Near-Field Microwave to THz microscopy: instruments, applications, and calibration challenges

Problems of Measurement and Calibration at the Nano-scale

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Network Analysis at the Nanoscale: Measurement and Metrology Challenges

•Nanoscale devices are typically very high impedance; Network Analyzers are optimized at 50 ohms

•Probing solutions for the nanoscale do not exist but Atomic Force Microscopes (AFM) can provide a platform for approaching this issue

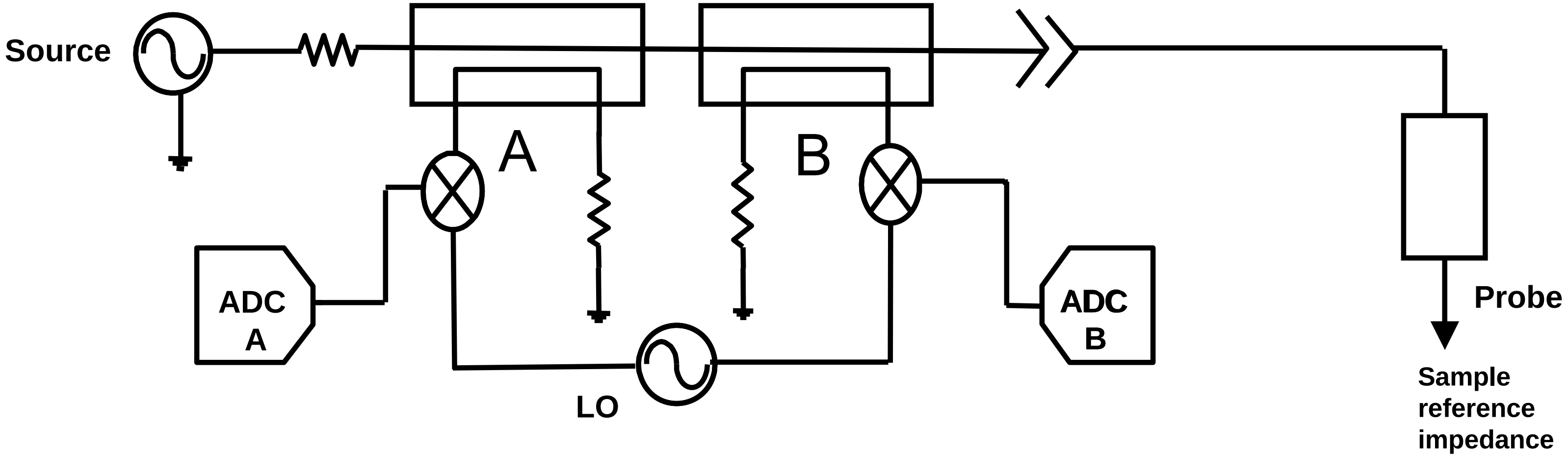
•Calibration standards other than shorts, opens, and 50 ohms do not exist

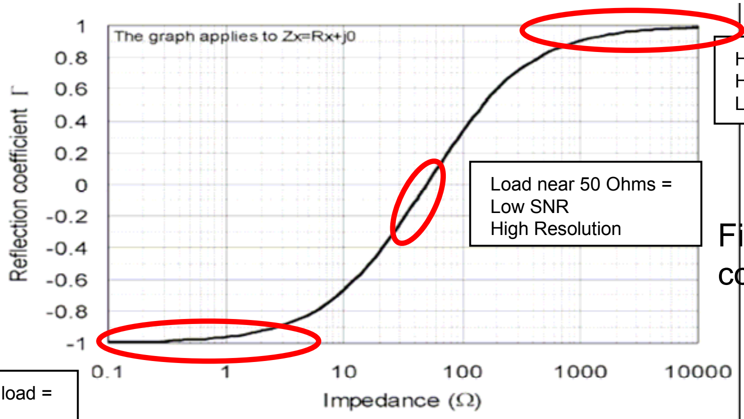
•The beginning of a solution: The Arbitrary Impedance Network Analyzer and the Scanning Microwave AFM (these bring forward their own issues)

•Near Field Microscopy can also be extended to THz

Standard Network Analyzer

Reflection Only





High impedance load =
High SNR
Low Resolution

Load near 50 Ohms =
Low SNR
High Resolution

Low impedance load =
High SNR
Low Resolution

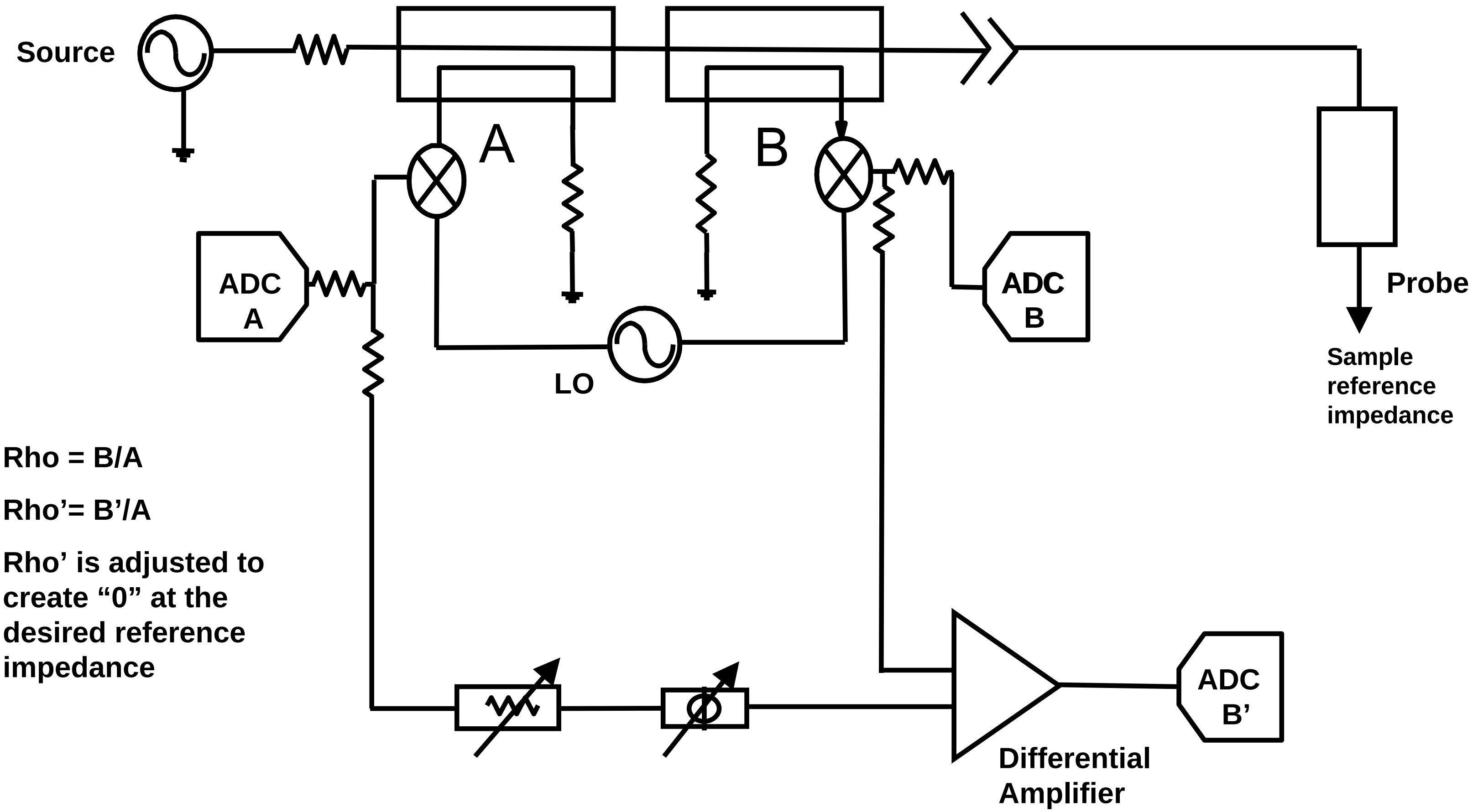
Figure 1: reflection coefficient vs impedance

$$S_{11} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$= B/A$

Arbitrary Impedance Network Analyzer

Reflection Only

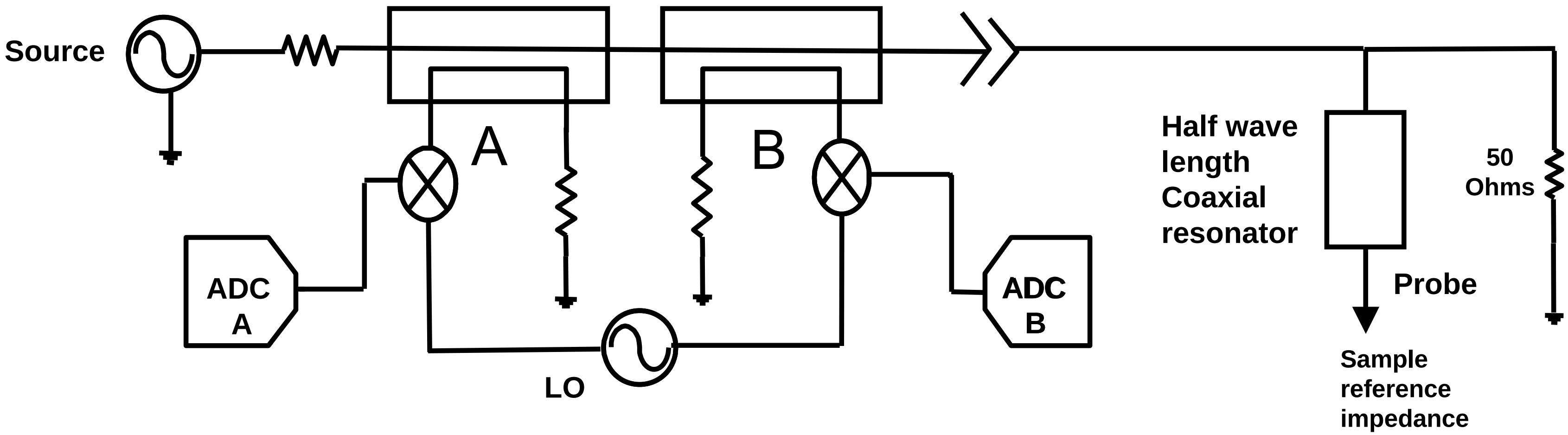


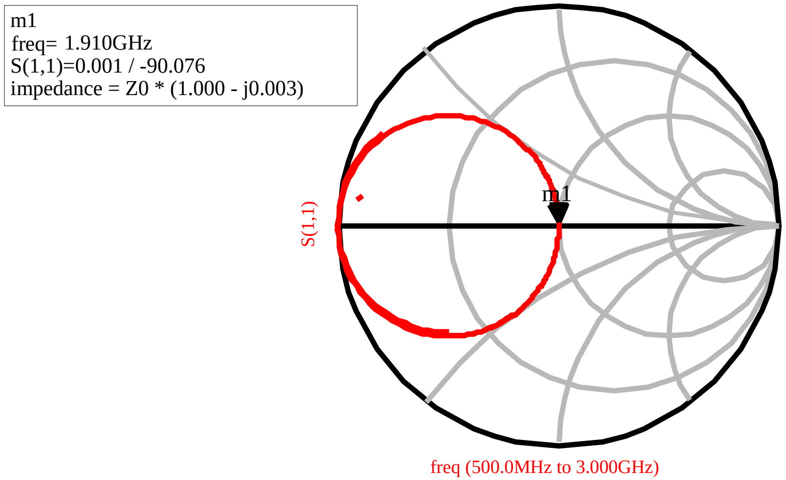
Rho = B/A

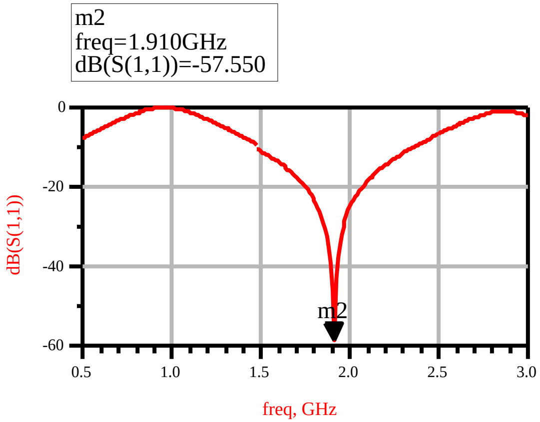
Rho’= B’/A

Rho’ is adjusted to create “0” at the desired reference impedance

Simplified Single Frequency Solution





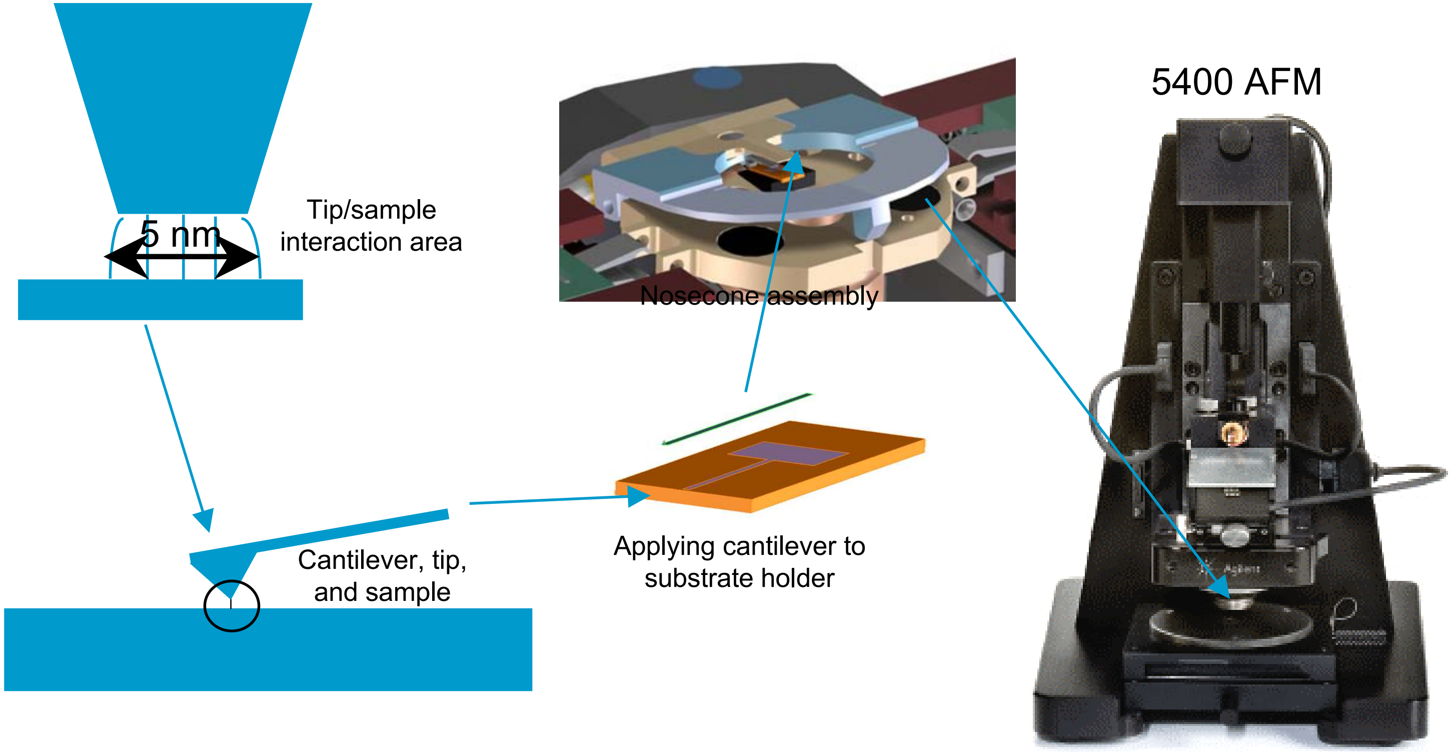


How do we measure small things?

-SMM is a near field system. The resolution is determined by the Electric field interaction area with the sample. This is on the order of 5-10 nm

-SMM uses a network analyzer to measure the vector reflection coefficient caused by the tip-sample interaction; this gives information about the material properties (dielectric properties)

-While an AFM needs “contact” to make a measurement the SMM can measure without contact. You can be 1-10 nm away from the sample and still have good sensitivity



5 nm

Tip/sample interaction area

Nosecone assembly

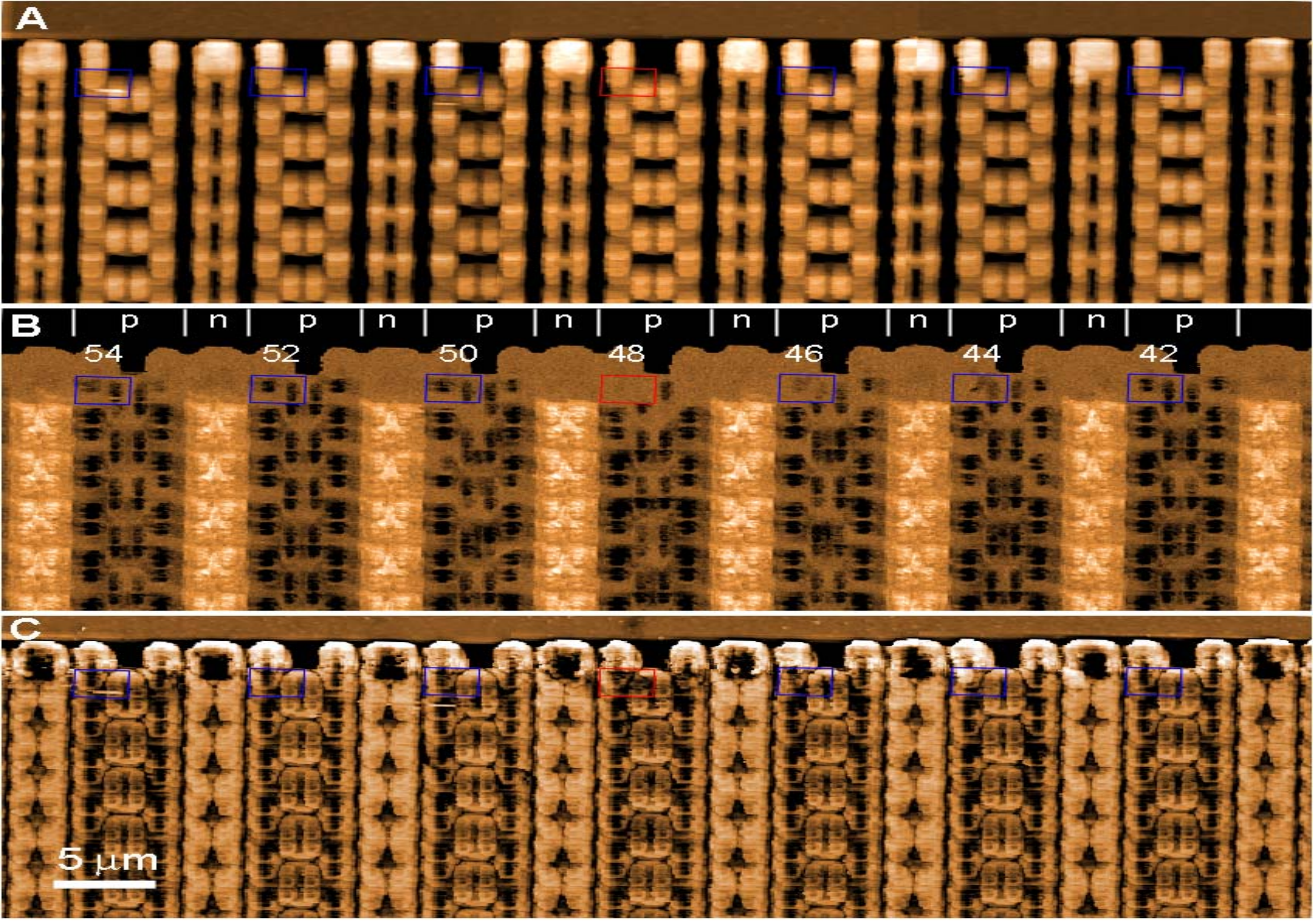
5400 AFM

Cantilever, tip, and sample

Applying cantilever to substrate holder

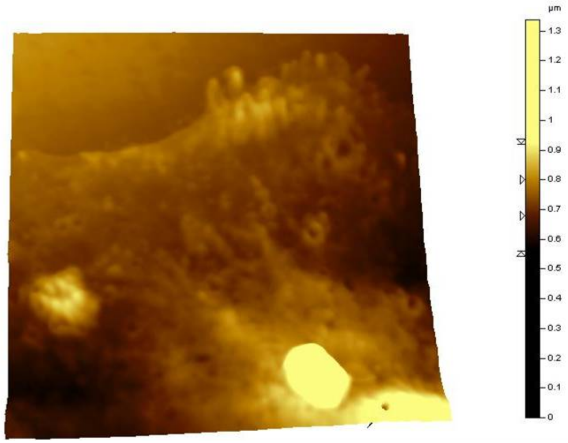
PNA network analyzer

SRAM Image



Topography (A), dopant concentration (B), and capacitance (C) images of the 0.25 um polished SRAM sample. In the dopant image (B), bright color represents n-type carriers, and dark color is p-type. Alternating lightly doped p and n wells are clearly resolved. Looking at the connection areas between the labeled transistors and their neighbor n wells, as marked by the rectangles, it is very noticeable that the dark (p) carriers seen in the connection areas of all good transistors (blue marked) does not appear for the 48th transistor (red rectangle). In stead, the area is fully filled with bright (n) carriers, indicating a short between that transistor and its neighbor n well. In the capacitance image (C), some difference of that transistor area (red) from other good (blue) ones is also visible. The topography image (A) does not show any difference. (W. Han, 7/10/2008, for Freescale)

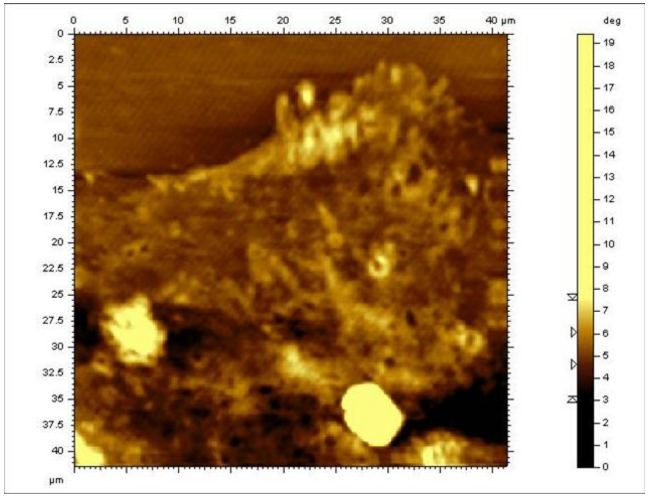
Life Science Examples

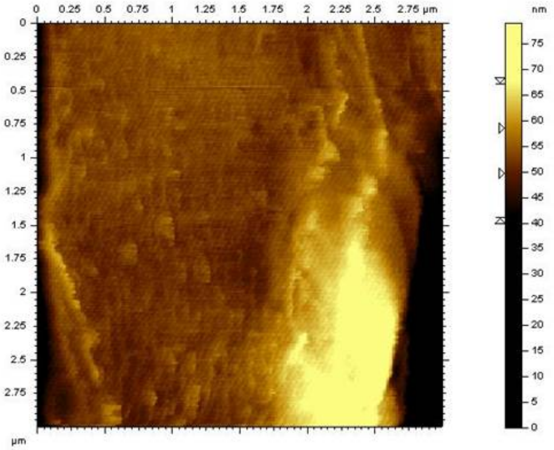


AFM

Cell

SMM

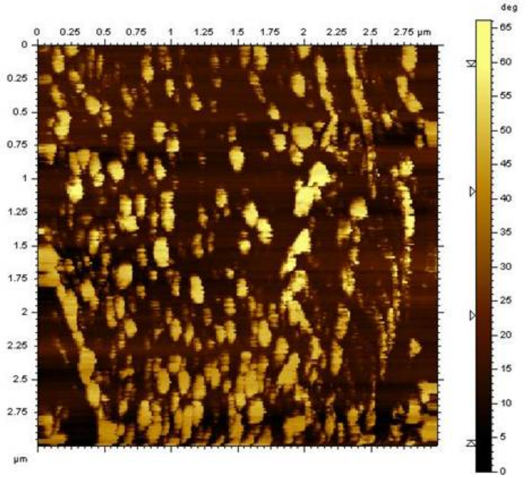




AFM

Virus

SMM



OK, now how do we calibrate this?

•SMM Measurements are currently reflection only. We can do a repetitive “tip up” (open circuit) calibration before every “tip down” measurement

•Capacitance is the major physical property that we are measuring. We are working with NIST (Pavel Kabos) on creating a calibration substrate

•In semiconductors, doping concentration vs depth is an important measurement. We can provide bias to the tip while measuring S11. This allows us to do “dC/dV” measurements as a function of depletion depth. We are working on providing quantified measurements and creating a calibration substrate

•In general, standard SOL cal standards are not applicable to this world. Standards will become application specific

So What about THz?

Courtesy: John Cunningham at U of Leeds

Plan: as part of the Leeds/Agilent project we will weld a conductive tip to the Goubau line and mount the THz chip on our AFM for scanning

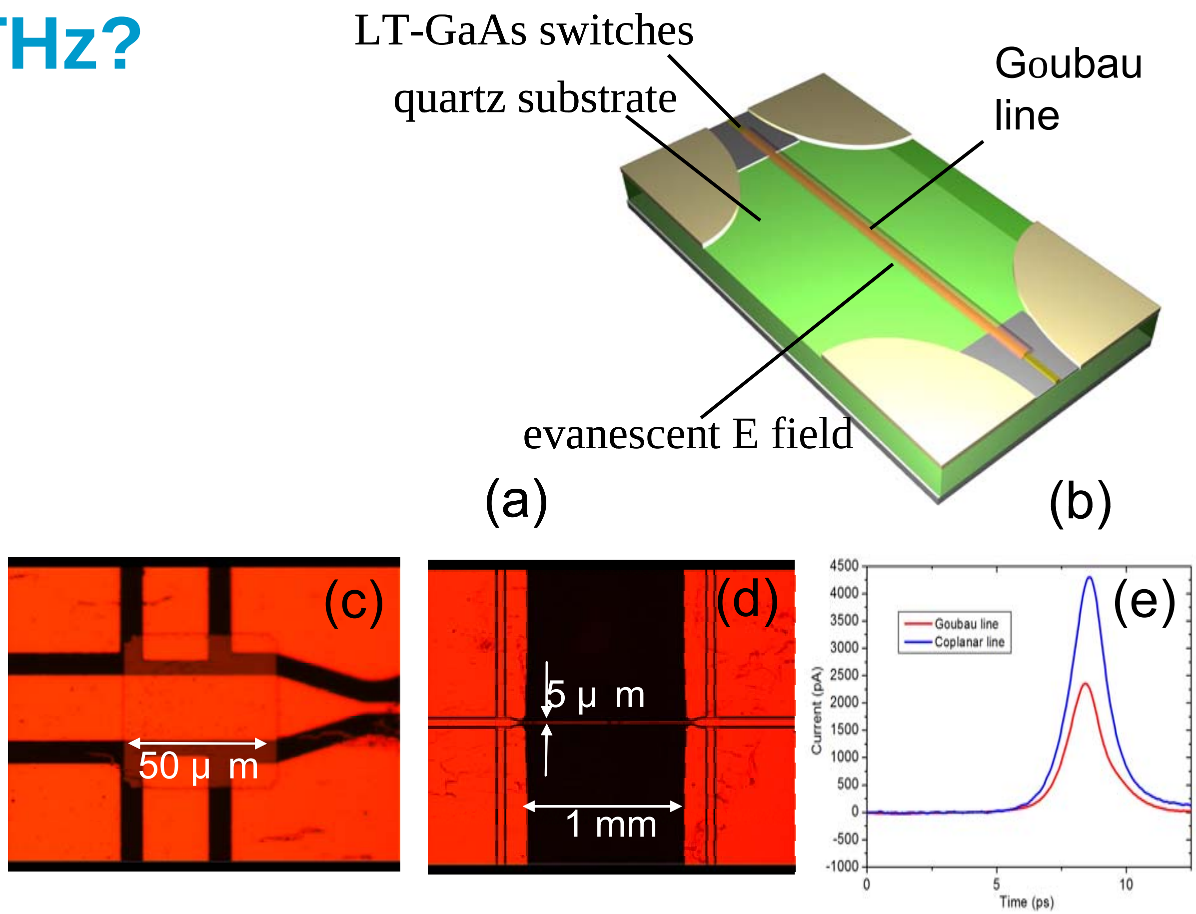


Figure 7 Schematic of the device layout for terahertz (a) coplanar line, and (b) Goubau line, each with integrated THz emitters and detectors. The region of evanescent field is shown in red for both. (c) detail of completed THz switch with coplanar / Goubau-line transition region (d) Goubau line device (e) Experimental data showing similar bandwidth terahertz pulses after propagation down 700 µm-wide coplanar and Goubau lines.

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- Nanoscale devices are typically very high impedance; Network Analyzers are optimized at 50 ohms
- Probing solutions for the nanoscale do not exist but Atomic Force Microscopes (AFM) can provide a platform for approaching this issue
- We need new, application specific calibration standards
- The Arbitrary Impedance Network Analyzer and the Scanning Microwave AFM begin to provide nanoscale solutions
- Near Field Microscopy can also be extended to THz