Investigation of the thermal emittance properties of multilayer insulation used in cryogenic applications

Uday Kumar[a, b], Parasuraman Swaminathan[b], and Hitensinh Vaghela[a]
[a]ITER-India, Institute for Plasma Research, Ahmedabad, India
[b] Indian Institute of Technology Madras, Chennai, India

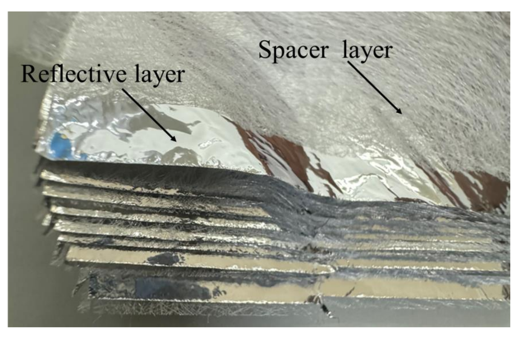
Poster Id:425

Abstract

Multilayer insulation (MLI) has a critical role in controlling the parasitic heat-in-leak through radiation. It consists of alternate layers of reflective aluminized mylar, separated by low thermal conductivity spacers. The thermal emissivity of the reflective layer plays a critical role in minimizing the radiative heat transfer through its layers. However, the formation of a native oxide layer on the aluminized surface can affect the emittance of the reflective layer. The exact microstructure and elemental composition of the native aluminium oxide is highly uncertain, and it is commonly identified as an amorphous combination of different oxides and hydroxides. Due to the exposure of atmospheric oxygen and moisture, native oxide layer can vary in nature and thickness, making it essential to characterize the material and measure the emittance of the reflective surface before its application in cryogenic systems. This work aims to establish the approach for investigating the structural and functional quality of MLI before its use in cryogenic component.

Introduction

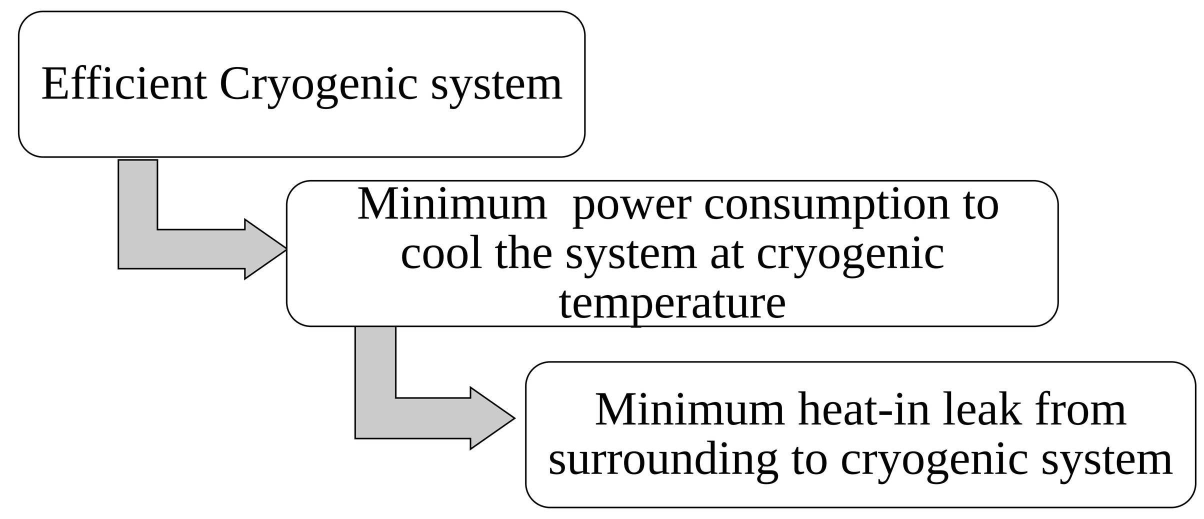
- **The objective of the MLI**
  - To control parasitic heat – in-leak from thermal radiation
  - For passive thermal control of systems
  - Reduce the static heat load



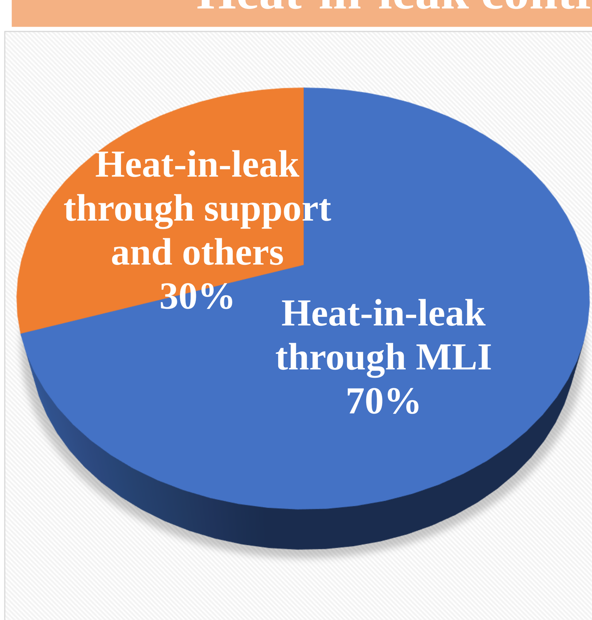
- **Typical composition of MLI is combination of**
  - Reflector: Aluminized mylar
  - Spacer: Mylar, Teflon, Kapton, Fiberglass woven cloth (Beta cloth)
- The combination of aluminized Mylar of 12µm thick and glass fabric of 76.2µm thick is the best for MLI.
- 20 plus years lifetime of the cryogenic system
- It need to be stored in controlled environment with low humidity (recommended storage temperature is 15-27 °C)

$$q = \frac{C_S(\bar{N})^{2.56}T_M}{N_S+1}(T_H - T_C) + \frac{C_R\varepsilon_{RT}}{N_S}(T_H^{4.67} - T_C^{4.67})$$

Motivation



Heat-in-leak contribution in Cryolines



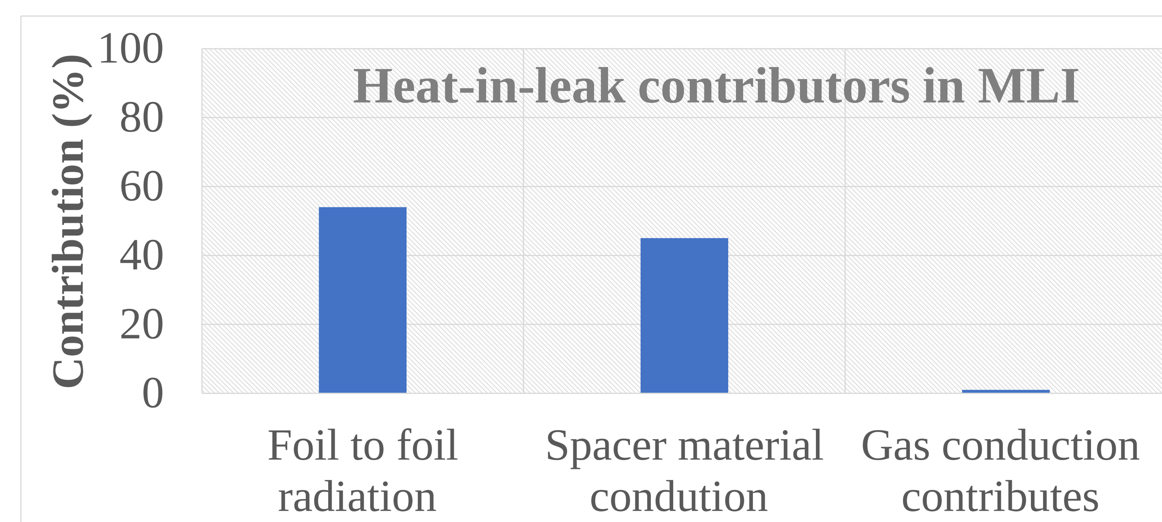
- **Heat-in-leak through MLI depends upon**
  - Operating pressure
  - Number of radiation shield layer (N_S)
  - Radiation shield layer density ($\bar{N}$)
  - Emissivity of reflective layer
  - Spacer material
  - Boundary temperature (T_H and T_C)

Objective

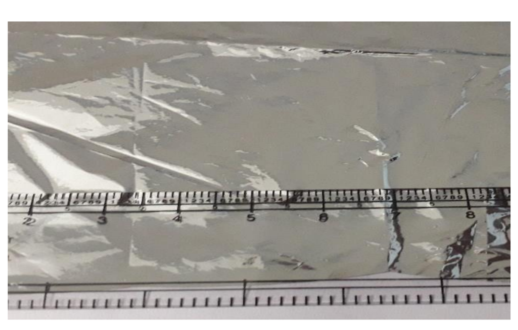
Establish the approach for investigating the quality of MLI before its use in cryogenic component

Requirement:

- Nuclear facility regulation needs thorough testing and qualification of material for the intended operational conditions before its use
- Dynamic nature of aluminum coated surface due to native oxide formation
- Operational upset conditions including thermal cycles and poor insulating vacuum

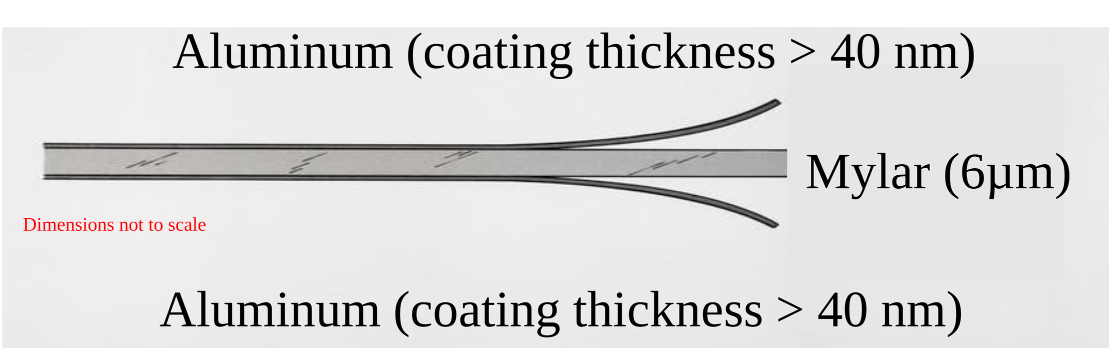


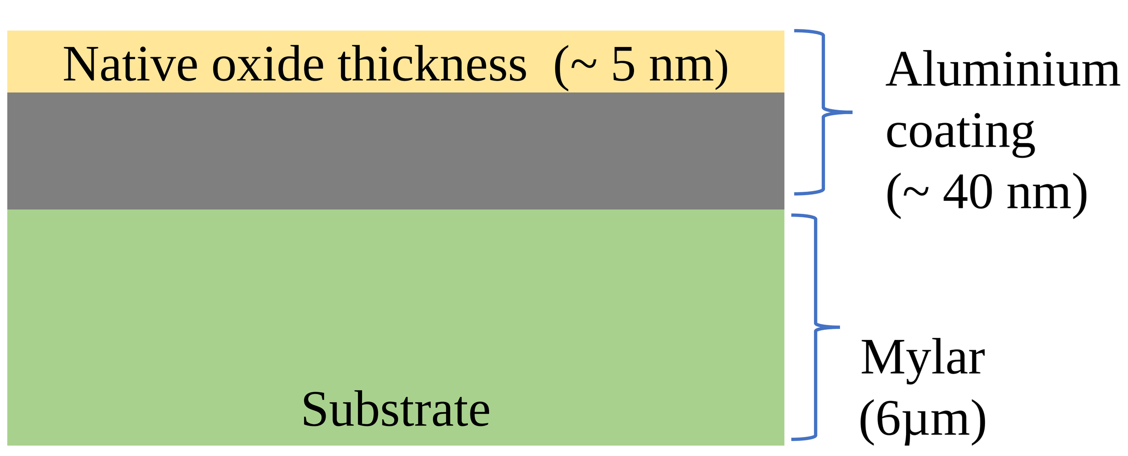
Material and method

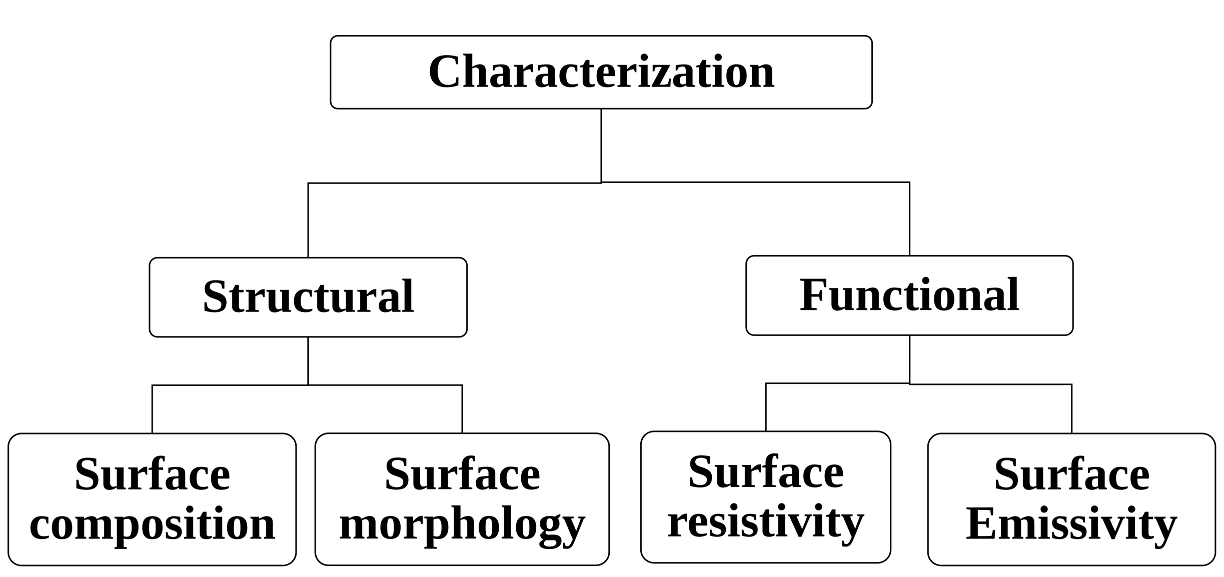


(a) Double aluminized reflector layer

(b) Spacer layer of MLI



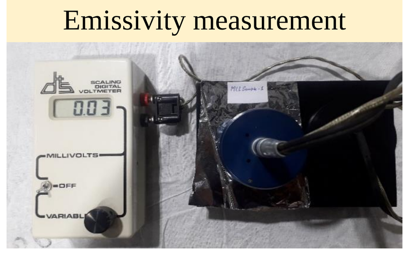




ASTM C1371-15(2022): Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers)

Portable emissometer	
Model	Model: AE1/RD1 (Devices and services USA)
Readout	D&S Scaling Digital Voltmeter
Wavelength range	3 – 30 µm
Detectors	Radiation detector
Repeatability	± 0.01 emittance units

Emissivity measurement

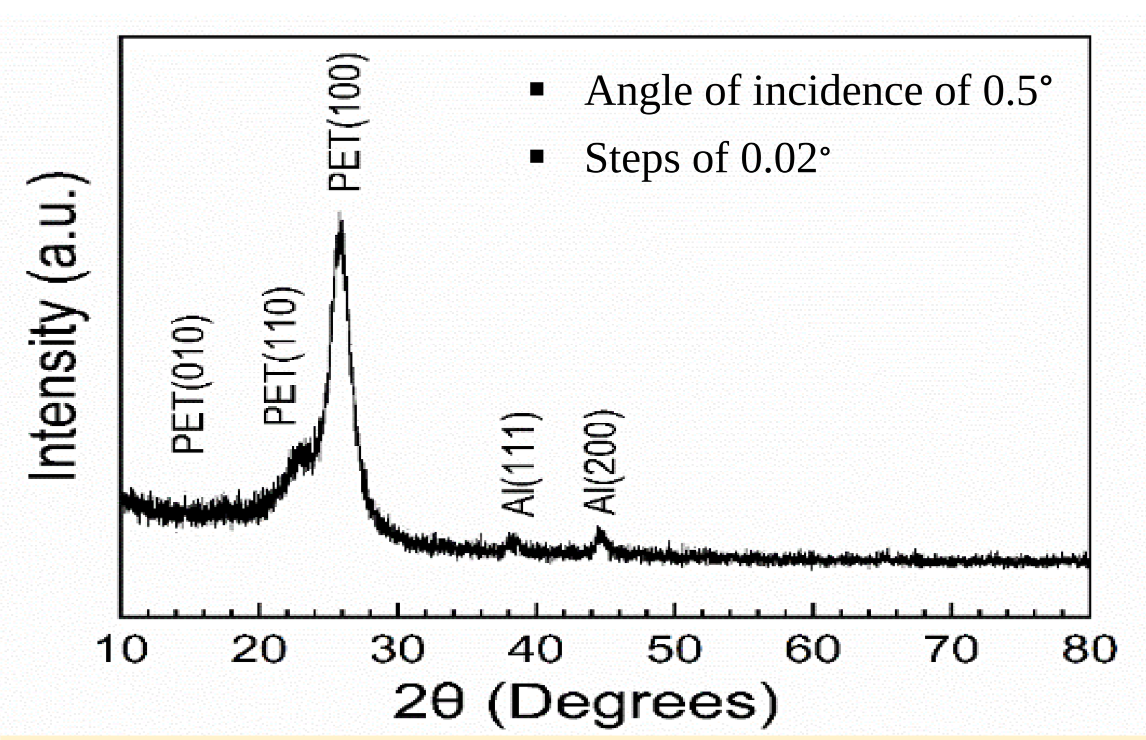


Surface resistivity measurement

Analysis Results

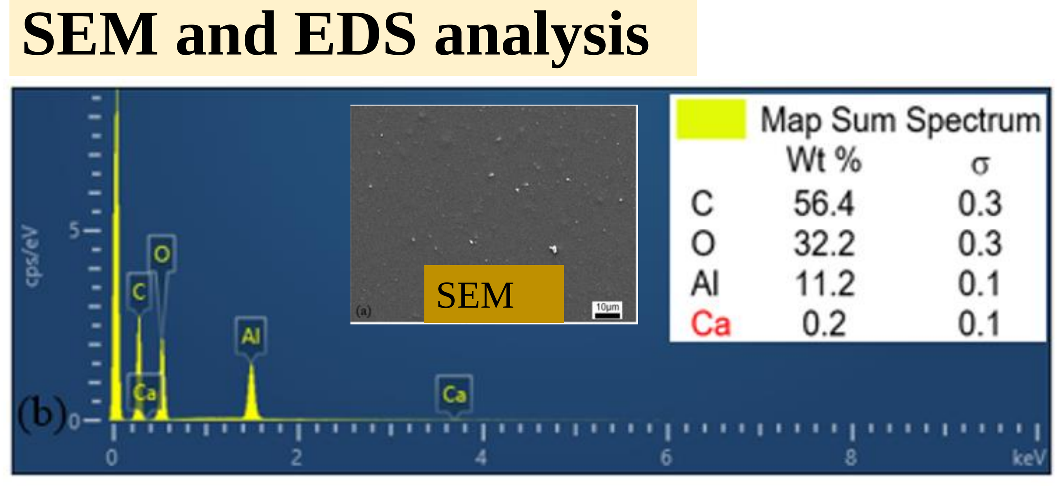
GIXRD analysis

Cu-Kα radiation (λ= 0.154056 nm)



- GIXRD analysis shows the diffraction peaks for PET as a substrate (at 2θ = 26°) and aluminum as a coating material (at 2θ = 38.47° and 44.74°).

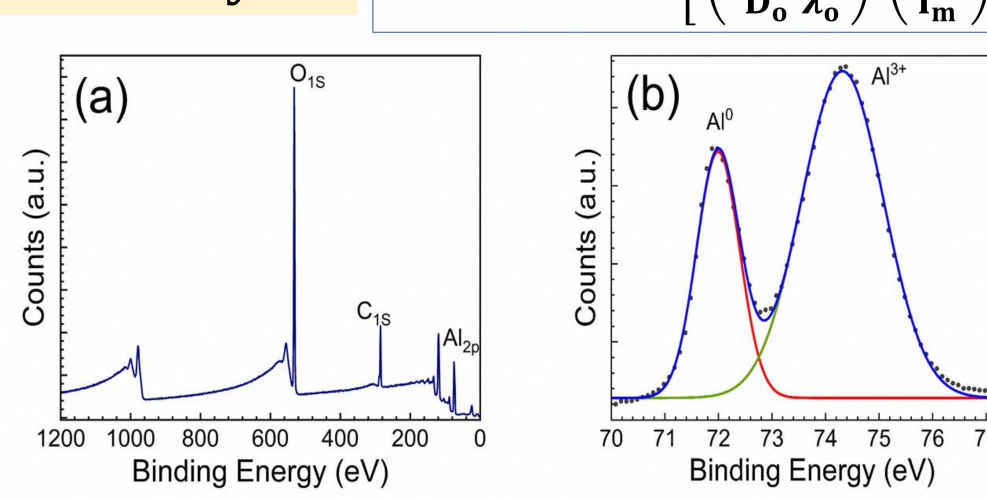
SEM and EDS analysis



- The elemental analysis through EDS shows the presence of C, O, and Al.
- The EDS results are consistent with the GIXRD results.

XPS analysis

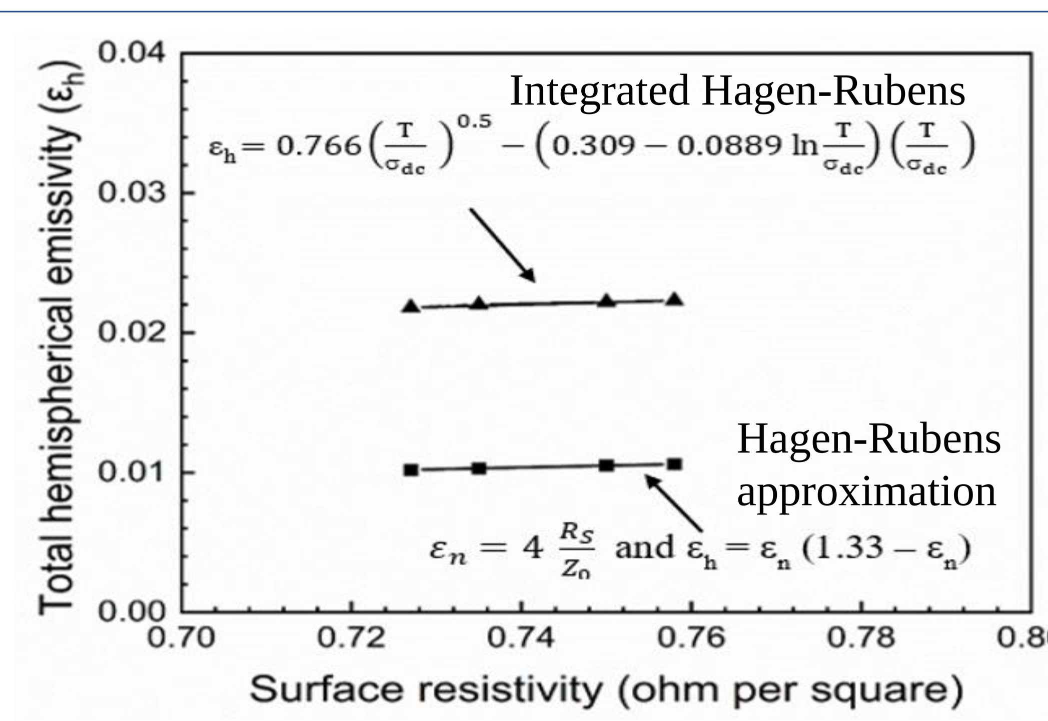
$$t_o = \lambda_o \sin\theta \ \ln\left[\left(\frac{D_m\ \lambda_m}{D_o\ \lambda_o}\right)\left(\frac{I_o}{I_m}\right) + 1\right]$$



Where to: the oxide layer thickness, λ_m (2.57 nm) and λ_o (2.68 nm): inelastic electron mean free path in aluminium and the oxide respectively, obtained from NIST reference database, θ is the angle between the specimen and detector, D_m and D_o are the atomic densities in Al and Al_2O_3 [11], and I_m and I_o are the peak intensities for Al and Al_2O_3 obtained from XPS.

- The calculated thickness of the oxide layer is ~ 3 nm.

Observations



Conclusions

- The structural and functional characterization of the reflective surface of MLI performed to establish the approach for quality confirmation reflective layer.
- The total hemispherical emissivity obtained from the surface resistivity using Hagen-Rubens free electron model is considerably lower than the measured value using a portable emissometer at room temperature.
- The integrated Hagen-Rubens relation over all wavelengths gives a more realistic total hemispherical emissivity value than the simple free electron model.
- The difference between the two results is due to the assumption of a perfectly smooth surface and ideal defect-free material in the case of the Hagen-Rubens approximation.

Acknowledgement

The authors gratefully acknowledge the support provided by IPR and IIT Madras. XPS analysis was performed at the Advanced Material Research Center, IIT Mandi. SEM and GIXRD measurements were performed at the Central Instrumentation Facility, IIT Gandhinagar.

Presenter greatly acknowledge the Indian Cryogenic Council for providing the conference registration support.

References

1.Gonczy, J.D et al. Advances in Cryogenic Engineering, vol 35. Springer, Boston, MA. https://doi.org/10.1007/978-1-4613-0639-9_60
2.Bapat, S. L., Narayankhedkar, K. G., & Lukose, T. P. (1990). Experimental investigations of multilayer insulation. Cryogenics, 30(8), 711-719
3.Charu Dwivedi, Priyanka Bamola, Bharti Singh, Himani Sharma, Chapter 2 - Infrared radiation and materials interaction: Active, passive, transparent, and opaque coatings,
4.Goutam Kumar Dalapati, Mohit Sharma, Energy Saving Coating Materials, Elsevier, 2020, Pages 33-56, ISBN 9780128221037, https://doi.org/10.1016/B978-0-12-822103-7.00002-9.
5.https://frakoterm.com/cryogenics/multi-layer-insulation-mli/
6.Multilayer Insulation Material Guidelines, NASA/TP-1999-209263
7.B. C. Deng et al 2017, Simulation and experimental research of heat leakage of cryogenic transfer lines IOP Conf. Ser.: Mater. Sci. Eng. 278 012017