setup for magnetic-field/topography scanning (left) and results of simulated and measured 10 GHz normal-directed magnetic field and CPW sample topography (right).

Conclusion

Two new concepts in combined high-frequency field and topography probing were realized, tested, and published. Both electric and magnetic fields can now be probed on the micrometer or sub-micrometer scales along with sample topography, using primarily commercial instrumentation operating at room temperature, a significant advance in the state of the art.

Publications, Presentations and Patents Resulting from this Work

Publications

V. Agrawal, P. Neuzil, and D. W. van der Weide, "Simultaneous probing of microwave magnetic field and topography," to appear in *Applied Physics Letters*, October 20, 1997.

P. Neuzil, D. W. van der Weide, and G. S. Kino, "Characteristics of nanoscale Schottky diodes for near-field photodetection optical microscopy," submitted to *Applied Physics Letters*, 1997.

E. A. Chowdhury, J. Kolodzey, J. O. Olowolafe, G. Qiu, G. Katulka, D. Hits, M. Dashiell, D. W. van der Weide, C. P. Swann, and K. M. Unruh, "Thermally oxidized AlN thin films for device insulators," *Applied Physics Letters*, vol. 70, pp. 2732-34, 1997.

D. W. van der Weide, "Localized picosecond resolution with a near-field microwave/scanning-force microscope," *Applied Physics Letters*, vol. 70, pp. 677-79, 1997.

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.

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. 1046-7, 1995.

Presentations

D. W. van der Weide and P. Neuzil, "The nanoscilloscope: Combined topography and AC field probing with a micromachined tip," presented at Third Workshop on Industrial Applications of Scanned Probe Microscopy, NIST, Gaithersburg MD, 1996. (Invited)

D. W. van der Weide, P. Neuzil, T. Bork, J. Bergey, and V. Agrawal, "Localized microwave spectroscopy with modified scanning force microscopes," presented at 71st Colloid and Surface Science Symposium, American Chemical Society, Newark DE, 1997.

V. Agrawal, D. W. van der Weide, T. Bork, J. Bergey, and P. Neuzil, "Deconvolving probe characteristics to enhance field resolution in near-field microwave spectroscopy," presented at 71st Colloid and Surface Science Symposium, American Chemical Society, Newark DE, 1997.

D. W. van der Weide, "Picosecond/nanometer resolution with a near-field microwave/scanning-force microscope," presented at Ultrafast Electronics and Optoelectronics, OSA, Incline Village NV, 1997.

D. W. van der Weide, "Measurements with a near-field microwave/scanning-force microscope," presented at Fourth Workshop on Industrial Applications of Scanned Probe Microscopy, NIST, Gaithersburg MD, 1997.

D. W. van der Weide and P. Neuzil, "The nanoscilloscope: Combined topography and AC field probing with a micromachined tip," presented at 40th International Conference on Electron, Ion, Photon Beam Technology and Nanofabrication, Atlanta GA, 1996.

D. W. van der Weide and P. Neuzil, "The nanoscilloscope: Combined topography and AC field probing with a micromachined scanning force microscope tip," presented at Silicon Nanoelectronics Workshop, IEEE, Honolulu HI, 1996.

D. W. van der Weide and P. Neuzil, "The nanoscilloscope: Combined topography and AC field probing with a micromachined tip," presented at Solid-State Sensor and Actuator Workshop, Hilton Head Island SC, 1996.

D. W. van der Weide, P. Neuzil, T. Bork, and J. Bergey, "The nanoscilloscope: Combined topography and AC field probing with a micromachined SFM tip for building in reliability," presented at International Integrated Reliability Workshop, IEEE, Lake Tahoe CA, 1996.

Patents

D.W. van der Weide, "Combined topography and electromagnetic field scanning probe microscope," U.S. patent pending.