Innovating Test Technologies

Optimizing IV Measurement Systems for Speed and Accuracy

October 8, 2004
Terry Burcham
Terry_Burcham@cmirco.com

Outline

- Principles of guarding & shielding
- Elements of on-wafer IV measurement systems
- Temperature test issues & remedies
- Impacts of residual capacitance on IV accuracy & speed

Typical DC/CV Parametric Test System

- 4156C Parameter Analyzer
  - 1fA Resolution
- 4284A LCR Meter
  - 20Hz – 1MHz CV
- B2200A Switching Matrix
  - 1fA Leakage
- S300 Prober

3

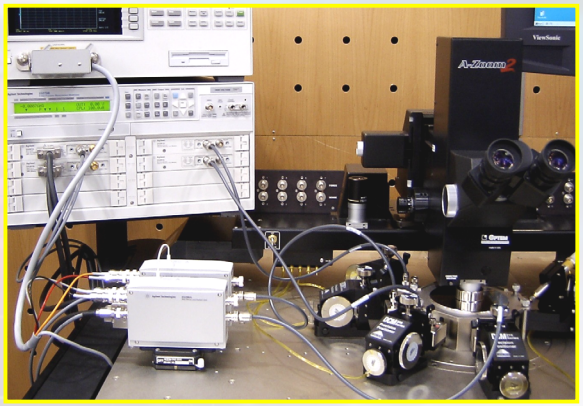
Parameter Analyzers

- 4156C
  - 4 SMUs
  - 1fA
  - I/CV Lite

- 4157A
  - E5270A
    - 8 SMUs
    - 10fA
  - I/CV Lite

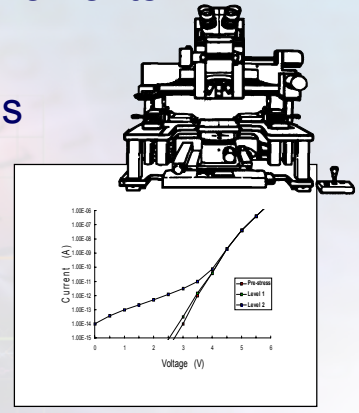
New E5288A Atto-Sense Unit

- Switch between CV and IV via SW - no hardware changes
- 100 aA resolution with ASU



Prober Measurement Issues

- Limited current measurement floor
- Extremely slow measurements
- Dielectric absorption
- High probe noise levels
- High substrate noise
- Residual capacitance
- Thermal chuck noise



6

Prober Measurement Limitations

- All issues can be traced to lack of guarding techniques
  - cables
  - probes
  - probe cards
  - thermal chucks

- System noise and residual capacitance
- Material choices - dielectric absorption

7

Guarding

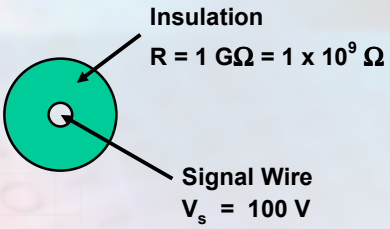
Guarding

- Definition: A conductor connected to a low impedance point in the circuit that is at nearly the same potential as the high impedance lead being guarded.
- Layman's definition: A conductive material at nearly the same electrical potential (voltage) (V_g) as the signal (V_s) that you are trying to measure.
- Concept is to surround (as much as practical) the signal that you are trying to measure with a guard.

Guarding Example

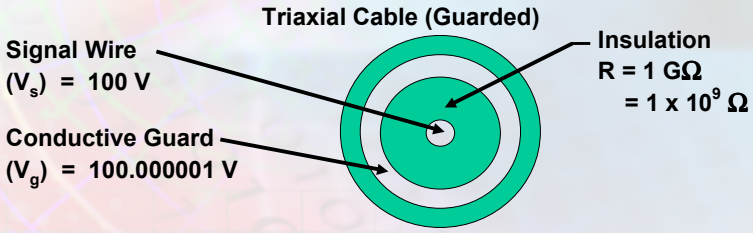
Regular Coax Wire

(Non-Guarded)



$$\text{Leakage Current} = \frac{100\ \text{V}}{1 \times 10^{9}\ \Omega} = 1 \times 10^{-7}\ \text{A} = 0.1\ \mu\text{A} = 100\ \text{nA}$$

Guarding Example



$$\text{Leakage Current} = \frac{\Delta V}{R} = \frac{(100.000001\ \text{V} - 100\ \text{V})}{1\ \text{G}\Omega} = \frac{1 \times 10^{-6}\ \text{V}}{1 \times 10^{9}\ \Omega}$$

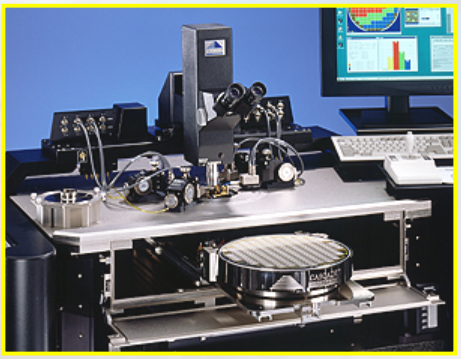
$$= 1 \times 10^{-15}\ \text{A} = 1\ \text{fA}$$

Leakage current reduced by a factor of 100,000,000 !!!

MicroChamber Shield Enclosure

Metal "Faraday Cage" enclosure

- Isolate 50/60 Hz sources
- Shielding to eliminate electromagnetic / electrostatic interference
- Light Tight



MicroChamber

MicroChamber

Electrostatic Interference

- Occurs when an electrically charged object comes near an uncharged object.
- Not a problem for low resistance materials because charge dissipates quickly.
- Unstable measurements can occur for high resistance materials because charge does not decay quickly.
- DC or AC electrostatic fields can cause problems.
- DC field can be caused by movement of a person nearby.
- AC fields caused most often by power lines and RF fields.

Shielding (Enclosures and Cables)

- Enclose the measurement area with conductive material (metal box, meshed screen) and measurement cables with a metal shield or braid.
- Electrically connect shielding enclosure and cable shields to the test instrument common (shield) and/or to earth ground.
- Use as large a distance as practical from the shielding enclosure to the test circuit (to reduce capacitance and vibration effects).
- For light shielding, eliminate light leaks through gaps around doors and hinges, tubing and cable entry points, connectors and connector panels, and seams/joints between panels.
- Fill seams/gaps/joints with conductive caulking or gaskets.

Shielding Summary

- Keep all charged objects (including people) and conductors away from the measurement area.
- Use highly conductive materials instead of insulating materials near the test circuit.
- Avoid movement and vibration near the measurement area (air currents can cause movement &/or vibration).
- When measuring currents < 1 pA, shield the measurement area with a conductive (metal) enclosure and connect the enclosure to the test instrument common (shield) and/or to earth ground.
- Minimize the capacitance between the shielding enclosure and the test circuit.

Shielding vs. Guarding

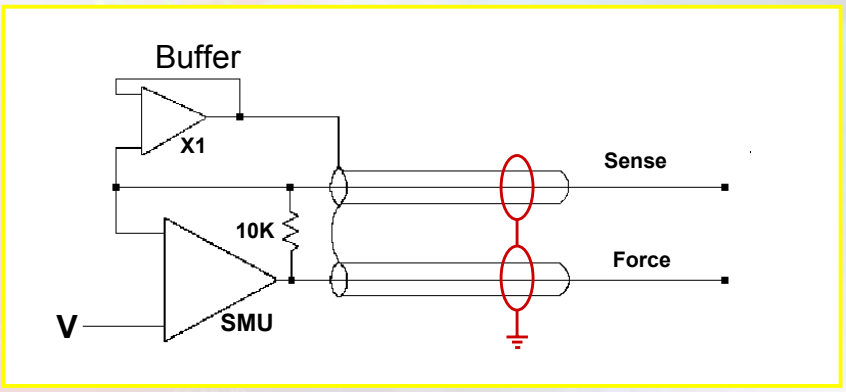
- Shielding used to prevent electrostatic interference from affecting the measurement.
- Guarding used to intercept any interfering voltage or current.
- A shield does not act as a guard.
- A guard does not necessarily provide good shielding.
- The more completely a guard and/or shield surrounds, the better the performance.
- Use both guarding and shielding for measurements < 1pA.

Parameter Analyzer Connection

Agilent E5270A

Agilent 4156C

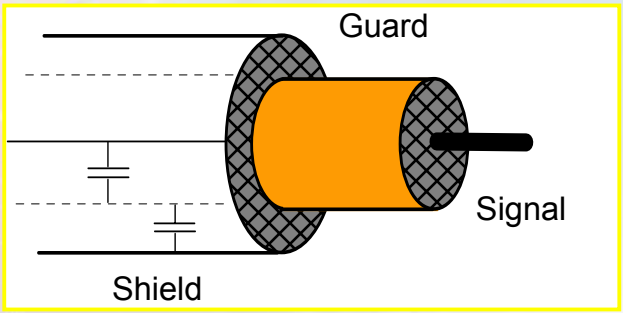
Typical Agilent SMU



Using Guard in a Triaxial System

Use the same path for DC and CV

- Guard eliminates cable capacitance
- Not all triax cables are low noise



Triaxial Low Leakage Cable

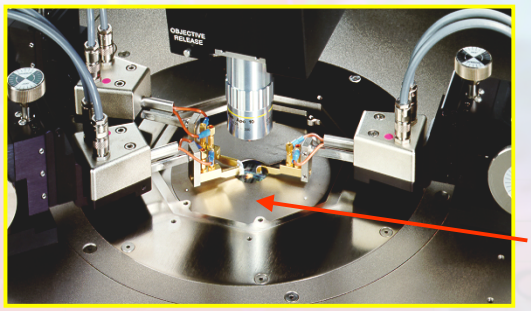
Making the Triaxial Connection

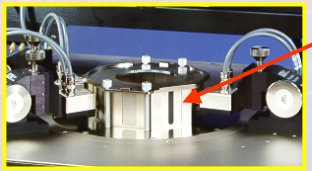
Probe and Chuck Connections

- Instrument ready triax, quadrax & dual triax compatible mating panels

- No loss of guard or shield integrity

S300-861 AttoGuard™



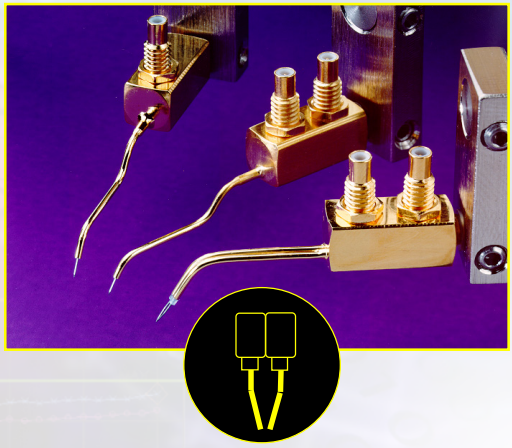


- AttoGuard shields chuck from probes
- Top hat seals out light & EMI/RFI

Low-Noise Guarded Coax Probes

Guarded Coax

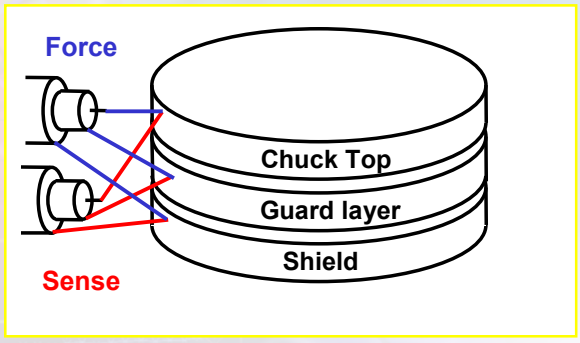
- Probe body at Guard potential to the tip
- 50 fF residual capacitance
- Replaceable tips



Chuck Guarding

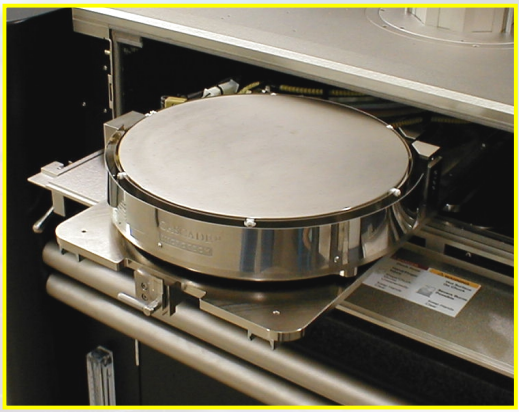
True Kelvin Chuck Guarding

Driven guard layer stops leakage from chuck to the outside environment.



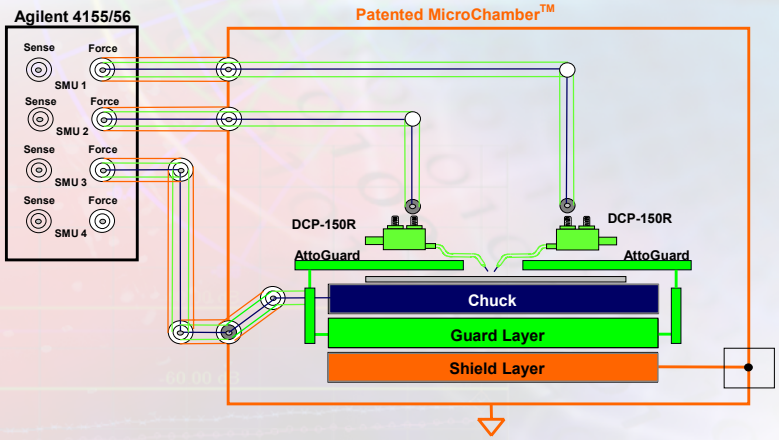
Guarded Thermal Chuck

- True kelvin measurement node
- -65°C to +300°C
- No vacuum rings
  - Holes zoned to handle shards
- Roll out stage for safe wafer handling

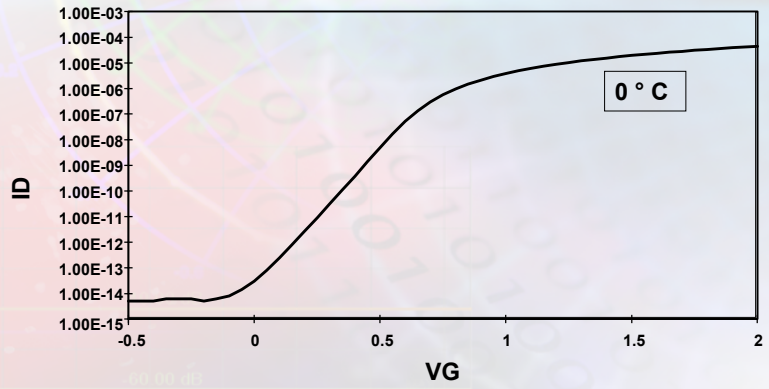


Total Measurement Environment

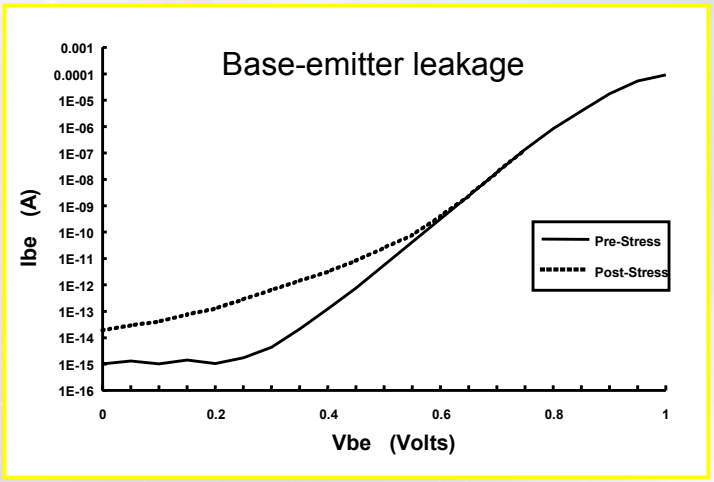
Complete triaxial system



Low-Noise Measurements at Temperature



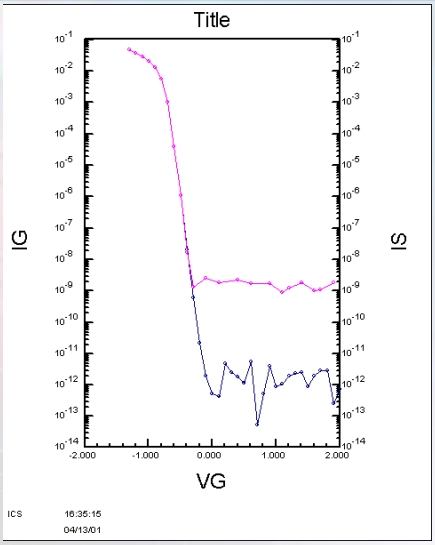
Bipolar Transistor WLR Measurement



26

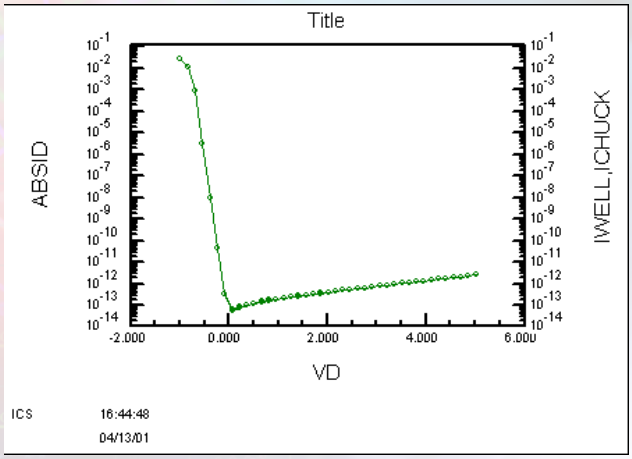
Diode Test on a Floating Chuck

CONDITIONS:	
ID:	G
UNIT:	SMU1
MODE:	SWEEP
START:	-1.3
STOP:	2
PNTS:	34
STEP:	0.1
ID:	S
UNIT:	SMU2
MODE:	CONST
VALUE:	0



Diode Test on a Guarded Chuck

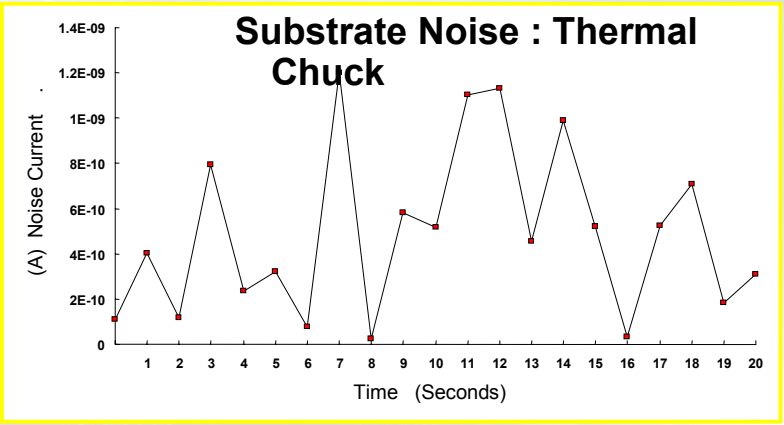
CONDITIONS:	
ID:	D
UNIT:	SMU1
MODE:	SWEEP
START:	5
STOP:	-1
PNTS:	41
STEP:	-0.15
ID:	S
UNIT:	SMU3
MODE:	CONST
VALUE:	0
ID:	B
UNIT:	SMU2
MODE:	CONST
VALUE:	0



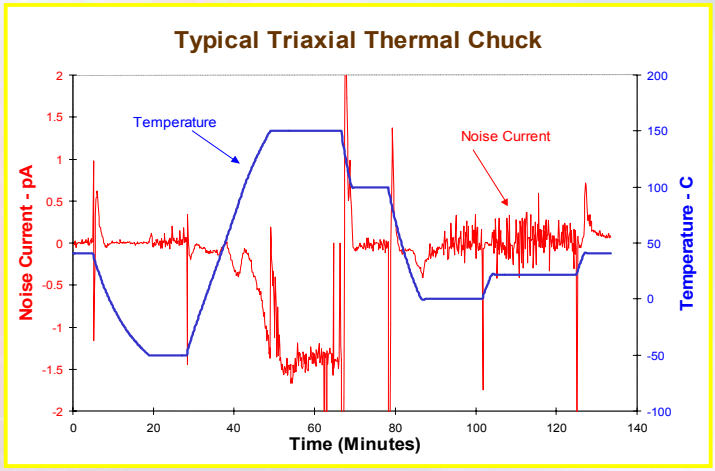
Wafer At Temperature Issues

- High electrical noise
- High capacitance
- Unreliable service loop
- Frost and purge issues

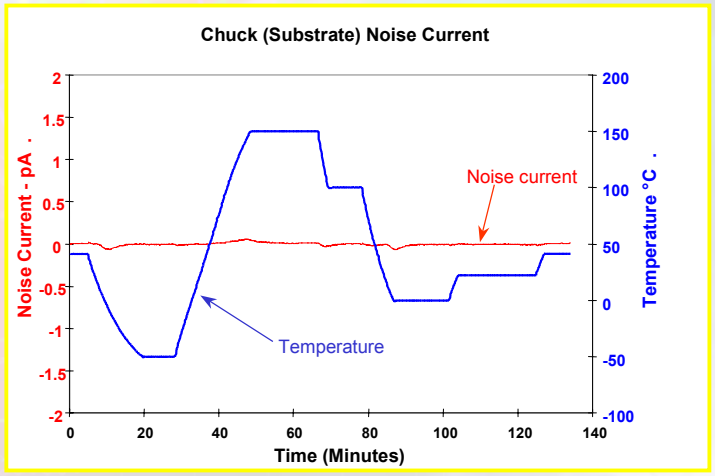
Un-Guarded Thermal Chuck



High Isolation Thermal Wafer Chuck

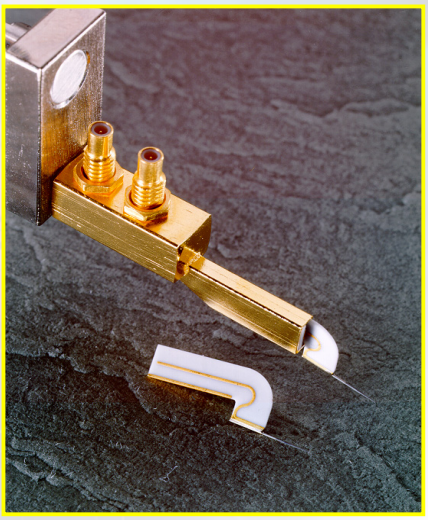


CMI Improved Thermal Chuck

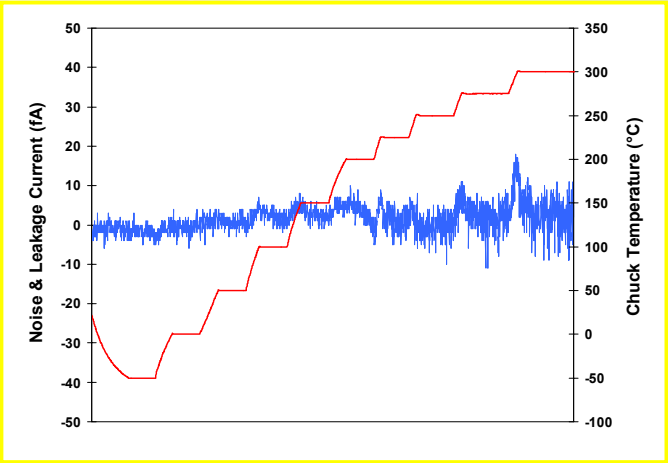


Low-Noise Ceramic Probe

- 300°C Wafer Temp
- Controlled Noise
- 100 fF Capacitance
- Replaceable blade

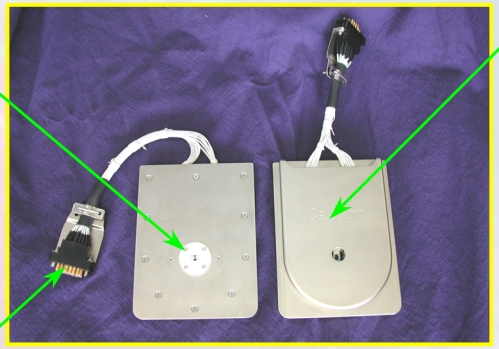


Low-Noise Probe at Temperature



Low-Leakage Probe Card System

48 Guarded ceramic needle probes



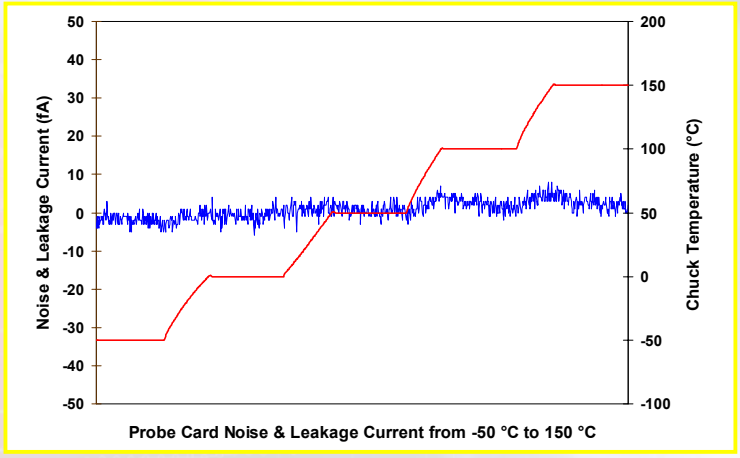
Metal shielded enclosure

2 each 24 Pin guarded coax to triax connectors

Attofast™ Probe Card

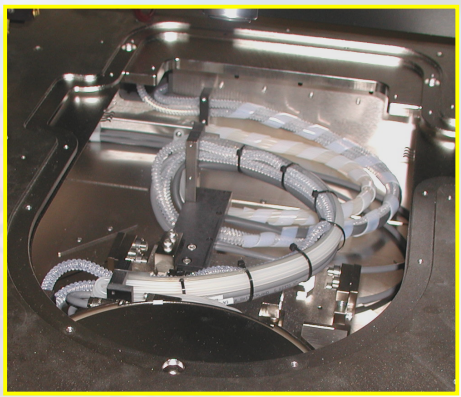
-65°C to +300 °C

Probe Card Noise at Temperature



Low-Noise Chuck Service Loop

- Low noise current
- Low tribo-electric effect
- Low-dielectric absorption
- Fast recovery
  - Settling in milliseconds after a move
- Dual input for true Kelvin measurements



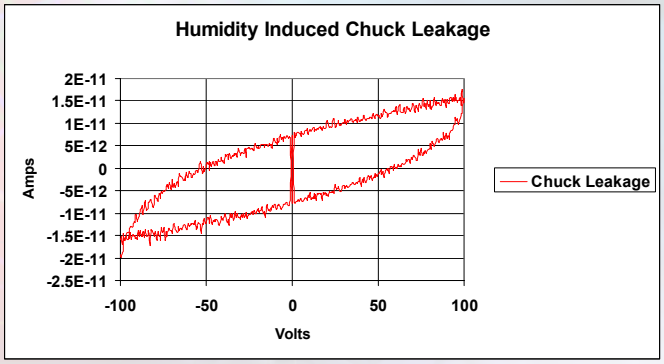
Dewpoint - Frost Issues

- Quick Purge MicroChamber
  - <15 minutes
  - 2 scfm
- Flow Rate
  - 0.5 scfm
- Dewpoint
  - <0.3% RH
- CDA or Nitrogen

MicroChamber

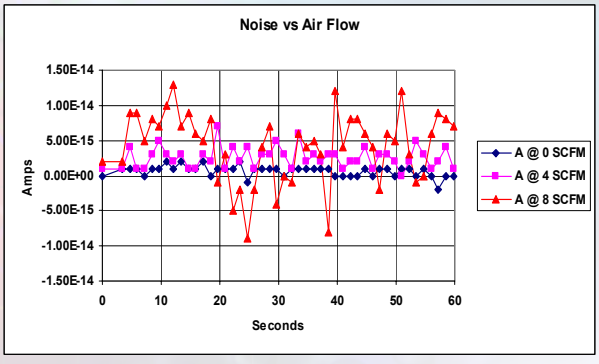
Moisture Degrades Measurements

- Effects of moisture
  - Dielectric soakage
  - High residual capacitance
  - High leakage
  - High noise
- Leakage test on the 4156 Prober Evaluation disk
- Bake out chuck @ 200°C for 24 Hrs



Air Flow Impacts Noise

- MicroChamber requires only 0.5 scfm CDA for frost-free tests to -55°C
- Nitrogen is better than CDA



Capacitance Impacts Test Time

- Most modern probers can achieve femtoAmp current levels
- Smaller Residual Capacitance is always better
  - Reduces capacitive error current

$$i = C\,dV/dt + V\,dC/dt$$

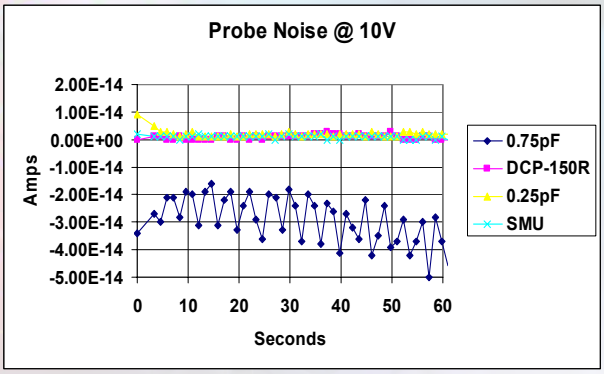
  - proportional to test time

$$T_{new} = T_{ref}\,C_{new}/C_{ref}$$

    - True for cables, probes, probe cards, chucks & switching matrixes

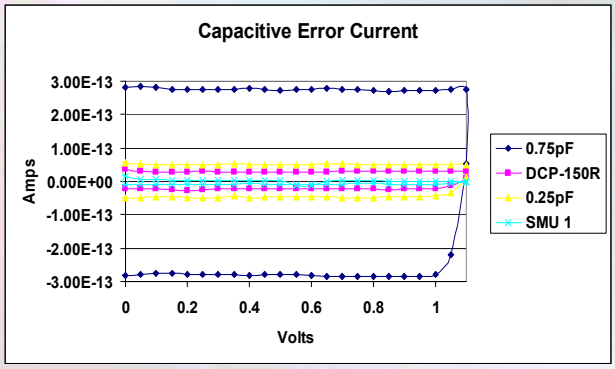
Capacitance Effects Probe Noise

- High residual capacitance degrades system "zero"
  - Offset current
  - Threshold shift
- Noise test on the 4156 Prober Evaluation disk



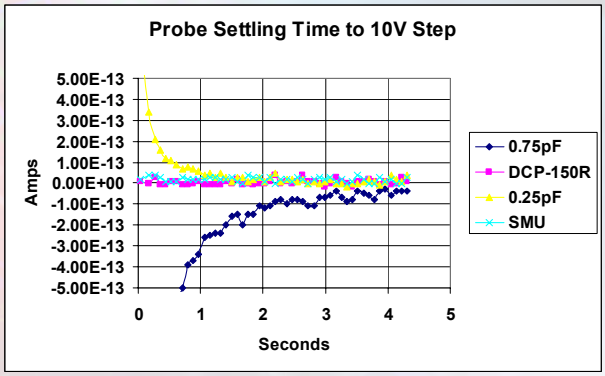
Residual Capacitance – Error Current

- Errors in threshold shifting measurements
- Avoid by longer Integration time
  - >> Longer test time
- IV-Error test on 4156 Prober Evaluation disk

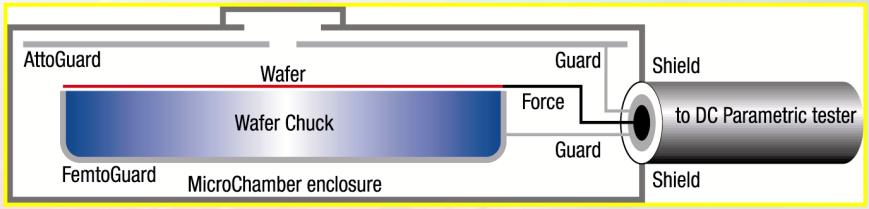


Capacitance - Probe Settling Time

- Avoid by longer Holdoff time
- Settling test on 4156 Prober Evaluation disk

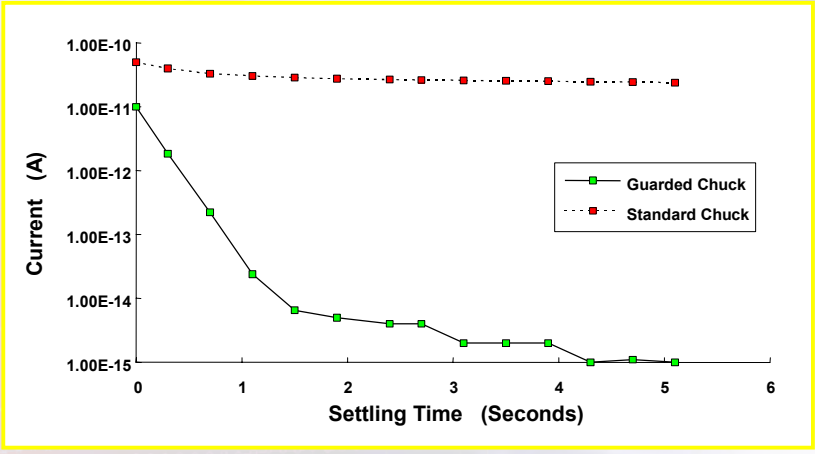


Enhanced Guarding for IV Measurement Speed & Accuracy



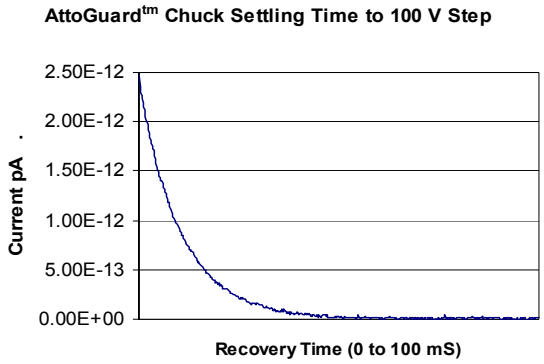
- FemtoGuard surrounds the chuck with guard potential
- Patented AttoGuard above the chuck with guard potential
  - Thermal Chuck noise < 20 fA
  - Residual Capacitance < 1 pF
- Reduces probe noise < 1 fA

Guarding Effects Chuck Settling



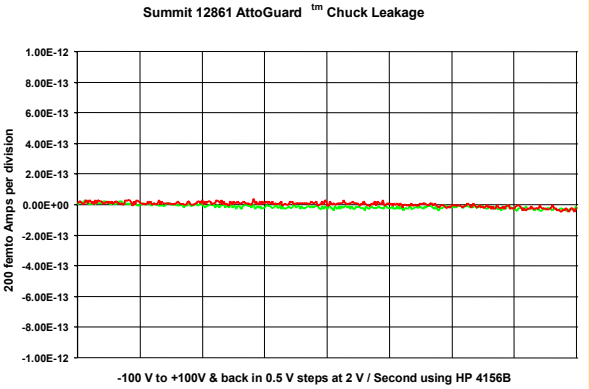
<1 pF Thermal Chuck Residual Capacitance

- Recover to 50 fA in < 50 milliseconds from 100 V step
- 50 X faster chuck measurement speed
- Residual Capacitance & Settling test on the 4156 Prober Evaluation disk



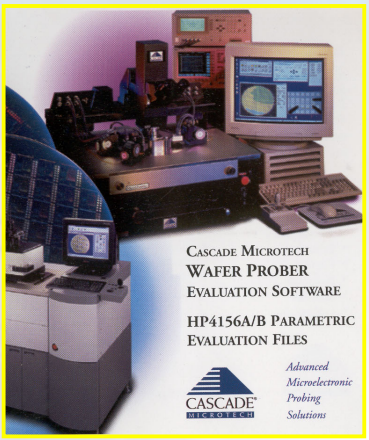
Ultra low Wafer Backside Capacitance

- <1 pF residual capacitance
- 3 fF Δ capacitance
- <20 fA noise
- Low dielectric absorption
- Ideal for low current, threshold shift measurements
- Leakage & residual capacitance test on the 4156 Prober Evaluation disk



Probing System Evaluation SW

- Contains 4156 Setup Files – Ready to Load
- Evaluation Measurements
  - Noise
  - Residual capacitance
  - Leakage
  - Settling time
  - IV-Error
- Word and Text Documents



Summary

- Full guarding and shielding are required to get to femtoAmp measurement level
  - Shielding is not guarding
- Use an effective metal shield enclosure
- Fully exploit the SMU guard
  - Probe, chuck & cables
- Use low-noise triax cable
- Residual capacitance is proportional to test time and accuracy