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

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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

Solder pads: 100 µm cu /immersion Ag

1 mm Ag5%Au coated REBCO tape

Heat sink at JT shield

Composite support structure

Cold end transition board

Bolted joint — transition to ADR magnet leads

Connector — transition to standard harness

Warm end transition board
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

![Graph showing resistance over time](image)
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 mm² 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 $\rightarrow$ 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:
  – \( x \) = HTS end to voltage tap distance
  – In early boards, \( x \) varied
  – Measure joint \( R \) at 77K
  – \( dR/dx \) = 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 $5 \text{ K} < T < 16 \text{ K}$
  - $R \approx 0$ for $T \lesssim 5 \text{ K}$ ($T_c \text{ InSn 7.1 – 7.5 K}$)

- Normalized by mean (8 – 16 K)
  - Still ~ 2 x 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 $I$
Distribution of Joint Resistances at 77 K

- 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
    \[ y = A t^n e^{Q/RT} \]
  - Predicts \( \Delta y \approx 2.5 \mu m \) in 4 yr
    ➔ will maintain compliant InSn layer
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