Integrated MLI (IMLI)

Innovative Thermal Solutions

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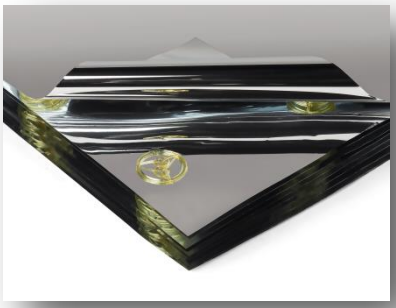
Integrated MLI (IMLI) Overview

IMLI is a high performance insulation developed by Quest Thermal Group for NASA. IMLI uses proprietary Discrete Spacer Technology™ with low thermal conductivity polymer spacers to reduce heat leak, control layer spacing and density, and provide unique structural capabilities. IMLI offers half the heat leak per layer as netting MLI, robust structure, predictable performance, fewer layers and lower mass then netting MLI, can span large spaces and support external loads.

IMLI's engineered structure can be designed for specific heat flux or structural loads for mission requirements.



IMLI Capabilities

- IMLI has half the heat flux per layer as conventional MLI, allowing fewer layers and less mass
- IMLI has predictable thermal performance, within 10% of modeled
- IMLI spacers provide structural capabilities, including supporting external loads, Broad Area Cooled shields & lightweight vacuum shells
- Vapor cooled IMLI systems offer 50 – 70% further reduction in heat flux
- High performance IMLI systems are available for on-orbit insulation, in-air, high altitude, Mars and lunar surface operation.

Applications

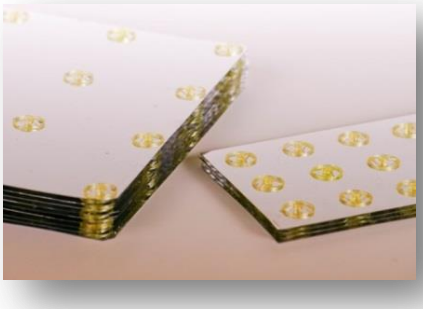
- Cryogenic Fluid Management applications
- Cryogenic Propellant Storage and Transfer
- Cryopropellant tanks for spacecraft and launch vehicles
- ISRU tanks for liquefaction and storage
- Very low heat flux, long duration cryogenic missions
- Applications using passive or active vapor cooling
- Missions requiring lightweight, effective MMOD shielding
- Applications requiring low mass dewars/tanks
- LH_2 tanks for UAVs, aircraft, transportation

Differentiators

- Discrete Spacer Technology™ solutions provide superior thermal performance and structural capabilities
- Discrete spacers and IMLI are the first real advance in multilayer Insulation in 60 years
- Quest IMLI has a robust structure, predictable performance, lower heat flux, lower mass
- Active and passive vapor cooled IMLI offer very high thermal performance
- Lightweight vacuum shell spacer supported IMLI offers in-air/soft vacuum operation
- Quest Thermal provides custom design, analysis, fabrication and installation of IMLI systems
- Innovative thermal solutions are our specialty and expertise.

Programs/Missions

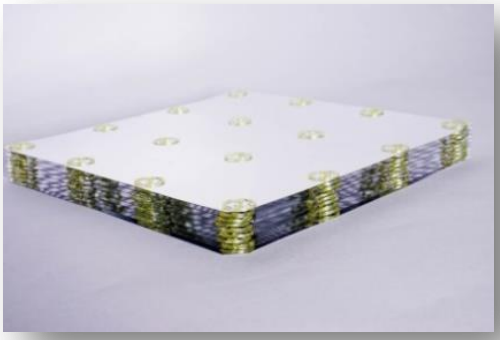
- IMLI has three successful spaceflights, at TRL 9 (GPIM, RRM3 and Lucy)
- Vapor cooled IMLI for Lunar Landers
- IMLI for lunar surface science payloads
- ISRU surface liquefaction and storage for lunar and Mars surface
- Lightweight vacuum jacket IMLI designed for Mars surface and high altitude operation
- Lightweight LHe dewars for stratospheric operation
- LH_2 UAV and aircraft tank insulation systems
- IMLI is in use on NASA's NEOS and Roman Space Telescopes



Measured thermal performance for IMLI configurations

IMLI thermal performance has been extensively tested via boiloff calorimetry at Quest Thermal Group, Ball Aerospace, NASA KSC Cryogenics Test Lab, Glenn Research Center and Marshall Space Flight Center. The Table below is measured data with and without a broad area cooled shield, to illustrate the high thermal performance available from IMLI based systems.

Insulation layers	Cold Boundary Temperature	Warm Boundary Temperature	Heat flux W/m2
5 layers IMLI	77K	295K	2.0
10 layers IMLI	77K	295K	0.95
20 layers IMLI	77K	295K	0.45
10 layers IMLI	20K	293K	1.032
20 layers IMLI	20K	293K	0.52
5 layers IMLI	20K	90K	0.36
10 layers IMLI	20K	90K	0.18
20 layers IMLI	20K	90K	0.081



IMLI performance compared to conventional MLI

IMLI tested@KSC	**LDMLI** @KSC	**MLSTC** @GRC	**Perfed MLI** @KSC
20-layer	**60-layer**	**61-layer**	**30-layer**
77 - 295K	77 - 295K	93 - 250K	77 -230K
0.405 W/m^2	0.332	0.342	0.87
0.000061 W/m-K	0.000093	0.000187	0.000040
e* 0.00095	0.00080	0.0016	0.0055
0.41 W/m^2 (20 layers)	1.00 for 20 layers	1.04 for 20 layers	1.30 for 20 layers
0.39 – 0.91 kg/m^2	2.9 (60 layers)	3.1 (61 layers)	1.5 (30 layers)

Example IMLI configurations

Thot (K)	Tcold(K)	Spacing (in)	2		
295	77	Spacing (cm)	5.08		
Number of layers	**Thickness (cm)**	**Heat Leak (W/m2)**	**Mass (g/m2)**	**e***	**k***
5	0.72	2.162	209	0.0051	0.1565
10	1.63	1.039	430	0.0024	0.1688
15	2.53	0.683	650	0.0016	0.1727
20	3.43	0.509	870	0.0012	0.1746
30	5.23	0.337	1311	0.0008	0.1764
40	7.04	0.252	1751	0.0006	0.1773

Thot (K)	Tcold(K)	Spacing (in)	2		
295	20	Spacing (cm)	5.08		
Number of layers	**Thickness (cm)**	**Heat Leak (W/m2)**	**Mass (g/m2)**	**e***	**k***
5	0.72	2.218	209	0.0052	0.1606
10	1.63	1.064	430	0.0025	0.1730
15	2.53	0.700	650	0.0016	0.1769
20	3.43	0.522	870	0.0012	0.1789
30	5.23	0.345	1311	0.0008	0.1807
40	7.04	0.258	1751	0.0006	0.1816

IMLI family of thermal solutions

- Quest Thermal has various discrete spacers that allow optimizing heat flux vs structural strength. IMLI can be custom engineered to meet any given heat flux or external load.
- Load Bearing MLI offer up to 90 psi capability.
- Wrapped MLI for cryogenic feedlines offers 26-fold lower heat flux than spiral wrapped netting MLI.
- Launch Vehicle MLI acts as an aeroshell with 66-fold lower heat flux than SOFI and 67% lower mass.
- LRMLI, Honeycomb IMLI and Vacuum Jacket IMLI operate both in-air and in-space.
- MMOD MLI uses discrete spacers with ballistic and radiant barrier layers for light weight integrated insulation & MMOD shielding.
- Vapor cooled IMLI versions support on-tank cooling, vapor cooled shields, and vapor cooled structural supports. Vapor Cooled IMLI had up to 93% reduction in heat leak through tank supports.