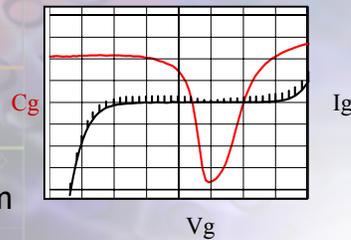




Innovating Test  
Technologies

# Optimizing On-wafer CV Measurements Using Agilent 4284A and 4294A

February, 2004  
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## Outline

- General equipment for on-wafer CV
- MOS CV measurement basics
  - Thin oxide impact
  - Configuring the test for success
- Implementing a total high frequency CV measurement system
  - 4294A test procedure
- A 4284A – 4294A correlation study
- Conclusions



## Agilent 4284A & 4294A



### 4284A LCR Meter

- CV to 1 MHz
- Simple calibration
- Works with E5250A Switch Matrix



### 4294A Impedance Analyzer

- CV to 110 MHz
- Advanced calibration
- New Impedance Probe



## S300 System - General

- Semi-Automatic / Manual 300mm
- Small Footprint
- Easy to install & setup
- DC and RF probing
- WLR and FA tools





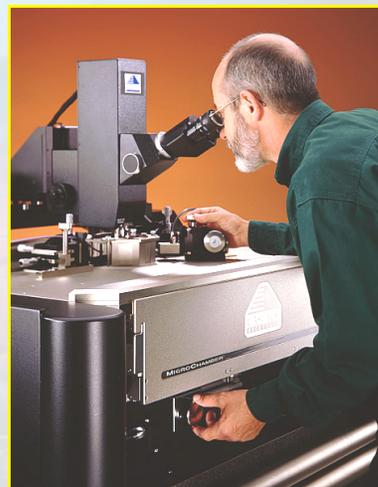
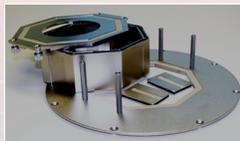
## S300 System - MicroChamber

- Dark, Dry, EMI/RFI shielded
- Supports  $-55$  to  $300^{\circ}$  C
- Air cooled platen (HT systems)
- Safety interlocks – Motion, High Voltage
- Easy wafer loading with MicroChamber front access



## S300 System - MicroChamber

- Full access to all controls
  - XY stage & Z/Theta
  - Probes - positioners
  - Microscope
- Optional High EM-Shield for noise measurements



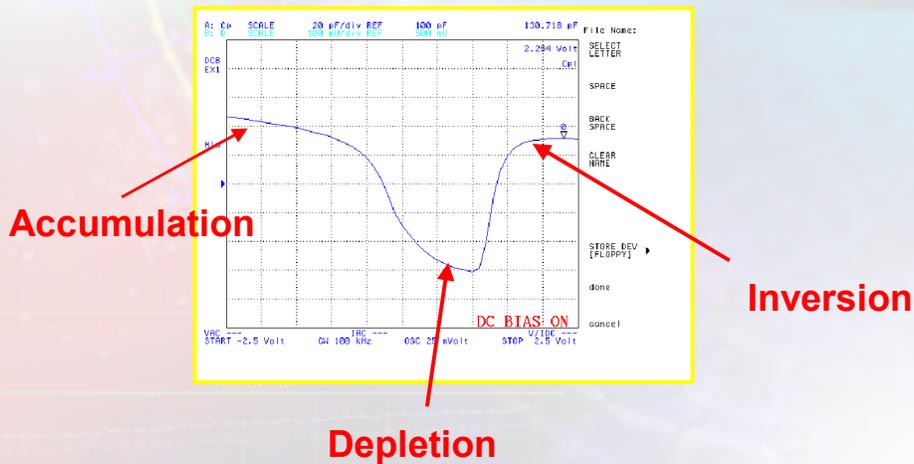


## S300 System - Chuck

- Roll-out wafer chuck
- New Thermal / non-thermal service loop
- Integrated AUX chucks (2)
  - Fixed  $\varnothing$ : no need to re-align
  - Thermally isolated
- Kelvin low noise triax to chuck
- Easy Multi Zone vacuum
  - (0.5, 6, 8, 12" )



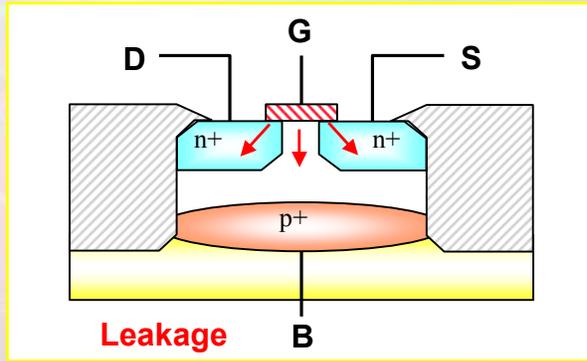
## Classic CV Measurement



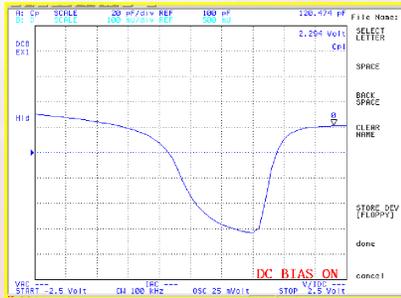


## Challenges of CV on thin oxides

- Higher leakage
- Higher frequency measurement
- Smaller capacitances

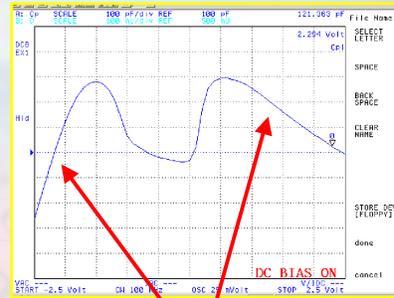


## Why High Frequency CV?



Low leakage

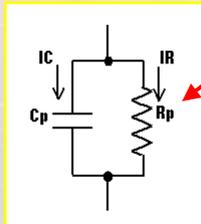
$$I_C \gg I_R$$



High leakage

$$I_C \ll I_R$$

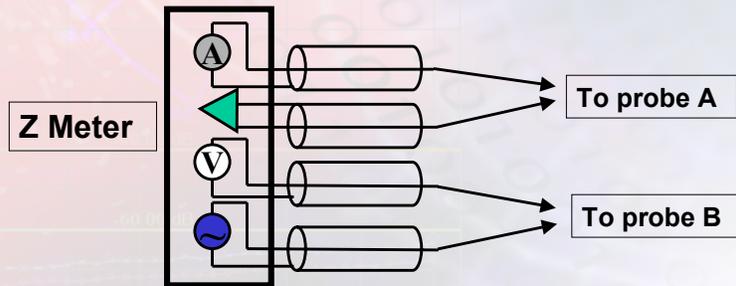
- $I_C$  proportional to frequency





## Why Four Terminal Pair - 4TP?

- Reduces effects of cable inductance
- Stimulus and Sense are separate
- Connect at or very near the DUT

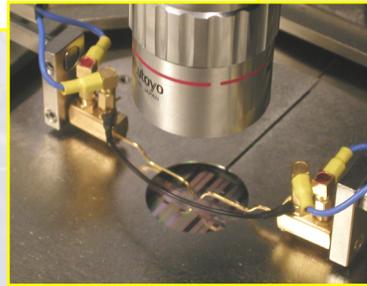
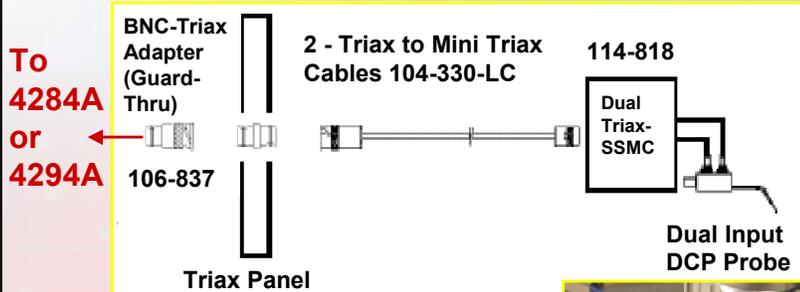


## CV Connection Methods

Method	Description	Advantage	Disadvantage
Four Terminal Pair – <b>4TP triaxial</b> system	Two probe – terminal pairs connected at dual input DCP probe  One topside probe using chuck for back connection	Convenience - dual use for DC & CV  Connect direct to wafer substrate if topside connection unavailable	Frequency limited about 20 MHz  Frequency limited to about 5 MHz
Four Terminal Pair – <b>4TP Coaxial BNC – SSMC</b>	Two probe – terminal pairs connected at dual input DCP probe	Flexibility for non ground-signal device layout	Frequency limited $\cong$ 50 MHz Cannot run DC Tests
<b>Impedance Probe - 42941</b>	Single probe for grounded device – G-S Layout	Best Performance to 110 MHz	Not applicable for DC tests G-S Layout

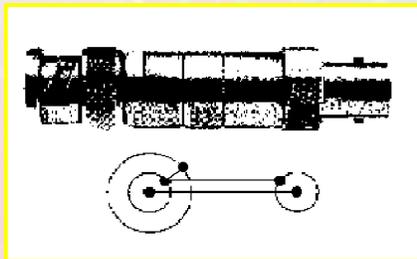


## Coaxial-triaxial 4TP Method



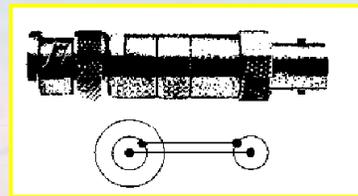
## Coax to Triax Adapters

4284A  
 $\leq 1$  MHz



Guard-Shield Short  
PN 104-341

4294A  
 $>1$  MHz to 110 MHz



Guard Thru Shield Open  
PN 106-837

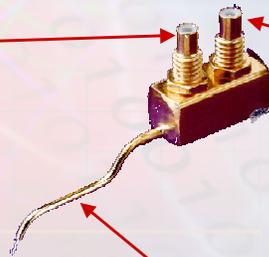


## Dual Input DCP Probe

Designed for 4TP – Shield to tip

High Current  
or Low  
Current

High Pot or  
Low Pot



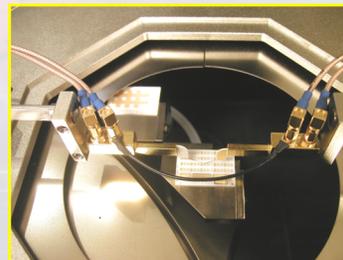
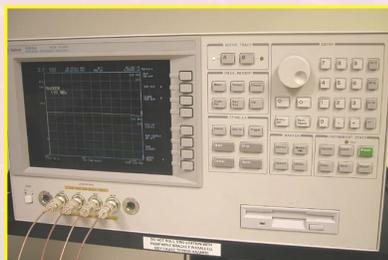
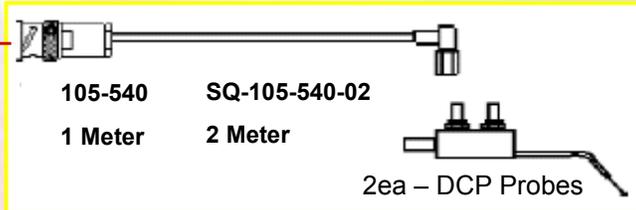
Probe Body and  
arm - Shield - to  
the tip



## Coaxial 4TP

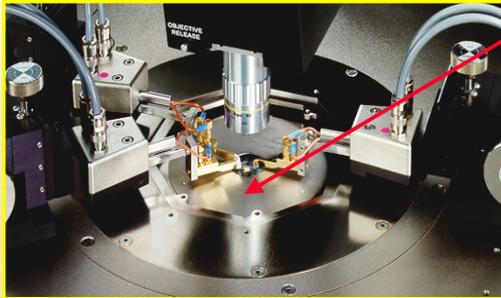
To  
**4284A**  
or  
**4294A**

4 ea - BNC-to-SSMC Coaxial Cables





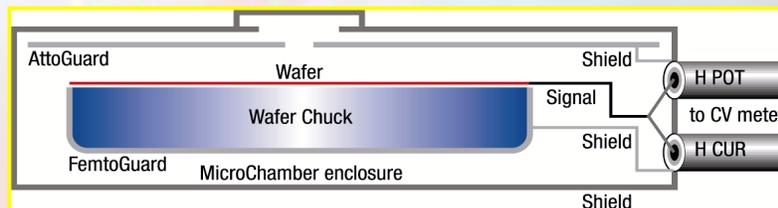
## AttoGuard Technology



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



## AttoGuard Enhanced CV Measurements

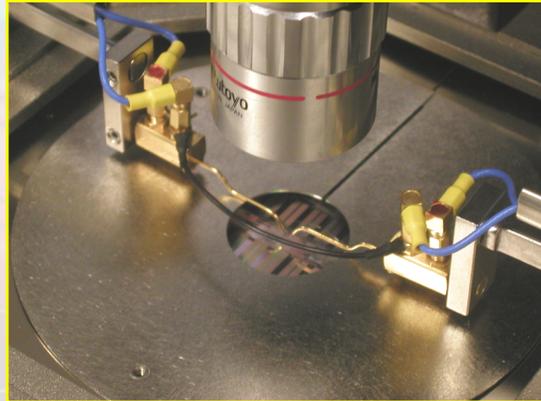


- FemtoGuard surrounds the chuck at shield ground
- Patented AttoGuard above the chuck at shield ground
- Creates a virtual double-shielded Faraday enclosure
  - 10 atto Farad CV measurement resolution
  - Zero CV meter only one time



## AttoGuard Shield

- Reduces residual capacitance
- No need to compensate for position related capacitance variation

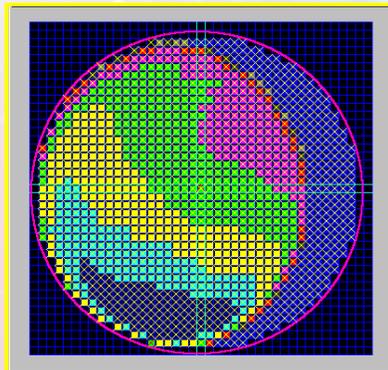


Capacitance Variation  $< 2$  fF



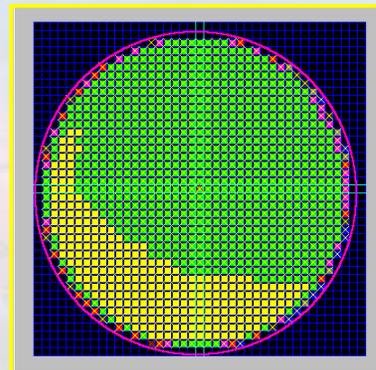
## Location Dependent Chuck Capacitance Variation

**Without AttoGuard**



Capacitance Variation  $> 30$  fF

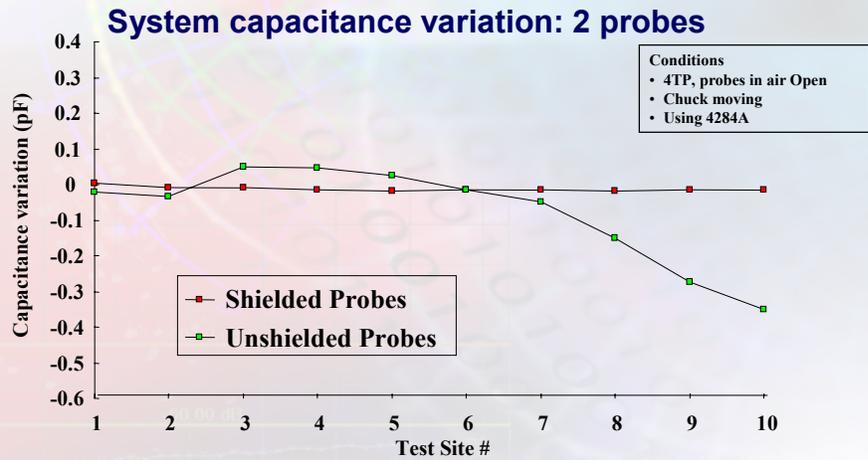
**With AttoGuard**



2 fF Variation



## Capacitance Variation



## Implementing Total HF CV Solution



300 mm System with Agilent 4294A



## New 110 MHz CV Instrument

- CV to 110 MHz
- Improved architecture
- 50  $\Omega$  Output Z
- Advanced calibration
- New Impedance Probe

**Agilent 4294A  
40 Hz to 110 MHz  
Precision Impedance Analyzer**

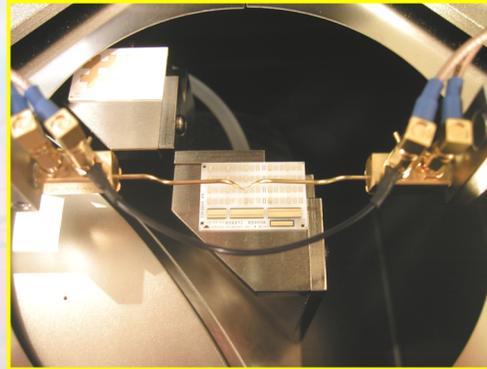
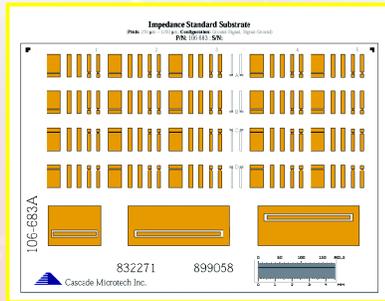


## Recommended CV Accessories

<i>CMI Part</i>	<i>#</i>	<i>Description</i>	<i>Use</i>
<b>DCP-150</b>	$\geq 2$	Dual input 4TP Probe	4TP coaxial configuration
<b>105-540</b>	4	1 meter bnc-ssmc cable	1 meter 4 TP configuration
<b>SQ-105-540-02</b>	4	2 meter bnc-ssmc cable	2 meter 4 TP configuration
<b>123-625</b>	$\geq 1$	DCP to DCP Strap	4 TP coax or triax configuration
<b>106-837</b>	4	BNC-Triax Adapter, guard-thru, shield removed	4 TP triax configuration – for 4294A use above 1 MHz
<b>104-341</b>	4	BNC-Triax Adapter, Guard-Shield short	4 TP triax configuration – for 4294A use $\leq 1$ MHz or for 4284 use
<b>SQ-127-911-01</b>	1	RF positioner mount for the 42941 Impedance Probe	Mount for one probe when using the 42941 Impedance Probe
<b>106-683</b>	1	G-S SOL Impedance Standard with ref caps	For 4294A calibration and system verification
<b>I40-A-GS-XXX</b>	1	Infinity Probe	Ground-Signal Probe for 42941 use
<b>SQ-127-742-01</b>	$\geq 1$	BNC-triax adapter force-guard short	Use on chuck when substrate is biased



## SOL Calibration for 4294 HF CV



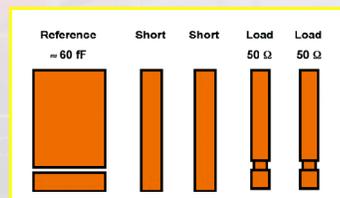
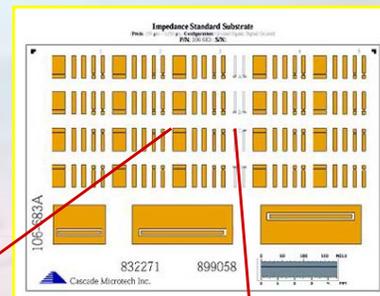
Impedance Standards  
PN 106-683

Thermally Isolated Auxiliary Chucks



## Impedance Standard Substrate

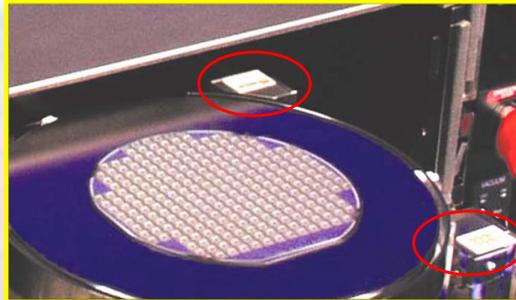
- Calibration to the probe tip
- Short-Open-Load Calibration Standards
- Multiple Sets
- 50  $\Omega$  Loads trimmed to 0.3%
- 50 to 1250 micron pitches





## Auxiliary Chucks for ISS

- Thermally isolated from thermal chuck
- Calibration to the probe tip
- Minimized drift in calibration standard values
- Repeatable calibrations

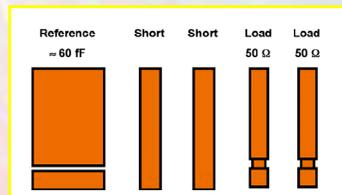


Auxiliary Chucks

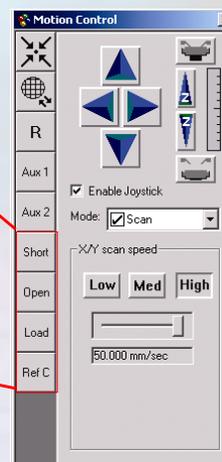


## Fast Calibration & Verification

- One click move to Short-Open-Load Cal element locations



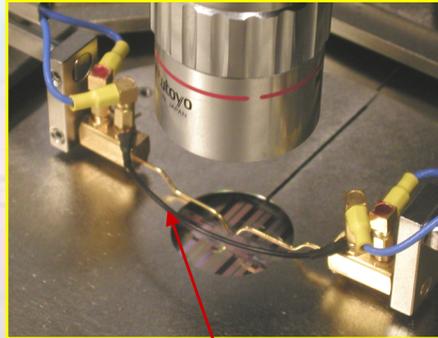
- Reference capacitors for system verification





## Ground Strap for HF CV >5 MHz

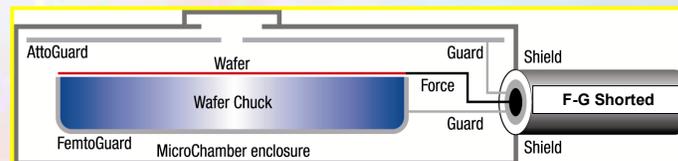
- 4294 cannot be grounded to the prober
  - All CV  $\geq$  5MHz
- Strap minimizes the ground return path



DCP – DCP Ground Strap  
PN 123-625

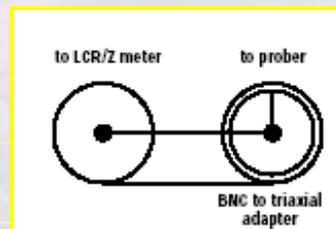


## Chuck Shorted – Top Side Capacitance



### Guard shield above wafer

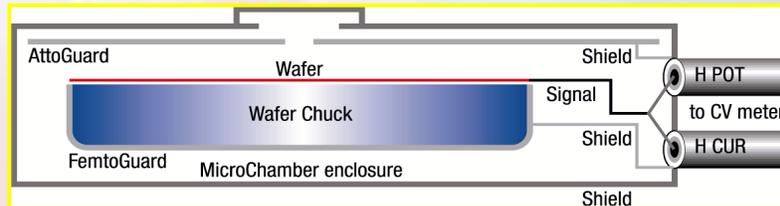
- Reduces probe field disturbances by wafer chuck
- Reduces capacitance variation
- Use Force-Guard shorting plug on wafer chuck



PN SQ-127-742-01



## Top Side to Backside Measurements

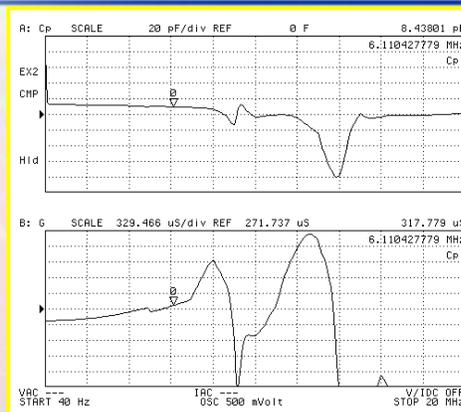


### 4284A & 4294A

- High Potential & High Current on chuck terminal
- Low Potential & Low Current on topside probe



## Top Side to Backside Measurements



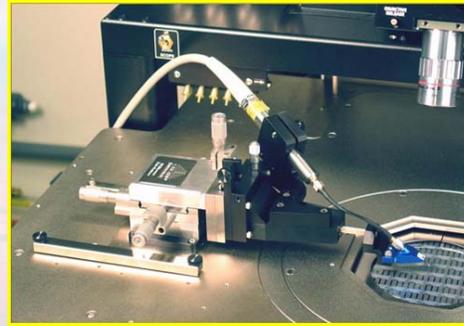
- 4294A measurements reliable to 5MHz with Open, Short calibration



## Impedance Probe Method >50MHz



Agilent 42491A Connects  
to 4 terminals of the  
4294A analyzer



Cascade positioner mount and  
cable – SQ-127-911-01



## Infinity RF Probe

- Designed for low and stable contact resistance on aluminum
- Requires fixed pitch Ground-Signal top side contacts
- Recommend probe for the Agilent 42941

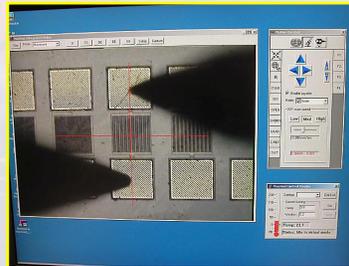


Infinity RF Probe



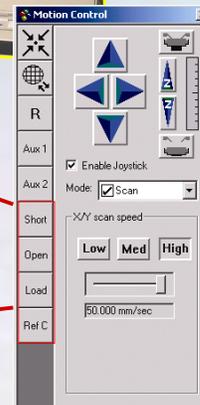
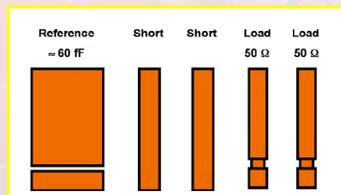
## 4294A CV Step Procedure

1. Assemble the test system
2. Adjust the probes to fit the DUT pads
  - Must remain the same for proper calibration



## 4294A CV Step Procedure

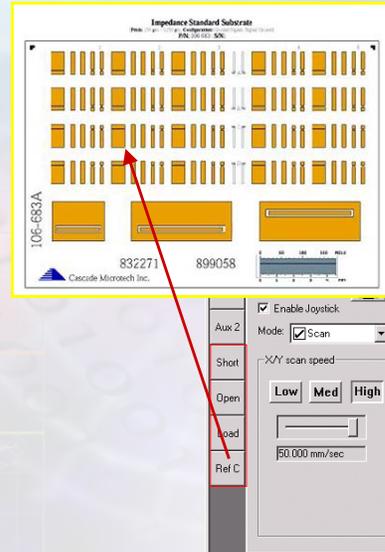
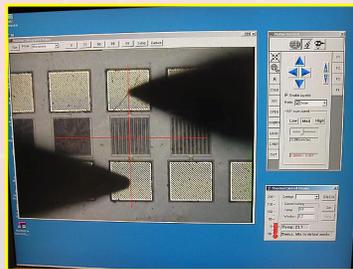
3. Perform 4294A phase compensation
4. Perform 4294A S-O-L calibration





## 4294A CV Step Procedure

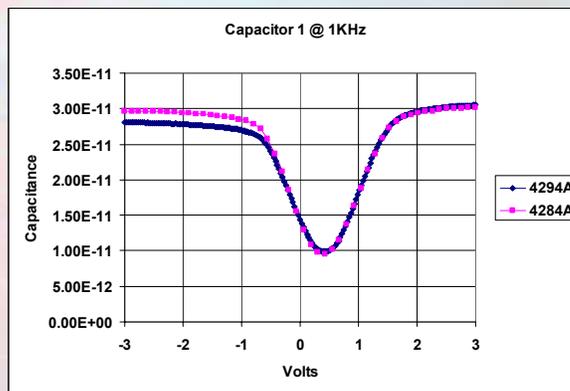
5. Measure ISS reference capacitors for system verification
6. Move back to DUT and measure



## 4284A – 4294A Correlation Study

### Test Conditions

- Top to backside measurement
- $T_{OX} = 60\text{\AA}$
- $C_P - D$
- 1 KHz
- 90% correlation

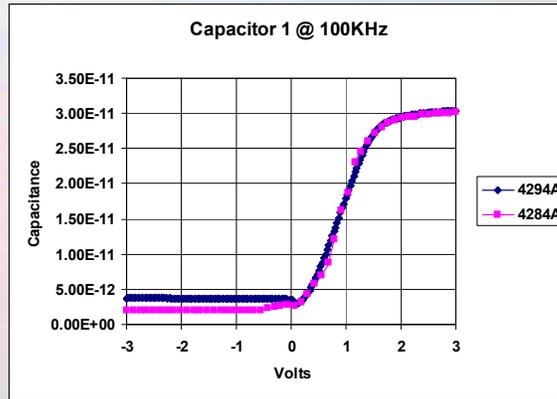




## 4284A – 4294A Correlation Study

### Test Conditions

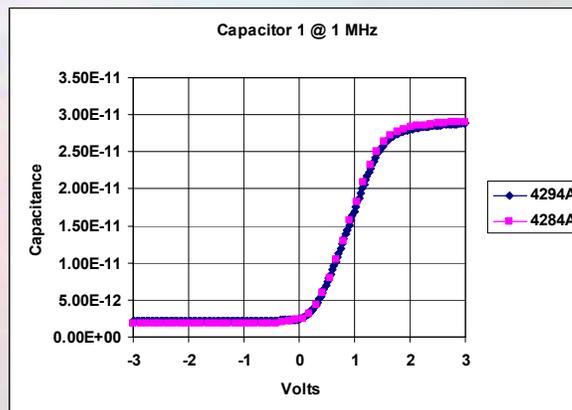
- 100KHz
- 90% correlation



## 4284A – 4294A Correlation Study

### Test Conditions

- 1MHz
- 98% correlation





## Application Support

- **Agilent**
  - Impedance Measurement Handbook
    - 3<sup>RD</sup> Edition – December 2003
  - Evaluation of MOS Capacitor Oxide C-V Characteristics Using the 4294A.
    - Product Note 4294-3
- **Cascade Microtech**
  - Configuring a Precision System for On-wafer Capacitance
    - Application Note CVMOS-APP-0103



## Conclusions

- Thin oxides are driving CV to higher frequencies
- New methods and accessories are now required
- Cascade can complete the Agilent solution

