THE NANOSCILLOSCOPE: COMBINED TOPOGRAPHY AND AC FIELD PROBING WITH A MICROMACHINED TIP

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ABSTRACT

We introduce a new concept for combined probing of topography and local AC fields based on a micromachined silicon coaxial tip, and we report preliminary results of scale-model measurements and tip fabrication.

INTRODUCTION

The scanning force microscope (SFM) has been used extensively for measuring topography of samples ranging from soft biological materials to integrated circuits; it has recently been used in measuring AC fields via a frequency-mixing technique that relies on the nonlinear response of the cantilever to voltage differences between the sample and the scanning tip[1, 2]. While this approach is useful for measuring local voltages on integrated circuits, it requires injecting a signal onto the SFM cantilever which is synchronized with the IC signal to be measured, limiting its range of application.

Here, by contrast, we are extending near-field scanning optical microscopy (NSOM) down in frequency from the visible—where cylindrical waveguide, a tapered and metal-coated optical fiber, is used—by employing a *coaxial* micromachined waveguide/tip[3] while maintaining the topographic and tip-sample distance control capabilities of the SFM[4]. Because this instrument can be used to measure both AC fields and topography simultaneously with nanometer-level localization, we call it a NANOSCILLOSCOPE.

Frontal and side-view cross-sections of scanning-force/evanescent-wave microscope tip and cantilever (from U.S. patent application)

Key:
Cantilever material
Tip metal
Center-conductor, outer-conductor, and shield metal
Air or dielectric material

Figure 1. Schematic layout of combined SFM/coaxial tip with a coplanar waveguide running along the cantilever.

Coaxial waveguide exhibits no cutoff frequency, unlike the cylindrical tapered waveguide used in NSOM, so if coax is tapered to a tip, a near-field antenna results. Essentially a shielded SFM tip with a planar transmission line integrated

along the cantilever, this new structure allows simultaneous measurement of topography and local AC electric fields. With appropriate instrumentation at the root of the cantilever, the frequencies of these fields could be in the several-hundred GHz regime[5, 6].

SCALE-MODEL MEASUREMENTS

We have performed scale-model experiments using available coaxial transmission line tapered to a $\sim 20 \mu\text{m}$ tip radius, and have measured field amplitude and phase contrast in transmission between two tips with wavelength-relative resolution $> 10^{-6}$, indicating the essentially electrostatic nature of the fields at the tapered tip[3], also shown in the calculation of Fig. 2. These measurements were made over a frequency range of 1–1000 MHz, limited only by the equipment available.

Figure 2. Quasistatic calculation of electric field lines between scale-model coaxial tips in transmission mode. A metallic grid sample is being scanned between the two tips, as shown in the close-up.

Using just a tapered coaxial tip in reflection has already given measurable contrast in the phase of the electric field at microwave frequencies[7], so this mode of the principle is well-established. A final operating mode to be established is that of detection, whereby fields from the sample itself are measured locally. While again a larger-scale example of this principle is regularly employed in many microwave laboratories to measure local electric (magnetic) field strengths by using an open-ended (loop-terminated) coaxial cable, we can also make a rough estimate of the signal voltage expected in this configuration at the scale of the present tip: As depicted in Fig. 3, voltage of 1 V across two conductors spaced by $1 \mu\text{m}$ results in a $\sim 10^4 \text{ V/cm}$ electric field. Immersing into this field a coaxial tip with $\sim 50 \text{ nm}$ tip-shield spacing will result in a $\sim 50 \text{ mV}$ signal—

fully measurable. This simple argument has neglected losses, but also accounts only for the in-plane components of the field; we expect a contribution from the normal components, as well.

Figure 3. Coaxial tip geometry probing the electric field between two conductors.

MICROMACHINED STRUCTURE

To bring the scale-model experiments into the microscopic regime, we have fabricated a silicon/polysilicon coaxial tip using a method similar to that in [8]. This tip (shown in Figs. 4 and 5), when integrated with a modified coplanar waveguide running along the cantilever, will result in a complete NANOSCILLOSCOPE. While this realization does not use the hybrid metallic/dielectric structure described in Fig. 1, it can achieve a sharper tip radius and can be integrated more readily with existing VLSI processes.

Figure 4. SFM image of silicon/polysilicon coaxial tip; actual tip height is $\sim 5 \mu\text{m}$.

Figure 5. Close-up of coaxial structure; tip radius is $\sim 10 \text{ nm}$; horizontal scale is in $1000 \text{ \AA}$ increments.

CONCLUSIONS

By integrating a micromachined coaxial tip with a planar transmission line/cantilever structure, we achieve an instrument capable of simultaneous localized AC field measurements and sample topography. We expect that the NANOSCILLOSCOPE will be useful in IC failure analysis, local probing of surface chemistry, and electrical characterization of neural function on the nanometer scale.

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