Cryogenic Selective Surfaces

A Phase 2 NIAC Project

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If we place a sphere in deep space at 1 AU from the sun, what will its temperature be, assuming it absorbs radiation from the sun and emits infrared radiation in all directions?

Our goal is to find a way to make this sphere as cold as possible so that we can potentially store liquid oxygen or operate superconductors.
Companies such as Sheldahl sell second surface mirror sheets composed of silver on FEP (type of Teflon). These flexible reflectors/radiators have been used to remove waste heat from the Shuttle and the Hubble telescope while in the presence of the Sun.

These materials absorb about 9-10% of the Sun’s power and can emit with 75-80% efficiency in the infrared, but that’s not good enough to reach cryogenic temperatures.
Under our Phase 1 work we modelled a new coating composed of a scattering layer followed by a silver layer. The scatterer handles the UV and visible reflectance and the silver reflects mid-long wave radiation.

A pressed salt disk scattering bright light.
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We modeled this new coating, published the results, and have a patent pending.

Our models show that these coatings can be constructed to absorb less than 0.1% of the Sun's illuminated power!

Predicted steady-state temperatures for a sphere coated with 5 mm of various broad transparent band materials.

The solid line is the theoretical best performance-adapted from Hibbard (1961).
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Under our Phase 2 funding we developed rigid versions of the coatings.

We take BaF2 powder, add water to make a paste, press it into a mold, and fire it in a kiln.
This is our best sample to date. It’s more than 3 inches in diameter (87 mm), 6-7 mm in thickness.

The SEM shows the particle sizes.
We’ve been testing our coatings in a cryocooler, evacuated and operating around 40 K, i.e. a simulated deep space environment. We’ve used a 375 nm Ultraviolet LED as the light source, located inside of the vacuum chamber.
This worked well. The sample absorbed less than $\frac{1}{4}\%$ of the illumination. It is staying under 50 K while being illuminated with 17,000 microWatts of 375 nm radiation.

This validates the performance of the coating in a deep space environment but only for UV illumination.
NASA has a significant technology shortfall—

With the current state of the art cryogenic fluid cannot be stored in deep space without the use of cryo-coolers.

Heat reaches to the cryogenic tank via:

1. Solar illumination
2. Infrared illumination from nearby warm objects
3. Conduction along support struts.

A proposed design for a Mars vehicle with a liquid oxygen tank.
We’ve chosen to model a Mars vehicle as having a LOX tank located between two warm objects.

1. The tank is coated with our new selective surface to minimize solar power absorption.
2. Infrared shields are proposed to minimize infrared coupling with warm spacecraft components.
3. By using low thermal conductivity struts and coating them with our new selective surface, heat is radiated away rather than reaching the LOX tank.

The resulting modeling shows that LOX can be taken to Mars using shields and our new coating.

Our partner at the Glenn Research Center is assessing the impact of this on various proposed missions.
Phase 2: 2nd year plans

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Refine the coating:

1. How do we attach it?
2. How thick should it be?
3. How strong is it?
4. Can it handle launch vibrations?
5. Can it be cold shocked?
6. How do we clean it?
7. Can it be sealed?
8. Should we introduce other broadband optical materials?
9. How do we optimize the optical performance?
10. Is the silver working properly.
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Testing with a Solar Simulator

Our partner at the Glenn Research Center has purchased a Newport Solar Simulator which will be mated to a cryo-cooler to allow higher fidelity testing.

The goal is to test in the summer of 2018.
The launch service program wants to maintain LOX in low-earth orbit. Our new coating can minimize the solar heat load, but it will absorb the infrared radiation generated by the Earth.

We are considering a LOX tank with multi-layer insulation (MLI) coating the lower section and our new coating on the top.

Early analysis shows our coating may be able to radiate sufficient power to make up for the heat that gets through the MLI, allowing LOX to be maintained passively in a low earth orbit tank.
We’ve begun modeling a possible Cube-Sat to test the low earth orbit concept.

The Launch Service Program has agreed to fund a portion of this development.
A concept image of a Mars Lander with liquid oxygen and liquid methane. One of the liquid methane teams is current considering our coating.

Development of a liquid hydrogen based nuclear thermal rocket is underway. We have been asked to consider the impact of our new coating on the cryogenic thermal management of this vehicle.
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Co-funding provided by

The Kennedy Space Center
The International Space Station
The Launch Service Program
NASA’s Game Changing Program
Various programs at the Glenn Research Center.
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Questions?
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The Payload Bay doors of the Space Shuttle Orbiter were coated with a selective surface to allow heat rejection in the presence of the sun. But these coatings absorb 8-10% of the Sun’s irradiance and cannot be used to reach cryogenic temperatures.

During our Phase 1 we proposed a new coating. Hibbard (1961) showed that 40 K could be achieved with ideal materials. But real world materials are not ideal. We have found a material that is closer to the Hibbard ideal than any off-the-shelf coating.

Selective Surfaces (i.e. thermal control coatings) reflect Sunlight while emitting IR energy, providing cooling.

We showed that with this new coating we can take LOX to Mars. If we coat the LOX Tank with our cryogenic selective surface to minimize solar absorption, use coated struts (as shown to the right), and use IR shields composed of multi-layer insulation, the heat load will be sufficiently minimized to allow LOX storage on a trip to Mars.

Phase 2 First Year: Rigid Material, Ultraviolet Testing

Hibbard (1961) showed that 40 K could be achieved with ideal materials. But real world materials are not ideal. We have found a material that is closer to the Hibbard ideal than any off-the-shelf coating.

We modeled this coating, projected that cryogenic temperatures could be reached, published our work in Optics Letters (3/16) and applied for a patent.

We can now make rigid coatings. Mix powder (BaF2) with water to make a paste. Mold it and sinter it to form a solid entity. The SEM image below shows that we’ve retained the particles needed for scattering.

The samples are tested in a simulated deep space environment, cold and under vacuum. Looking at the plot below, turning on a 375 nm UV LED at hour 47, shows that less than 0.25% of the radiation hitting the BaF2 sample is absorbed—partially validating the concept. The orange, blue, and grey plots are the aperture, sample, and wall temperatures, respectively.

Phase 2 Second Year: Better Coatings, Solar Testing, and a New Mission

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