Engineering Notes

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Hydrogen Outgassing Considerations for an Orbiting Aluminum Molecular Shield

R.A. Outlaw*
NASA Langley Research Center, Hampton, Va.

Introduction

THE concept of an orbiting molecular shield and molecular beam apparatus suggests the unique possibility of conducting numerous physics and materials experiments which require the simultaneous conditions of extremely low gas density ($\sim 10^3$ cm^{-3}) and microgravity ($\sim 10^{-4}$ g).[1-3] Past investigations have shown that such conditions, within these orbiting facilities, would be useful in studies of free-jet expansions, atomic oxygen/surface interactions, metals purification, cross-beam experiments, and others.[3,4] However, in order to achieve the low gas density within such facilities, appropriate vacuum materials must be selected for fabrication of the apparatus. Further, these materials must be extensively processed to provide a minimum outgassing rate. Calculations of the internal density within an orbiting hemispherical shell (molecular shield) have shown that the ultimate internal density ($n_H = 200$ cm^{-3} for an orbital altitude of 500 km) is limited by the atomic hydrogen flux entering the shield from the aft half-space of the atmosphere.[1] Ideally then, the internal outgassing rate from the shield material should be sufficiently low that its contribution to the shield gas density, compared to that generated by the atomic hydrogen flux, is negligibly small. Hueser and Brock[2] have shown that using baked-out stainless steel as a shield material results in a density contribution of approximately 3.5 times that generated by the atomic hydrogen flux (orbit height = 500 km). In addition, the outgassing from the experimental apparatus, diagnostic instrumentation, and other hardware contained within the shield could easily increase the operational density a factor of 10 or more. The purpose of this Note is to show that a molecular shield and associated experimental hardware constructed of pure aluminum vacuum-processed at high temperature would have a sufficiently low outgassing rate that the resulting density contribution would be substantially less than the atomic hydrogen limitation.

Experimental Technique

Following a thorough bakeout, the major component of outgassing from metals is molecular hydrogen, primarily since atomic hydrogen is the major gas component dissolved in the bulk. The outgassing of hydrogen ν_d from a metal sheet of thickness d into the vacuum space is given by

$$\nu_d(t) = \frac{4c_0 D}{d} \sum_{n=0}^{\infty} \exp\left[\frac{-D(2n+1)^2\pi^2 t}{d^2}\right] \qquad (1)$$

where c_0 is the initial concentration, D the diffusion constant, and t the time.[5]

Measurements of the hydrogen concentration and diffusion coefficient in cylindrical samples of as-received pure-cast aluminum (99.995 wt.%), vacuum-melted aluminum (heated to 815°C in vacuo for 4 h), and vacuum-degassed aluminum (heated to 600°C in vacuo for 4 h) have been made by employing a dynamic method in an ultrahigh vacuum furnace. The details of this procedure have been reported elsewhere.[6,7] Figure 1 shows typical evolution curves of hydrogen desorbing from the bulk of as-received aluminum and as-received 347 stainless steel heated to 600°C.

Results

Table 1 shows the initial concentration values along with the appropriate diffusion coefficients extrapolated to 20°C (assumed to be the average orbital temperature of the shield). From these data and Eq. (1), outgassing rates for 3 mm thick metal sheets (estimated maximum shield thickness) after five days have been calculated and are also shown in Table 1. It is interesting to note that although the diffusion coefficient for aluminum at 20°C is comparable to most metals, the outgassing rates for vacuum-processed aluminum are much lower. The reason for this is the inordinately low hydrogen solubility in aluminum.[8] As-received aluminum was determined to have a hydrogen concentration of only 6.3×10^{17} cm^{-3} (10 ppm), but the hydrogen concentration of vacuum-processed aluminum is as low as 6×10^{10} cm^{-3}. In the as-received aluminum, 99% or more of the hydrogen is lodged in the cast-in interdendritic porosity and the balance is in solid solution.[6] Vacuum processing of the aluminum above the melting point removes all of the hydrogen in the pores (since the pores are eliminated) and reduces the amount in solid solution to that in equilibrium with the low hydrogen partial pressure (2×10^{-9} Torr H_2 for the experimental system used in this work). Vacuum processing just below the melting point also removes the hydrogen in the pores and actually lowers the hydrogen in solid solution to much less than above the melting point, since the equilibrium solubility is lower by a factor of

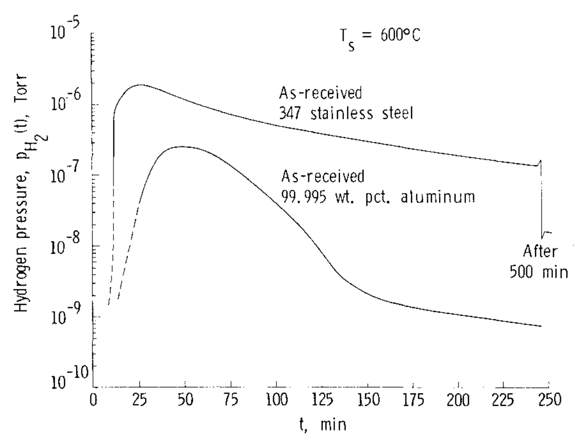

Fig. 1 Hydrogen evolution from the bulk of as-received 99.995 wt.% aluminum compared to 347 stainless steel at a sample temperature of 600°C (dashed lines are the estimated leading edge of the bulk desorption curves). Note that the stainless steel is still desorbing hydrogen after 8 h.

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*Research Scientist, Space Systems Division.

Table 1 Outgassing parameters for aluminum

Material	c_0, cm^{-3}	$D_H(20°C)$, $cm^2 \cdot s^{-1}$	ν_d, Torr $l \cdot cm^{-2} \cdot s^{-1}$
As-received Al	6.3×10^{17}	3.2×10^{-10}[a]	8.0×10^{-11}
Vacuum-melted Al	2.1×10^{12}	3.2×10^{-10}	2.7×10^{-16}
Vacuum-degassed Al	5.8×10^{10}	3.2×10^{-10}	7.4×10^{-18}

[a] Diffusion coefficient assumed for porous Al.
[b] Units for outgassing presented here are those most often employed.

Table 2 Molecular shield gas density parameters for vacuum-processed aluminum

Material	ν_d, Torr $\ell \cdot cm^{-2} \cdot s^{-1}$	n_d, cm^{-3}	n_d/n_H [a]
As-received Al	8.0×10^{-11}	6.0×10^4	3.0×10^2
Vacuum-melted Al	2.7×10^{-16}	0.2	1.0×10^{-3}
Vacuum-degassed Al	7.4×10^{-18}	5.5×10^{-3}	2.8×10^{-5}

[a] n_H = molecular shield gas density due to the atomic hydrogen flux at orbital altitude of 500 km = 200 cm^{-3}.

nine at 660°C. Unfortunately, the latter process does not remove the porosity. Other researchers have also indicated that low outgassing rates of aluminum and aluminum alloys can be achieved. Young[9] measured 4×10^{-13} Torr $\ell/s \cdot cm^2$ after only a 15 h, 250°C bake. Halama and Herrera[10] determined the outgassing rate for 6061 aluminum to be less than 1×10^{-14} Torr $\ell/s \cdot cm^2$ after 24 h at 200°C. In these experiments, however, the time and temperature of the vacuum processing may not have been sufficient to desorb all of the bulk hydrogen which would accordingly prevent achieving the lowest outgassing rate. Austenitic stainless steels vacuum processed at high temperature (~1000°C) also yield low outgassing rates and have recently been compared with the aluminum discussed in this work.[7]

Molecular Shield Gas Density

The density distribution within a hemispherical molecular shield is given by[2]

$$n_d(r,\mu) = 2\nu_d(\sqrt{\pi}\nu'_m)^{-1}\int_0^{\pi/2} h(r,\mu,\zeta)\,d\zeta \qquad (2)$$

where ν'_m is the most probable speed of the desorption gas, μ, ζ are azimuthal angles, $h(r,\mu,\zeta) = f[E(k), K(k)]$, $E(k)$ and $K(k)$ are complete elliptic integrals of the first and second kind with modulus k, and r is the normalized radius. The density at the origin of the shield due to outgassing ν_d reduces to

$$n_d(0,0) = (2\sqrt{\pi}/\nu'_m)\nu_d \qquad (3)$$

The calculated shield densities $n_d(0,0)$, due to outgassing [molecular hydrogen desorbing at 20°C and $\nu'_m = (2kT/m)^{1/2} = 1.56 \times 10^5$ cm/s] for the vacuum-processed aluminum are given in Table 2. The lowest value obtained is for the vacuum-degassed aluminum. A shield constructed of this material would result in a density due to outgassing 3.6×10^4 times lower than n_H, the shield density due to the atomic hydrogen flux. This material would still contain the porosity, however, and may result in unwanted pinholes. The most desirable processing for the aluminum would be to go through vacuum melting, thus eliminating the porosity, and then follow with vacuum degassing in the solid state to insure the lowest ultimate outgassing rate and therefore the lowest shield density. Since aluminum is also very light in weight, possesses a stable surface oxide, is difficult to recharge with hydrogen, and can be vacuum processed at relatively low temperatures (<700°C), it appears to be a suitable candidate construction material for an orbiting molecular shield.

References

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Computer Controlled Operation of Ultraviolet Spectrometer and Polarimeter on Solar Maximum Mission Satellite

R.A. Rehse* and M.E.C. Bruner†
Lockheed Palo Alto Research Labs, Palo Alto, Calif.
and
H.D. Tinsley‡
SCI, Inc., Huntsville, Ala.

Hardware Organization

Overview

THE Ultraviolet Spectrometer and Polarimeter (UVSP)[1] is one of the instruments on NASA's Solar Maximum Mission (SMM) satellite. This instrument has four optical path mechanisms which control and select solar light reaching

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*Senior Scientist, 0/52-12, Advanced Systems Division.
†Staff Scientist, 0/52-12, Advanced Systems Division.
‡Principal Engineer, Government Division, Computer Department.