Using Thermochromic Materials for Mobile Space Suit Heating Applications

Intermediate Environments

Building and operating machinery will be essential in Martian exploration. For astronauts to leave the spaceship environment to do work, these three human needs must be met: sufficient counter pressure, oxygen to breathe, and warmth. Full Pressure Suits (FPS) have been used in past missions, and in effect these suits are miniature self-contained atmospheres. The tradeoff is that the pressure differential created by these suits makes movement awkward and the large helmet severely decreases visibility. This not only makes movement cumbersome, but dramatically increases the amount of energy the astronaut must expend. In addition, FPS severely limit dexterity, adaptability, and the ability to move rapidly in and out of the living areas.

The restrictiveness of FPS was not as critical a factor in past missions to the moon because time on the surface was limited and physical work was minimal. A mission to Mars however, will be much longer. A prolonged mission is necessitated by the respective orbits of Earth and Mars. Robert Zubrin from the Mars Society estimates an 18-month stay on Mars [1]. An astronaut in a FPS can only work for limited amounts of time. Besides the time restriction due to oxygen toxicity, the energy required to move inside the suits is high and cannot be sustained for long periods of time. These restrictions will serious impair the astronaut’s ability to work effectively and efficiently. Work on Mars will be frequent and demanding, as there will be a great need to do servicing, building, and maintenance work on Mars. The nature of the work and the length of the mission magnify the negative aspects of a FPS to an unacceptable level. A new solution is necessary to facilitate astronauts on Mars in performing useful work.

In past research we investigated and proposed the use of an intermediate environment [2]. It is termed an intermediate environment because it has the pressure of the living quarters but uses plentiful Martian air as the ambient. The use of an intermediate environment can solve the pressure requirement effectively. An intermediate environment pressurized with Martian air would provide sufficient external pressure, allowing the use of a thinner, light-weight suit. The astronauts would need oxygen or mixed gas masks, but would not need their bulky outside suits to provide counter pressure. This will allow improved mobility, dexterity, visibility and astronaut energy efficiency. An intermediate environment also has additional benefits in minimizing flammability concerns, minimizing decompression sickness, and saving cost on resources.

Staying Warm on Mars

With pressure and oxygen requirements met, the remaining task is to find a solution for providing heat to the astronauts in a subzero ambient environment. This problem has the constraint that it is desirable to keep the suits thin in this pressurized environment so that mobility is not restricted. Our solution is to use directed microwaves which could be absorbed by the material of the space suit and then heat the astronauts through conduction. Heating the astronauts directly rather than heating the empty space around them will save on energy [3]. This idea is analogous to warming oneself in front of a fire. The infrared rays warm the individual directly without having to heat the entire surroundings first. We choose to use microwaves rather than infrared because microwaves are easier to direct.

For the absorbing material we propose using thermochromic material. Thermochromic materials are able to reversibly change their optical properties when heated past a critical
This means that the material can switch states between absorbing radiation of certain frequencies to reflecting it. By supplying heat in this manner, material can be kept thin. This will keep the astronauts warm but will not restrict motion so that useful work can be done.

This ability to undergo a phase transition according to temperature is advantageous for our space suit material application. This allows our material to act as a self-regulating thermostat. Our objective in making thermochromic material is to prepare it so that it demonstrates switchable properties in the microwave region. Secondly, we would like to prepare our material so that its critical temperature is at an appropriate level for heating astronauts by conduction. Achieving these objectives requires careful setup of the preparation conditions.

**Designing Heater Substrate**

After a literature review we found a study done by Wang et al. [4] which suggests a preparation method using a thin film of vanadium dioxide to coat glass. Vanadium dioxide is a fascinating material for its property of undergoing a phase transition from a semiconductor to a metal at a temperature of around 68°C [5]. This change in state is accompanied with a change in its optical properties.

We planned to deposit our glass samples with vanadium dioxide using a RF magnetron sputterer at BYU (Fig. 1). To produce a single phase of vanadium dioxide, Wang suggests the need to reach temperatures greater than 600° C [4]. Higher temperature will not only allow us to access different structures, but will also increase atom mobility allowing the atoms to diffuse. This will allow us to create bigger crystals with fewer defects. The challenge was that our RF magnetron sputterer did not have the capability to heat our samples to the desired temperature.

![Figure 1: RF magnetron sputterer commonly referred to as “Joey”](image)

In order to achieve temperatures greater than 600° C we decided to design a substrate heater. To connect a substrate heater to our RF magnetron sputterer required that we purchase a feedthrough to act as a connector. It was necessary that this feedthrough be made of conductive material so that it could carry high currents. It is important to drop as much of the power as possible into our heater substrate not only to improve efficiency but also to prevent damage of other parts. Copper was chosen as a suitable material to meet these needs. Copper has a high conductivity that allows us to reach temperatures well over 600° C. We found a suitable copper feedthrough made by CeramTec capable of conducting 185 Amps of electricity (Fig 2).

![Figure 2: A ¼ inch high current feedthrough for a 2 ¾ inch ConFlat flange from CeramTec (Part# 16705-01-CF).](image)
After the feedthrough was purchased we began the design of a bracket. To ensure a proper fit we measured the dimensions of our feedthrough cross section, our quartz substrate area, and the diameter of our RF magnetron sputterer opening. These dimensions served as the constraints to create a first draft on paper. This design was further modified and later modeled on the computer using SolidWorks (Fig. 3).

![Figure 3: Bracket modeled in SolidWorks](image)

![Figure 4: Assembly of bracket mounted to feedthroughs](image)

This bracket was designed to be assembled with the feedthrough and the quartz slide as seen in Figure 4. To cut the copper we decided to use a water jet which is available in the Precision Machining Laboratory at BYU. We created a drawing based on our computer model and then used its dimensions to program the water jet. The water jet was chosen over a saw because of the small size of the piece and the curved surface on the bottom of the piece. Water jet cutting is not as precise as other methods such as the Wire EDM, but tight tolerances were not necessary for this design. After the part was cut out, the holes were drilled by use of an end mill. Finally, to attach this bracket to the feedthroughs we tapped a hole on the sides for a set screw which could be tightened by use of an Allen wrench (Fig 5).

![Figure 5: Set screw used to attach bracket](image)

![Figure 6: Model of quartz slide designed in SolidWorks](image)

Now that the bracket was designed and attached to the feedthrough, the quartz slide needed to be modified to fit between the brackets. The quartz slide design is seen in Figure 6. Cutting quartz however, was a greater challenge than cutting copper. Our quartz substrates are highly cross-linked to allow them to heat up to high temperatures. Though this is good for our heating application, this cross linking makes the quartz break in unpredictable ways. Because the quartz is brittle rather than ductile, and its size is small, cutting our substrate was a challenge. In 1995 Allred and Todd published a paper on techniques for cutting glass using a water jet [6]. This paper suggests that by using Styrofoam for support and weights to hold down the material, glass can be cut by use of the water jet. This method is currently being pursued in the machining lab.
Future Work

This section presents work that has not yet been done, but will be in the upcoming months either by myself or another student. This part of the project was not in the original scope of our study, but is a logical follow-up to our work. An outline of the procedure is described below. Though the outline is simple, the work is not trivial.

First, we will deposit the glass with vanadium dioxide using a RF magnetron sputterer located in U234 of the Eyring Science Center (ESC). The newly built heater substrate will allow us to achieve the higher temperatures necessary for our thermochromic material. To produce a single phase of vanadium dioxide we will experiment with different oxygen-argon ratios (controlled by use of a mass spectrometer), temperatures, and bias. This process will be iterated until we find optimal depositing conditions.

After we have sputtered the films we will use the ellipsometer in C376 of the Benson building to analyze our sample. This will allow us to determine the optical constants of our sample, the thickness, and the deposition rate.

Next we will put our sample on a hot plate heated to approximately 375 K. Because vanadium dioxide is thermochromic, we hope to observe a color change indicating a metal to semiconductor switch as it heats past the critical temperature and another switch as it cools back down.

When we are satisfied with the composition of our sample we will make a thicker one, about a micron in thickness. We will also use X-ray diffraction techniques using the SCINTAG XRD in S318 of the ESC. This will allow us to determine the phase of our material. Again we will run it through the ellipsometer to determine the optical constants and other properties of our material.

Lastly, we will use a microwave source to test our material to determine if in fact it does demonstrate switchable properties. This will be followed up with testing to determine how temperature varies with microwave intensity, frequency, and distance as microwaves pass through our material in both the reflectance and transmittance state.

References


