SWTEST 2026 CONFERENCE

35th ANNIVERSARY

New PEMS Probe and Wire Probe Designs Enabled by High-Conductivity Pd Alloys

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PT&K Co., LTD.
HIGH TECHNOLOGY

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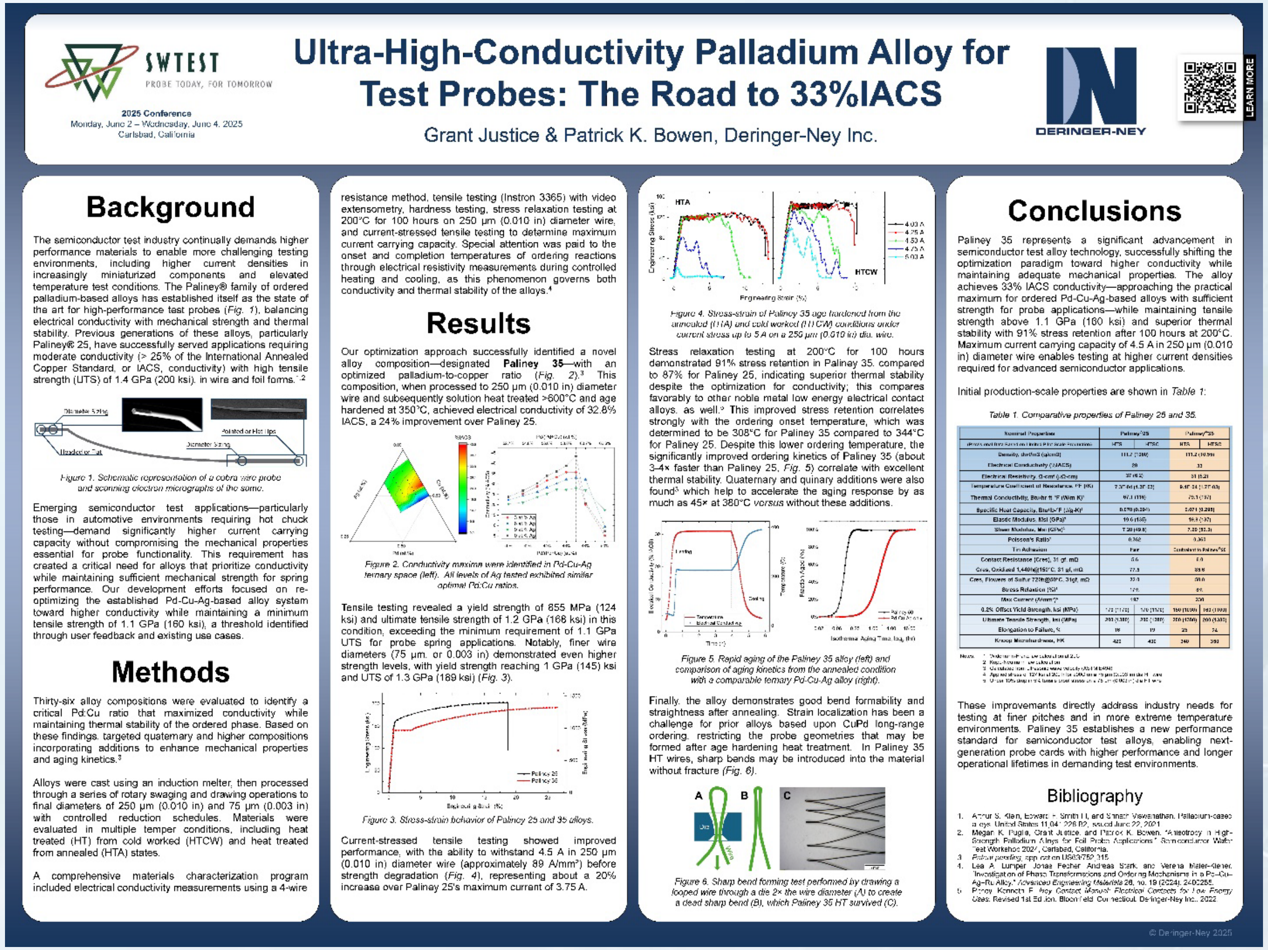
PT&K Co.

Overview

- Background on Paliney® 35 alloy design
- Objectives of the current study
- Package test opportunities with PT&K PEMS probes
- Opportunities for new Nidec wire probes
- Discussion of probe performance trends
- Summary & next steps

Background – Alloy Design



Ultra-High-Conductivity Palladium Alloy for Test Probes: The Road to 33%IACS

SWTEST PROBE TODAY, FOR TOMORROW

2025 Conference
Monday, June 2 – Wednesday, June 4, 2025
Carlsbad, California

Grant Justice & Patrick K. Bowen, Deringer-Ney Inc.

Background

The semiconductor test industry continually demands higher performance materials to enable more challenging testing environments, including higher current densities in increasingly miniaturized components and elevated temperature test conditions. The Paliney® family of ordered palladium-based alloys has established itself as the state of the art for high-performance test probes (*Fig. 1*), balancing electrical conductivity with mechanical strength and thermal stability. Previous generations of these alloys, particularly Paliney® 25, have successfully served applications requiring moderate conductivity (> 25% of the International Annealed Copper Standard, or IACS, conductivity) with high tensile strength (UTS) of 1.4 GPa (200 ksi), in wire and foil forms.[1,2]

Figure 1. Schematic representation of a cobra wire probe and scanning electron micrographs of the same.

Emerging semiconductor test applications—particularly those in automotive environments requiring hot chuck testing—demand significantly higher current carrying capacity without compromising the mechanical properties essential for probe functionality. This requirement has created a critical need for alloys that prioritize conductivity while maintaining sufficient mechanical strength for spring performance. Our development efforts focused on re-optimizing the established Pd-Cu-Ag-based alloy system toward higher conductivity while maintaining a minimum tensile strength of 1.1 GPa (160 ksi), a threshold identified through user feedback and existing use cases.

Methods

Thirty-six alloy compositions were evaluated to identify a critical Pd:Cu ratio that maximized conductivity while maintaining thermal stability of the ordered phase. Based on these findings, targeted quaternary and higher compositions incorporating additions to enhance mechanical properties and aging kinetics.[3]

Alloys were cast using an induction melter, then processed through a series of rotary swaging and drawing operations to final diameters of 250 µm (0.010 in) and 75 µm (0.003 in) with controlled reduction schedules. Materials were evaluated in multiple temper conditions, including heat treated (HT) from cold worked (HTCW) and heat treated from annealed (HTA) states.

A comprehensive materials characterization program included electrical conductivity measurements using a 4-wire resistance method, tensile testing (Instron 3365) with video extensometry, hardness testing, stress relaxation testing at 200°C for 100 hours on 250 µm (0.010 in) diameter wire, and current-stressed tensile testing to determine maximum current carrying capacity. Special attention was paid to the onset and completion temperatures of ordering reactions through electrical resistivity measurements during controlled heating and cooling, as this phenomenon governs both conductivity and thermal stability of the alloys.[4]

Results

Our optimization approach successfully identified a novel alloy composition—designated **Paliney 35**—with an optimized palladium-to-copper ratio (*Fig. 2*).[3] This composition, when processed to 250 µm (0.010 in) diameter wire and subsequently solution heat treated >600°C and age hardened at 350°C, achieved electrical conductivity of 32.8% IACS, a 24% improvement over Paliney 25.

Figure 2. Conductivity maxima were identified in Pd-Cu-Ag ternary space (left). All levels of Ag tested exhibited similar optimal Pd:Cu ratios.

Tensile testing revealed a yield strength of 855 MPa (124 ksi) and ultimate tensile strength of 1.2 GPa (168 ksi) in this condition, exceeding the minimum requirement of 1.1 GPa UTS for probe spring applications. Notably, finer wire diameters (75 µm, or 0.003 in) demonstrated even higher strength levels, with yield strength reaching 1 GPa (145) ksi and UTS of 1.3 GPa (189 ksi) (*Fig. 3*).

Figure 3. Stress-strain behavior of Paliney 25 and 35 alloys.

Current-stressed tensile testing showed improved performance, with the ability to withstand 4.5 A in 250 µm (0.010 in) diameter wire (approximately 89 A/mm²) before strength degradation (*Fig. 4*), representing about a 20% increase over Paliney 25's maximum current of 3.75 A.

Figure 4. Stress-strain of Paliney 35 age hardened from the annealed (HTA) and cold worked (HTCW) conditions under current stress up to 5 A on a 250 µm (0.010 in) dia. wire.

Stress relaxation testing at 200°C for 100 hours demonstrated 91% stress retention in Paliney 35, compared to 87% for Paliney 25, indicating superior thermal stability despite the optimization for conductivity; this compares favorably to other noble metal low energy electrical contact alloys, as well.[5] This improved stress retention correlates strongly with the ordering onset temperature, which was determined to be 308°C for Paliney 35 compared to 344°C for Paliney 25. Despite this lower ordering temperature, the significantly improved ordering kinetics of Paliney 35 (about 3–4× faster than Paliney 25, *Fig. 5*) correlate with excellent thermal stability. Quaternary and quinary additions were also found[3] which help to accelerate the aging response by as much as 45× at 380°C *versus* without these additions.

Figure 5. Rapid aging of the Paliney 35 alloy (left) and comparison of aging kinetics from the annealed condition with a comparable ternary Pd-Cu-Ag alloy (right).

Finally, the alloy demonstrates good bend formability and straightness after annealing. Strain localization has been a challenge for prior alloys based upon CuPd long-range ordering, restricting the probe geometries that may be formed after age hardening heat treatment. In Paliney 35 HT wires, sharp bends may be introduced into the material without fracture *(Fig. 6)*.

Figure 6. Sharp bend forming test performed by drawing a looped wire through a die 2× the wire diameter (A) to create a dead sharp bend (B), which Paliney 35 HT survived (C).

Conclusions

Paliney 35 represents a significant advancement in semiconductor test alloy technology, successfully shifting the optimization paradigm toward higher conductivity while maintaining adequate mechanical properties. The alloy achieves 33% IACS conductivity—approaching the practical maximum for ordered Pd-Cu-Ag-based alloys with sufficient strength for probe applications—while maintaining tensile strength above 1.1 GPa (160 ksi) and superior thermal stability with 91% stress retention after 100 hours at 200°C. Maximum current carrying capacity of 4.5 A in 250 µm (0.010 in) diameter wire enables testing at higher current densities required for advanced semiconductor applications.

Initial production-scale properties are shown in *Table 1*:

Table 1. Comparative properties of Paliney 25 and 35.

Nominal Properties	Paliney® 25		Paliney® 35	
[illegible]	HTS	HTSC	HTS	HTSC
Density	[illegible]		[illegible]	
Electrical Conductivity (%IACS)	28		33	
Electrical Resistivity	37 (6.2)		31 (5.2)	
Temperature Coefficient of Resistance	[illegible]		[illegible]	
Thermal Conductivity	[illegible]		[illegible]	
Specific Heat Capacity	[illegible]		[illegible]	
Elastic Modulus, Msi (GPa)	[illegible]		[illegible]	
Shear Modulus, Msi (GPa)	[illegible]		[illegible]	
Poisson's Ratio	[illegible]		[illegible]	
Tin Adhesion	Fair		[illegible]	
Contact Resistance (Cres)	[illegible]		[illegible]	
Cres, Oxidized	[illegible]		[illegible]	
Cres, Flowers of Sulfur	[illegible]		[illegible]	
Stress Relaxation (%)	[illegible]		[illegible]	
Max Current (A/mm²)	[illegible]		[illegible]	
0.2% Offset Yield Strength, ksi (MPa)	[illegible]	[illegible]	[illegible]	[illegible]
Ultimate Tensile Strength, ksi (MPa)	[illegible]	[illegible]	[illegible]	[illegible]
Elongation to Failure, %	18	19	25	[illegible]
Knoop Microhardness, HK	420	[illegible]	340	[illegible]

These improvements directly address industry needs for testing at finer pitches and in more extreme temperature environments. Paliney 35 establishes a new performance standard for semiconductor test alloys, enabling next-generation probe cards with higher performance and longer operational lifetimes in demanding test environments.

Bibliography

1. Arthur S. Klein, Edward F. Smith III, and Srinath Viswanathan. Palladium-based alloys. United States 11,041,226 B2, issued June 22, 2021.
2. Megan K. Puglia, Grant Justice, and Patrick K. Bowen. "Anisotropy in High-Strength Palladium Alloys for Foil Probe Applications." Semiconductor Wafer Test Workshop 2024, Carlsbad, California.
3. Patent pending, application US63/752,315.
4. Lea A. Lumper, Jonas Fecher, Andreas Stark, and Verena Maier-Kiener. "Investigation of Phase Transformations and Ordering Mechanisms in a Pd–Cu–Ag–Ru Alloy." *Advanced Engineering Materials* 26, no. 19 (2024): 2400255.
5. Pitney, Kenneth E. *Ney Contact Manual: Electrical Contacts for Low Energy Uses*. Revised 1st Edition. Bloomfield, Connecticut: Deringer-Ney Inc., 2022.

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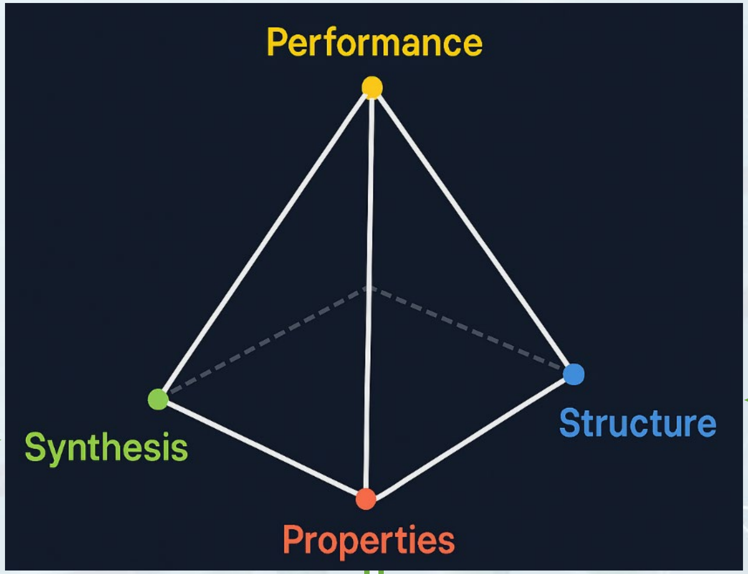
- **Introduced Paliney 35 alloy with 33% IACS in 2025**
- **Prior work emphasized testing of:**
  - Thermal stability
  - Current carrying capacity of wire
  - Formability
  - Production-scale property data

Background – Alloy Design

- **Multiple cold work & anneal steps for casting breakdown**
- **Wire drawing and strand annealing**
- **Age hardening heat treatment, optimized per form (spooled wire *vs.* cut lengths)**



- **Compositions based on Pd-Ag-Cu-Re**
- **Three-phase structure**
  - **FCC disordered solid solution**
  - **CsCl-type long range order**
  - **HCP Re-based**

<u>Paliney 25†</u>

- **200 ksi UTS**
- **19% elong.**
- **27% IACS**
- **HK 400**

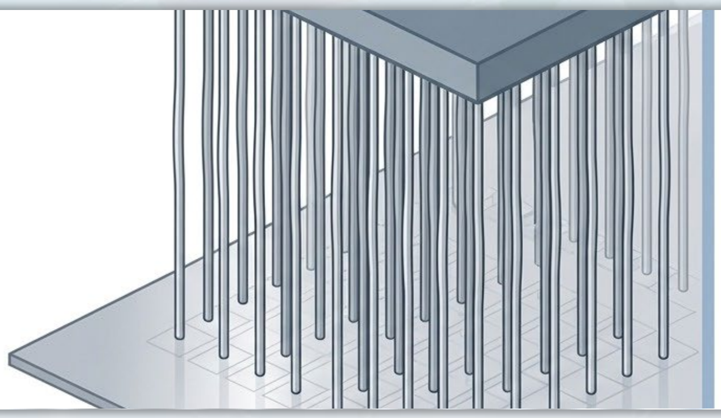
<u>Paliney 35‡</u>

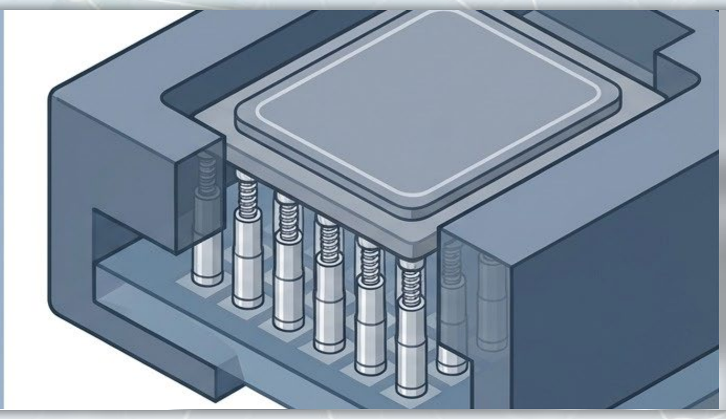
- **200 ksi UTS**
- **24% elong.**
- **33% IACS**
- **HK 350**

† US Patent 10,385,424
‡ US Patent Pending

Objectives of this Work

- Compile collaborative Paliney 35 alloy test data on PEMS and cobra wire probe geometries
- Analyze new material performance vs. baselines
- Determine if new alloy will enable new probe, probe card, and/or socket designs
- Interpret probe performance through a materials science lens





Background – PEMS Probes

The PEMS Probe was developed at PT&K to overcome limitations of MEMS probes:

PEMS (Press Engineering Mechanical System) vs. **MEMS (Micro-ElectroMechanical Systems)**

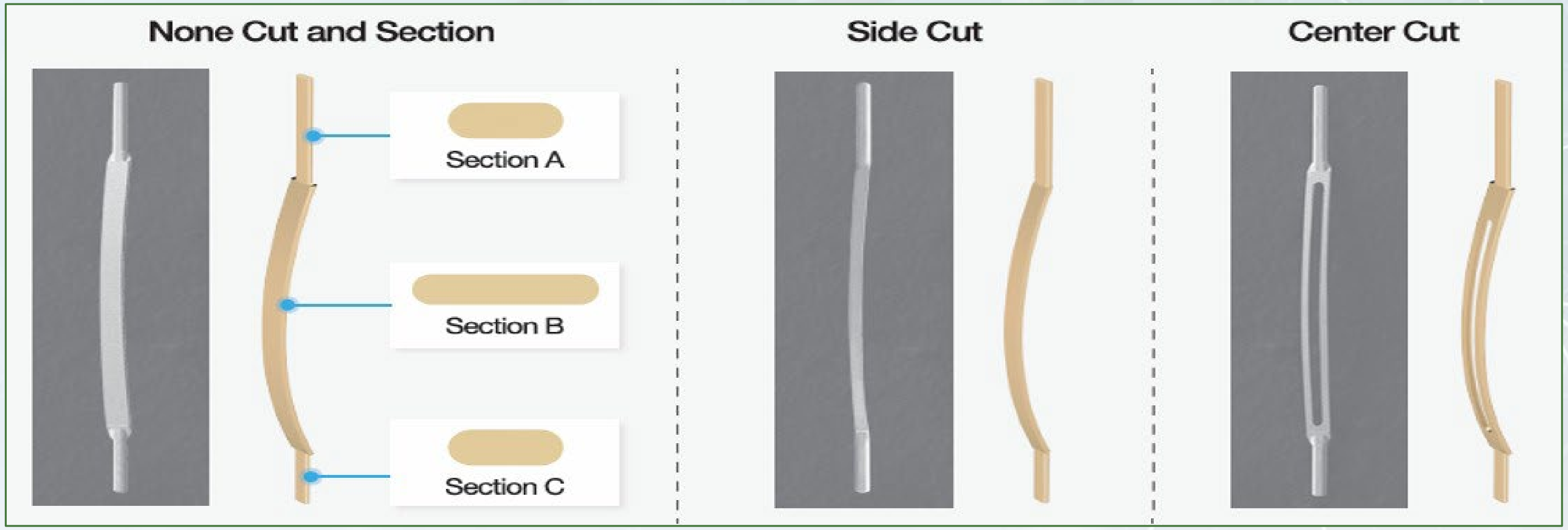
PEMS (Press Engineering Mechanical System)

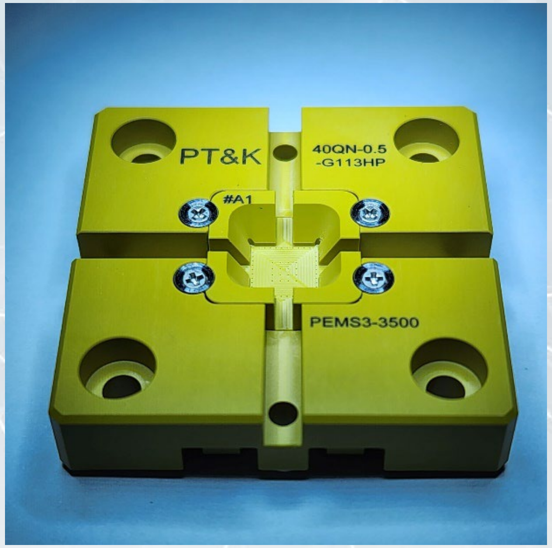
- Manufactured by precision press and tooling
- Preserves monolithic alloy electrical and physical properties
- Suitable for testing increasingly miniaturized circuits

MEMS (Micro-ElectroMechanical Systems)

- Multilayer structures that can deteriorate rapidly
- Suffer in high- and low-temperature testing applications

PEMS:



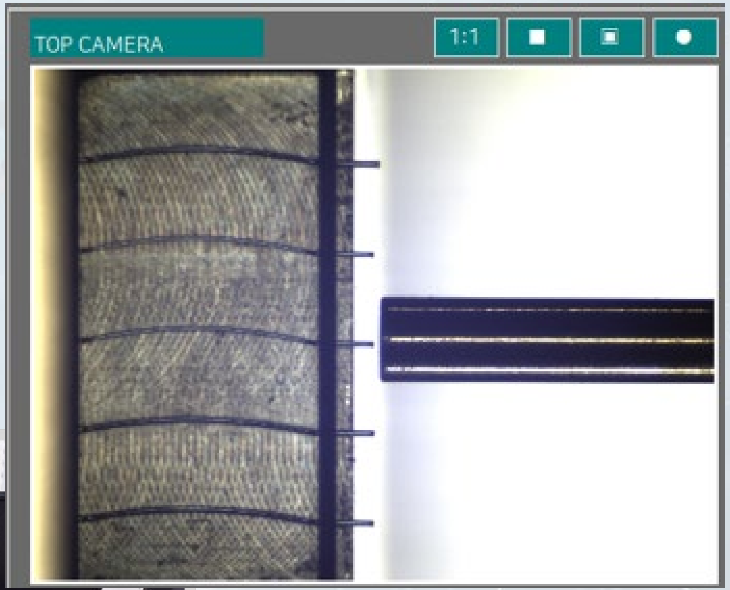


Methods – PEMS Probes

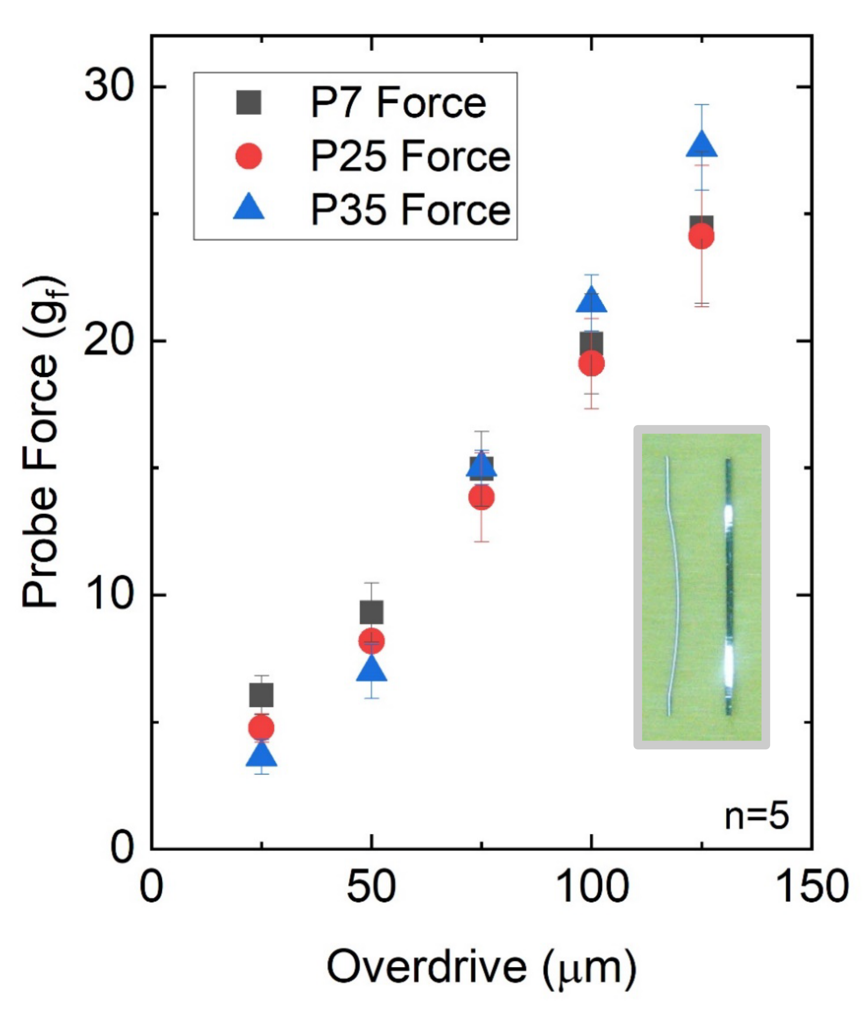
PEMS pins used in test:

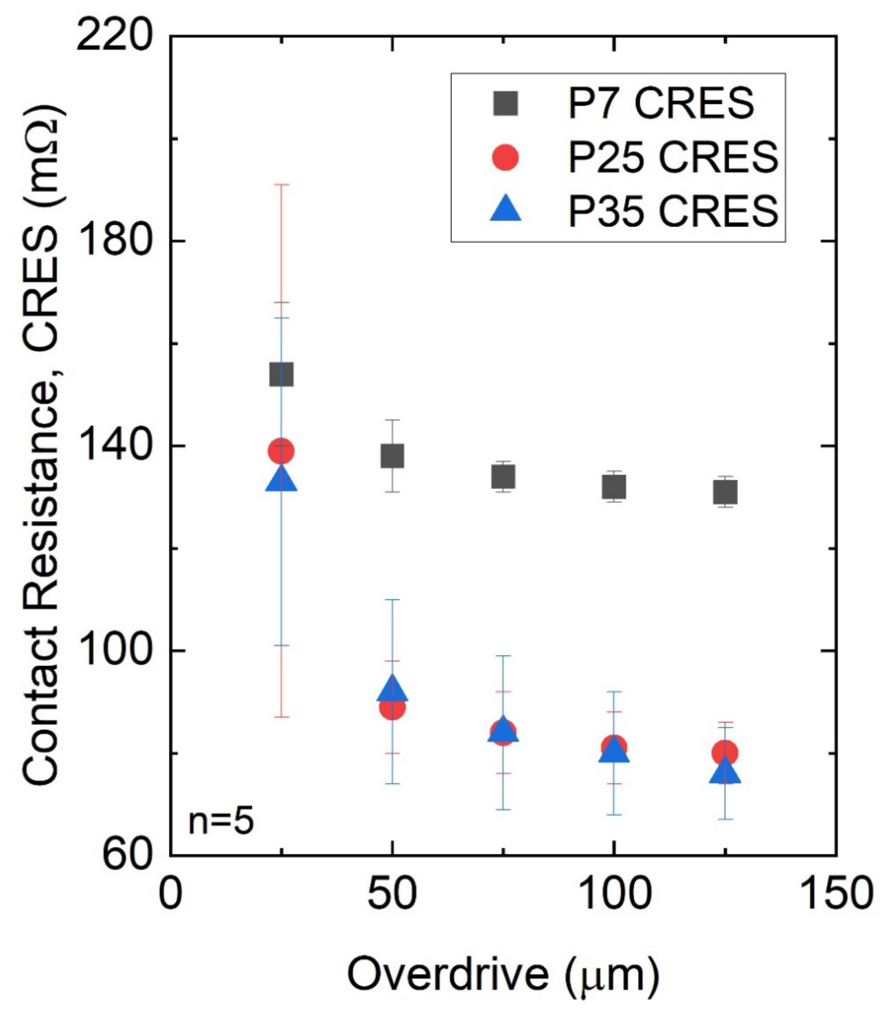
- **Wire diameter: 0.003in (75.4µm)**
- **Total length: 3.5mm**
- **Materials :**
  - Paliney 7 (P7)
  - Paliney 25 (P25)
  - Paliney 35 (P35)
- **20°C ambient**
- **n=5 replicates**

Pin Force / Contact Resistance (CRES)/ Current-Carrying Capacity (CCC) Tester:



Results – PEMS Probes

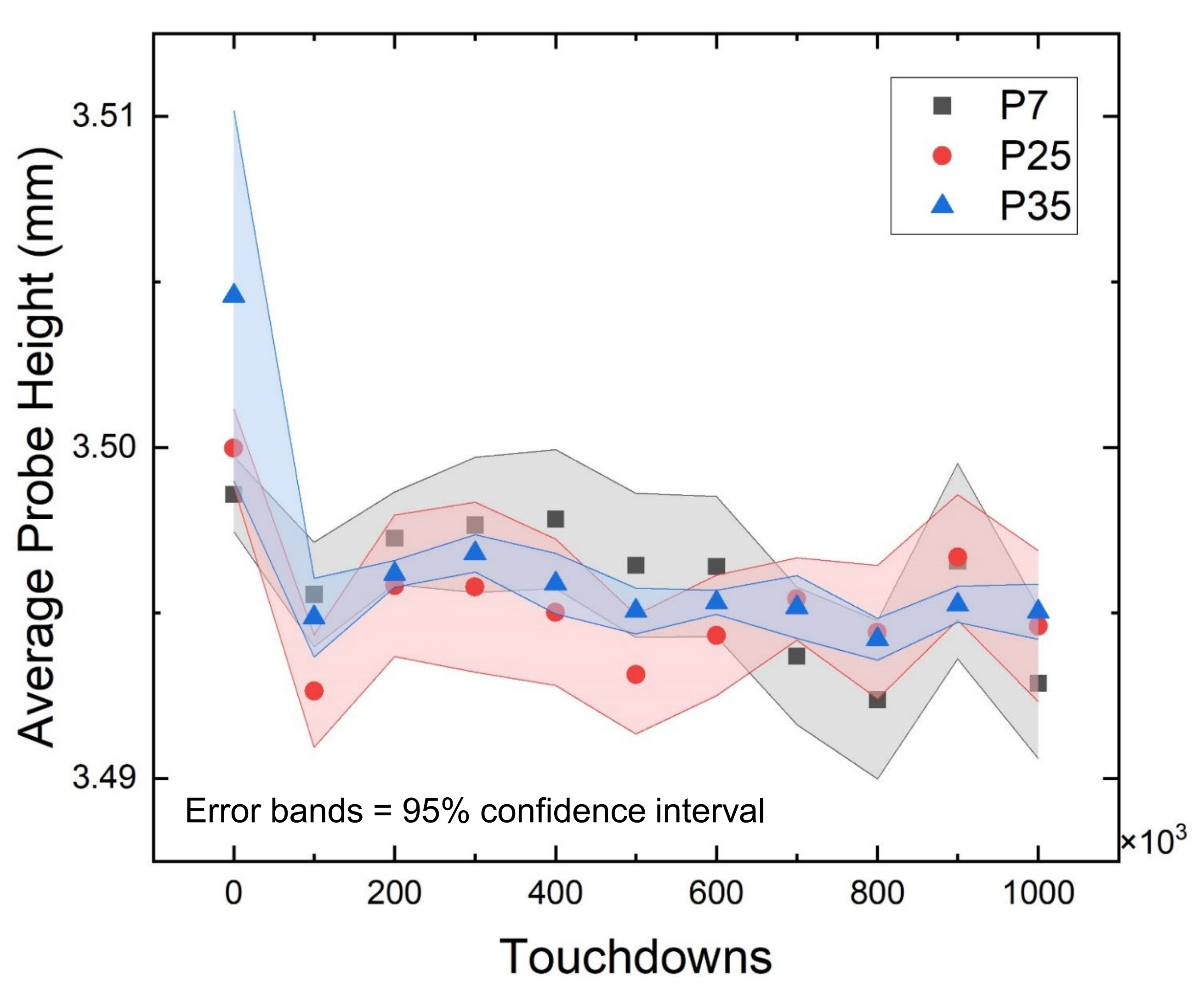




- Force-deflection behavior is similar for all tested materials in PEMS geometry
- CRES is very similar between P25 & P35 PEMS
- P25 & P35 CRES superior to P7

Results – PEMS Probes

- **Pin heights initially decrease, then vary within a fixed range of ±5µm**
- **Array height trends overlap significantly between all materials**
- **Dimensional stability is confirmed over 1M touchdowns for modern (P25, P35) and legacy (P7) PEMS pin materials**

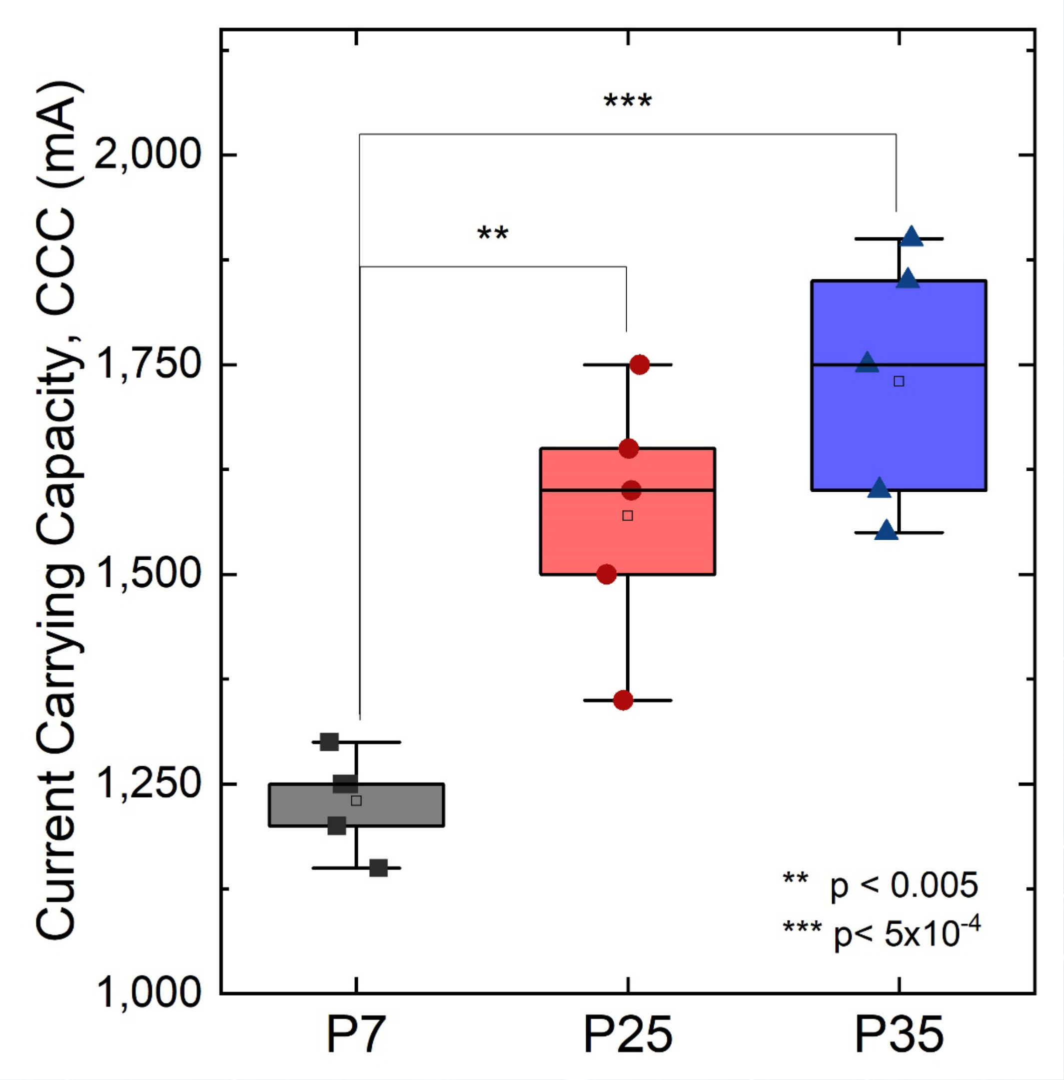


Results – PEMS Probes

- **Both modern alloys—P25 and P35—were confirmed to have higher CCC than legacy P7 alloy**
- **Expected vs. observed CCC increase from material data:**

Alloy	P25	P35	P35-P25Δ
Datasheet	197 A/mm^2	230 A/mm^2	+ 16.8%
PEMS	1,570 mA	1,730 mA	+ 10.2%

- **Statistical significance of CCC increase from P25 to P35 could not be confirmed at n=5 replicates**

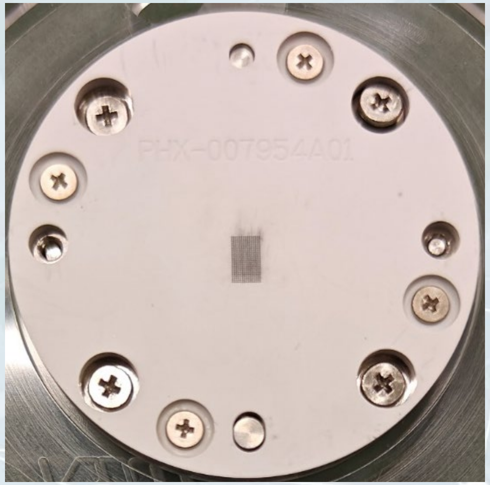


Methods – Wire Wafer Test Probes

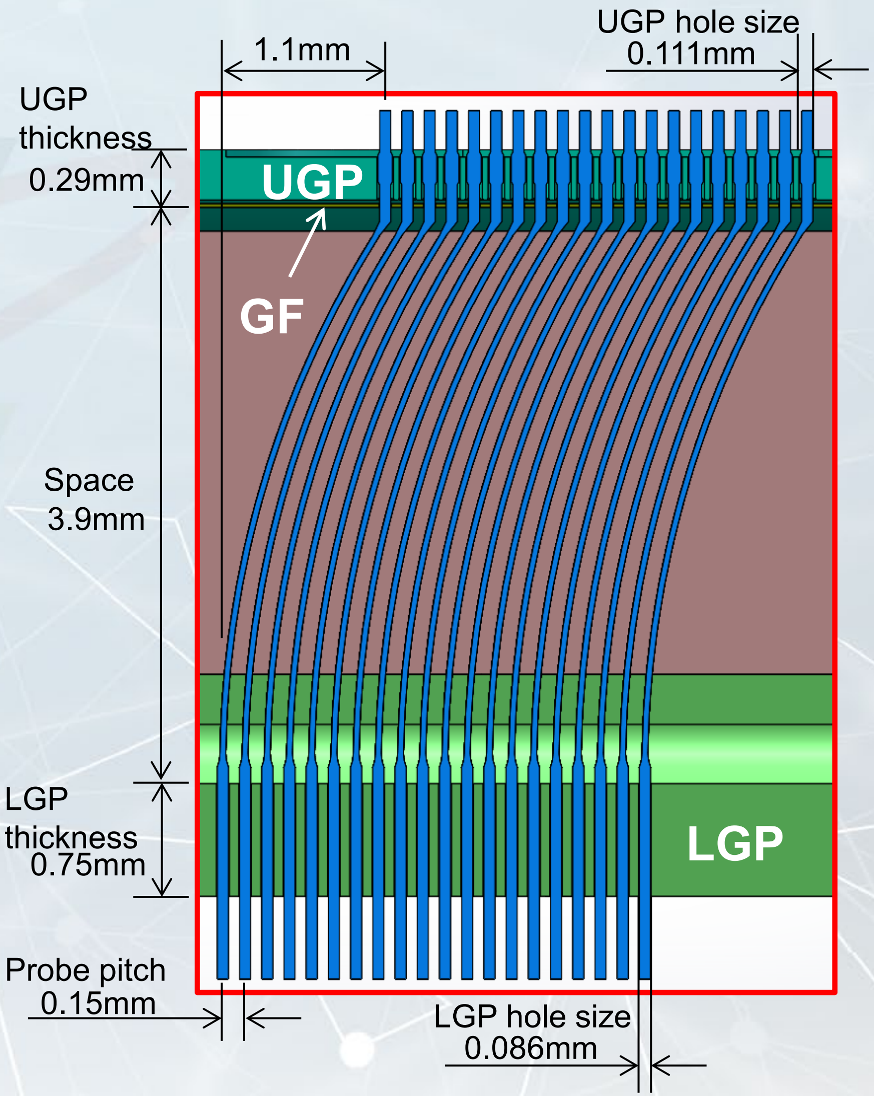
Nidec performed a 1-million touchdown test with P35 and conventional Paliney H3C “cobra”-style wire probes:

Condition	Conditions
Prober	UF3000
Chuck temp	150°C
OD	Ø125µm at 0 – 500k touchdowns
	Ø90µm at 500k – 1M touchdowns

Criterion	Spec	Target
Alignment	±25um	Variation from initial point: < 20µm
Planarity	38um	< 50µm
Probe force	-	± 30% from initial value
Contact resistance	-	< 3Ω at initial



DUT side

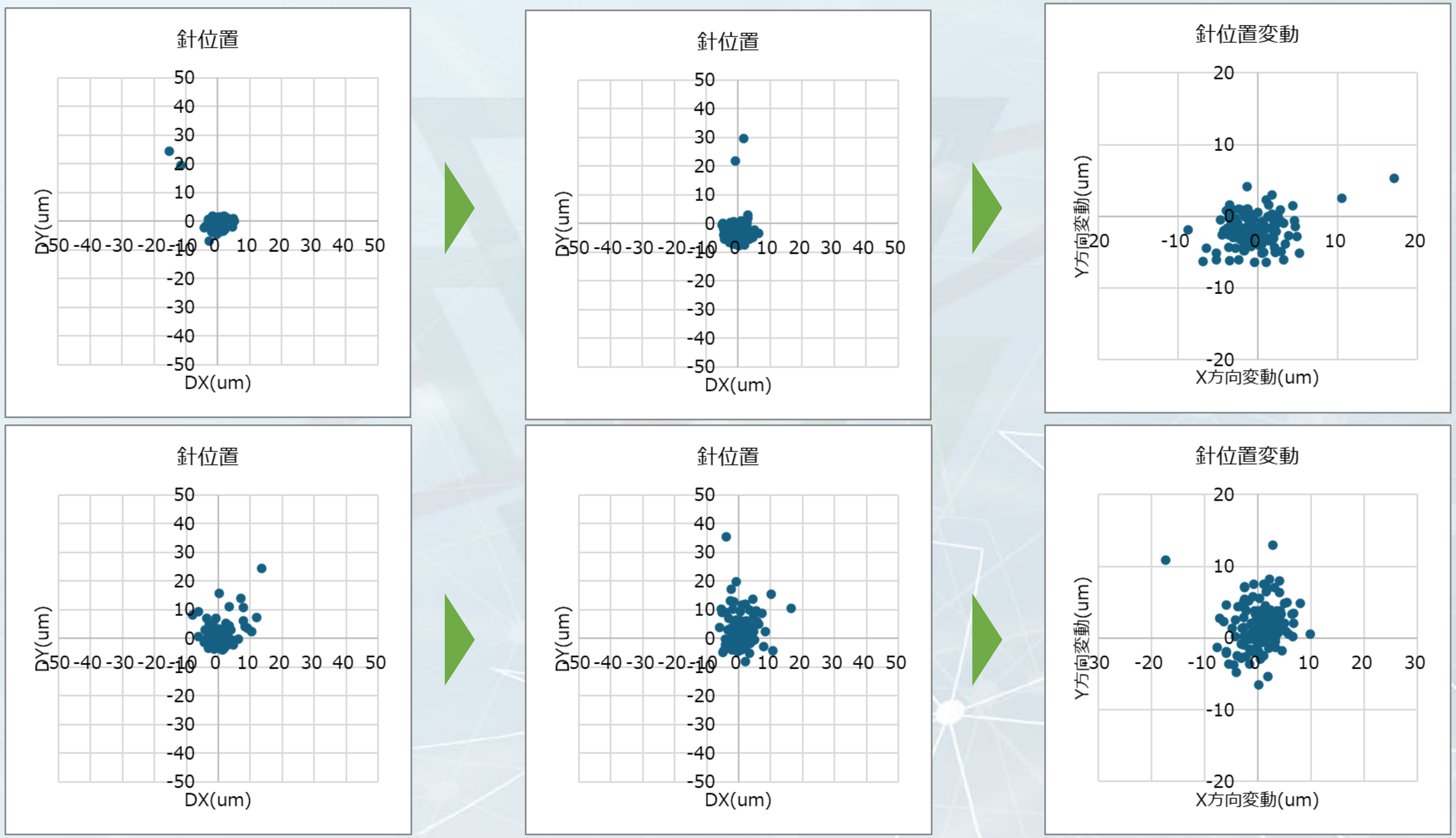


Results – Wire Wafer Test Probes

Beginning state | **Finish state** | **Δ Position**

Paliney H3C

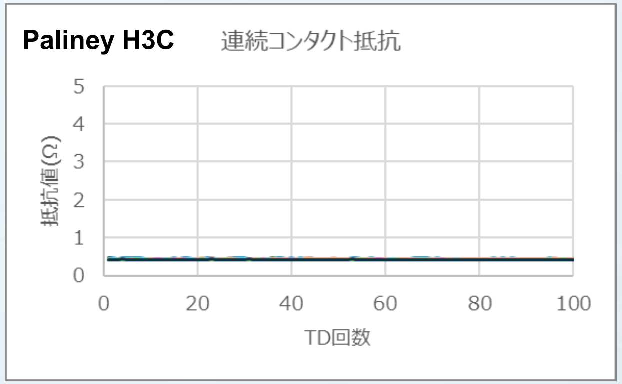
Paliney 35

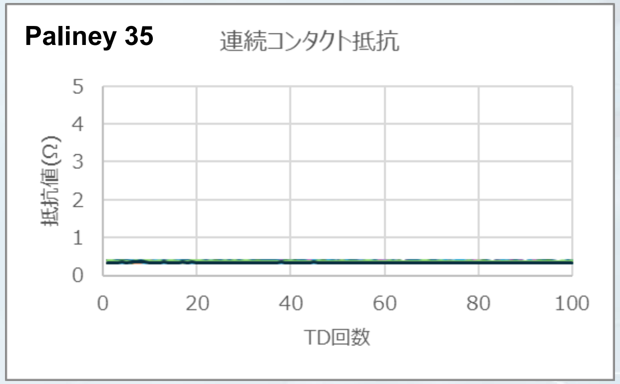


The magnitude of positional change is equivalent between materials

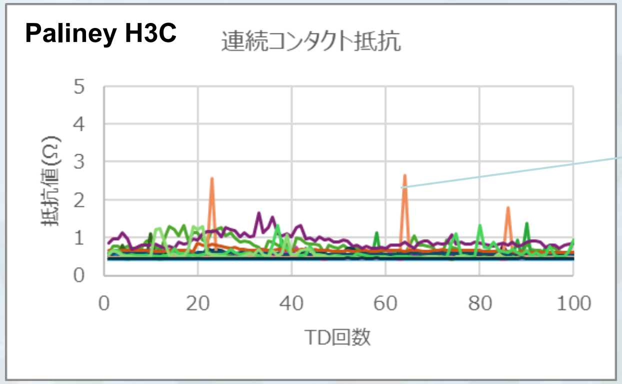
Results – Wire Wafer Test Probes

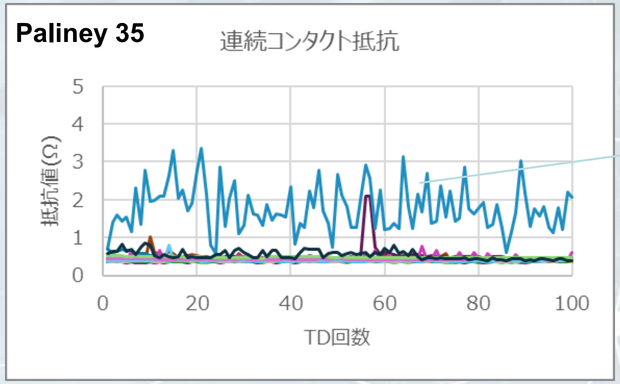
Initial Condition CRES



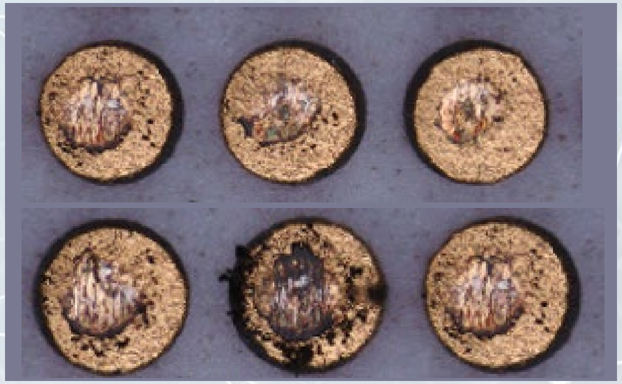


Final Condition CRES





Visual Final Condition

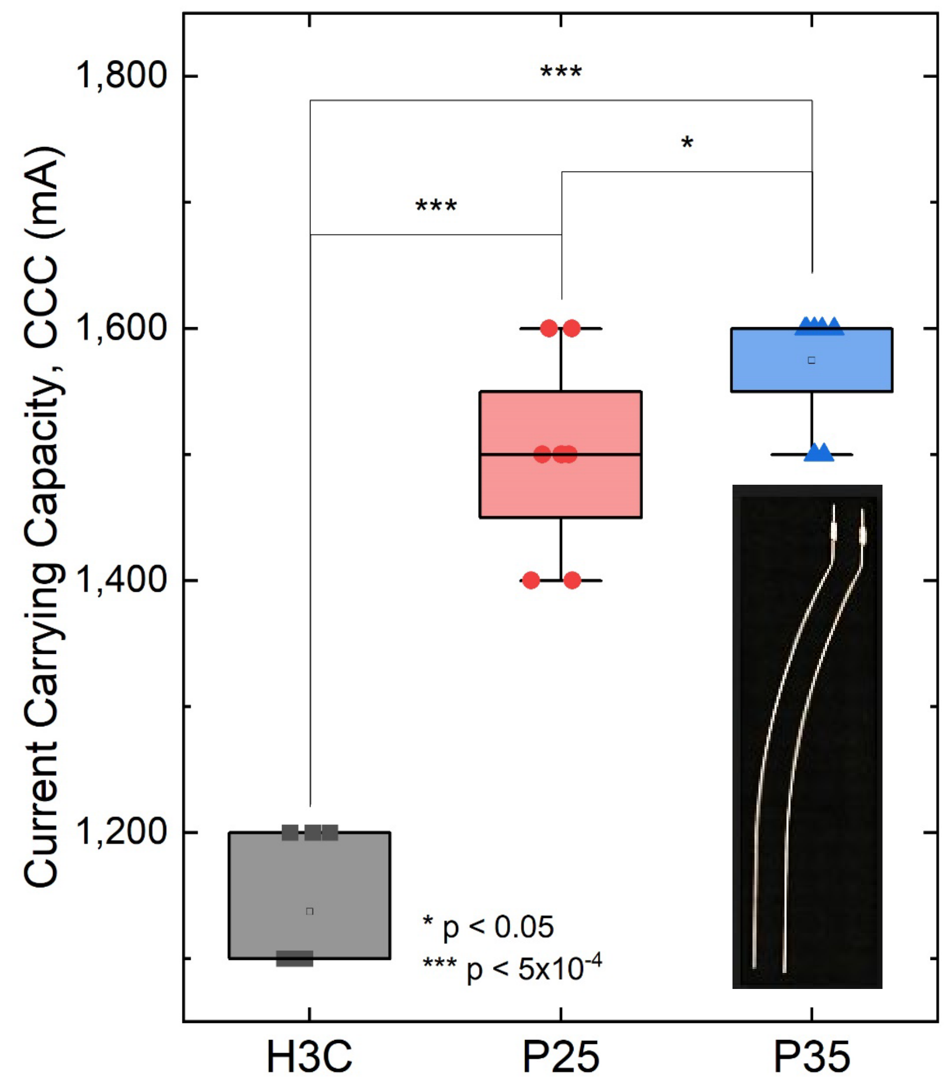


P35 and H3C materials exhibit qualitatively similar CRES variation and debris accumulation after prolonged use

Results – Wire Wafer Test Probes

- Both modern alloys—P25 and P35—were confirmed to have higher CCC than legacy H3C alloy
- At n=8, CCC increase from P25 to P35 was statistically significant
- Expected vs. observed CCC increase from material data:

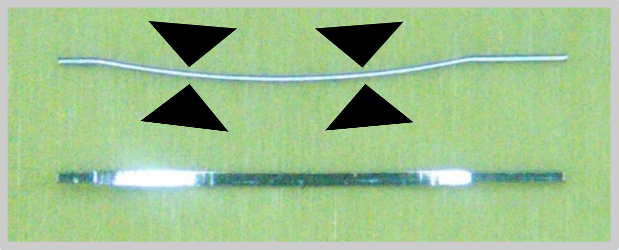
Alloy	P25	P35	P35-P25Δ
Datasheet	197 A/mm^2	230 A/mm^2	+ 16.8%
Cobra	1,500 mA	1,575 mA	+ 5.0%

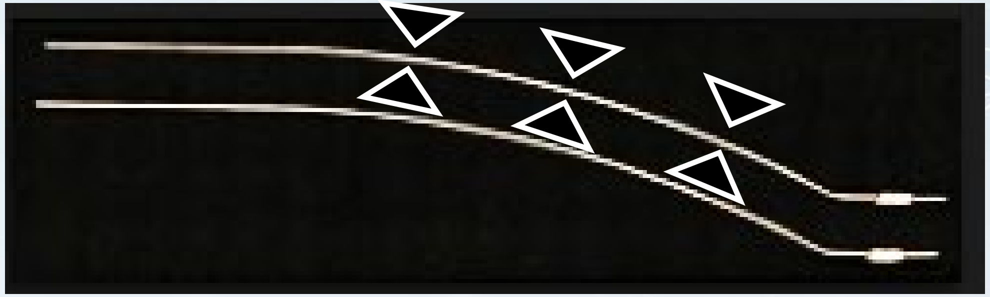


Discussion – Probe CCC

Alloy	P25	P35	P35-P25Δ
Datasheet	197 A/mm^2	230 A/mm^2	+ 16.8%
PEMS	1,570 mA	1,730 mA	+ 10.2%
Cobra	1,500 mA	1,575 mA	+ 5.0%

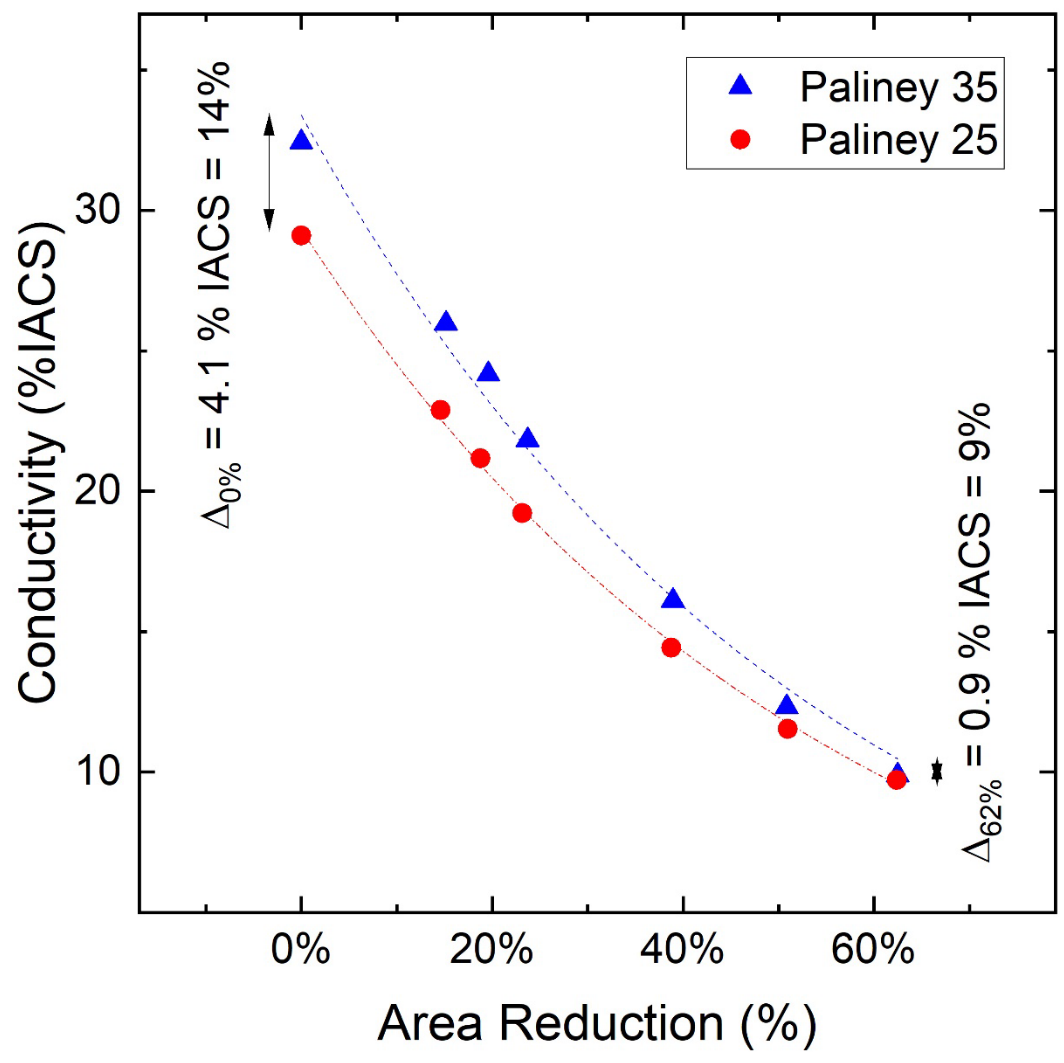
Deformed areas





- Increases in CCC are observed
- Magnitude of the increase less than expected for the cobra-style probes studied
- Hypothesis: plastic deformation of the material during probe manufacturing may reduce CCC benefit of the new alloy

Results – Deformation effects



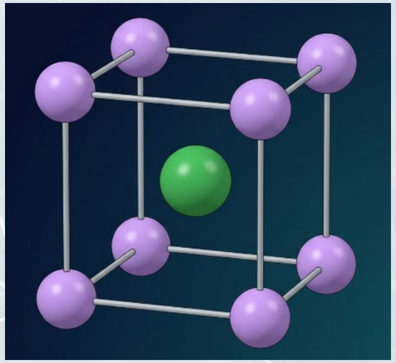
- Performed additional cold wire drawing of age hardened P25 and P35 wires from Ø0.009 to 0.0055 in, then measured electrical conductivity
- 35% of conductivity improvement of P35 over P25 is lost at maximum area reduction
- This is a plausible explanation for diminished CCC returns in cobra probes

Summary

- **PT&K PEMS conclusion:**
  - P35 showed the highest average value of 1,730 mA, making it the most suitable material for high-current socket applications.
- **Nidec wire probe conclusion:**
  - Paliney 35 can be used as probe material.
  - Using Paliney 35 should improve burned probe issues.
- **Deringer-Ney conclusions:**
  - The new Paliney 35 alloy is expected to enable new probe, socket, and probe card designs based on the feedback.
  - A diminished CCC benefit of P35 vs. P25 cobra probes of ~5% actual vs. ~17% predicted was observed.

Follow-On Work

- **Collect additional lifetime test data to build statistically robust comparisons between legacy and modern alloys**
- **Review mechanism of Paliney 35 CCC decrease after area reduction in more detail. Is it:**
  - Disordering of the age hardened material?
  - Distortion of the ordered superlattice?
  - Some other effect?



- **Test additional probe designs to optimize CCC and probe force balance per application requirement**