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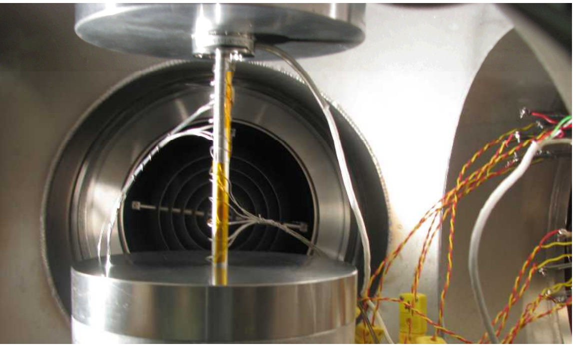

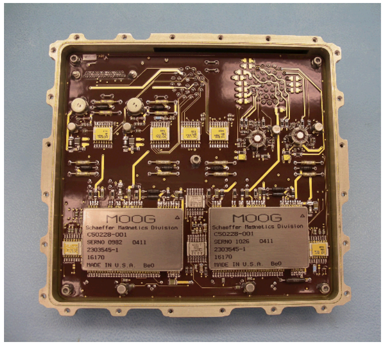

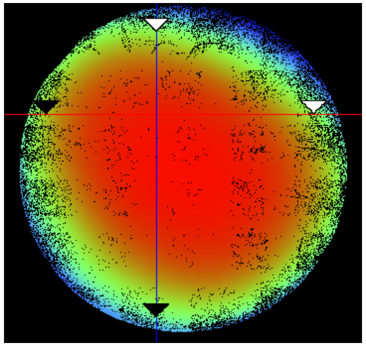

Thermal Contact Conductance of Radiation-Aged Thermal Interface Materials for Space Applications

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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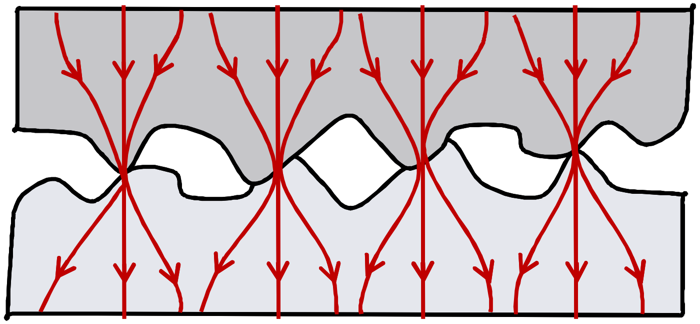
Thermal Contact Resistance

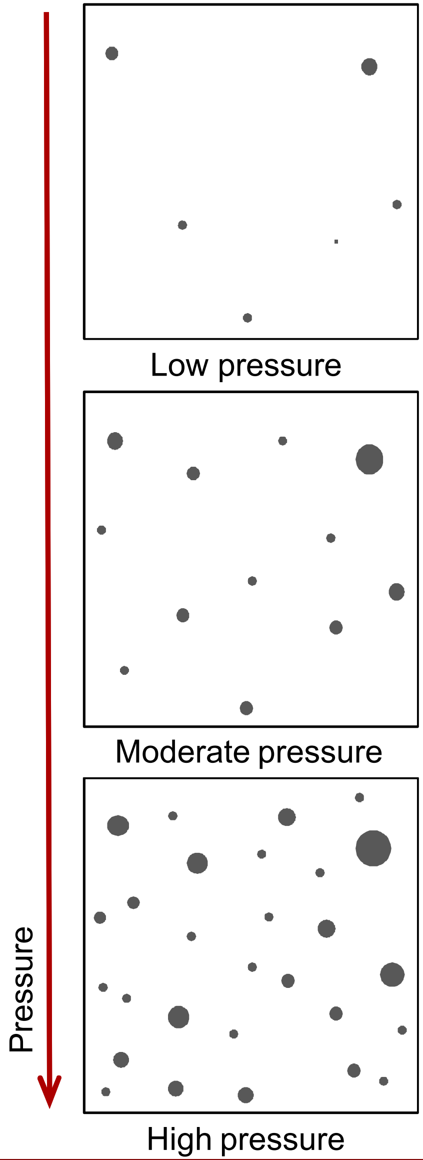
- For interfaces in contact, the real area of contact is typically 2 to 6 orders of magnitude less than the apparent area of contact $\frac{A_r}{A} = \frac{P}{H}$
- In vacuum, thermal contact resistance (TCR) of a Gaussian surface is given by

$$R = 0.88 \frac{\sigma}{km} \left(\frac{H}{P} \right)^{-0.94} = aP^b$$

- For systems with multiple interfaces, TCR can consume a significant part of the thermal budget

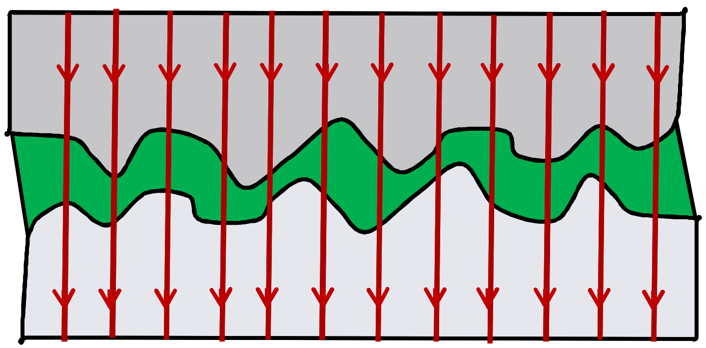


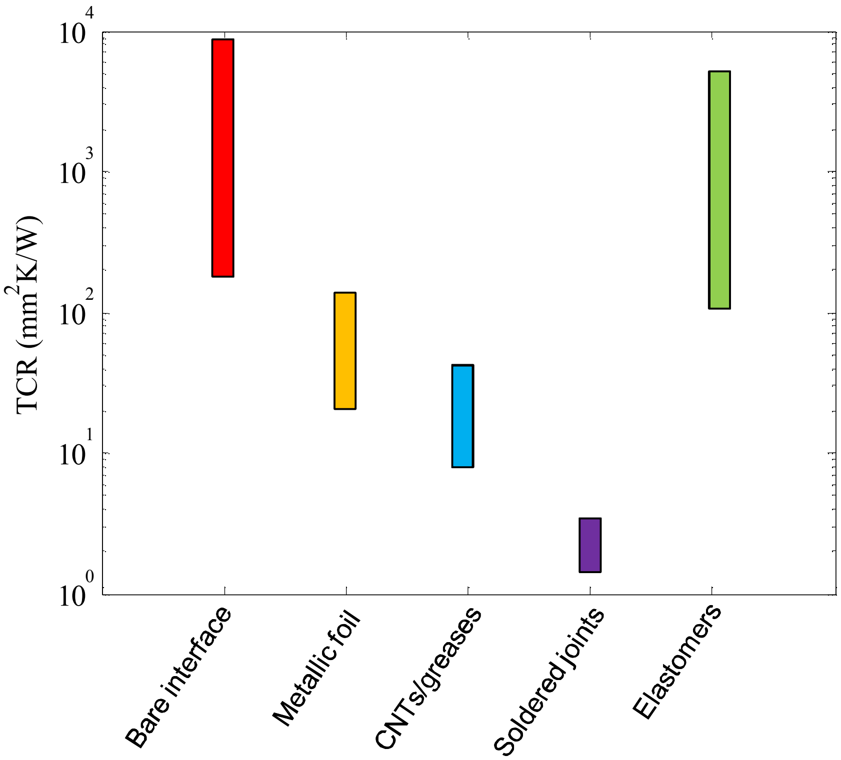
A	Apparent contact area
A_r	Real contact area
a,b	Constants
H	Hardness
k	Thermal conductivity
m	Asperity slope
P	Contact pressure
R	Contact resistance
σ	Surface roughness



Thermal Interface Materials

- Thermal interface materials (TIMs) provide a means of decreasing TCR by filling the gaps between asperity contacts
  - Thermal greases
  - Metallic foils
  - Carbon nanotube (CNT) materials
  - Elastomeric materials





TIMs in Satellite Systems

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- Special considerations are required for TIMs used in satellites
  - Vacuum compatible
  - **Electrically insulating**
- Space systems are exposed to a wide array of radiation sources
  - UV
  - X-ray
  - Charged particles
  - γ-ray

Absorbed and reflected by outer materials

Experience little attenuation
Easily reach and pass through all components
Doses as high as 10 Mrad /yr [1]
Interactions with TIMs are important

- Common TIMs
  - ~~Thermal greases~~
  - ~~Metallic foils~~
  - ~~CNT materials~~
  - Elastomeric materials

[1] R. Akau et al., 2012, Nexus Test Report for Thermal and Mechanical Study of Silver-Teflon Tape for Space Applications, SNL, Albuquerque.

TIMS used in this Study

Two different materials were investigated

- Cho-Therm 1671
  - Silicone elastomer filled with boron nitride particles
  - Reinforced with a fiberglass cloth
- ThermaCool R10404
  - Closed cell silicone sponge rubber

Property	Cho-Therm	ThermaCool
Color	White	Light green
Thickness (mm)	0.4	3.2
Thermal conductivity (W/mK)	2.6	0.36-0.86*
Thermal resistance (mm^2K/W)	150	3400-8600*
Hardness (Shore 'A')	90	13
Density (kg/m^3)	1550	1105

*Highly sensitive to compression of the TIM

Cho-Therm

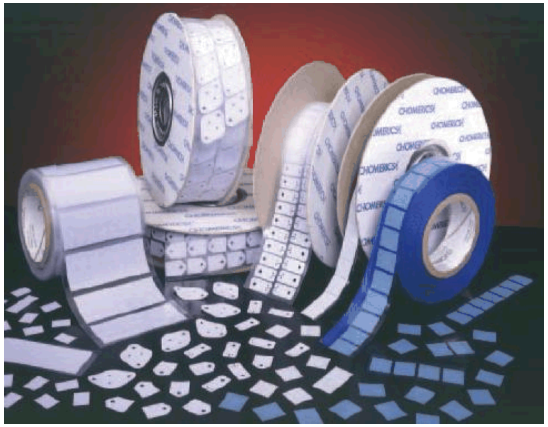


Image http://products.robertmckeown.com

ThermaCool

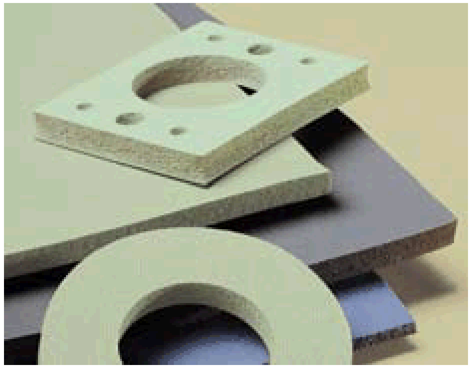
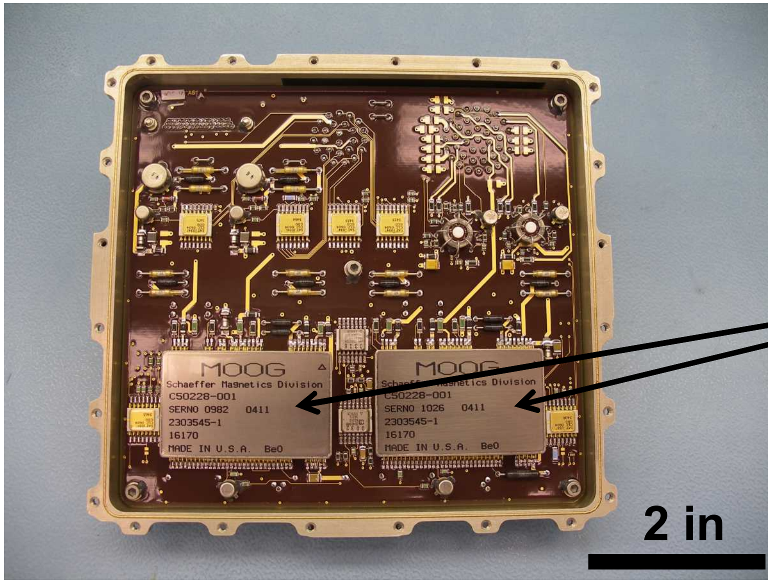
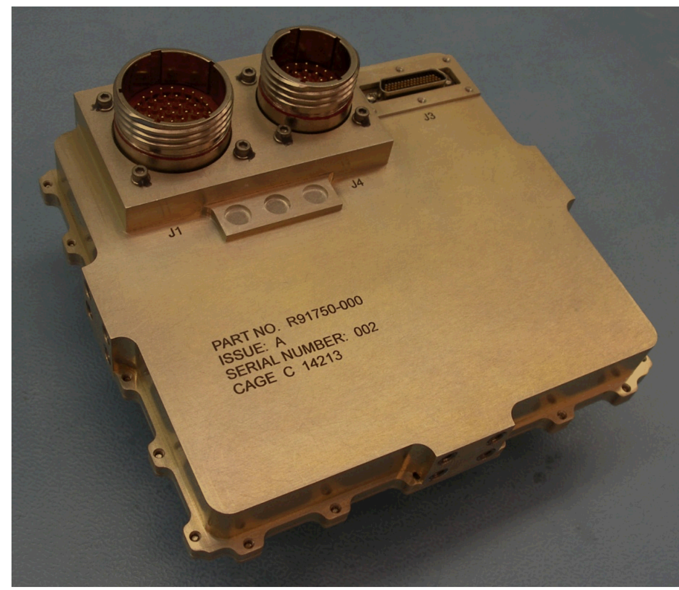


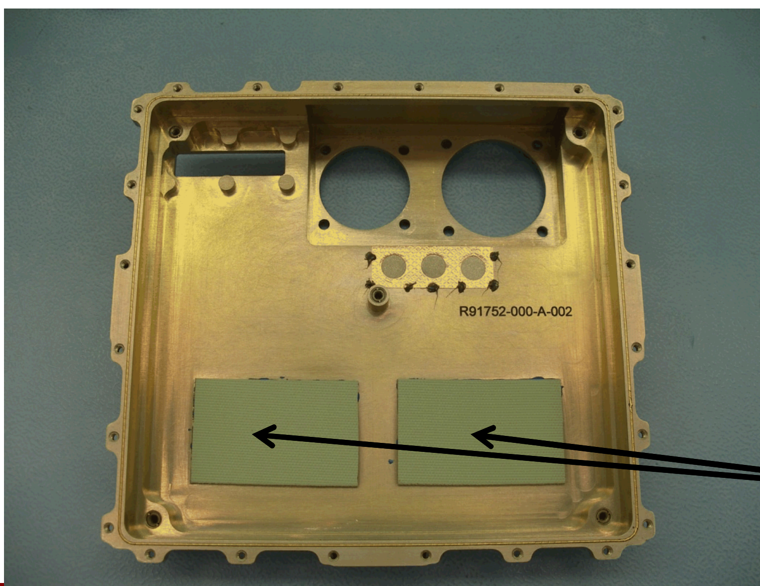
Image from ThermaCool R10404 Data Sheet, Saint-Gobain Performance Plastics

Filter Wheel Controller (FWC) Board



Power converters
4 W dissipated

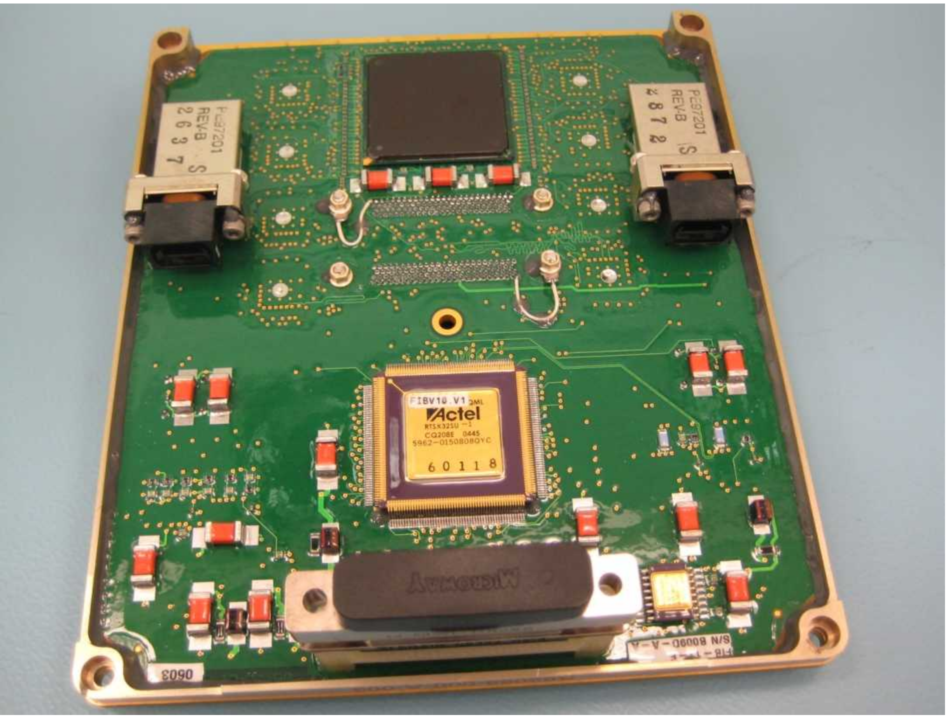


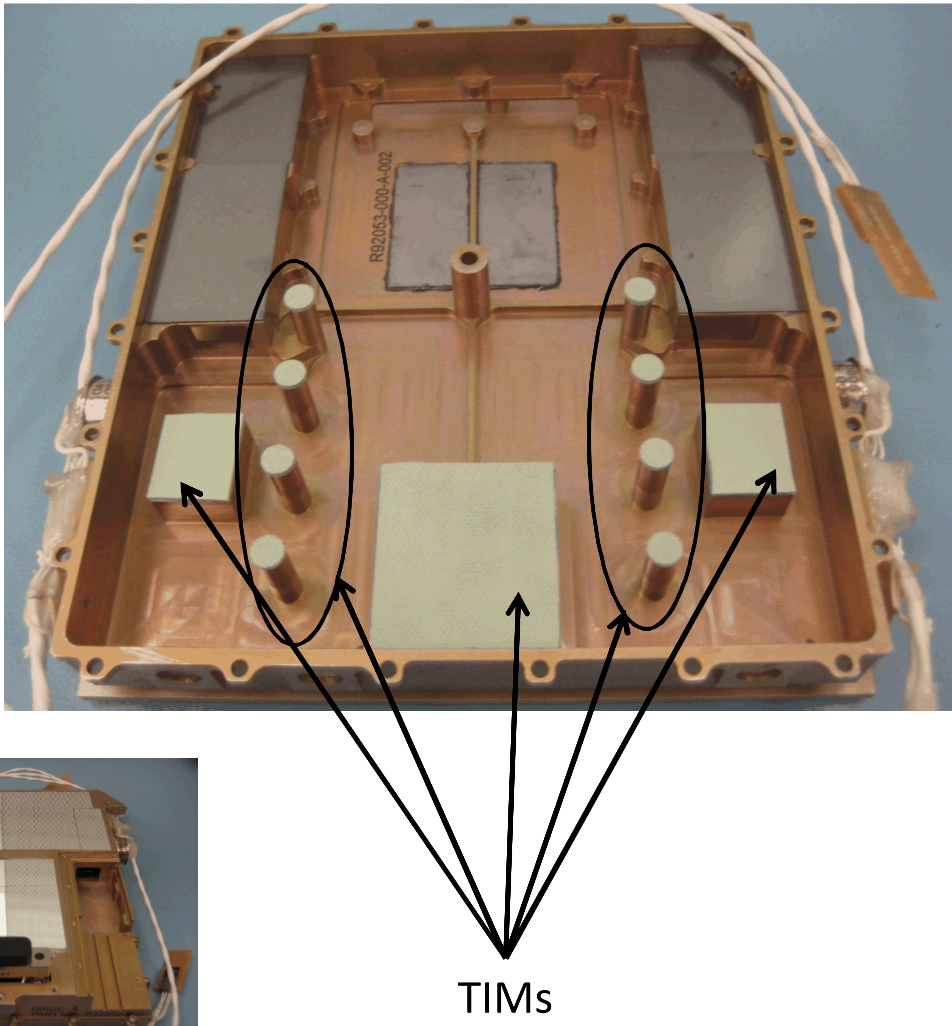


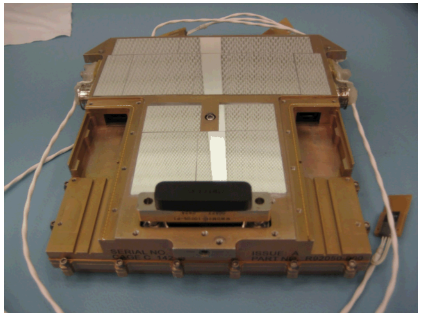
TIMs

Fiber Interface Board (FIB)

5 W dissipated

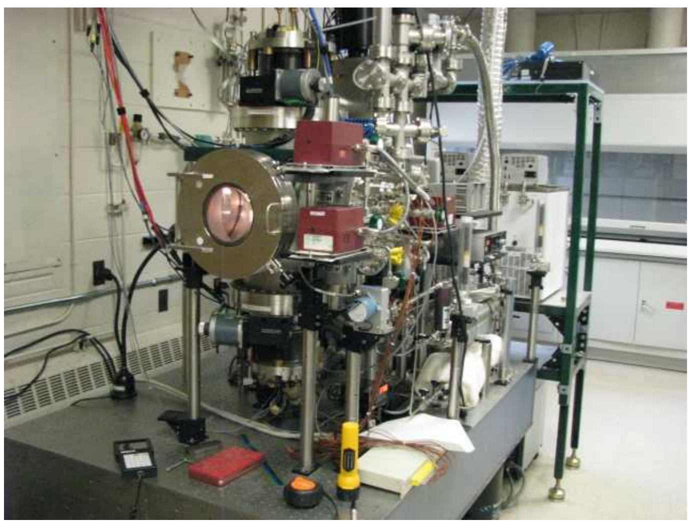


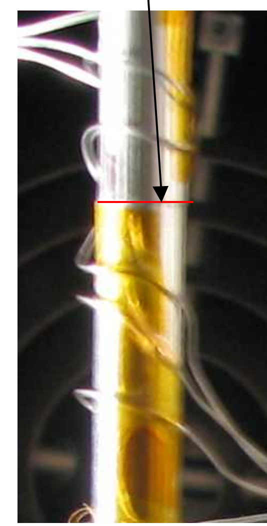




1-D Steady State Experimental System

- Minimum chamber pressure: 2 x 10^{-6} torr
  - Can also look at N_2, Ar, He, air and other gas environments up to 630 torr
- Maximum interface pressure: 10,000 psi
- Temperature range: 0 to 80 °C
- 12 thermocouples (6 per bar)

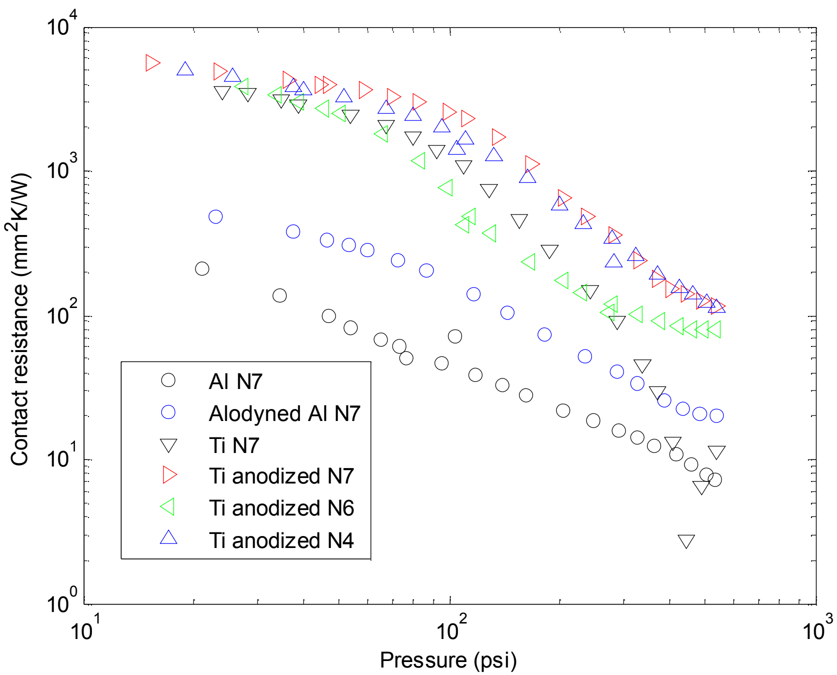




Metallic Samples

- Common metals used in satellite systems were chosen
  - Aluminum
  - Alodined aluminum
  - Titanium
  - Anodized titanium

Sample	Material	Surface treatment	Surface finish	Sample name	R_a (nm)	R_q (nm)	R_t (µm)	R_{sk}	R_{ku}
1	Aluminum	none	N7	Al_N7_N	119	162	2.5	-1.5	7.9
2	Aluminum	alodine	N7	Al_N7_T	271	440	3.9	19.0	-3.0
3	Titanium	none	N7	Ti_N7_N	168	219	1.1	4.6	-1.0
4	Titanium	anodize	N7	Ti_N7_T	582	750	3.8	3.7	-0.6
5	Titanium	anodize	N6	Ti_N6_T	643	822	2.5	3.9	-0.3
6	Titanium	anodize	N4	Ti_N4_T	540	692	2.5	3.7	-0.7

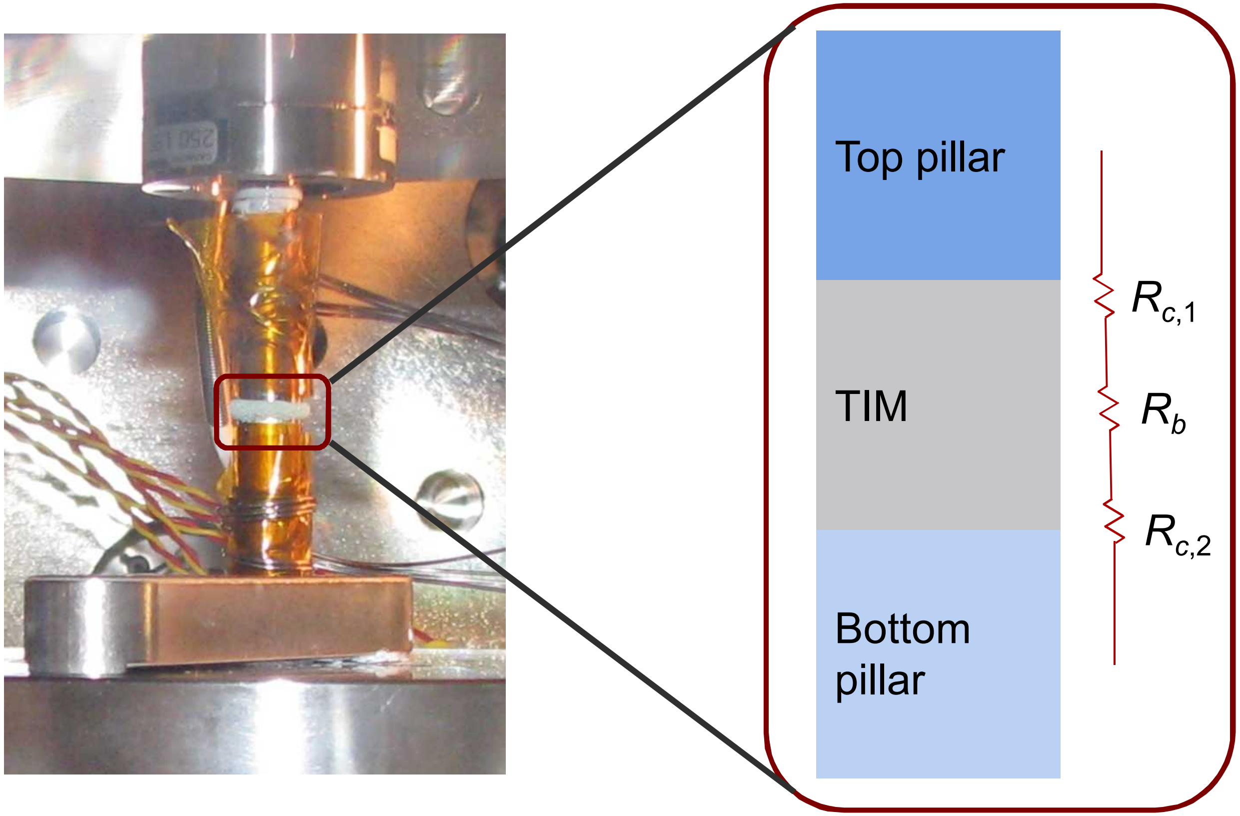


$$R = aP^b$$

Run #	Metal pillar	a	b
1	Al_N7_N	2.11E+04	-1.02
2	Al_N7_T	1.30E+05	-1.14
3	Ti_N7_N	2.12E+05	-0.86
4	Ti_N7_T	3.50E+04	-0.43
5	Ti_N6_T	1.41E+06	-1.22
6	Ti_N4_T	1.76E+05	-0.77
	All Ti samples	8.14E+04	-0.64

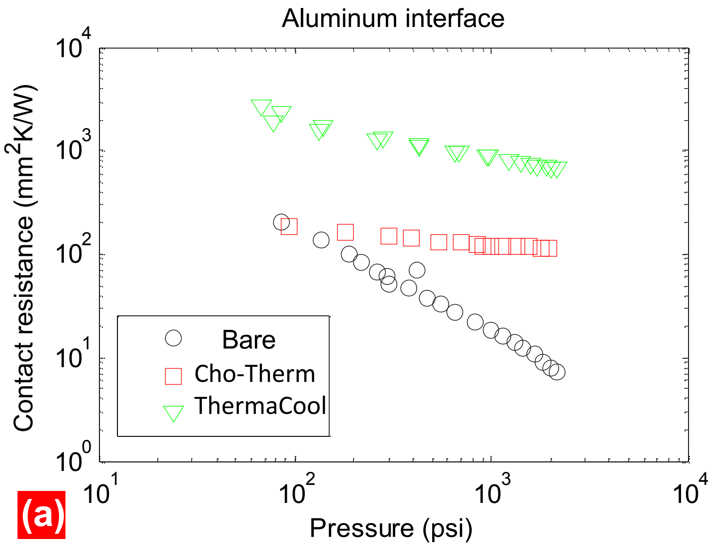
Total Thermal Interface Resistance

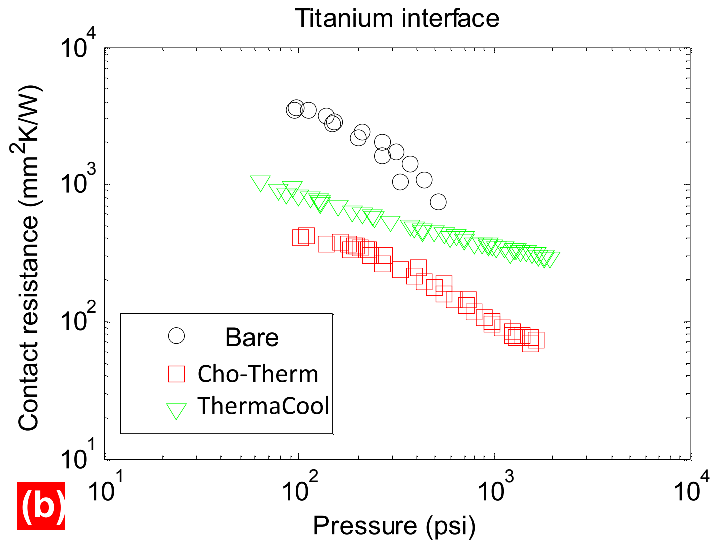
- The total thermal resistance at the interface when a TIM is used is the sum of contact resistance between the TIM and each metallic pillar and the bulk resistance of the TIM



Thermal Contact Resistance: TIMS

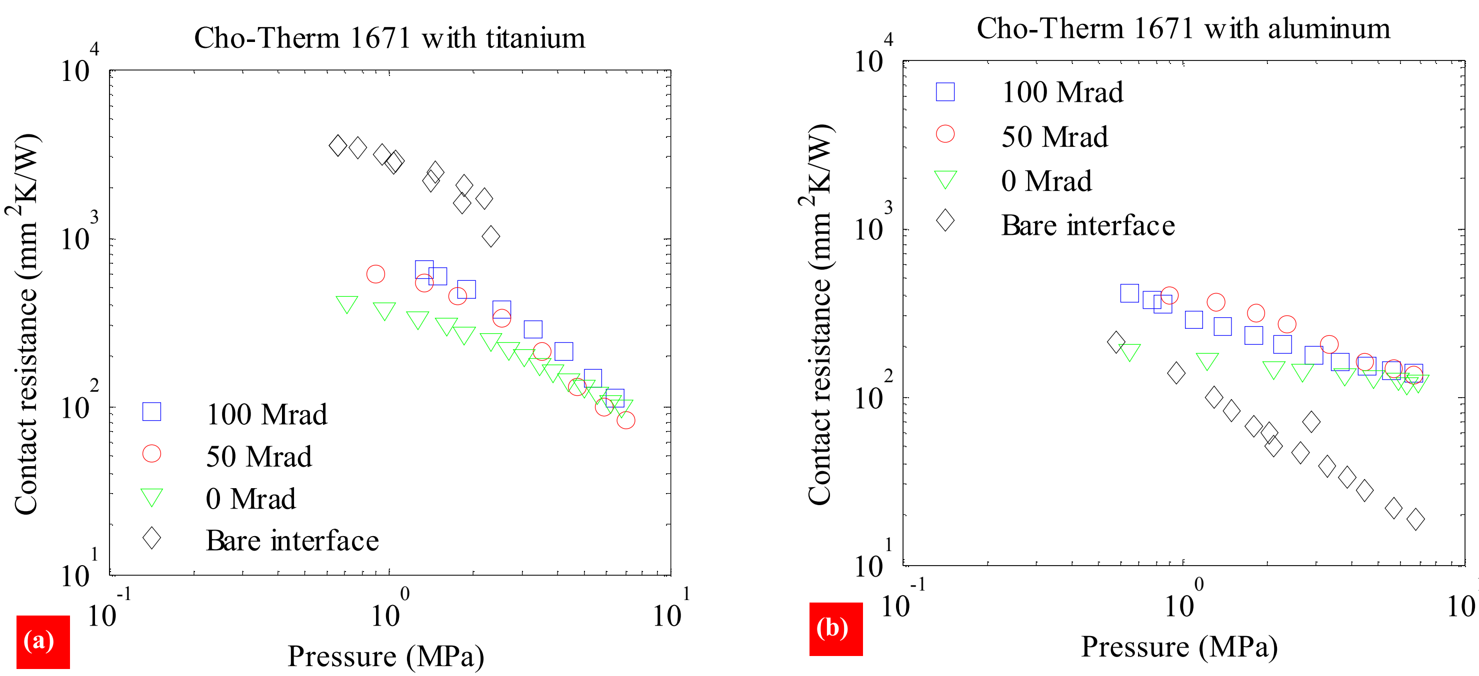
- TCR increased when TIM was inserted between Al contacts
  - Al has a low TCR due to high k and low H values
- TCR decreased when TIM was inserted between Ti contacts
  - Ti has a high TCR due to low k and high H values
- Cho-Therm out performs ThermaCool due to its much small thickness
- TIMs minimize the effect that pressure has on TCR





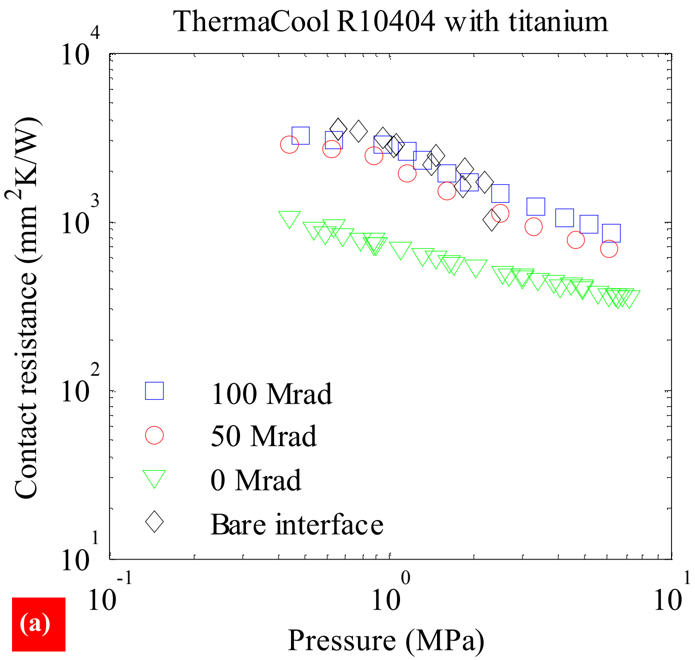
Radiation Aging: Cho-Therm

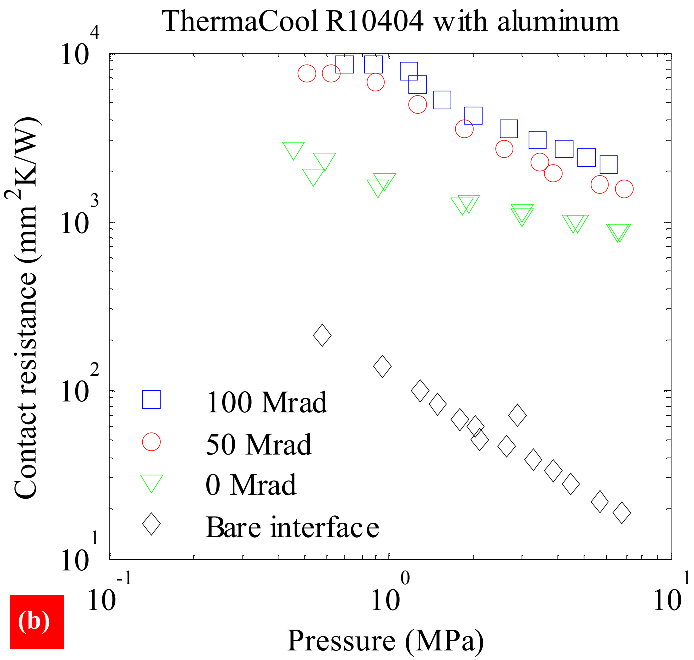
- Radiation aging increases the TCR
- Little difference between the 50 Mrad and 100 Mrad samples



Radiation Aging: ThermaCool

- Radiation aging increases the TCR
- Little difference between the 50 Mrad and 100 Mrad samples
- Much larger increase in TCR for the ThermaCool samples
- γ-ray radiation makes the sample much stiffer, thus increasing the bulk resistance
- Radiation aged samples are pressure independent under 170 psi





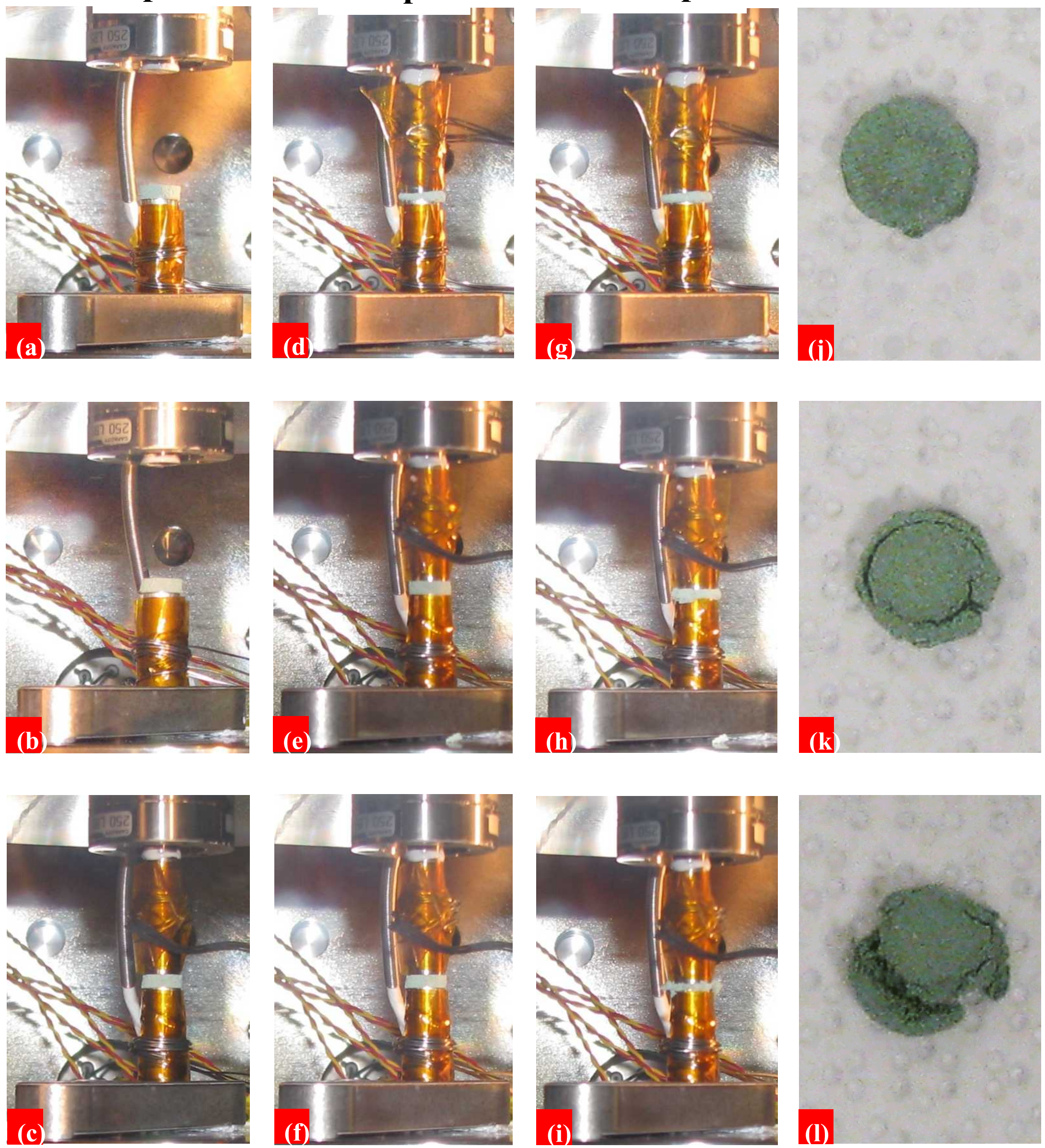
ThermaCool Compression

0 psi | 100 psi | 1000 psi

0 Mrad

50 Mrad

100 Mrad



Recommended TCR Values

- Values were found from a least squares fit to experimental data
- Typical pressure range is 200 to 300 psi.

$$R = aP^b$$

TIM	Dose (Mrad)	Aluminum a	Aluminum b	Aluminum P (psi)	Titanium a	Titanium b	Titanium P (psi)
Bare interface	0	1.61E+04	-0.98	80-990	1.34E+05	-0.78	90-340
Cho-Therm	0	4.13E+02	-0.18	90-1000	1.21E+04	-0.68	100-990
	50	7.97E+03	-0.59	130-960	1.28E+05	-1.05	130-1000
	100	3.54E+03	-0.49	90-960	2.46E+05	-1.11	190-930
ThermaCool	0	1.08E+04	-0.37	70-970	4.71E+03	-0.38	70-1000
	50	7.23E+03	0.00	70-170	2.65E+03	0.00	70-170
		1.73E+05	-0.70	170-1000	4.74E+04	-0.63	170-880
	100	8.23E+03	0.00	100-170	3.02E+03	0.00	70-170
		2.01E+05	-0.67	170-880	6.94E+04	-0.65	170-900

Conclusions

- A capability for testing TCR satellite materials before and after γ radiation has been developed
- TCR of two commonly used electrically insulating thermal interface materials was investigated
  - The effectiveness of the TIM depends on the contacting materials between which it is placed
  - TCR increased when placed between Al
  - TCR decreased when placed between Ti
- A significant increase in TCR was observed when the samples were γ radiation aged
  - TIM effectiveness decreases over the mission life
- Sample brittleness increased with radiation aging
  - Could potentially lead to system contamination through flaking or cracking of the TIM

Next Steps

- Investigate materials that are radiation-aged under compression
- Look into the effects of γ radiation on electrically conductive TIMs with superior thermal performance (CNTs and foils)

Acknowledgments

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- For technical review of this work:
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