Development of stable, low resistance solder joints for space-flight HTS lead assemblies

Edgar R. Canavan¹, Meng Chiao², Lyudmyla Panashchenko¹, and Michael Sampson³

¹ NASA – Goddard Space Flight Center
² Alcyon Technical Services, LLC
³ SGT, Inc
Background: Astro-H (Hitomi)/SXS

Soft X-ray Spectrometer used a microcalorimeter array operating at 50 mK

SXS Thermal System:
- (2x) 2 stage Stirling coolers
- JT cooler (4.5 K)
- 40 l LHe tank (1.2 K)
- 3 stage ADR (50 mK)

HTS leads for ADR magnet current (2 A) needed to meet stringent parasitic heat load requirements
- HTS allocation: 10 µW @ 1.2 K; 670 µW @ 4.5 K

17 February 2016: Hitomi launched; SXS performs flawlessly
Background: XARM/RESOLVE

- In first few weeks, SXS demonstrated unprecedented resolution & discovered important new results
- 26 March, 2016: Attitude control system incident disables spacecraft
- 2017 — Start recovery mission
  - RESOLVE instrument – identical to SXS
  - Rapid turn around (2019 delivery to JAXA)
  - “build to print” with very few exceptions
RESOLVE HTS Lead Assemblies — Approach

- Physical structure identical to Astro-H

- Composite support structure
- Bolted joint — transition to ADR magnet leads
- Cold end transition board
- Heat sink at JT shield
- Connector — transition to standard harness
- Warm end transition board
- Solder pads: 100 µm cu /immersion Ag
- 1 mm Ag5%Au coated REBCO tape

Madison, WI, July 10–14, 2017
RESOLVE HTS Lead Assemblies – Changes

• Changes driven by issues encountered in Astro-H
  – $I_c$ degradation, esp. in humid environment
    • SXS: REBCO 2G conductor, Ag/Au coated, slit to 1 mm after
    • Concern over lateral H2O & CO2 transport from exposed edges
    • RESOLVE: same conductor, coated after slitting
  – Solder joint degradation
    • SXS: measurements showed $R \propto \log(t)$ at ambient $T$
    • Slow consumption of 2 µm AgAu layer by In3%Ag solder
    • RESOLVE: 20 µm Cu plating over HTS at solder joints
  – Variability of void density & joint $R$

\[ \text{Graph showing resistance over time} \]
Updates to HTS/PCB solder process

• Prototype solder rig
  – Motivation: tight control of process parameters
  – Ball joint for uniform force
  – Diode for accurate temperature control
  – Wrapped tip heater uniform heating
  – Fine position adjustment
  – Accurate control of force
  – Typical parameters (for In48%Sn):
    • Apply 10 N (80 mm\(^2\) area)
    • Controller on; set point = 150 C
    • Wait 30 s after T = set point; controller off
    • When T < 100 C, remove force

• Production solder rig
  – Miniaturized to fit flight assemblies
Solder Tests – Materials

• Test boards
  – Solder pads similar to flight boards (2 x 40 mm)
  – Separate voltage tap points
  – 16 joints / board
  – Plating types:
    • Bare copper
    • Immersion tin
    • Electroless Ni/immersion gold

• Solder
  – In48%Sn (m.p. 118°C, eutectic)
  – 1 mm preforms
Measurements and Early Results

- X-ray images to determine void fraction, wetting
- Joint resistances at 77 K
- Joint $R$ vs $T$ (3 K – 300 K)
- Early development test
  - Varied $T_{solder}$ 150 – 165 K, Force 5 – 20 N, hold time 30 – 90 s
  - no obvious patterns in x-ray images or $R(77 \text{ K})$
- Cycled 20 x (300 K → 77 K); no change in any $R(77 \text{ K})$
- Comparison of surface treatment in process
  - Best results so far with manual pre-tinning of solder pads
Current Transfer Length

• Serendipitous measurement:
  – $x = \text{HTS end to voltage tap distance}$
  – In early boards, $x$ varied
  – Measure joint $R$ at 77K
  – $dR/dx = \text{trace resistivity} = 9.4 \ \mu\Omega/mm$
  – AstroH samples: trace resistivity = 8 $\mu\Omega/mm$
  – Intercept = average current transfer length, $\lambda = 0.43$ mm
  – In Astro-H samples, $\lambda = 2 - 4$ mm

• For subsequent boards, $x = 0$
Low Temperature Resistance

- Measured $R$ vs $T$ (3 – 300 K)
  - Plateau 5 K $< T < 16$ K
  - $R \approx 0$ for $T \lesssim 5$ K ($T_c$ InSn 7.1 – 7.5 K)

- Normalized by mean (8 – 16 K)
  - Still $\sim 2 \times$ variation at 70 K $\Rightarrow$ not a simple geometric effect

- Measure $I$-$V$ at 10 K
  - $I$ up to full operating current (2A)
  - Linear $\Rightarrow$ ohmic behavior
  - Derived $R$ matches those measured at low $I$
• Allows convenient comparison
• Astro-H
  – Test board & prototype measurements
  – Flight units (from post-vibe functional cool-down)
• 4 recent boards produced with same protocol

• Results
  – Values not directly comparable, but distributions are
  – Astro-H measurements all had wide distribution
  – Boards produced under new protocol show much tighter distribution
SEM/EDS of Cross-Sections

- EDS
  - Provides map of joint composition
  - Shows formation of inter-metallics at boundaries, largely unreacted solder in center
- Vianco, et al.:
  - CuIn growth rate follows
  - Predicts $\Delta y \approx 2.5 \, \mu m$ in 4 yr
    ➔ will maintain compliant InSn layer

$y = At^n e^{Q/RT}$
Conclusions

• RESOLVE: Rapid rebuild of Soft X-ray Spectrometer
• RESOLVE HTS lead assemblies to “build to print” except
  – Improved HTS material
  – New solder joint material & process
    • Plating protects Au layer from slow consumption by solder
    • New rig gives tight control of process parameters
• Solder process qualification tests
  – Good wetting and void levels (x-ray image)
  – Acceptable intermetallic layers at boundary
  – Ohmic behavior to full operating current
  – Excellent sample-to-sample variation in 77 K resistance
• Path forward
  – I-V testing to 5 A in prototype
  – Environmental degradation testing of joints an HTS tape