High Performance Windows for Applications in Space: Open Problems and Challenges

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Abstract

The growing interest in space exploration, not least for tourism purposes, requires comfortable and visually engaging accommodations in orbiting stations, with large windows to observe the Earth and the cosmos. While seemingly simple, these elements are complex engineering feats, of paramount importance to enhance both the functionality and the human experience of space missions. Designing space windows requires addressing a unique set of engineering demands to ensure safety, durability, and performance under the extreme space conditions. The key requirement is the capacity to withstand the pressure differential between the station's interior and the vacuum of space, about two order of magnitude higher than in terrestrial applications, without excessive deformation or failure. Furthermore, the glazing is particularly vulnerable to the temperature variations, from the intense heat of direct sunlight to the extreme cold of space, generating cyclically-varying thermal stress that can damage the materials. Finally, space windows must be designed to handle impacts from space debris traveling at high velocities. Other requirements are resilience, high fracture toughness, high endurance limit and lightweight. For these reasons, space glazing are usually composed of several layers, to provide: radiation/thermal shield (multiple plies, vacuum insulated); structural capacity (redundant pressure panes); protection against debris (external pane) and from scratch (internal sacrificial layer). The state of the art in space glazing is represented by the Cupola of the International Space Station, made of fused silica monolithic flat panels. To address the unique challenges of the space environment, it is not possible to transfer to this context the glazing technology used for terrestrial applications, and innovative transparent composite are necessary. With reference to the windows of the ISS Cupola, taken as paradigmatic examples, we discuss the design, conception, and modeling of high-performance transparent unitized cells for large spacecraft and space station windows, based on operational thermal, optical, and structural requirements.

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Keywords

Space Window; Space Station; Transparent Composite; Thermal Stress; Impact Resistance

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