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Cryogenic system for a thin solid hydrogen target

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November 29, 2000

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Abstract

A cryogenic system has been designed to make a thin target of solid hydrogen usable under vacuum, with a particle beam. This document describes the system developed and presents the first results obtained with a 2 mm thick target with a useful surface area of (20*25) mm².

1. Introduction

The development of solid phase hydrogen targets is part of the research program with secondary ion beams [1]. The main requirements imposed for such targets are: low thickness, very fine windows, and uniform thickness and density.

Target systems have already been designed in various laboratories, particularly by directly condensing H_2 gas to make the target [2,3]. In the system developed, we opted for a transition to the liquid phase (16.2K / 230 mb) before progressive solidification of the hydrogen (T< 13.9K).
Liquid helium is used as a cold source at 4 K and the growth of the crystal is imposed by the temperature gradient in the metal frame supporting the target.

Since the windows of the target are of mylar a few microns thick, the pressure is balanced on either side of the windows during the target solidification phase, to guarantee a constant target thickness. Viewers installed on the cryostat served to check the growth of the phases, as well as the transparency of the crystal produced.

2. Description of the system

2.1 Principle

The target is made using a metal frame to which mylar windows are glued. A stack of frames forms an H_2 target cell with an He cell on either side of the target.

During the target production phase, equivalent pressure is maintained on either side of the target windows. To do this, the pressure of a volume of helium gas matches the pressure variations of the hydrogen circuit during the phase transitions and up to the complete formation of the solid H_2 target (Figure 1). Once the target is formed, the helium gas is evacuated. The mechanical strength of the windows of the He circuit with respect to beam vacuum imposes the filling pressure, and hence the phase change temperature of the target gas.

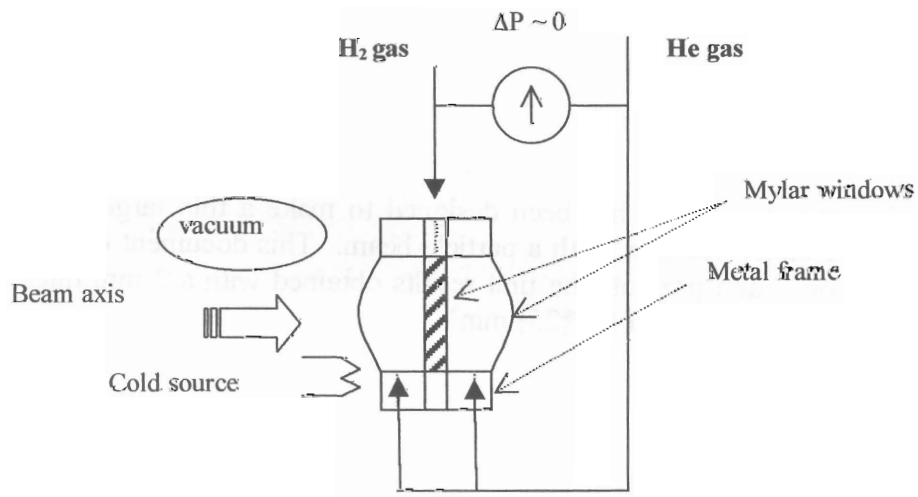

Fig.1 Shaping of the target

2.2 Cryogenic system

The cryogenic system consists of a cryostat with liquid helium circulation, of which the cold thimble (T = 4K) is mechanically coupled with the lower part of the target. This configuration helps to establish a temperature gradient aimed to make the solid grow towards the upper portion of the target. The gases enter through stainless steel capillaries (Φ 1-2 mm) welded at the bottom of the target for He and at the top for H_2. A thermalisation point is used from the cold thimble to reduce the power input by conduction of the capillaries at the top of the target. However, to prevent clogging, the H_2 circuits are kept at T>14 K during the target filling phase. This condition is essential to prevent the formation of bubbles caused by a lack of hydrogen feed during the formation of the solid.
The heat balance of the system gives a power received at the target of about 12 mW, 70% of it from thermal radiation (opening up the target to the beam axis). The heat transfer analysis reveals the possibility of obtaining the desired growth

of the crystal, by using a material whose thermal conductivity K at these temperatures is intermediate (0,6 W/m.K around 8K) and by adopting a suitable geometry for the target frame. This solution offers a compromise between the cooling of the target and the maintenance of the hydrogen gas in the capillaries in the gas phase.

The isotherms obtained in steady state conditions show the importance of the thermal radiation on the center of the target, but that the solid target nonetheless remains at a temperature relatively far from the triple point of H_2 (at least 3K below). (Figure 2). Calculations were made to determine the effect of the power deposited by the particle beam on the cryogenic target. With the beams used, the temperature elevation at the target remains negligible. The limit above which the triple point of H_2 is approached appears to lie around 9 mW for a 10 mm diameter beam (Figure 3).

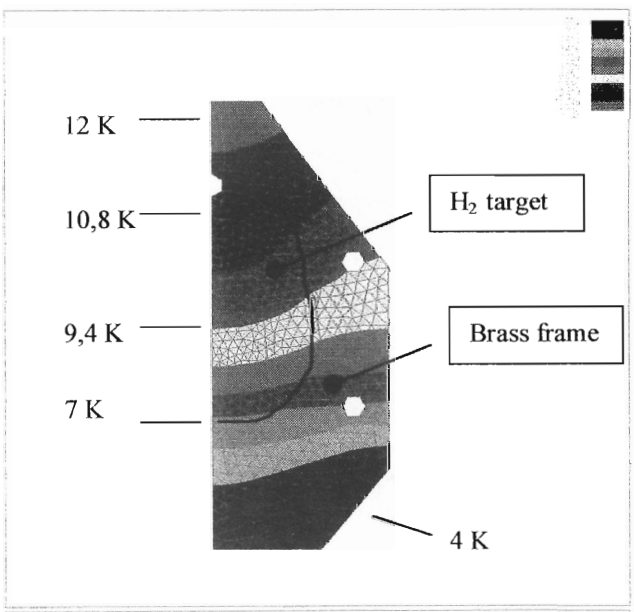

Fig. 2 Calculation of isotherms for a 2 mm thick target with brass frame

Solid H_2 target (25% para-H_2, 75% ortho-H_2)

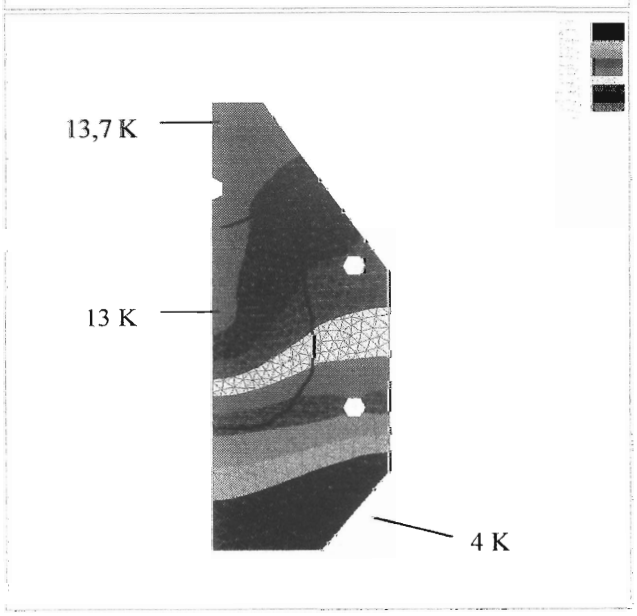

Fig. 3 Calculation of isotherms for a 2 mm thick target with brass frame, subjected to a beam of

Φ = 10mm and P= 9.2 mW

(25% para-H_2, 75% ortho-H_2)

For the remainder of the system, a liquid nitrogen circuit ensures the thermalisation of the capillaries of the target at 80 K as well as the cooling of a shield to limit the radiation towards the device. The change in temperature in the system is monitored by silicon diodes. The overall vacuum system is supported by a stainless steel flange to vacuum standard DN 160 ISO-K (Figure 4).

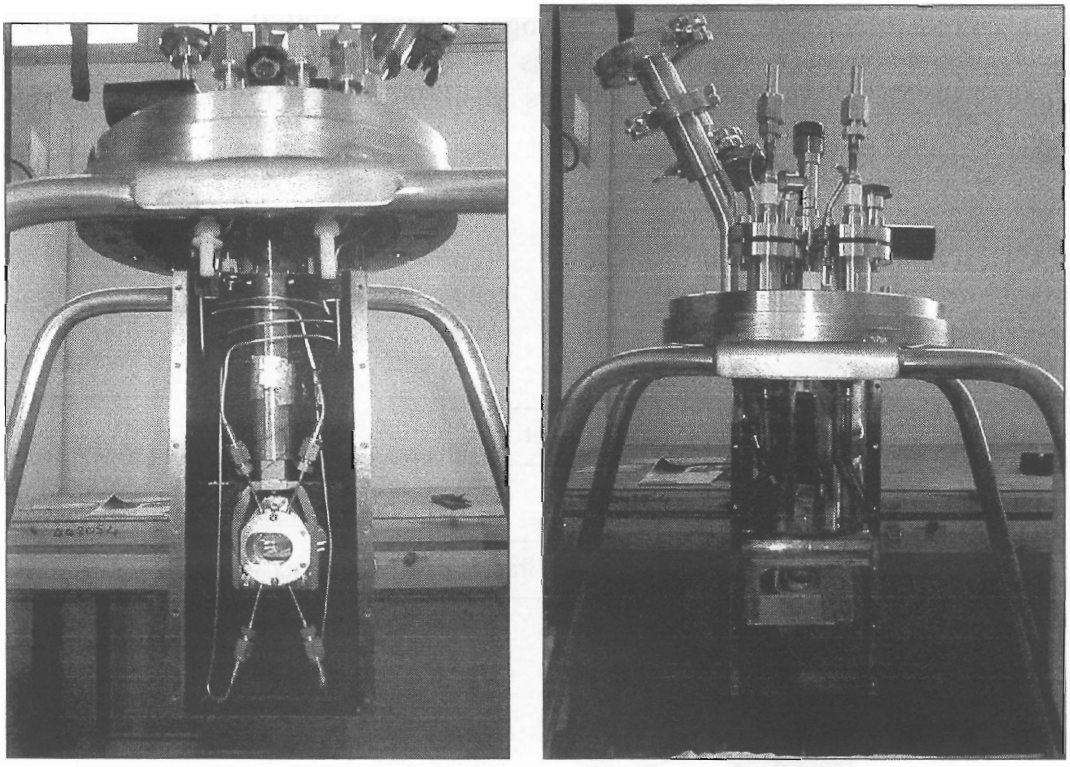

Fig. 4 Overall view of the device with and without 80 K shield

3. Results

The first results were obtained with a 2 mm thick target and 6 μm mylar windows. The observation of solid growth showed that as the temperature drops, the temperature gradient allows for the presence of the three H_2 phases in the target (Figure 5). The H_2 targets produced display no visible defect on a useful area of $(20*25)mm^2$, after 24 hours of operation (Figure 6).
The time required to produce the solid target, after placing the cryostat under vacuum, is about 3 hours and demands 10 liters of liquid helium. The system consumes ~1 l/h. of liquid helium to maintain the solid target at low temperature.

Note that the tests were conducted using transparent mylar (6 μm) thermalised by the copper shield at 80 K. In the present configuration of the system, this protection against thermal radiation is necessary for the satisfactory preparation of the target (solid growth without clogging the capillaries).

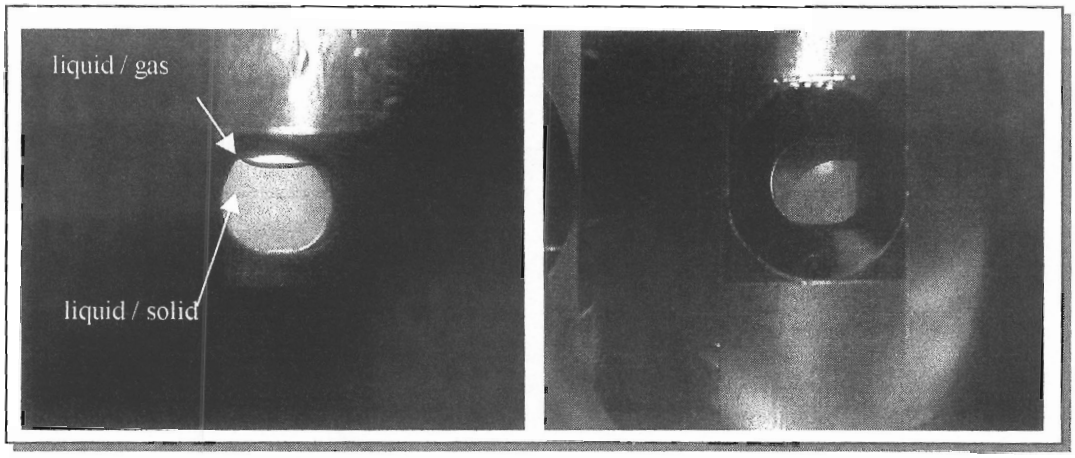

Fig. 5 Hydrogen target : solid growth

Fig. 6 Solid hydrogen target (2mm thick)

4. Conclusion

The system developed can be used to produce and maintain 2 mm thick solid hydrogen targets. Studies are underway to reduce the thickness of the target (1 mm), and on the use of finer mylar windows at the target. We have also initiated the design of an ortho/para converter operating at 20 K to produce hydrogen with a high proportion of p-H_2 (nearly 100%). This will help to prepare a uniform target and to exploit the high thermal conductivity of p-H_2 below 10 K (gain of several orders of magnitude) [4]. This substantial increase in the conductivity of the target will make it easier to evacuate the power deposited by the beam and the power produced by the thermal radiation.

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