SWTEST ASIA

PROBE TODAY, FOR TOMORROW

Novel True-Kelvin MEMS Analytical DC Probes to enable Accurate and Repeatable Characterization of Advanced-Node devices for AI applications

FormFactor™

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FormFactor

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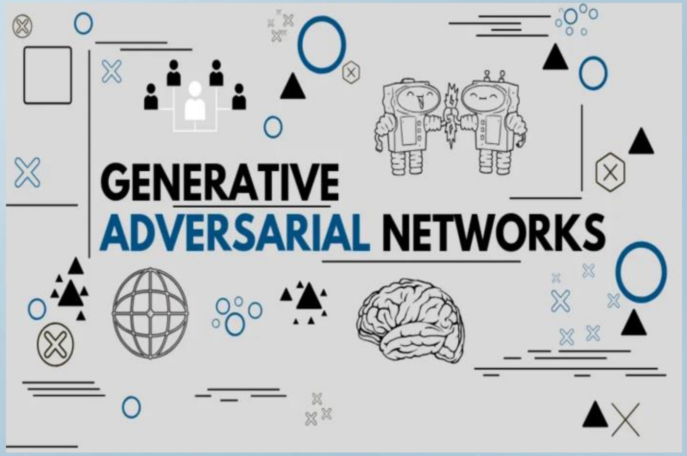
Outline

- Generative AI Applications
- Foundation Pillar in the Rise of AI - Semiconductor Technologies
- Accurate Wafer Tests with True-Kelvin MEMS Probes
- Conclusion
- Acknowledgement

Generative AI Applications

ChatGPT
(LLM for Human-Like Interaction)



GAN
(Gen Data for Model Training)

Precision Agriculture
(Yield, Pest & Disease Management)

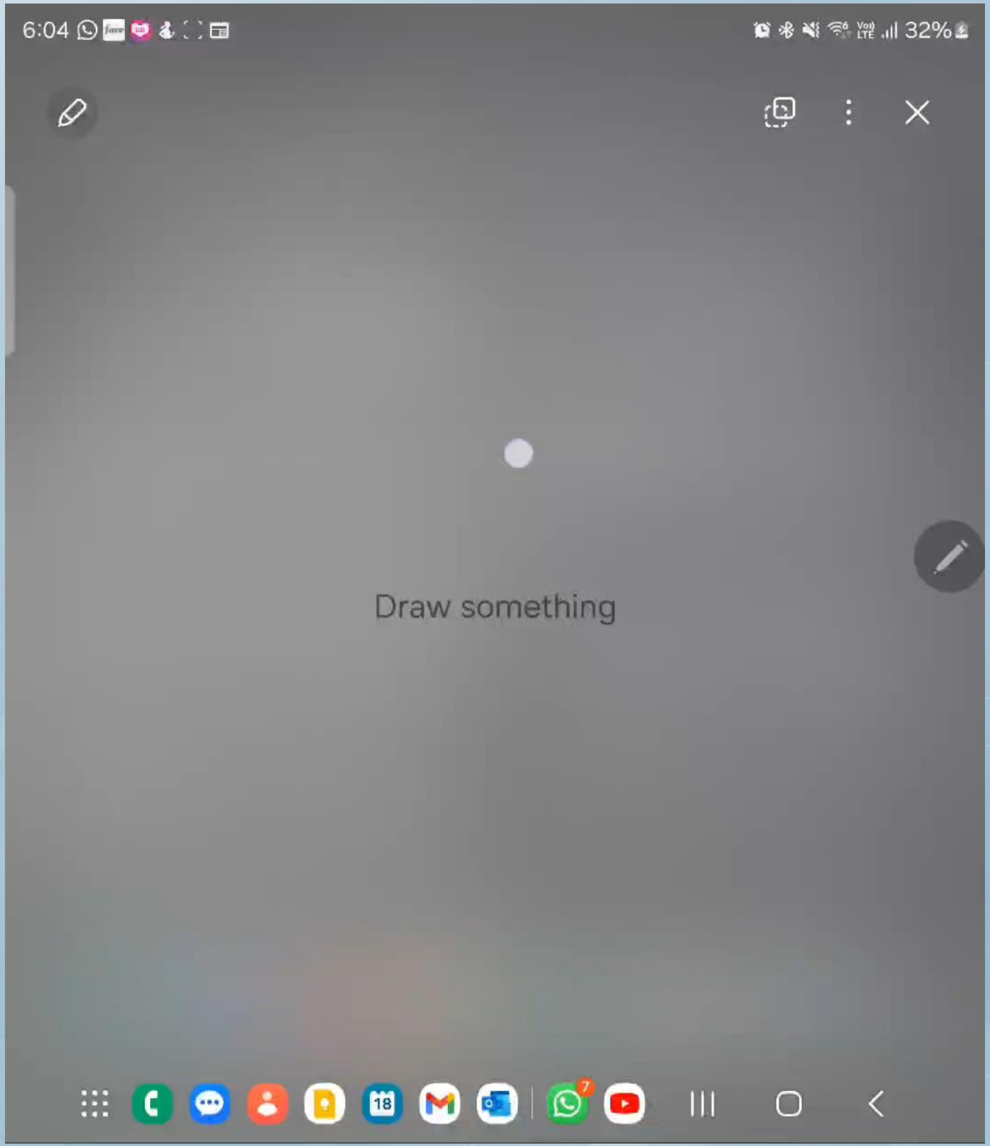
Gen AI in Finance
(Fraud Prevention & Risk Management)

Anomaly Detection
Medical Imaging

Image & Video Generation
(Efficient Gen High Quality Content)

https://hospitalityinsights.ehl.edu/chatgpt-overview ; https://www.linkedin.com/pulse/generative-adversarial-networks-gans-revolutionizing-artificial-s/ ; https://compai-lab.github.io/teaching/anomaly_seminar/
https://www.bitsathy.ac.in/blog/generative-ai-in-agriculture-revolutionizing-crop-management/ ; https://duolookmedia.com/text-to-image-artificial-intelligence-reshapes-marketing/

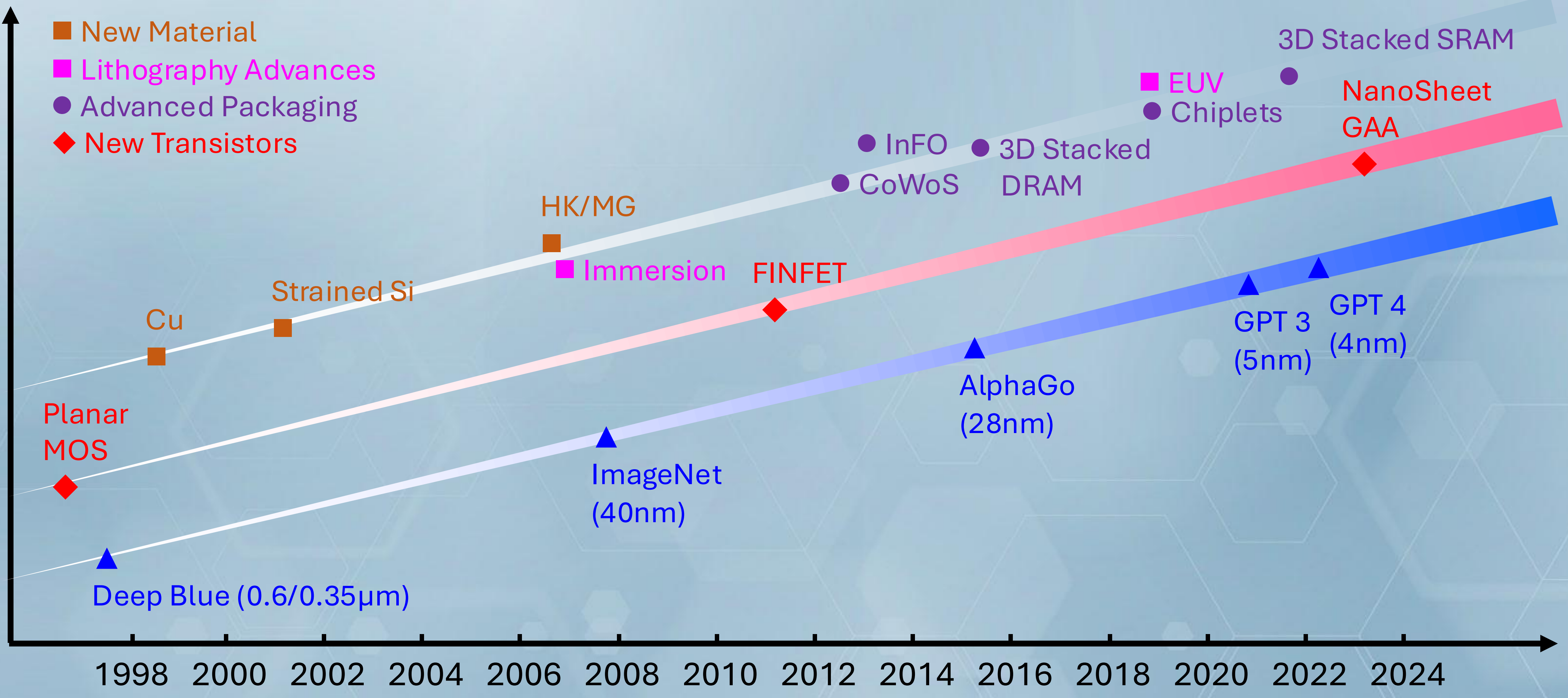
AI Image Generation



AI Applications are made possible by…

1. Innovations in Efficient Machine-Learning Algorithms
2. Availability of Massive Data to train Neural Networks
3. Energy-Efficient Computing through Advanced Semiconductor Technologies

AI systems vs Semiconductor Technologies

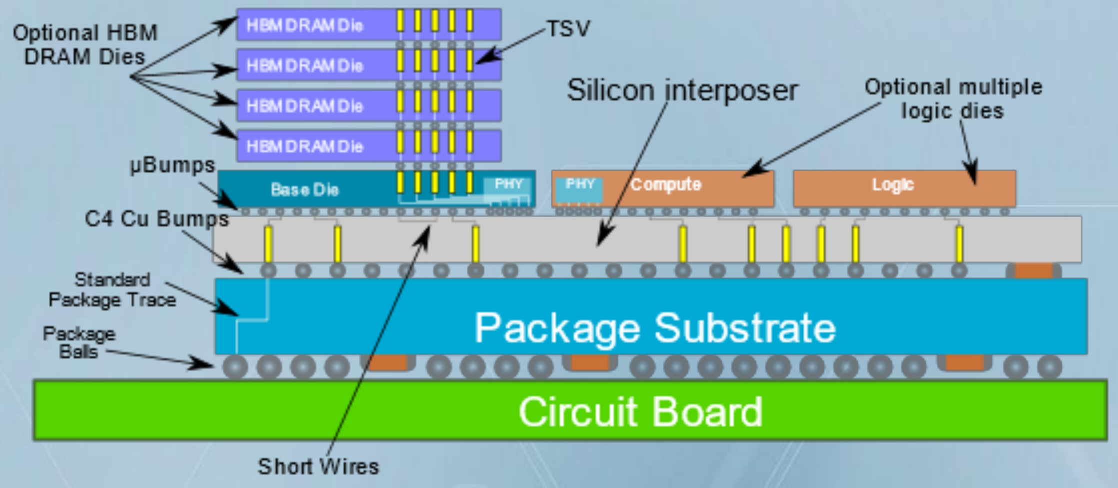


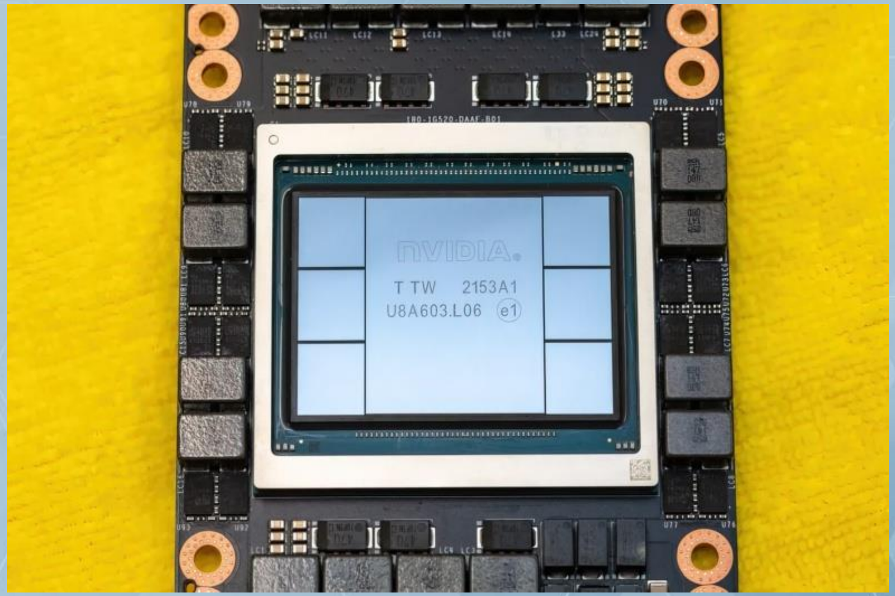
Advances in semiconductor technology [top lines]—including new materials, advances in lithography, new types of transistors, and advanced packaging—have driven the development of more capable AI systems [bottom line]

https://spectrum.ieee.org/trillion-transistor-gpu

From Integrated Devices to Integrated Chiplets

- ↓Feature Size, ↑Device Density.
- Reticle Limit – Unable to make ICs > 800 mm^2, 28.28×28.28mm.
- Attaching several chips onto a larger interposer.
- TSMC's chip-on-wafer-on-substrate (CoWoS) technology.
  - 6 reticle fields' worth of compute chips, along with a dozen high-bandwidth-memory (HBM) chips
- Nvidia's Ampere (54B Transistors), Hopper (80B T), Blackwell (208B T).
- Tens of thousands of these processors needed to train ChatGPT.

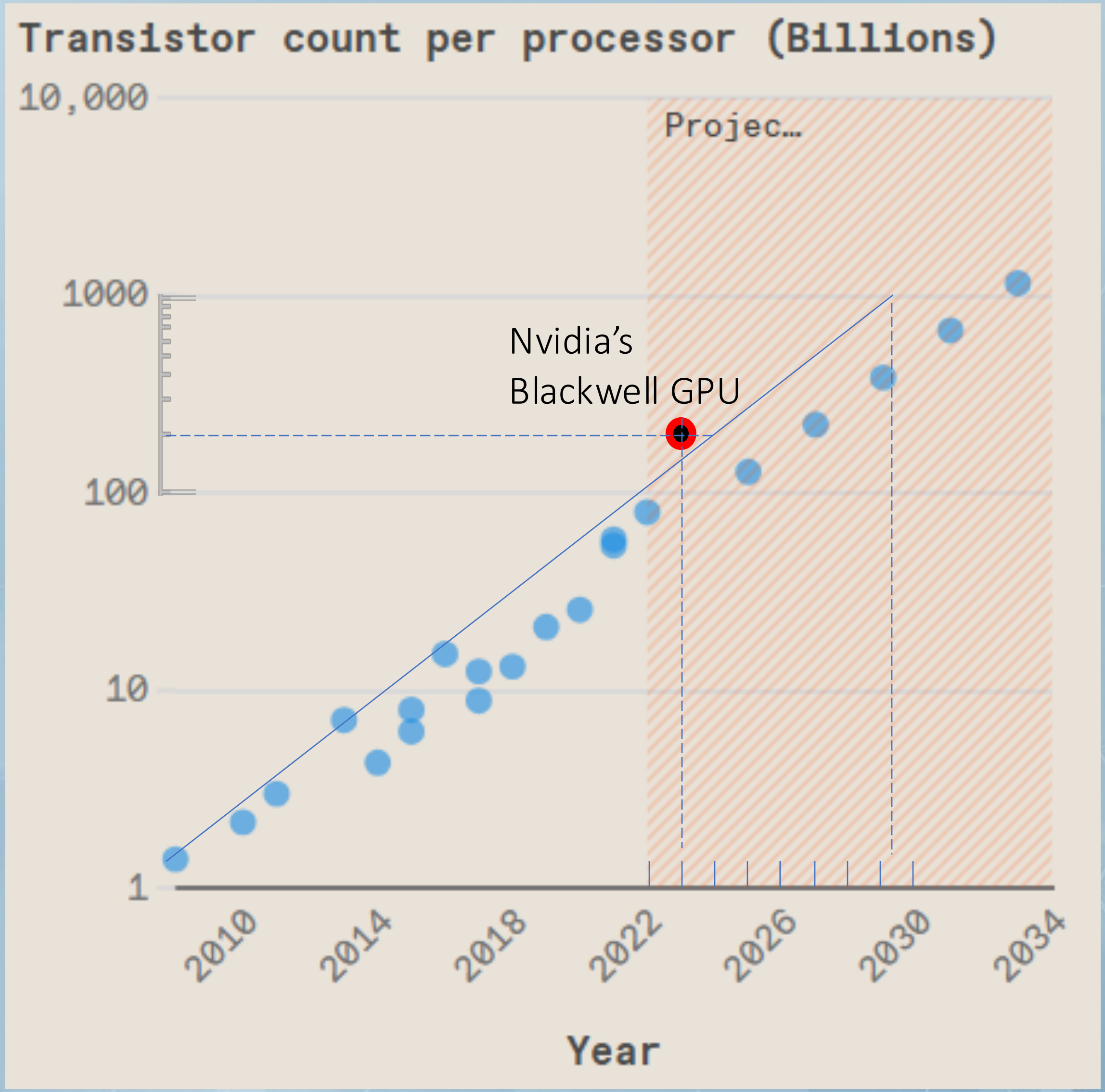




Source: Nvidia.

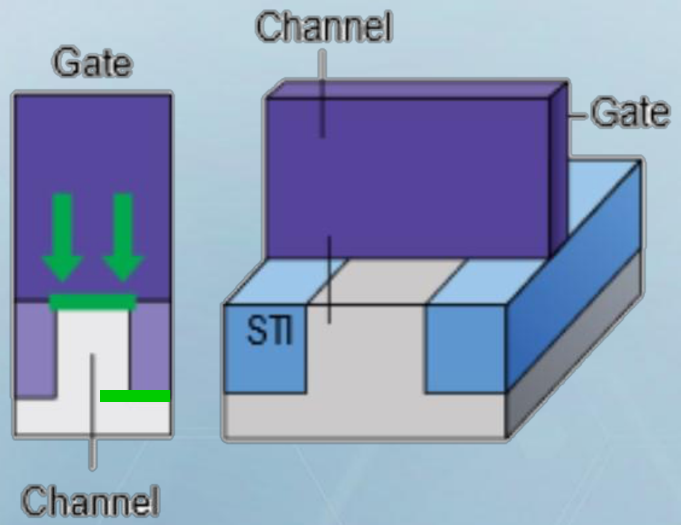
Towards GPUs with 1 Trillion Transistors

- **Transistors per processor.**
  - ↑ 1.73x every 2 years
- **Towards 1 Trillion Transistors by 2030!**

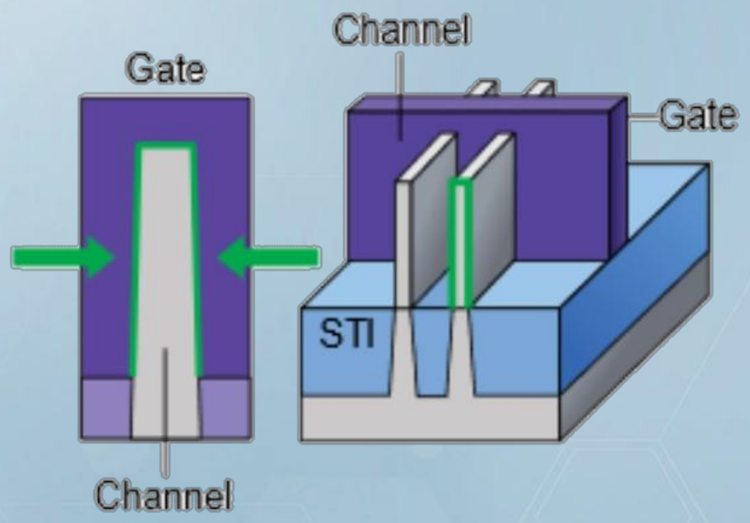


https://spectrum.ieee.org/trillion-transistor-gpu

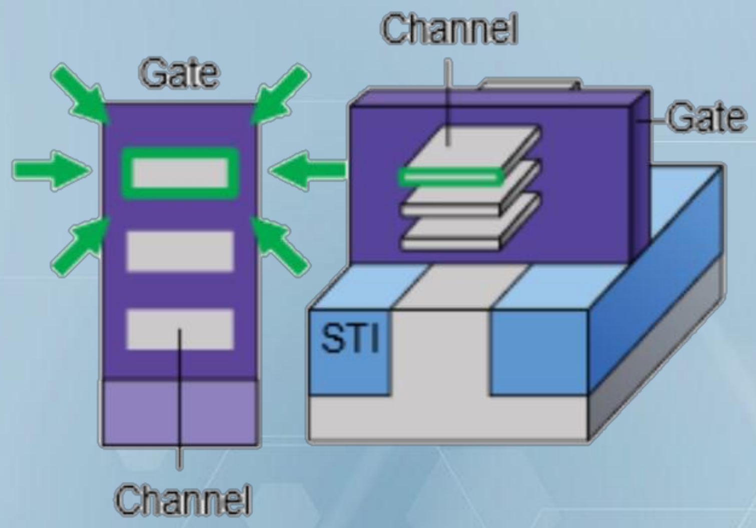
New Transistor Architecture – ↑ Energy Efficiency



Planar FET
1 Gate on Channel



FinFET
3 Gates on Channel



Gate-All-Around
4 Gates on Channel

↓Gate Length

↓R_{DS}

↑Vertical Channel Stacking

↓R_{DS}

The Silicon Age: Trends in Semiconductor Devices Industry, Journal of Engineering

Accurate Wafer IV Tests are Crucial

- **Transistor technology is the Foundational Pillar driving AI applications**
- **Development of GPUs**
  - Accurate SPICE, Device Reliability tests are needed.
  - 1st Pass Product Design Success and Reliable Performance.
- **Urgent need to overcome Test Challenges involving Advanced Node devices.**
- **Trends and Challenges**
  - V_D ↓
  - V_{TH} ↓
  - R_{DS} ↓
  - Test Pad Size ↓
  - Slotted Cu / Al capped test pads
  - Test Temperature Range ↑
  - Total number of Devices to Test & Model ↑
  - Requires Accurate & Repeatable Wafer Measurements
- **Better engineering probes are needed to address challenges!**

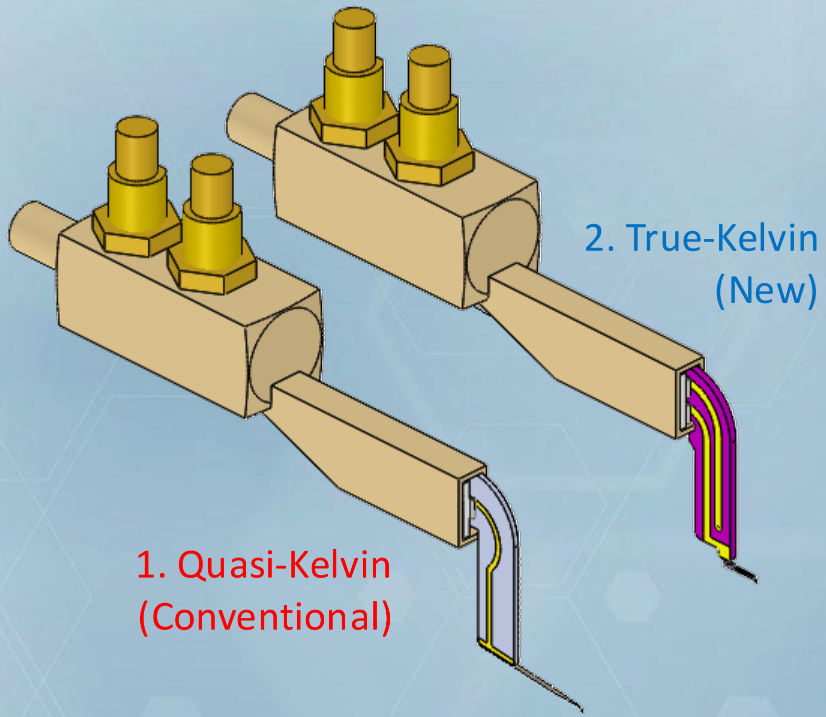
Mechanical Design & Performance

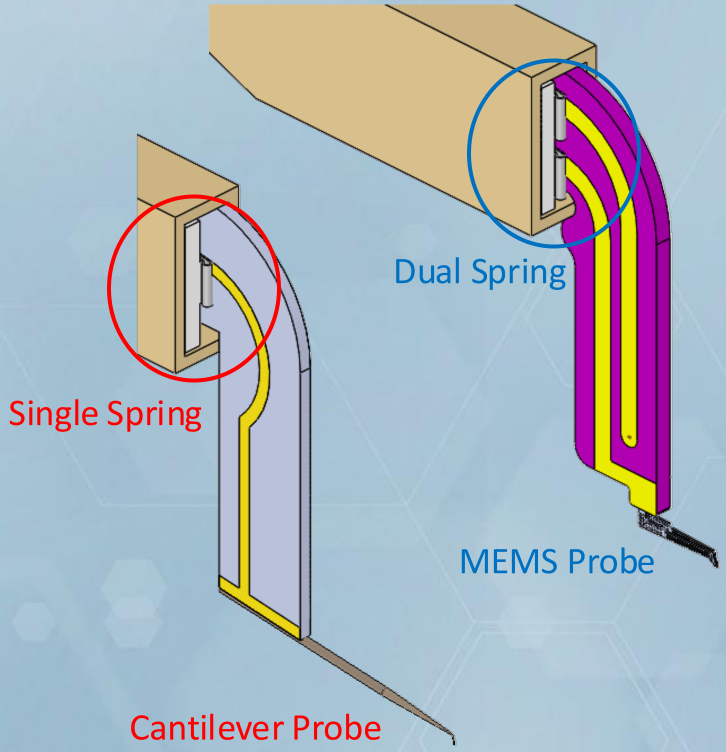
Overview of Novel True Kelvin MEMS Probe

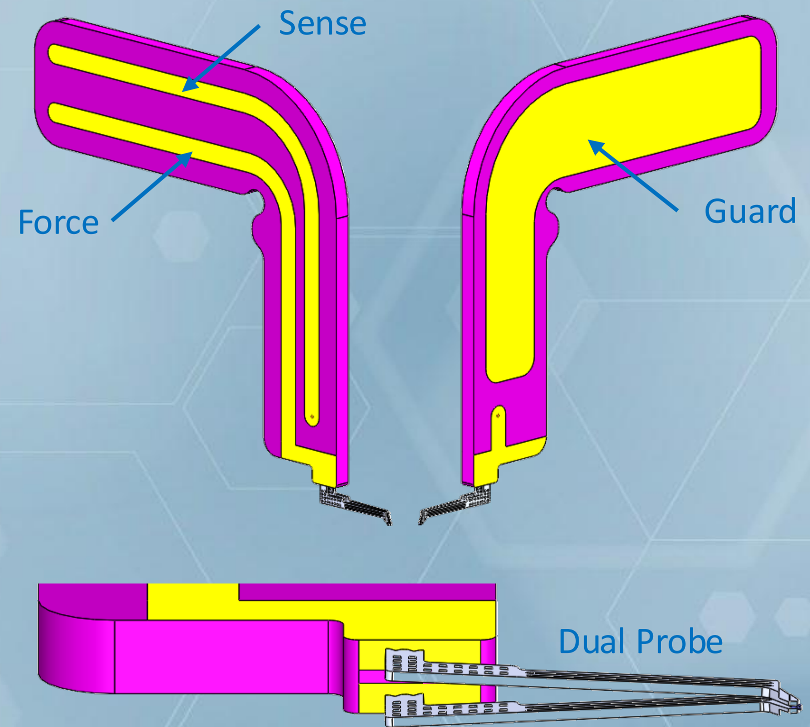
Engineering Probes:

1. Quasi-Kelvin: Single cantilever probe
2. True-Kelvin: Dual MEMS probe

These probes deliver fA-level measurements capability over a wide range of temperature for advanced characterization and reliability testing.

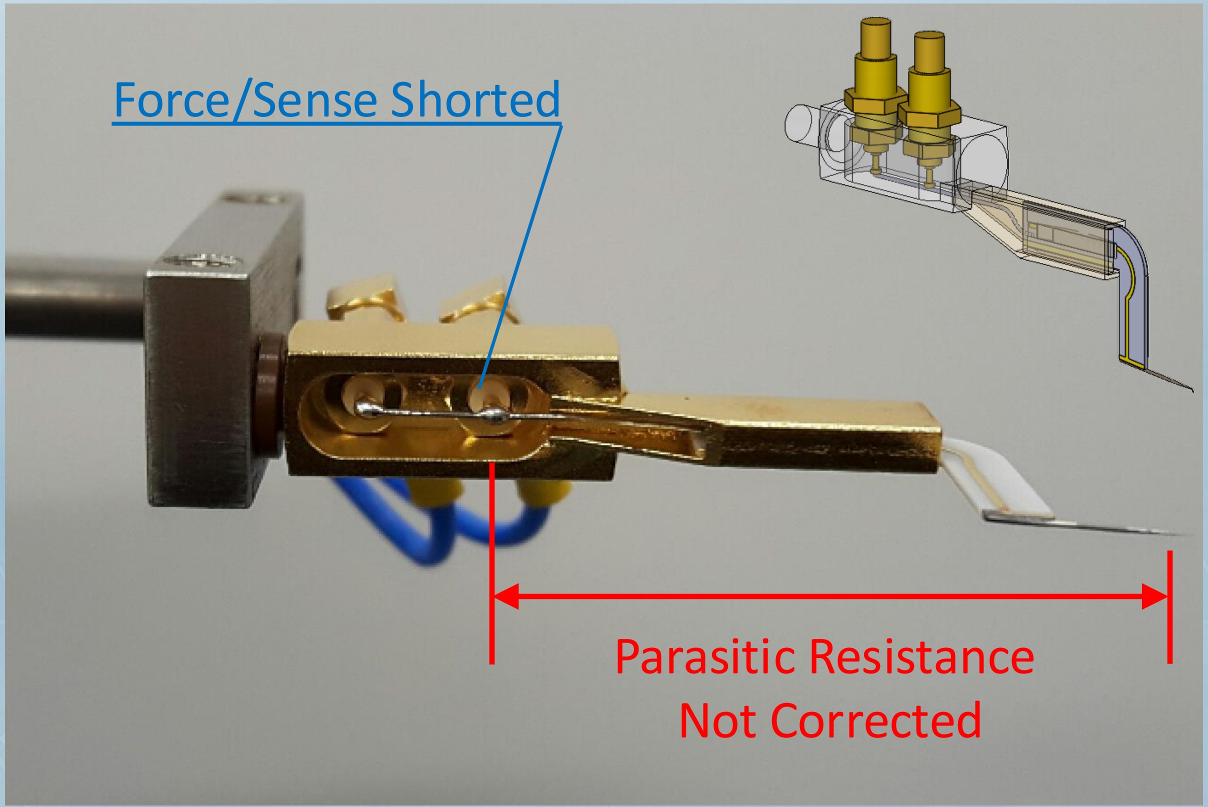




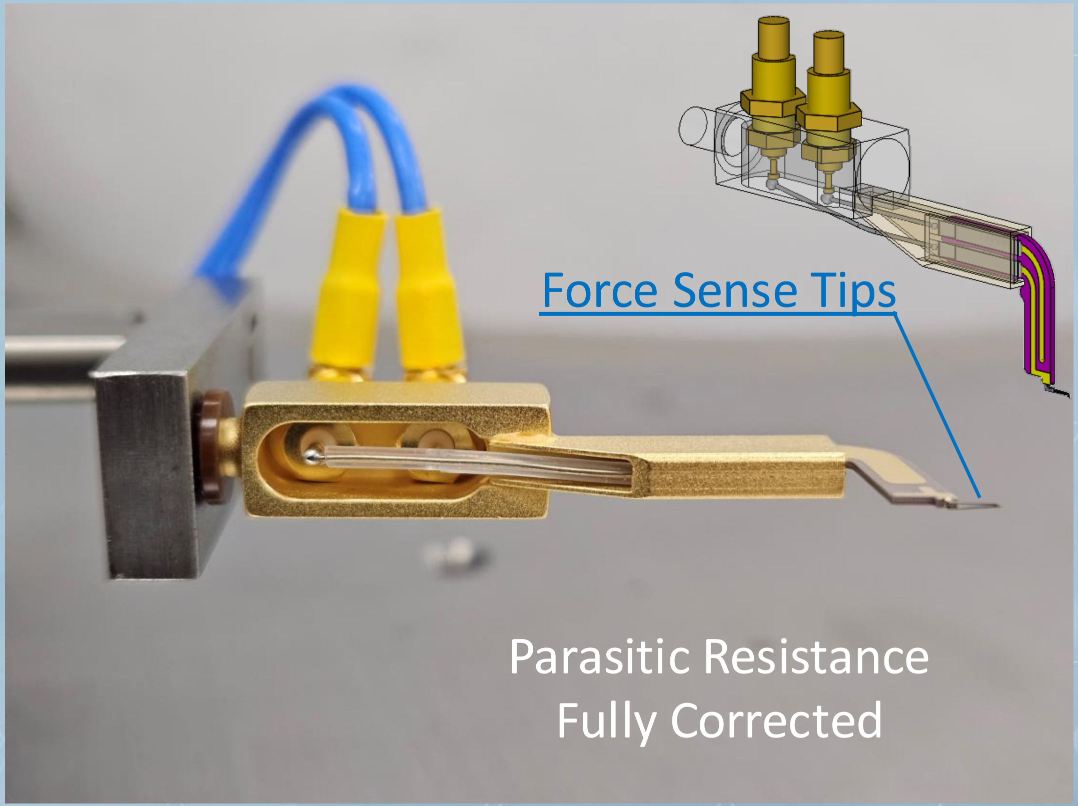


Quasi-Kelvin Cantilever vs True-Kelvin MEMS Probes

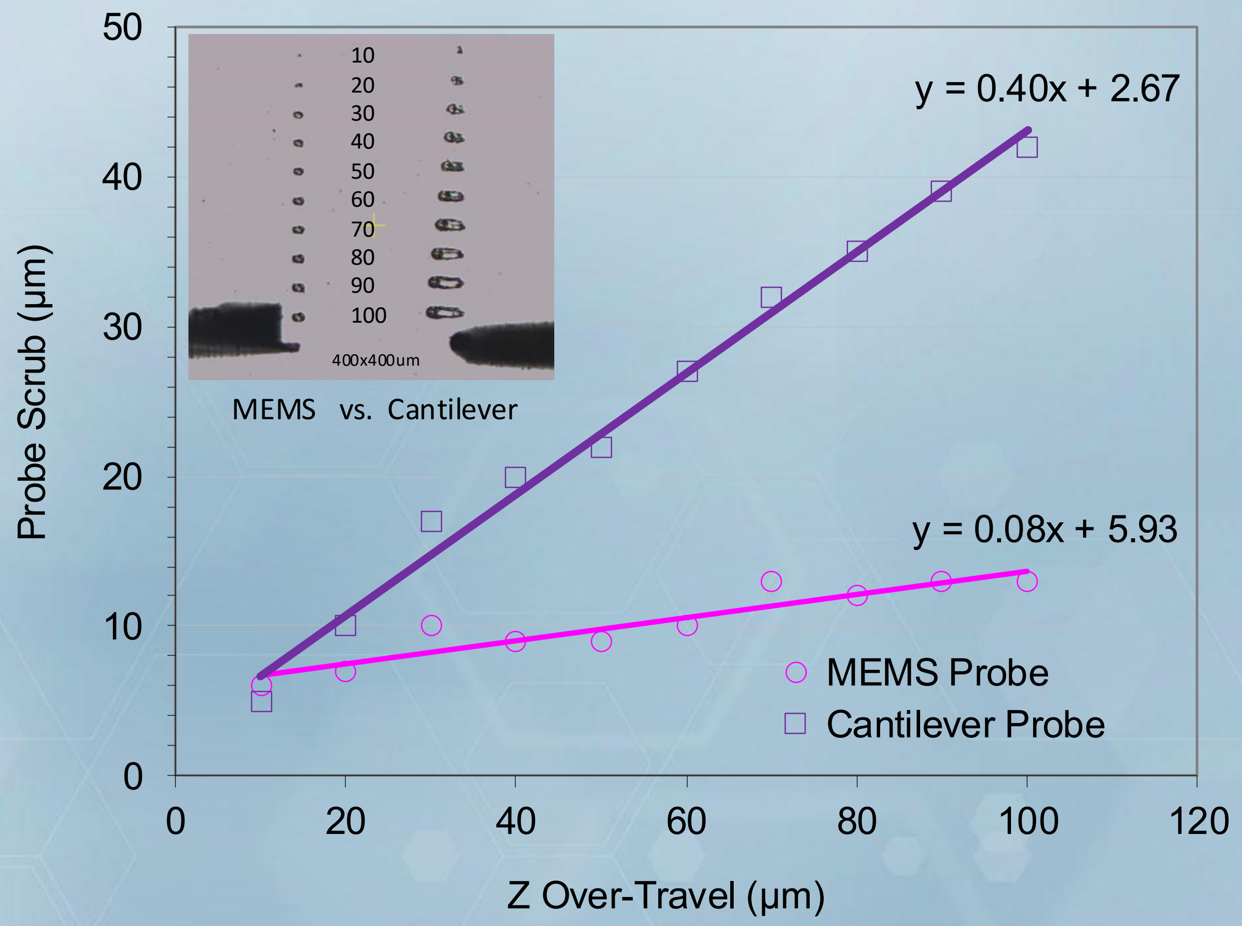
Quasi-Kelvin Cantilever



True-Kelvin MEMS Probe



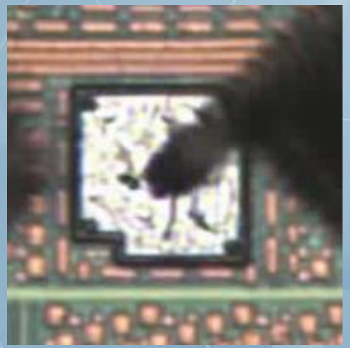
Probe Scrub versus Z Over Travel



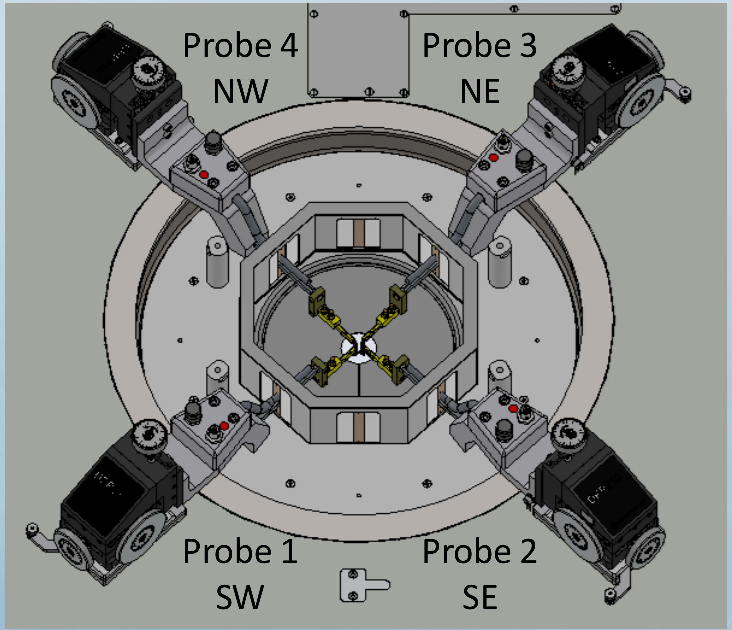
Item	Cantilever	MEMS
Recommended Z Over Travel	75µm	20µm
Probe Scrub Ratio	40%	8%
Probe Scrub	30µm	6-7µm
Slotted Cu Pads Handling	Tip Bending Observed	No Tip Bending

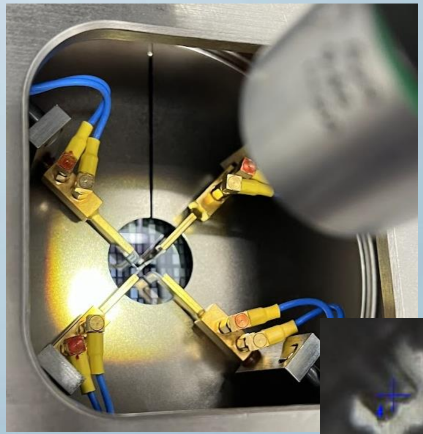
Benefits of using MEMS Probe:

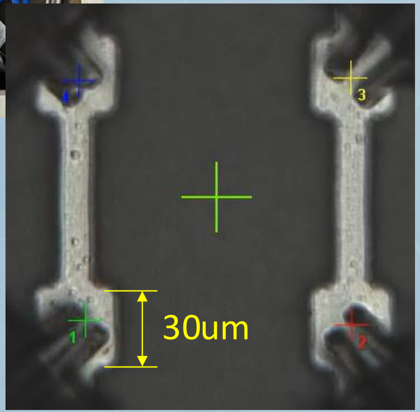
- Small scrub mark → Smaller pad size
- Lighter probe force → Less pad damage
- Repeatable measurement is possible

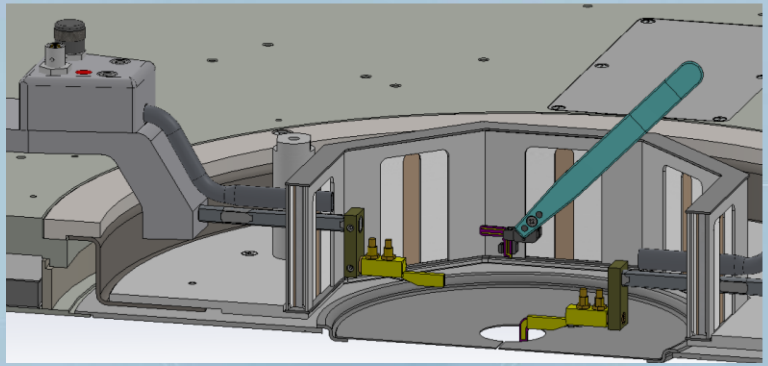


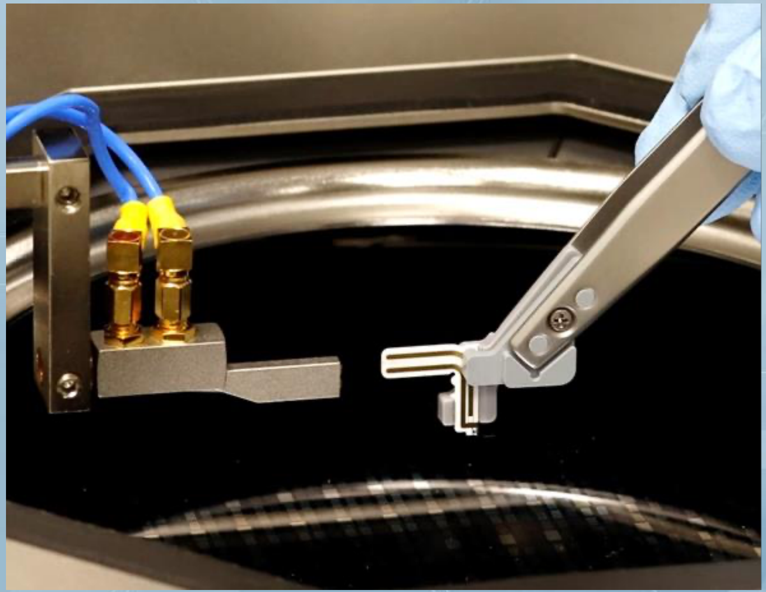
Setup of 4 True Kelvin MEMS Probes







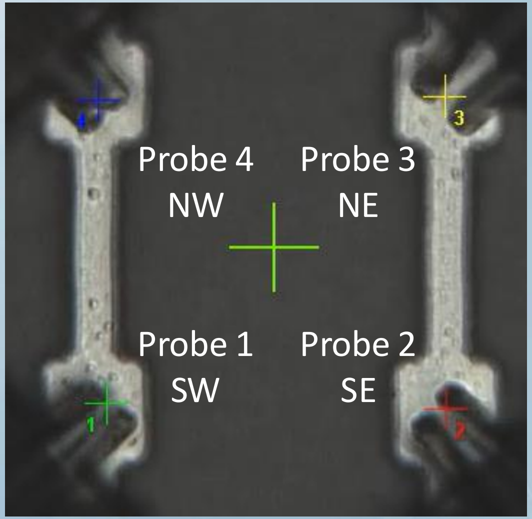


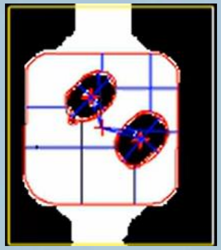


Test Setup:

1. Four positioners/probes are set in NW, NE, SW and SE positions.
2. True kelvin probes are used and probed on 30x30um pad size.
3. New tool is used for easy probe tip setup and replacement without removing positioners.

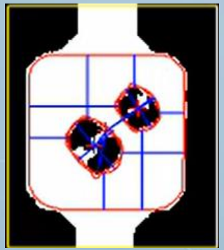
Over-Temperature PTPA on 30um Test Pads



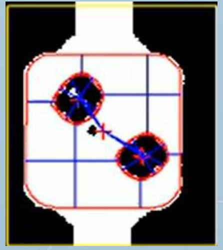


Probe 1
SW

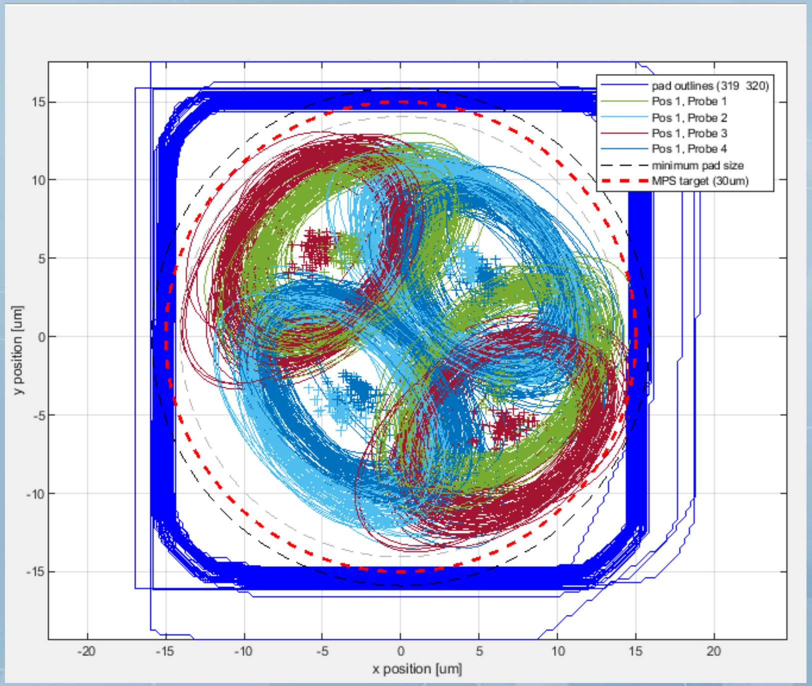
Probe 2
SE



Probe 4
NW



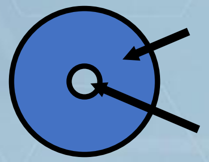
Probe 3
NE



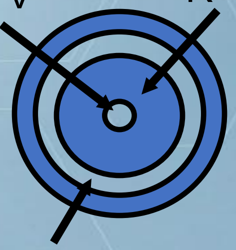
1. Autonomous DC Solution: Track all probes which are mounted on the motorized positioner. Thermal expansion can be automatically corrected.
2. Performance Analyzer: Software to analyze the minimum pad size capability.
3. Test Condition: 20TDs each at 25, 85, 150 and -40C as temperature.
   20TDs each x 4 pads x 4 different temperature = 320 total TDs.
4. Test Results: Achieving to contact all probes within 30x30um pad size.

Measurement Principles & Electrical Performance

Principle of Guarding - Triaxial vs Coaxial



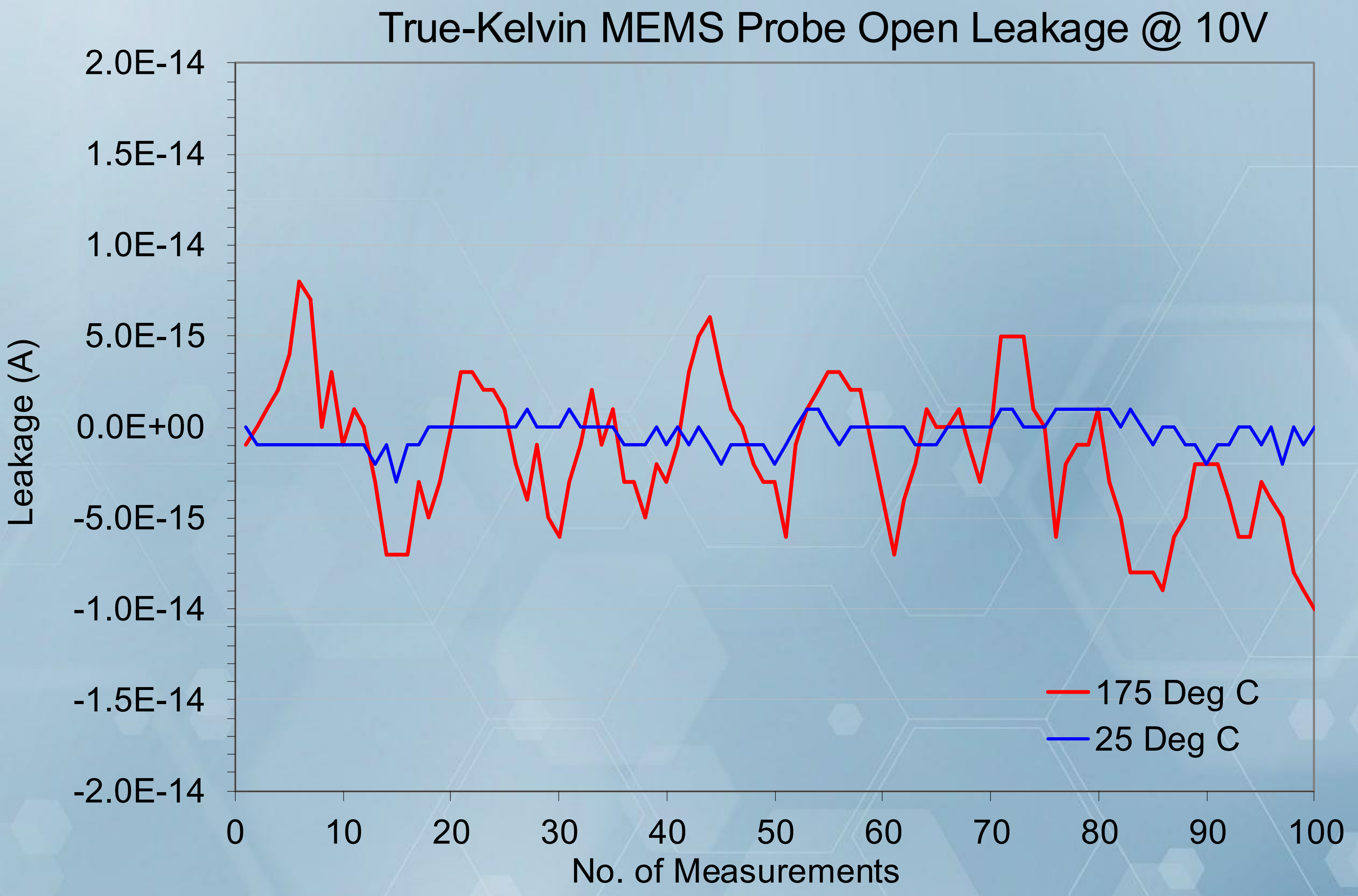
Regular Coax Cable
$I_{Leakage} = 100$ nA



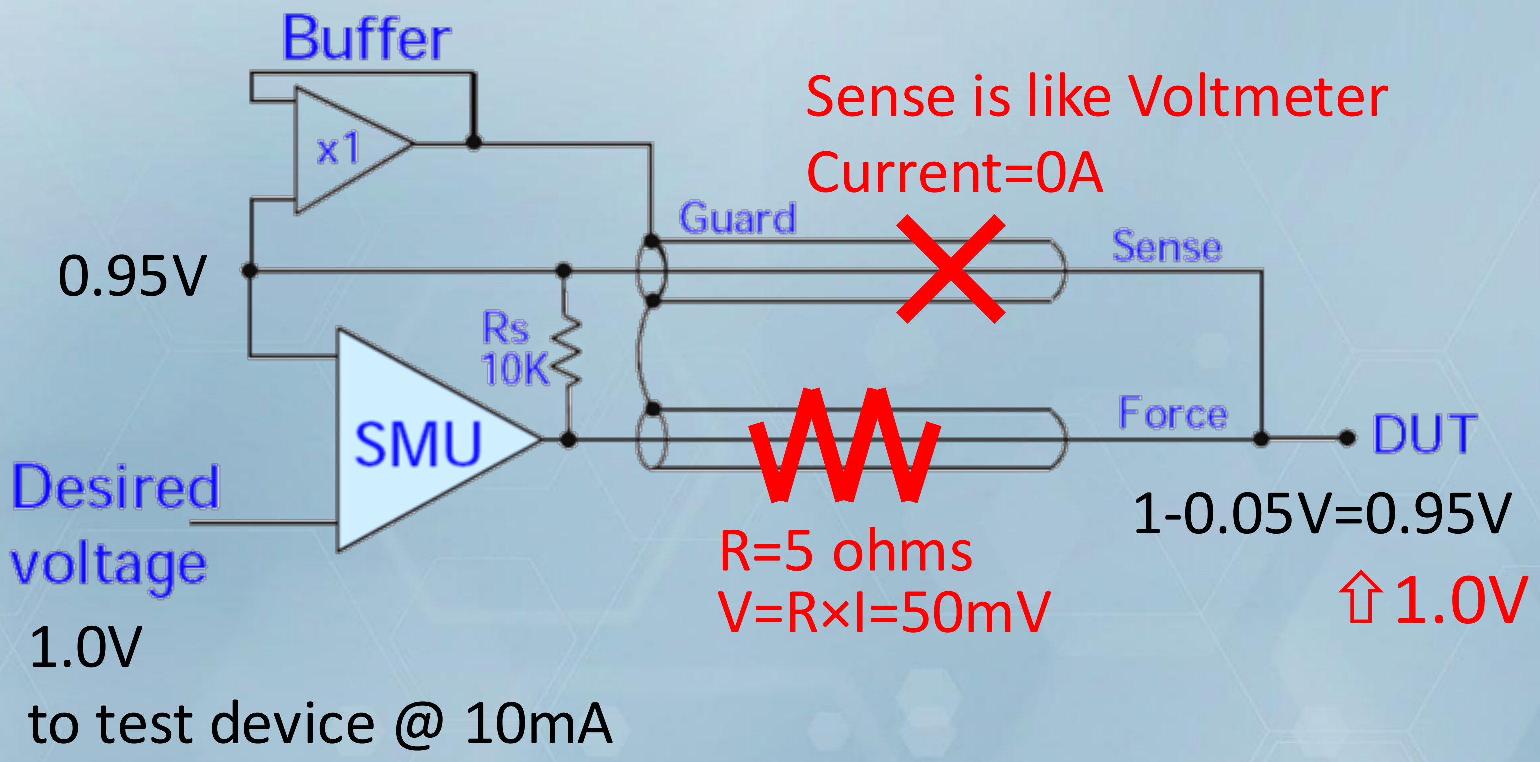
Triaxial Cable (Guarded)
$I_{Leakage} = 1$ fA

True-Kelvin MEMS Probe – Probe Leakage

- **Probe Leakage is critical for device off-state current measurements.**
- **Excellent leakage performance at 25 and 175°C.**
- **Guard design worked very well.**



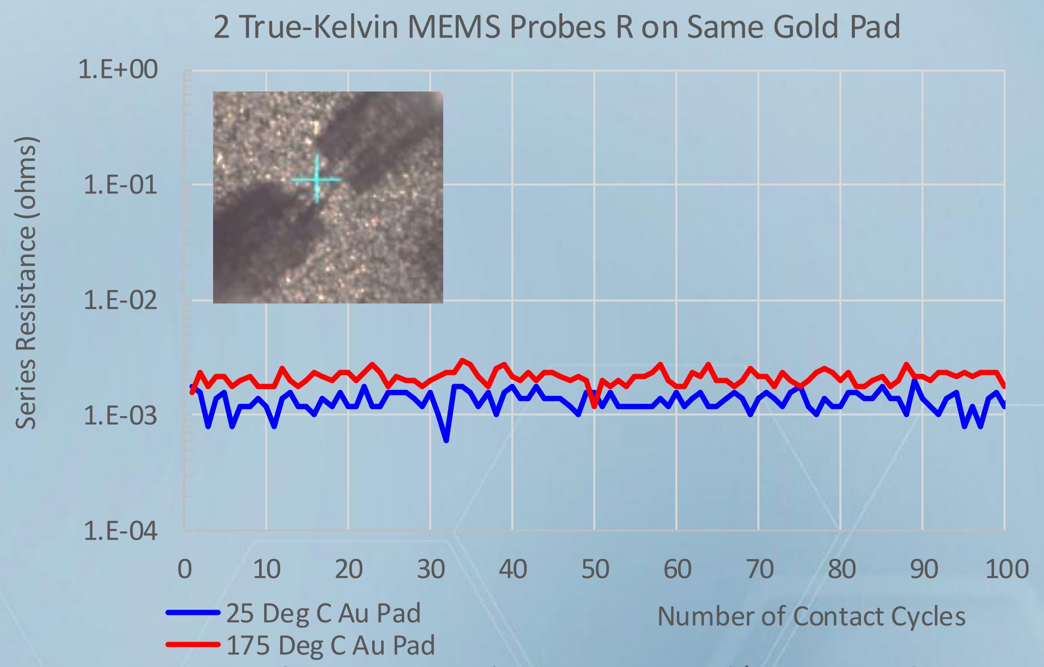
Principle of Kelvin Measurements

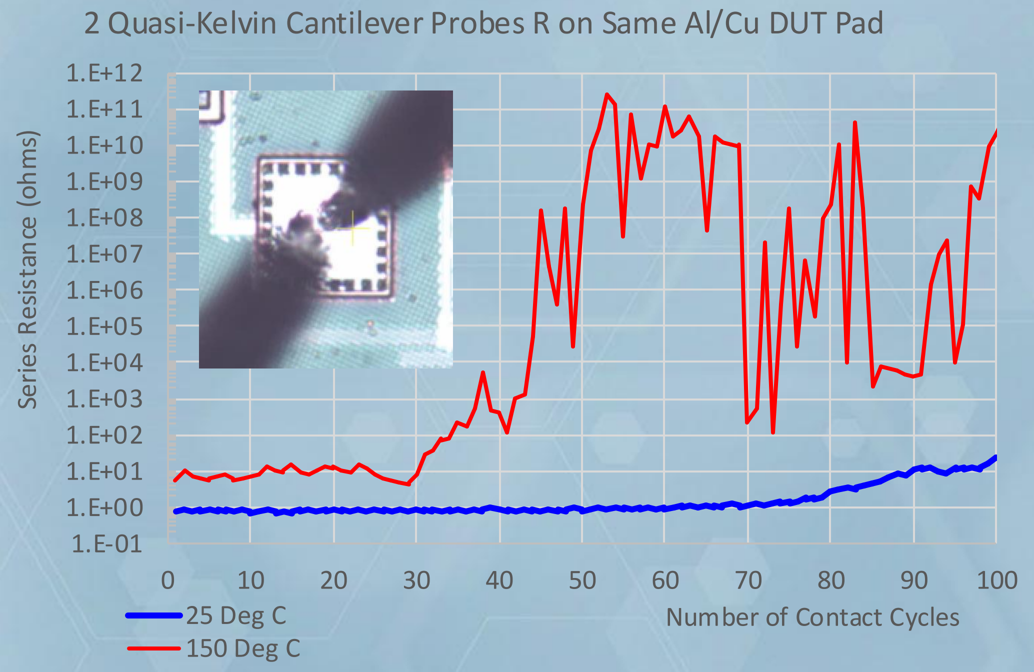


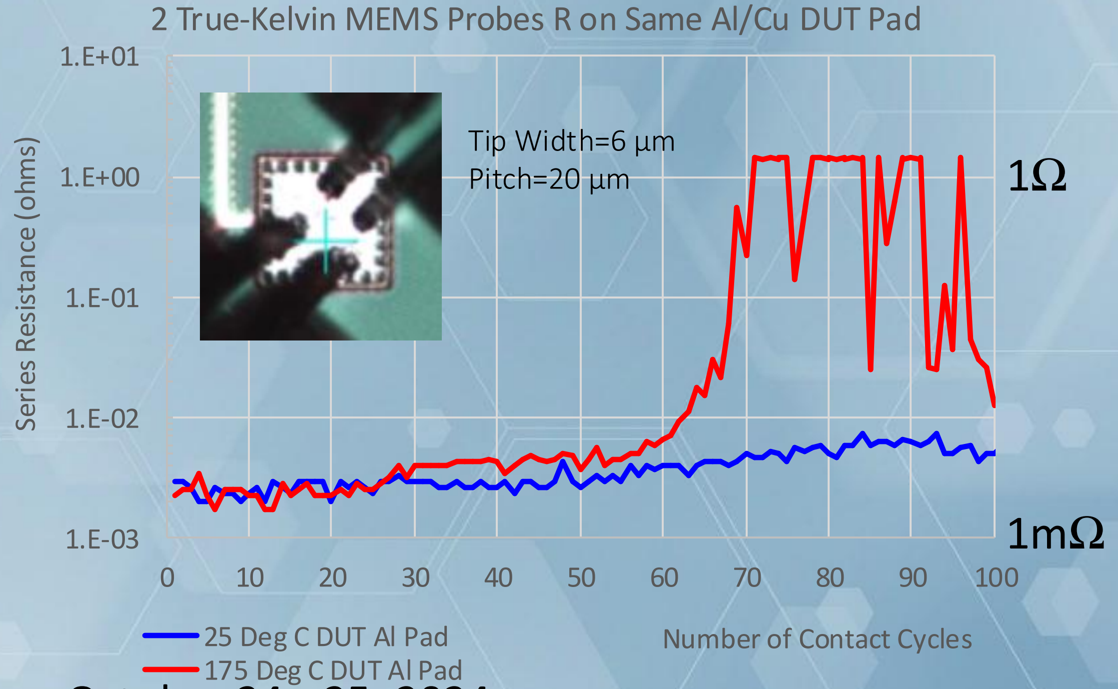
- Kelvin Measurement eliminates parasitic resistance
  - Resistance of Cables, Connectors, Probe Holders & Probes.
  - Ensure Accurate Bias Voltage as close to device as possible!

Probe Parasitic Resistance

- **Quasi-Kelvin Cantilever Probes**
  - Parasitic R – 1Ω at 25°C ; 5-10Ω at 150°C
    - 25°C vs 150°C = Parasitic R gap, Not Acceptable
  - 30th Contact Cycle – Open Circuit, Cu oxidation.
- **True-Kelvin MEMS Probes**
  - Al/Cu pads, 1st 50 contact cycles, < 5 mΩ
    - 25°C vs 175°C = no gap in Parasitic R.
  - Gold pads, ≈ 1-3 mΩ Rc, No metal oxidation.







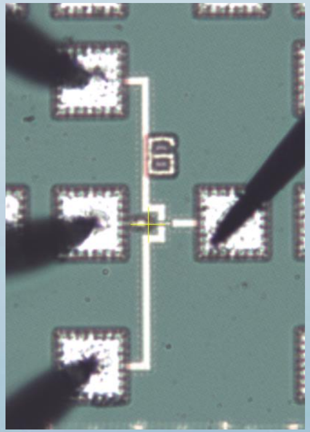
Accuracy of True-Kelvin MEMS probes

Drain Source Resistance vs Error	Quasi-Kelvin Cantilever Probe	True-Kelvin MEMS Probe
Worst Case Parasitic R of **2 Probes** @ High Temp on Al-Cu Pads	~10 ohms	3 milli-ohms
Error @ Device R_{DS} = 200 Ohm	5 %	0.0015 %
Error @ Device R_{DS} = 100 Ohm	10 %	0.0030 %
Error @ device R_{DS} = 10 Ohm	100 %	0.0300 %
Error @ device R_{DS} = 2 Ohm	500 %	0.1500 %
Error @ device R_{DS} = 1 Ohm	1000 %	0.3000 %

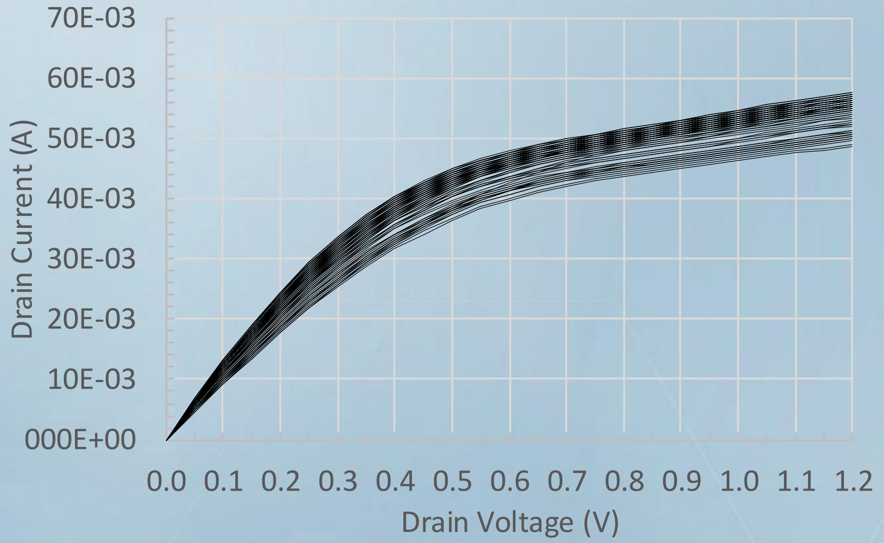
True-Kelvin MEMS Probes can...

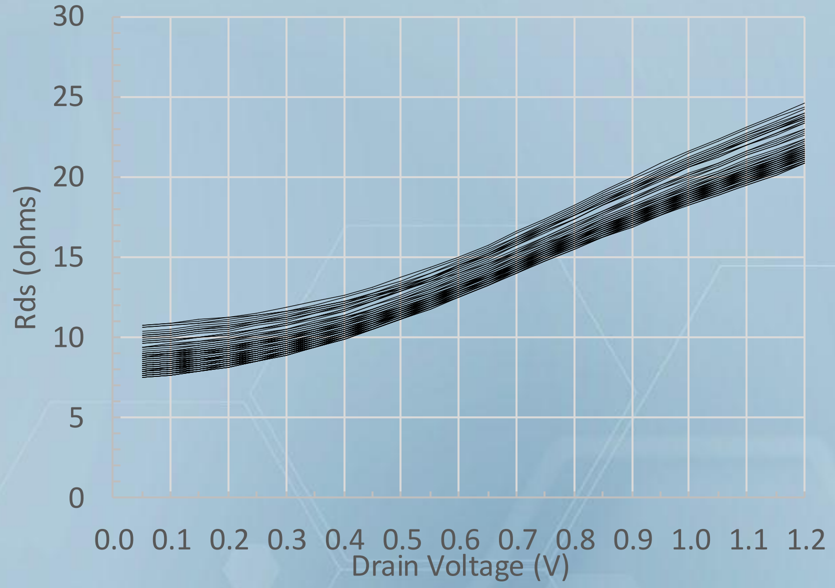
- **Accurately characterize advanced node transistors with ultra-low R_{DS}.**
- **Eliminate Errors introduced by Parasitic & Contact resistance of probes.**

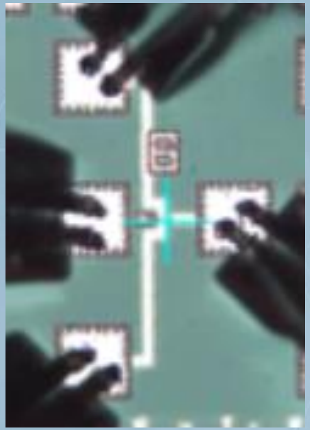
IV Measurements with TK MEMS Probe @ 25°C over 100 Contacts



Quasi-Kelvin Cantilever Probes @ 25°C

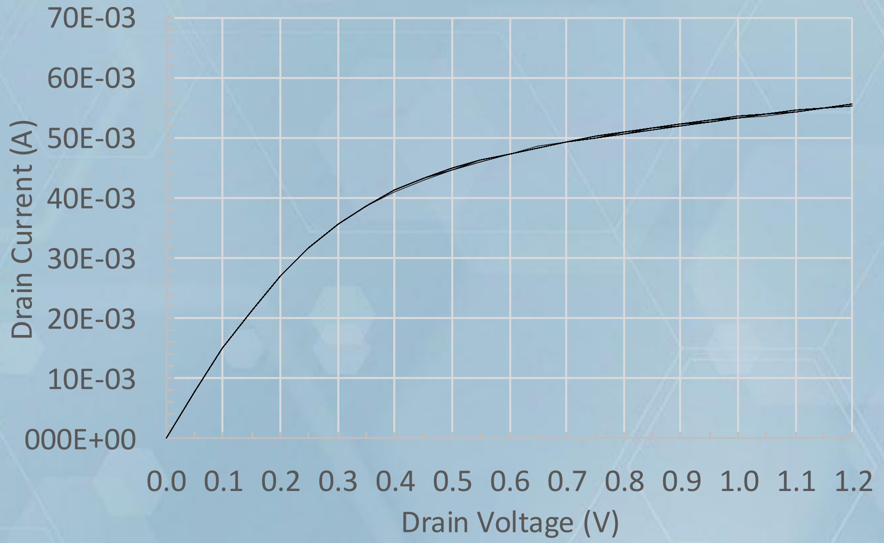


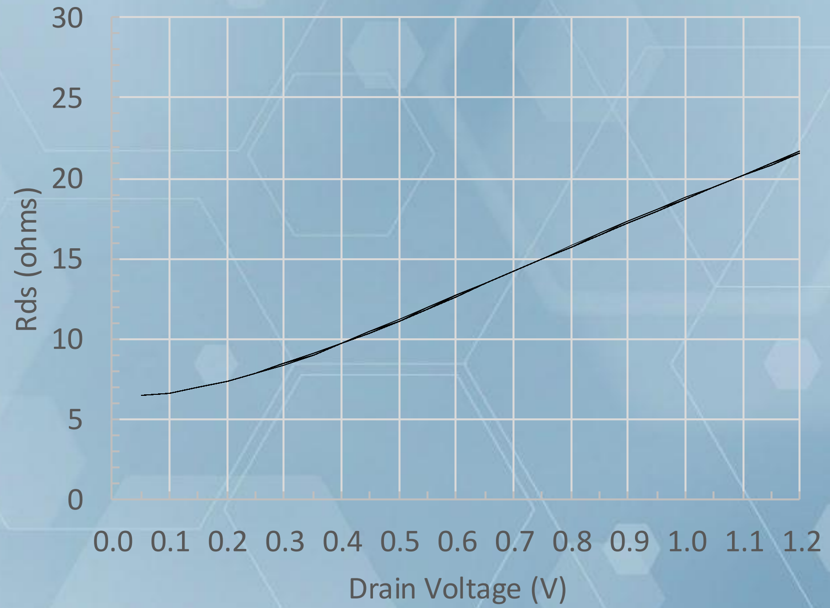




True-Kelvin MEMS Probes* @ 25°C

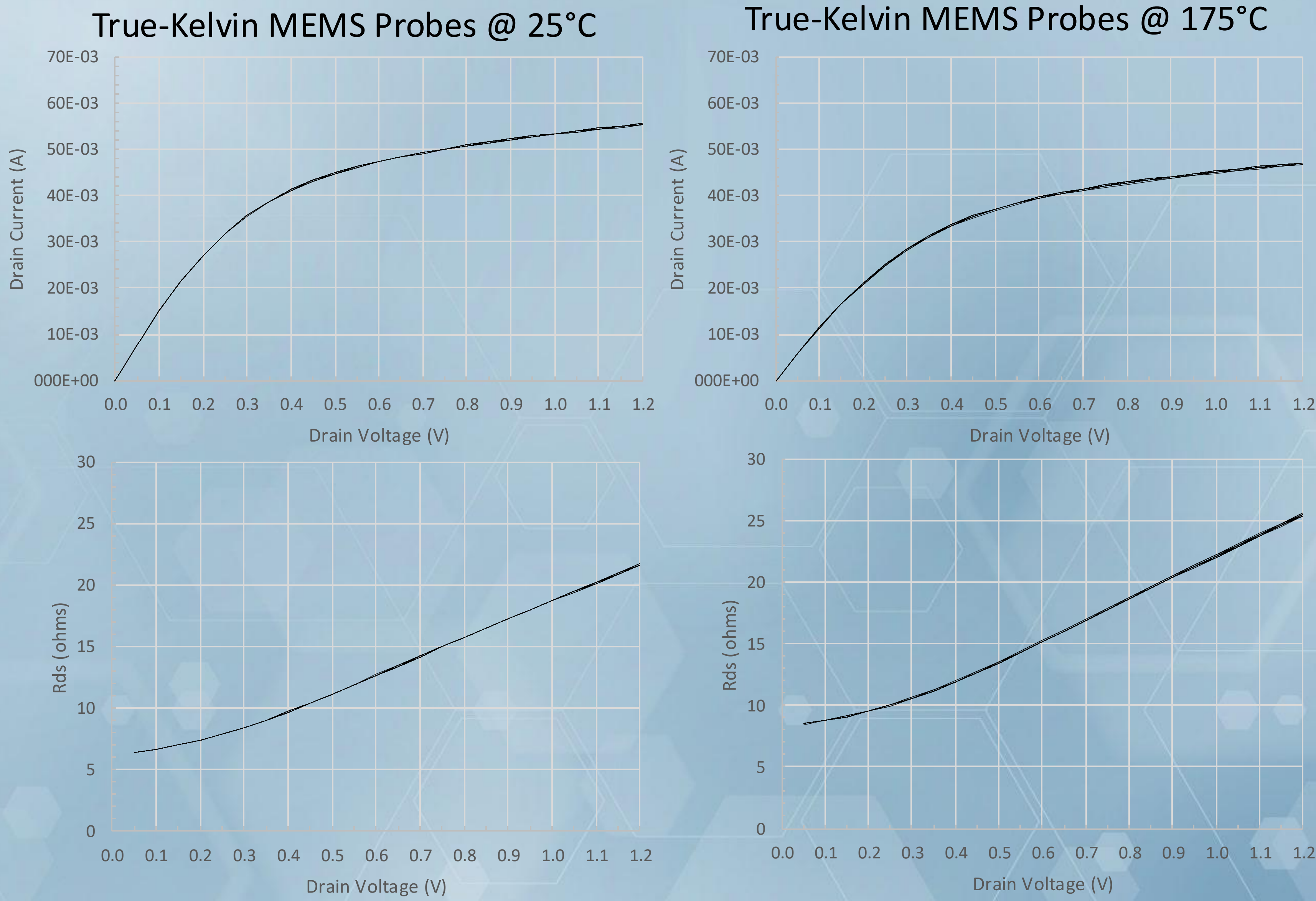
*Possible to use just 2 TK probes on Drain & Source Pads only





IV @ 25 & 175°C, 100 Contacts Cycles

- **True-Kelvin MEMS Probe**
  - Eliminate Probe $R_{Parasitic}$
  - Eliminate Probe RC on pads.
- **Achieve Accurate and Repeatable measurements.**



Raw Test Data, Id & Rds @ 175°C

Drain Current Id over 10 Contact Cycles

Vd	1	2	3	4	5	6	7	8	9	10
0.00	4.36E-06	4.32E-06	6.92E-06	3.89E-06	2.74E-06	4.54E-06	4.62E-06	2.98E-06	3.10E-06	3.31E-06
0.05	0.00589	0.00589	0.0059	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589	0.00589
0.10	0.01143	0.01143	0.01143	0.01143	0.01142	0.01143	0.01143	0.01142	0.01142	0.01142
0.15	0.01651	0.01651	0.01652	0.01651	0.0165	0.01651	0.01651	0.0165	0.01651	0.0165
0.20	0.02106	0.02107	0.02108	0.02106	0.02105	0.02107	0.02107	0.02106	0.02106	0.02106
0.25	0.02504	0.02505	0.02506	0.02505	0.02504	0.02505	0.02505	0.02504	0.02504	0.02504
0.30	0.02845	0.02846	0.02846	0.02845	0.02844	0.02845	0.02845	0.02844	0.02845	0.02844
0.35	0.03131	0.03132	0.03133	0.03131	0.0313	0.03131	0.03131	0.0313	0.03131	0.0313
0.40	0.03367	0.03368	0.03369	0.03367	0.03366	0.03368	0.03368	0.03367	0.03367	0.03367
0.45	0.03563	0.03564	0.03564	0.03563	0.03561	0.03563	0.03563	0.03562	0.03563	0.03562
0.50	0.03723	0.03725	0.03726	0.03724	0.03723	0.03724	0.03724	0.03723	0.03724	0.03723
0.55	0.03857	0.03859	0.0386	0.03858	0.03856	0.03858	0.03858	0.03857	0.03858	0.03857
0.60	0.03971	0.03972	0.03973	0.03971	0.03969	0.03971	0.03971	0.0397	0.03971	0.0397
0.65	0.04068	0.0407	0.0407	0.04069	0.04067	0.04068	0.04068	0.04068	0.04068	0.04067
0.70	0.04154	0.04155	0.04156	0.04154	0.04152	0.04154	0.04154	0.04153	0.04154	0.04153
0.75	0.0423	0.04231	0.04232	0.0423	0.04228	0.0423	0.0423	0.0423	0.0423	0.04229
0.80	0.043	0.04301	0.04301	0.043	0.04298	0.04299	0.04299	0.04299	0.04299	0.04298
0.85	0.04363	0.04364	0.04365	0.04364	0.04362	0.04363	0.04363	0.04363	0.04363	0.04362
0.90	0.04423	0.04424	0.04424	0.04423	0.04421	0.04423	0.04423	0.04422	0.04423	0.04422
0.95	0.04479	0.0448	0.0448	0.04479	0.04477	0.04478	0.04479	0.04478	0.04479	0.04477
1.00	0.04532	0.04533	0.04534	0.04532	0.0453	0.04532	0.04532	0.04531	0.04532	0.0453
1.05	0.04583	0.04583	0.04584	0.04582	0.04581	0.04582	0.04582	0.04582	0.04582	0.04581
1.10	0.04631	0.04632	0.04633	0.04631	0.04629	0.04631	0.04631	0.0463	0.04631	0.04629
1.15	0.04678	0.04678	0.04679	0.04678	0.04676	0.04677	0.04677	0.04677	0.04677	0.04676
1.20	0.04723	0.04723	0.04724	0.04722	0.04721	0.04722	0.04722	0.04722	0.04722	0.0472

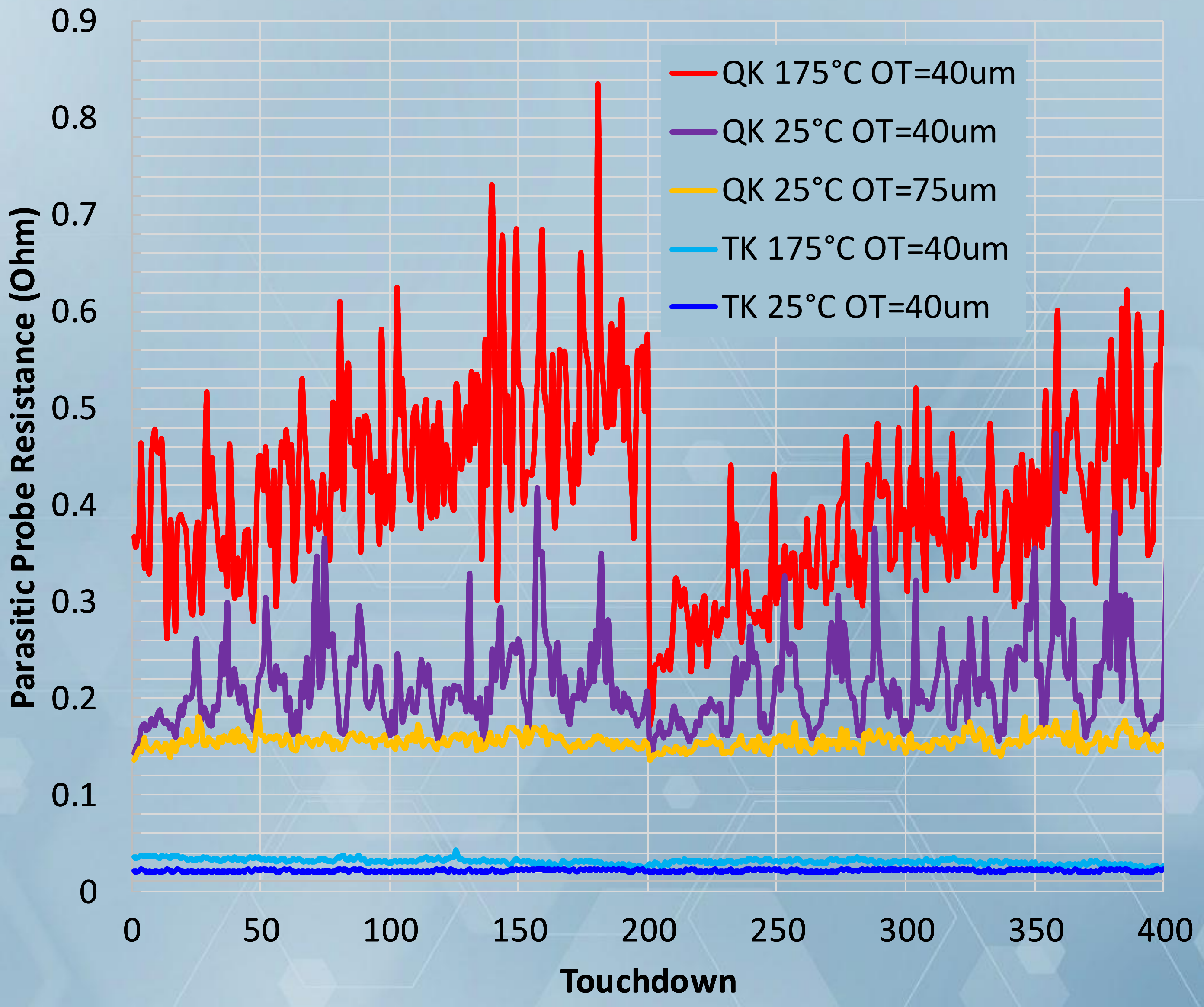
Channel Resistance Rds over 10 Contact Cycles

Vd	1	2	3	4	5	6	7	8	9	10
0.05	8.49055	8.48911	8.48174	8.49167	8.49602	8.48953	8.48951	8.4955	8.49204	8.49488
0.10	8.75197	8.75074	8.74523	8.75258	8.75664	8.75113	8.75136	8.75557	8.75365	8.75534
0.15	9.08595	9.08337	9.07891	9.08568	9.08959	9.08502	9.08463	9.08876	9.08617	9.08898
0.20	9.49487	9.49248	9.48897	9.49546	9.49898	9.49393	9.49442	9.49753	9.49568	9.49776
0.25	9.98227	9.97948	9.97614	9.98175	9.9857	9.9812	9.98116	9.98442	9.98251	9.9847
0.30	10.5444	10.5415	10.5395	10.5449	10.5487	10.5434	10.5433	10.5469	10.545	10.5471
0.35	11.1787	11.1759	11.1729	11.1785	11.1827	11.1779	11.1787	11.181	11.1787	11.1812
0.40	11.8789	11.8751	11.8727	11.8785	11.8823	11.8775	11.8782	11.8802	11.8788	11.8815
0.45	12.6314	12.6273	12.6246	12.6306	12.6353	12.6303	12.6301	12.6331	12.6306	12.6341
0.50	13.4287	13.4234	13.4206	13.4267	13.4317	13.4271	13.4274	13.4288	13.4282	13.4308
0.55	14.2581	14.2528	14.2503	14.256	14.2622	14.2567	14.2569	14.2581	14.257	14.2606
0.60	15.1105	15.1047	15.1029	15.1082	15.1165	15.111	15.1099	15.1116	15.1091	15.1131
0.65	15.978	15.9719	15.9693	15.9756	15.9825	15.9772	15.9775	15.979	15.9774	15.9811
0.70	16.852	16.8469	16.8443	16.8511	16.8591	16.8521	16.8528	16.8544	16.852	16.8569
0.75	17.7295	17.725	17.7225	17.7296	17.7369	17.7299	17.7308	17.732	17.7299	17.7353
0.80	18.6064	18.6017	18.5996	18.6066	18.6149	18.6079	18.608	18.6096	18.6082	18.6132
0.85	19.4803	19.4754	19.473	19.4795	19.4886	19.4821	19.4816	19.4838	19.4805	19.4869
0.90	20.3491	20.3439	20.3416	20.3477	20.3578	20.3505	20.3491	20.3524	20.3504	20.355
0.95	21.2096	21.2064	21.2035	21.2108	21.2199	21.2128	21.2113	21.2148	21.2108	21.2185
1.00	22.0648	22.0609	22.0576	22.0654	22.0749	22.0673	22.0674	22.0699	22.0663	22.0731
1.05	22.9125	22.9086	22.9045	22.9134	22.9229	22.916	22.9145	22.9178	22.9139	22.9222
1.10	23.7525	23.7483	23.7445	23.7538	23.7621	23.7553	23.7555	23.7576	23.7536	23.7615
1.15	24.5853	24.5814	24.5763	24.5857	24.5954	24.5884	24.5879	24.5903	24.5866	24.5951
1.20	25.4097	25.4063	25.4015	25.4106	25.419	25.413	25.4114	25.4147	25.4117	25.4211

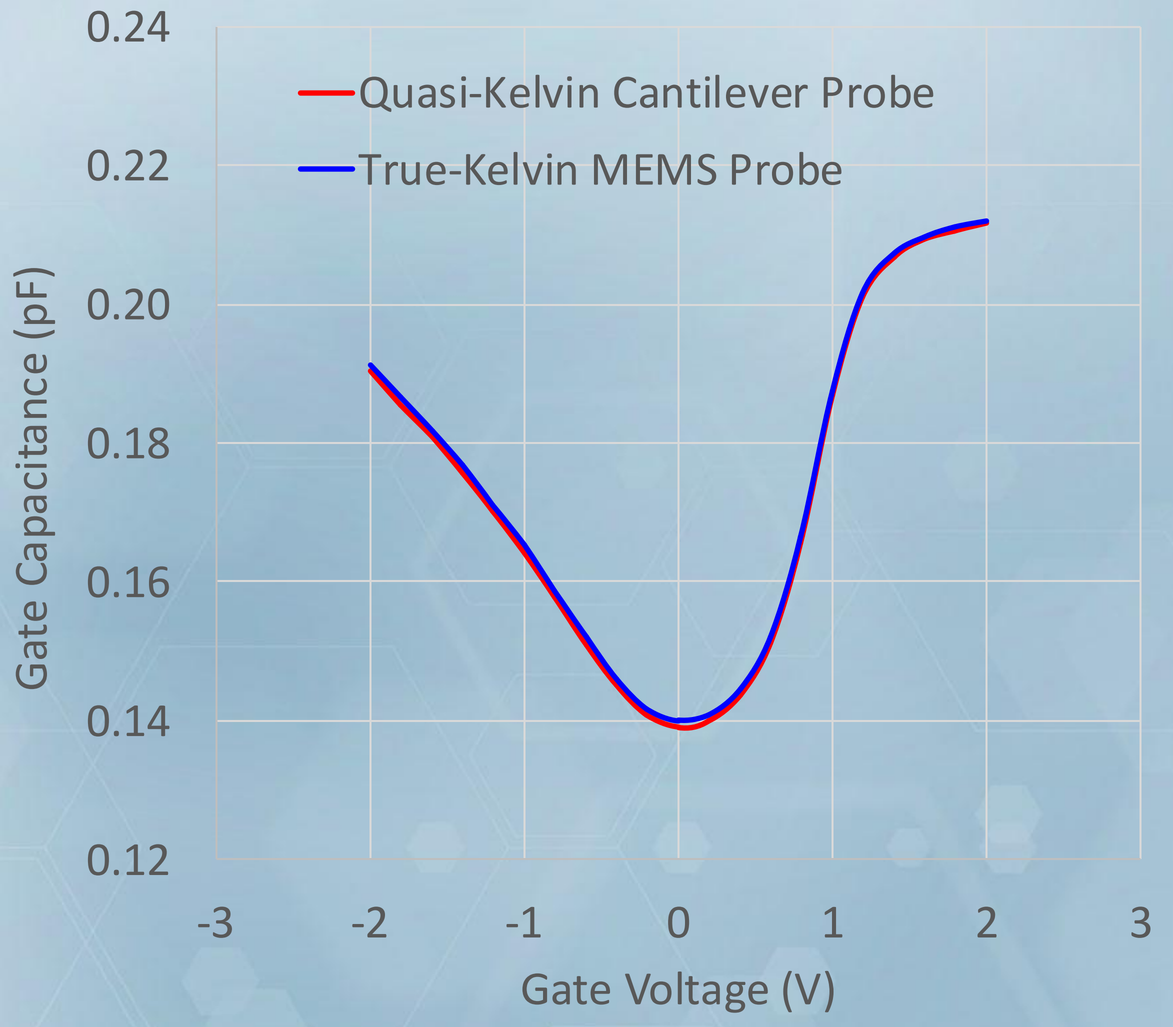
Probe Cleaning vs Touchdown

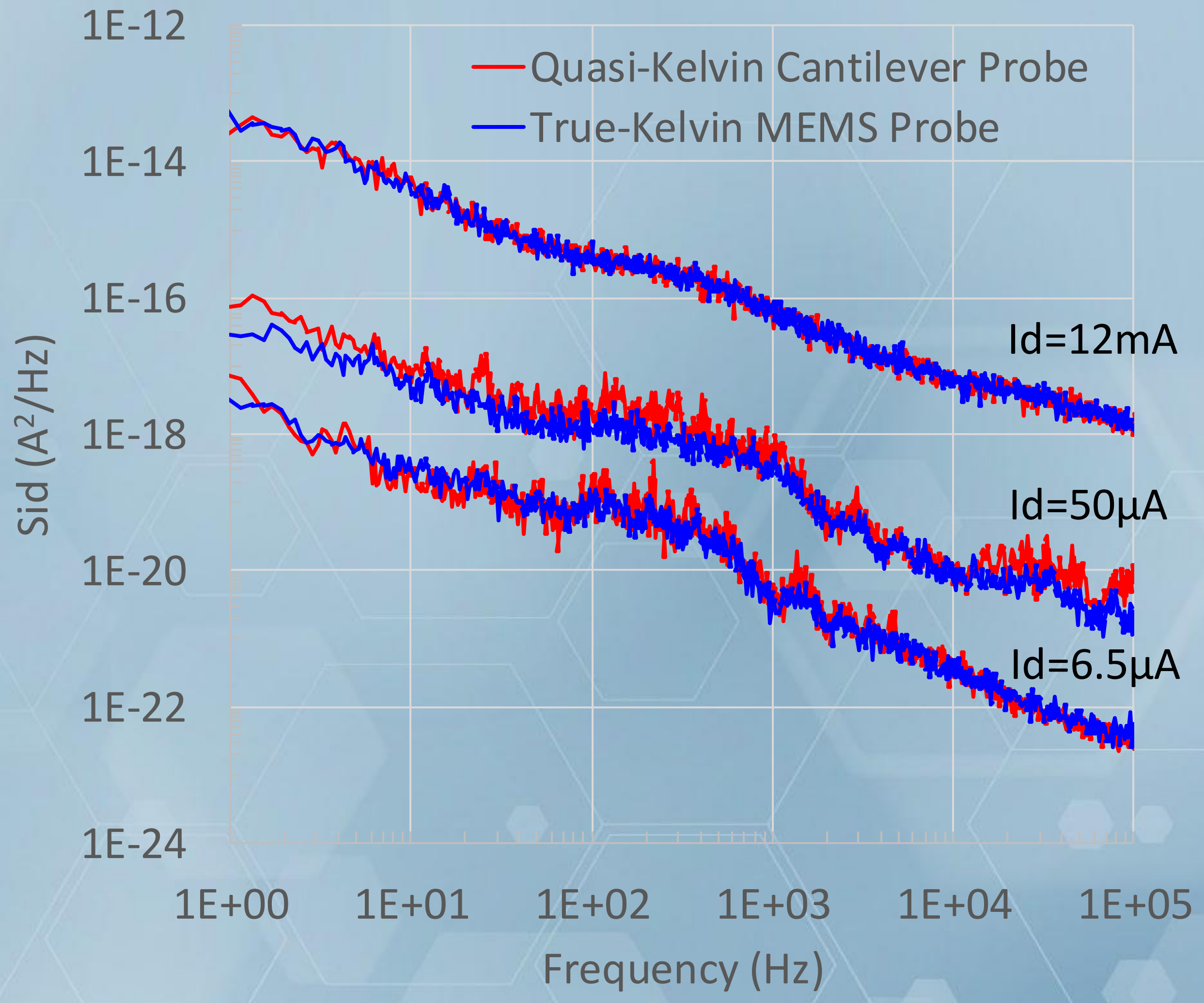
- **Quasi-Kelvin MEMS Probe**
  - Abrasive Probe cleaning needed
  - Deeper Probe Z overtravel

- **True-Kelvin MEMS Probe**
  - Minimal Probe Cleaning
  - Low and stable Rc (< 3mΩ)



CV & 1/f Noise Tests





Conclusion

- **Emerging GenAI Applications.**
- **Transistor Device is Foundational Pillar driving AI applications.**
- **True Kelvin MEMS Probes for Advanced-Node Tests**
  - Small Probe Scrub
  - Little Pad Damage
  - Minimal Probe Cleaning
  - Accurate and Repeatable IV measurements
  - Good correlations for CV and 1/f Noise measurements
  - Support Micro-Bump tests
  - Low Cost of Test with Long Lifetime

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Thank You!
Questions?

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