Testing Simple Capacitors on the PNDS

Rev C

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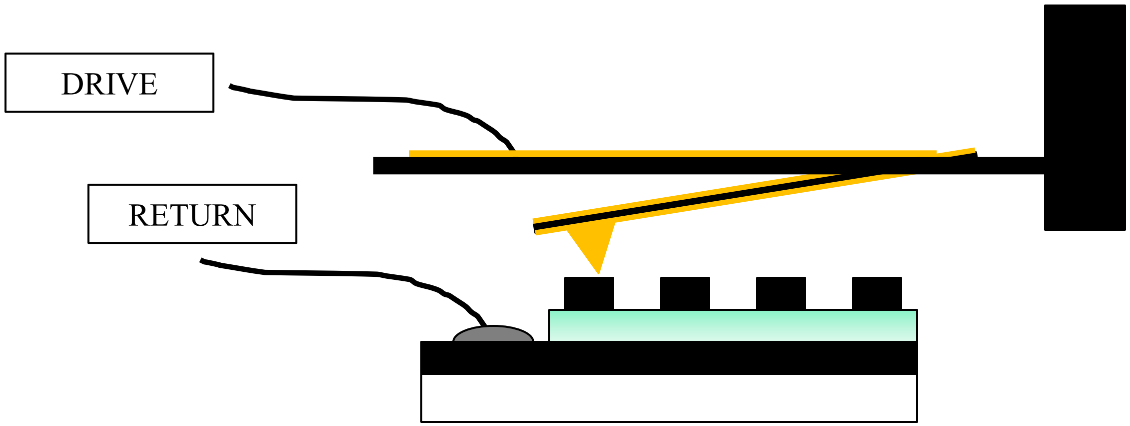
Summary

- Radiant's Precision Nano-Displacement System targets the measurement of piezoelectrically active samples.
- Samples on the PNDS are driven electrically by a Radiant tester independent of the PNDS' AFM operation.
  - Other AFMs can be configured to make the same measurements and the same rules and limitations apply.
- The optimal manner to test a sample is to package it and mount the package in the AFM with wires going to both sides of the capacitor.
- For simple capacitors, Radiant has recommended in the past to use conductive cantilevers to make electrical connection. It is now known that this technique generates errors.
- This application note describes how to create a sample geometry to allow a ***non-conductive AFM cantilever*** to be used on the Radiant PNDS or commercial AFMs to accurately measure simple capacitors without parasitic error.

Conducting Cantilevers

- A simple piezoelectric capacitor has only bottom and top electrodes with no electrical traces, bond pads, or solder pads with which to electrically connect with the capacitor.

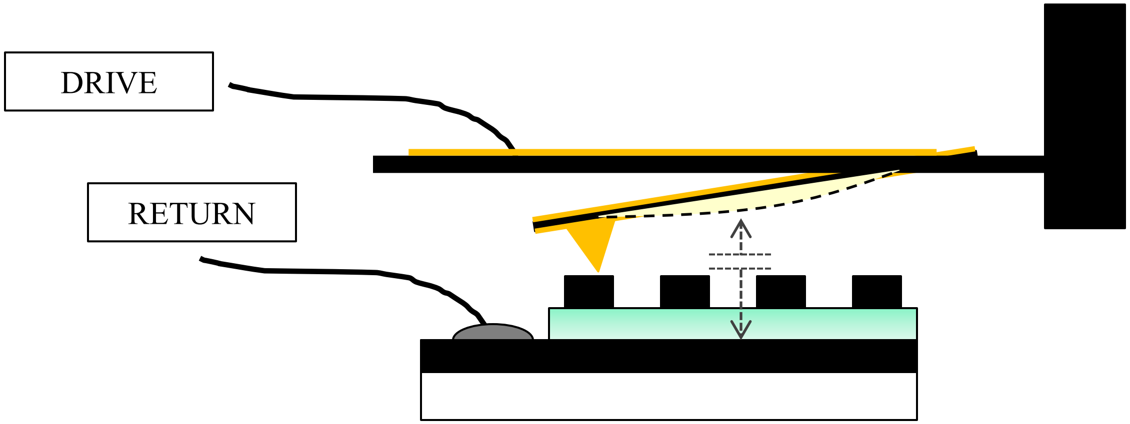
- To make electrical contact with the top electrode of such capacitors, traditional AFM cantilevers are coated with metal. Electrical connection is made to the cantilever through the AFM's cantilever holder.



- Recent research has demonstrated that electromotive forces act on the conductive cantilever to cause the cantilever to bend during electrical actuation of the capacitor through the cantilever, sending a false displacement signal to the AFM.

Bending Force

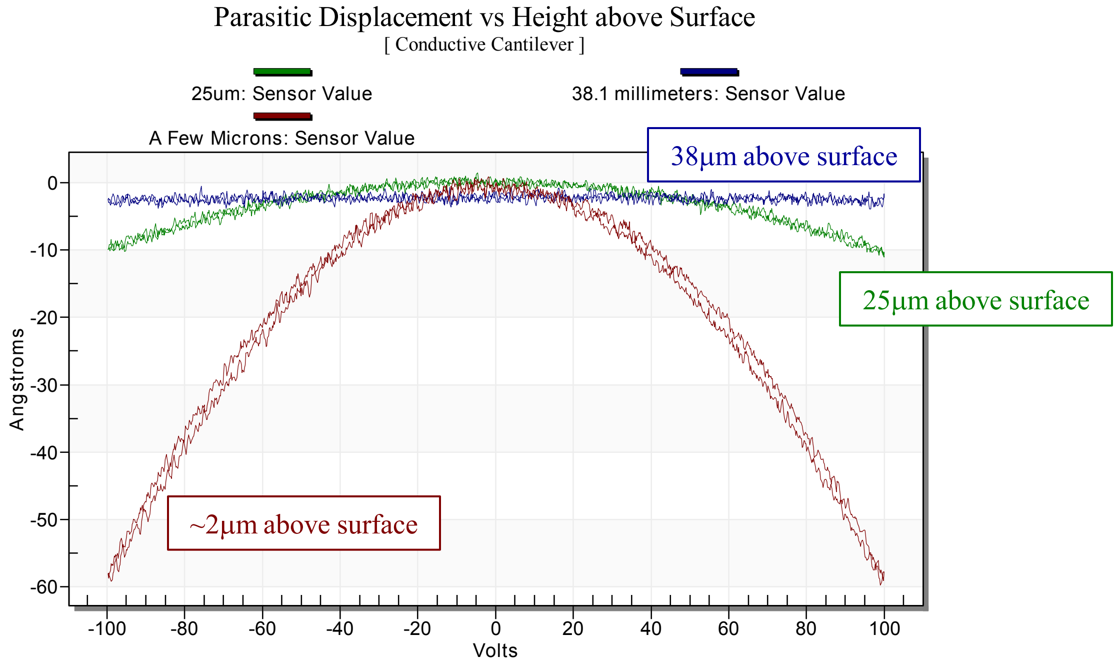
- There are two bending forces acting on the conductive cantilever.
- The first bending force acts between the **charged metal of the cantilever** and the **bottom electrode of the capacitor** coupled by the test voltage.



- Either polarity voltage causes the ***stem*** of the cantilever to bend down which in turn reflects the laser beam higher off the cantilever tip.
- This voltage-enforce bending ***increases*** the apparent vertical piezoelectric displacement of the sample.

Measurements

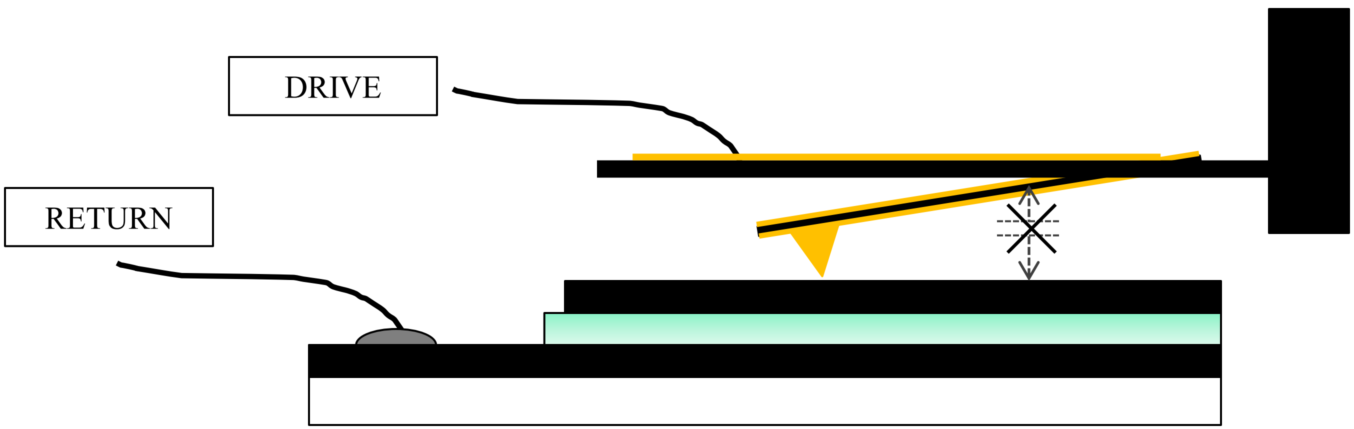
- The simplest way to prove the existence of this attractive force is to hold the cantilever tip ***just above*** the sample surface while executing a test.
- Without the cantilever tip in contact with the surface, the entire cantilever will bend downwards towards the bottom electrode of the sample, indicating a retreating sample surface even though the cantilever tip is not in contact with the sample surface.



Solution to Bending Force#1

- The cantilever will not be attracted to the bottom electrode if it is electrically shielded from that electrode by metal of the same potential.

- Make the top electrode diameter ***twice as wide as the cantilever length***.

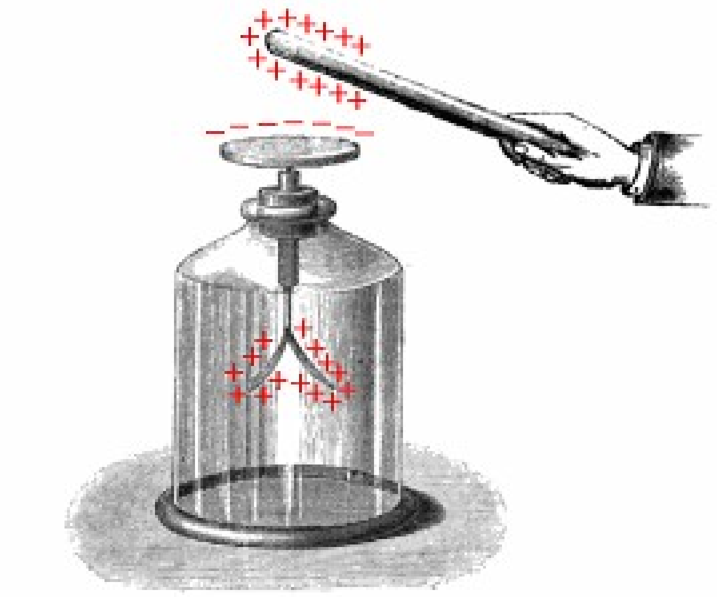


- The top electrode will be at the same electric potential as the cantilever, shielding the conductive cantilever from the attractive force of the bottom electrode.

- *This approach introduces a second error. The piezoelectric force of such large diameter electrodes will bend the substrate during a test, again giving a false displacement reading if the cantilever tip is not exactly centered.*

Self-Repulsion

- The second bending force causing an error arises from an effect used 300 years ago to create the forerunner to present day ferroelectric testers: the ***Electroscope***!



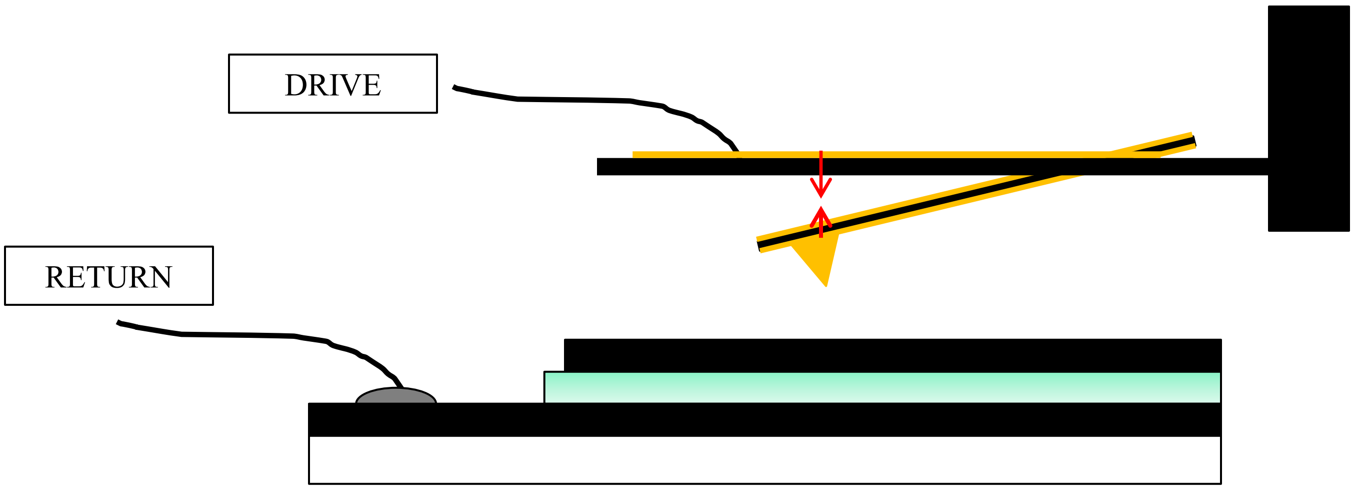
- The electroscope held two thin gold leaves which repelled from each other in proportion to the amount of like charge they held.

- *By Original version: Sylvanus P. Thompson Derived version: Chetvorno - Downloaded from Sylvanus P. Thompson (1881)* ***Elementary Lessons in Electricity and Magnetism****, MacMillan, New York, p.16, fig. 12, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3967378*

Self-Repulsion

- The cantilever and the AFM cantilever holder will always be at the same voltage so they will repel each other just like the two gold leaves in the electroscope.

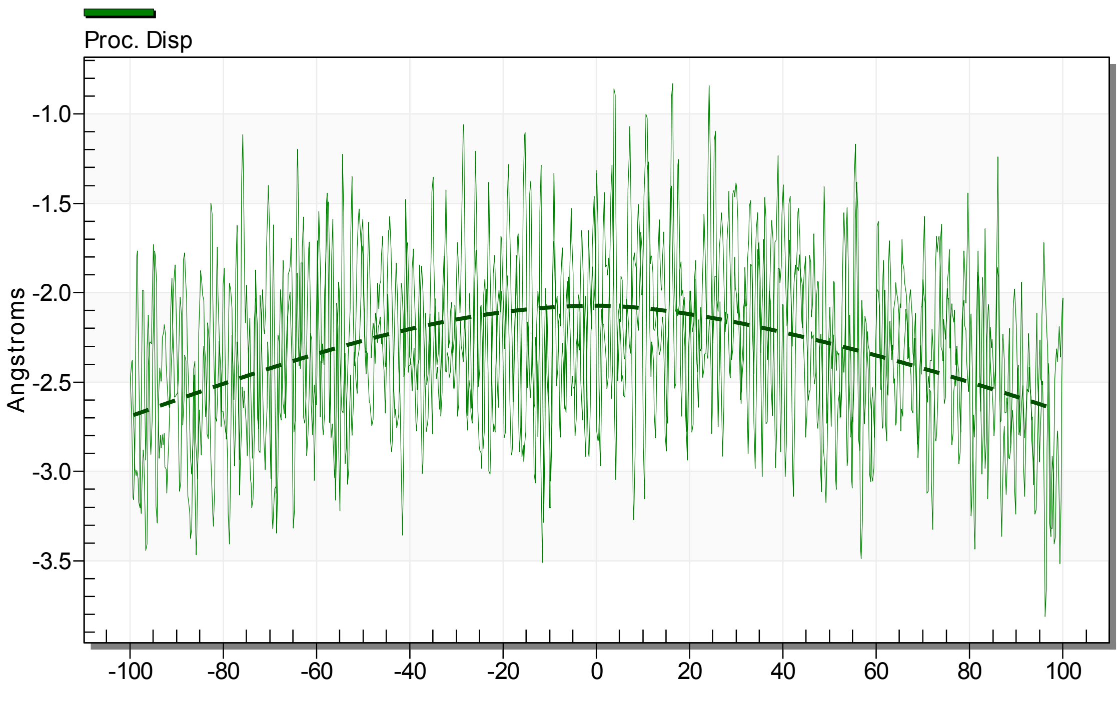
- The repelling force will bend the cantilever downwards giving the false impression of a downward moving sample surface if the tip is suspended or upward motion if the tip is in contact with the surface.



Self-Repulsion

- The effect is small but still in the range of a few Ångstroms so it will dramatically affect measurements of piezoelectric materials with small piezoelectric constants like Aluminum Nitride.

Cantilever Displacement 2.5 Inches Above Sample



Measured on Radiant PNDS at 1kHz 100V.

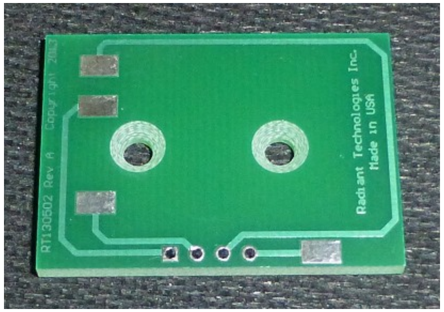
Solution: Non-conductive Cantilever

- The solution to both electromotive bending forces is to use a *non-conductive* AFM cantilever.
- With no metal coating, the cantilever will not respond to local electric fields.
  - Note: An *AFM cantilever fabricated from doped silicon substrates will have some internal conduction so it will respond mildly to local electric fields. If in doubt, use cantilevers specifically fabricated from intrinsic silicon wafers.*
- In order to use a non-conductive AFM cantilever tip, *both electrodes* must be connected to the Radiant tester with wires to DRIVE and RETURN.
- The piezoelectric film must be removed from atop the bottom electrode in order to make electrical connection.
- To prevent error from substrate bending, make the active capacitor area small.

PNDS Blank Sample Board

- The sample board has four solder pads that lead to solder holes from which wires can make connection to the sample.

- The board has a space 8mm x 18mm in the center between the countersunk bolt holes on which to mount samples. Samples may also be mounted along the outer edges of the board.

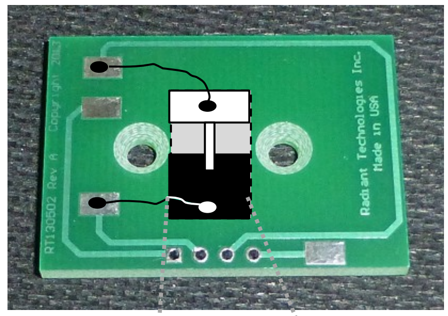


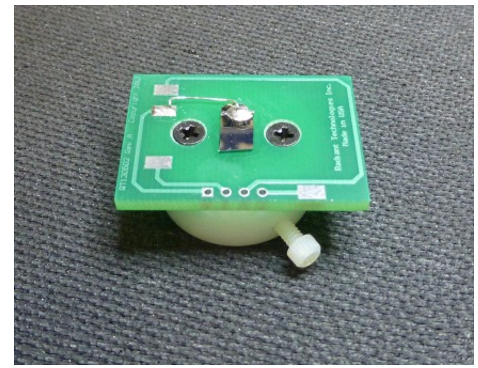
- The pads are arranged to keep one side of the board clear of wires. The AFM cantilever should approach the sample from that direction to prevent entanglement.

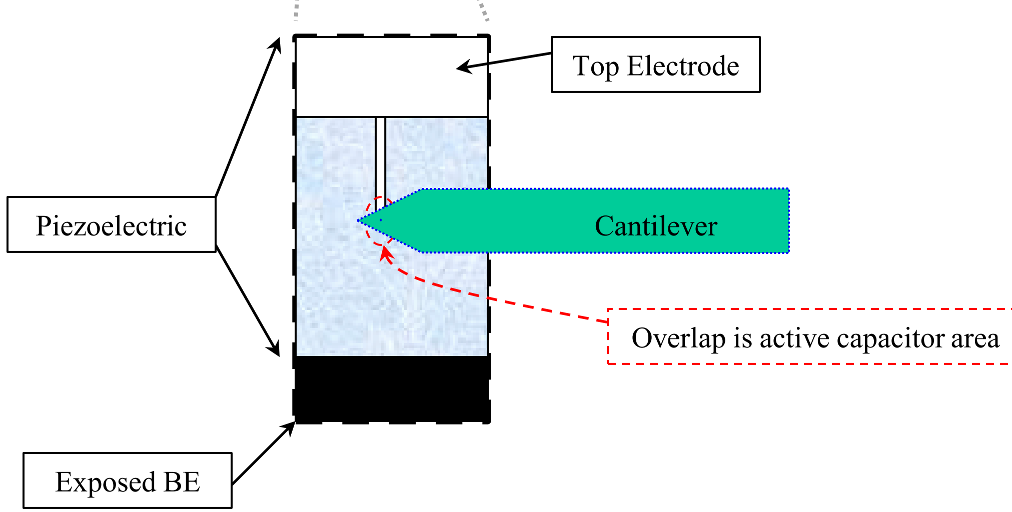
- The center of the board is clear of metal traces so that mounting surface is perfectly flat.

Simple Capacitor on the PNDS

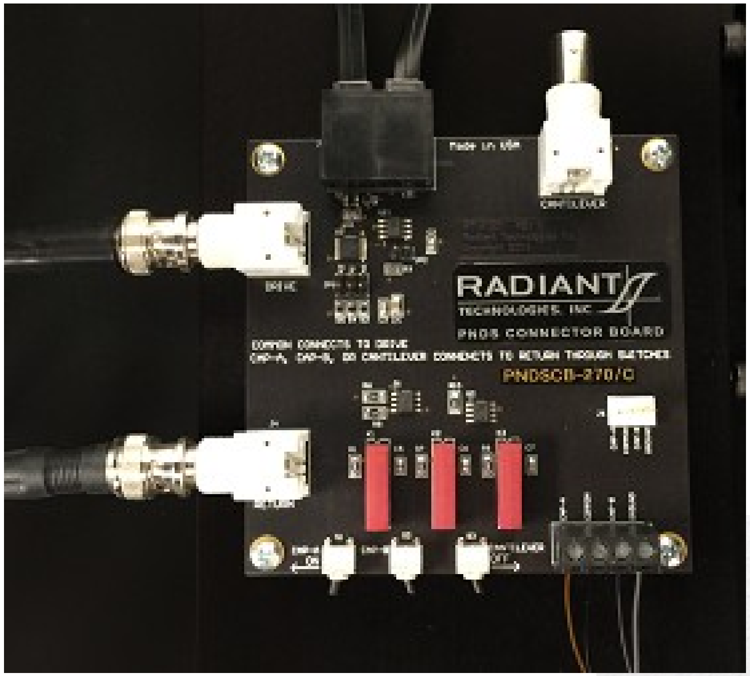
- On Radiant's simple capacitor sample board, the cantilever approaches the sample from the right. This sets the geometry for the sample electrodes.





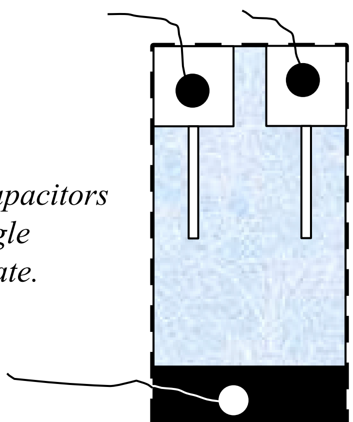


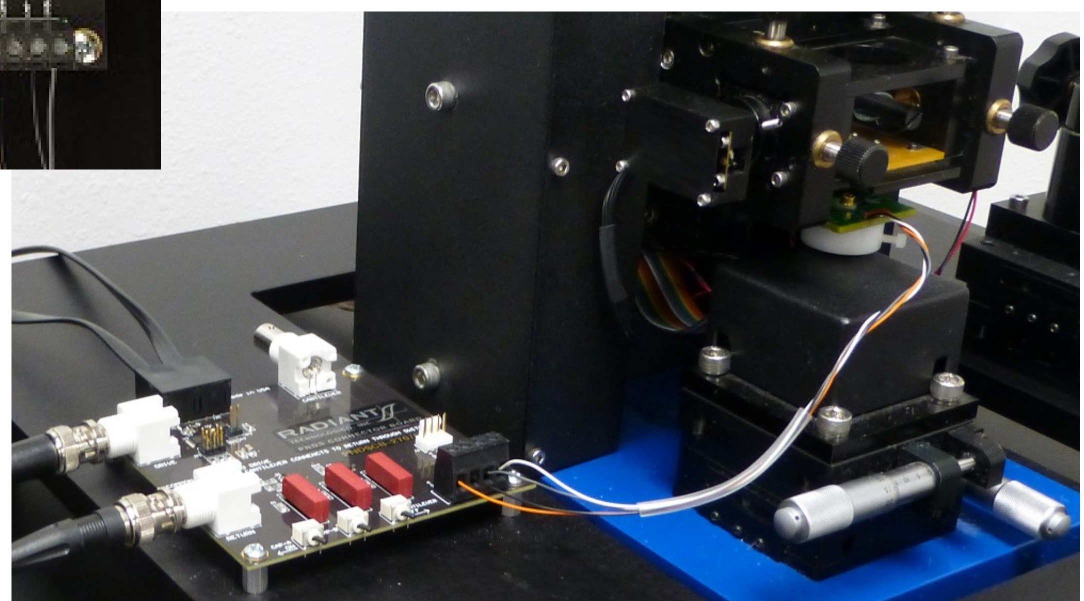
PNDS Sample Selection



The PNDS has a two channel mux to allow selection of two separate samples on the same substrate on the chuck. The PNDS Sample Selection Board is controlled automatically by Vision but can be operated manually using toggle switches.

Two capacitors on single substrate.





Conclusion

- Accurately measuring the piezoelectric displacement of simple capacitors fabricated with thin piezoelectric films requires a very specific sample geometry to prevent error.
- Parasitic cantilever displacements driven by local electromotive forces exceed an Ångstrom under the best circumstances but can be far larger.
- Parasitic errors are eliminated by using *non-conductive* AFM cantilevers. Electrical connection is not made to the top electrode using the cantilever.
- The sample design must allow both the bottom and the top electrodes to be connected to the tester by wire.
- The PNDS is equipped to control such samples. Its Sample Selection Board allows two independent capacitors to be tested on a single substrate.