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

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

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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]

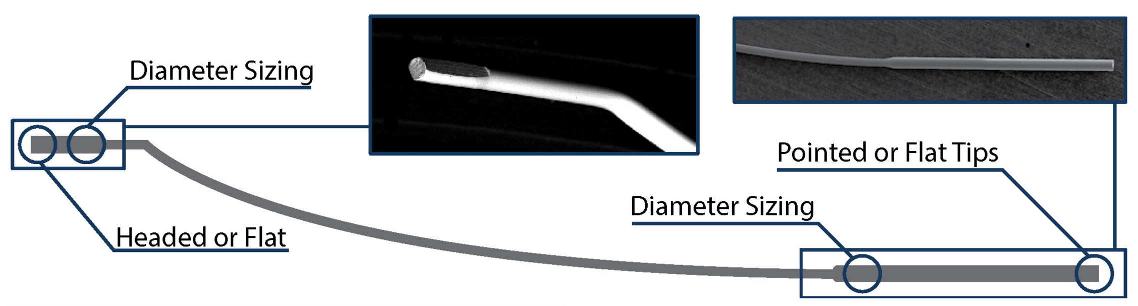

Figure 1. Schematic representation of a cobra wire probe and scanning electron micrographs of the same.

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.

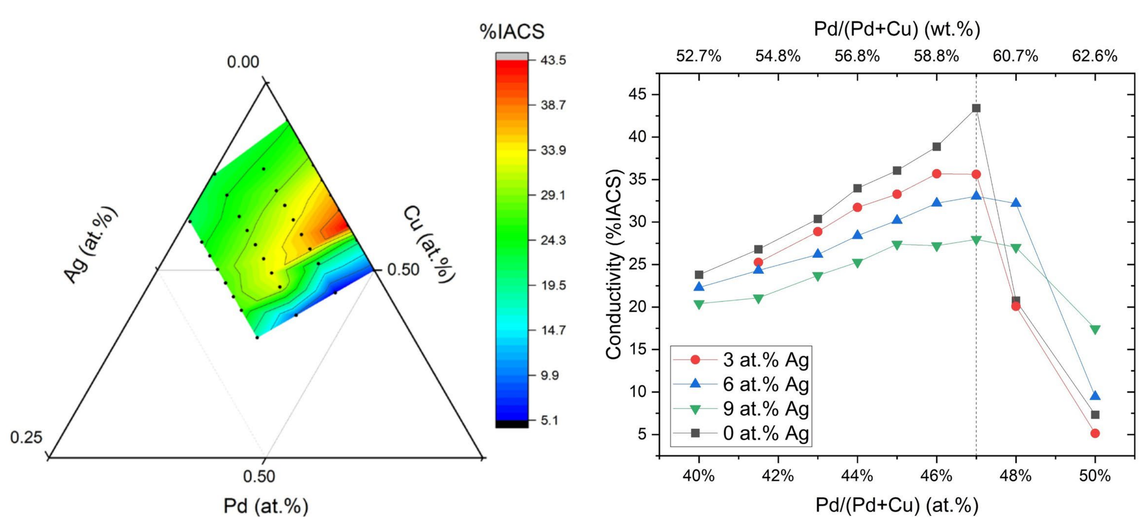

Figure 2. Conductivity maxima were identified in Pd-Cu-Ag ternary space (left). All levels of Ag tested exhibited similar optimal Pd:Cu ratios.

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*).

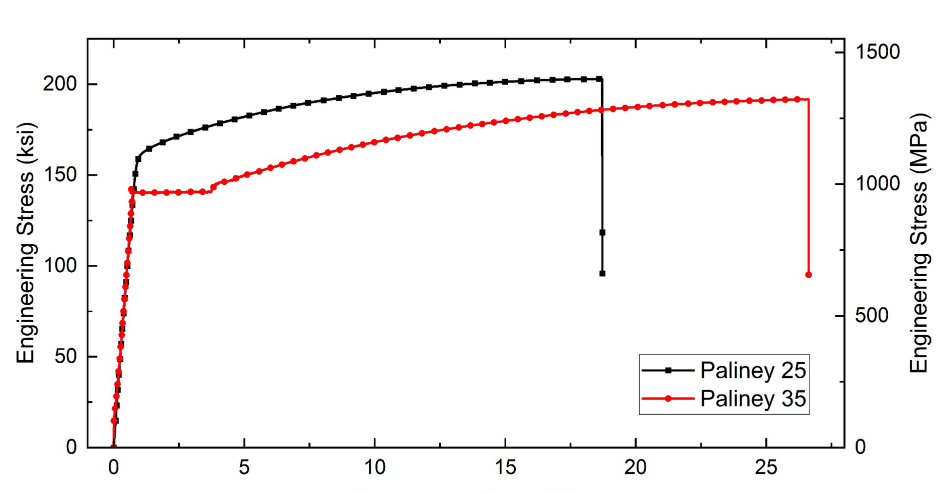

Figure 3. Stress-strain behavior of Paliney 25 and 35 alloys.

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.

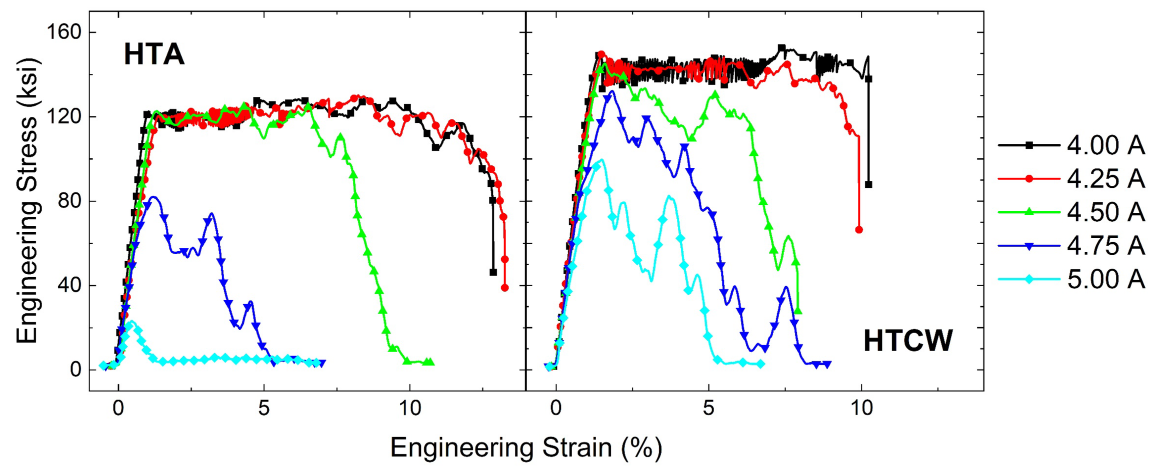

Figure 4. Stress-strain of Paliney 35 age hardened from the annealed (HTA) and cold worked (HTCW) conditions under current stress up to 5 A on a 250 µm (0.010 in) dia. wire.

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.

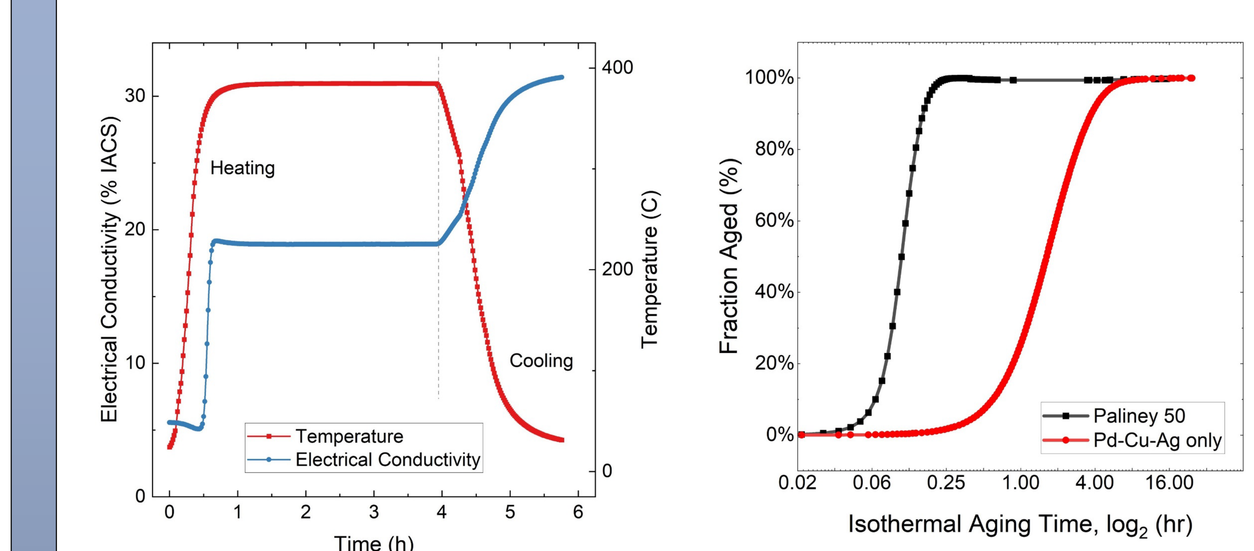

Figure 5. Rapid aging of the Paliney 35 alloy (left) and comparison of aging kinetics from the annealed condition with a comparable ternary Pd-Cu-Ag alloy (right).

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)*.

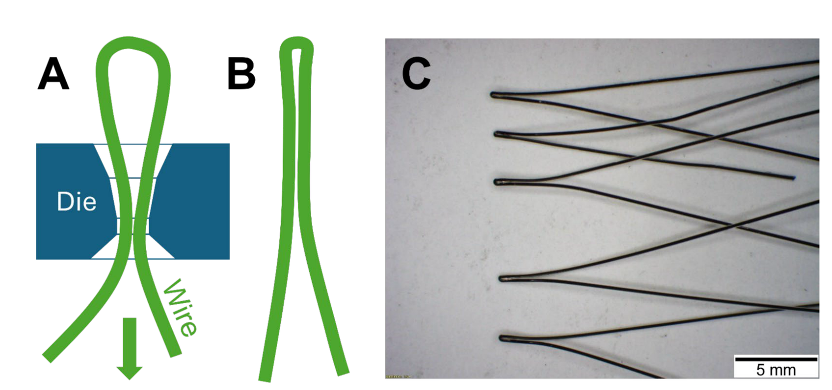

Figure 6. Sharp bend forming test performed by drawing a looped wire through a die 2× the wire diameter (A) to create a dead sharp bend (B), which Paliney 35 HT survived (C).

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	
(Provisional Data Based on Limited Pilot Scale Production)	HTS	HTSC	HTS	HTSC
Density, dwt/in3 (g/cm3)	111.7 (1060)		111.2 (10.55)	
Electrical Conductivity (%IACS)	28		33	
Electrical Resistivity, Ω-cmf (µΩ-cm)	37 (6.2)		31 (5.2)	
Temperature Coefficient of Resistance, /°F (/K)	7.3E-04 (1.3E-03)		9.4E-04 (1.7E-03)	
Thermal Conductivity, Btu/hr-ft-°F (W/m-K)[1]	67.1 (116)		79.1 (137)	
Specific Heat Capacity, Btu/lb-°F (J/g-K)[2]	0.070 (0.294)		0.071 (0.298)	
Elastic Modulus, Msi (GPa)[3]	19.6 (135)		19.8 (137)	
Shear Modulus, Msi (GPa)[3]	7.20 (49.6)		7.29 (50.3)	
Poisson's Ratio[3]	0.362		0.360	
Tin Adhesion	Fair		Equivalent to Paliney®25	
Contact Resistance (Cres), 31 gf, mΩ	5.6		6.0	
Cres, Oxidized 1,440h@150°C, 31 gf, mΩ	77.5		85.6	
Cres, Flowers of Sulfur 720h@50°C, 31gf, mΩ	22.0		50.0	
Stress Relaxtion (%)[4]	17%		8%	
Max Current (A/mm²)[5]	197		230	
0.2% Offset Yield Strength, ksi (MPa)	170 (1170)	170 (1170)	150 (1030)	160 (1100)
Ultimate Tensile Strength, ksi (MPa)	200 (1380)	200 (1380)	200 (1380)	200 (1380)
Elongation to Failure, %	16	19	25	24
Knoop Microhardness, HK	420	400	340	350

Notes:
1. Widemann-Franz law calculation at 20C
2. Kopp-Neumann law calculation
3. Calculated from ultrasonic wave velocity (ASTM E494)
4. Applied stress of 127 ksi at 200 h for 200C on a 75 µm (0.003 in) dia HT wire
5. Under 10% drop in 5% tensile proof stress on a 75 µm (0.003 in) dia HT wire

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.

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