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Development of a Cryogenic Target System for the FOREST Experiments

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A new cryogenic target production system for a 4π γ-ray detector FOREST has been installed in the GeV-γ experimental hall. The achieving temperature at the target is 4.5 K. It can maintain solid or liquid H_2/D_2. The target system enables us to make up solid or liquid hydrogen in a short time ~2 hours after 3 hour-precooling.

§1. A New Cryogenic H_2/D_2 Target Production System

We have constructed a 4π γ-ray detector named FOREST [1] in the GeV-γ experimental hall at Laboratory of Nuclear Science. The FOREST is used for the study of elementary reactions such as $N(\gamma,\pi^0)X$. A hydrogen/deuterium (H_2/D_2) target is important in our study. We need to construct the H_2/D_2 target fitted to the FOREST detector. At first, we constructed a solid hydrogen target in a small vacuum chamber, using a cryostat. Then, we have made many tests under various conditions with a new vacuum chamber, which is planned to be used in our experiments. We have succeeded in making a solid hydrogen target. The new cryogenic H_2/D_2 target system consists of three parts: a gas cooling system, a heat shield defending a cryostat from heat radiation, and a vacuum chamber. Figure 1 shows a schematic view of the system.

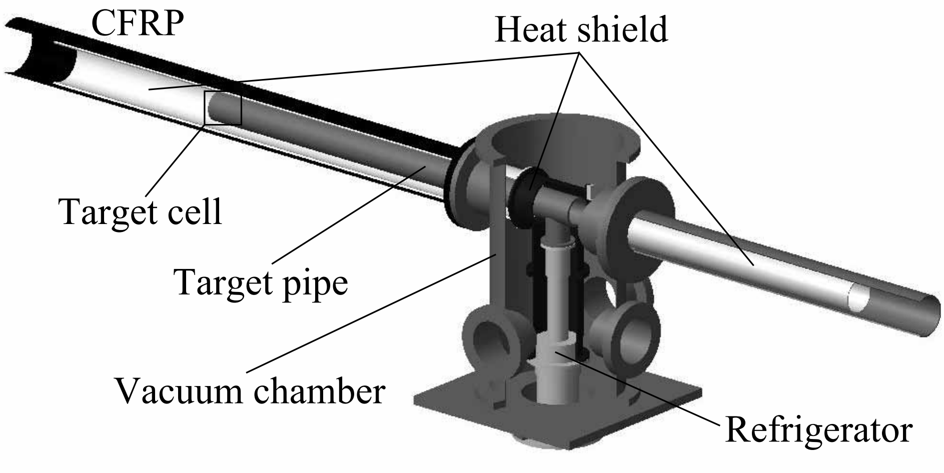

Fig.1. Schematic view of a target system.

1.1 Gas cooling system

A gas cooling system is mainly comprised of two parts: a 1000 mm long target pipe and a 2-stage Gifford-McMahon refrigerator. The target pipe made of aluminium is mounted on the top of the 2nd stage of the refrigerator. The target cell is located at the end of the pipe. A solid or a liquid H_2/D_2 target is made up in the cell.

We used, at first, a target pipe made of an A6063 aluminium alloy and a Sumitomo Heavy Industries SRDK-408D-W71C cryocooler (31 W cooling power at 40 K for the 1st stage and 1.0 W cooling power at 4.2 K for the 2nd stage). Our target pipe is so long that we can not cool down the cell enough for making solid H_2/D_2 because of thermal conductivity of A6063 and refrigerator's power shortage, so we replaced the target pipe and the refrigerator with new ones. A Sumitomo Heavy Industries SRDK-415D-W71C is used for a new refrigerator. Its cooling power is 35 W at 50 K for the 1st stage and 1.5 W at 4.2 K for the 2nd stage. We also made a new target pipe made of 4N pure-aluiminium which has 10 times higher thermal conductivity than A6063. Figure 2 shows thermal conductivity as a function of temperature for some materials [2]. Pure-aluminium is proper to our target system since it has good thermal conductivity at our operation temperature $\sim$10 K.

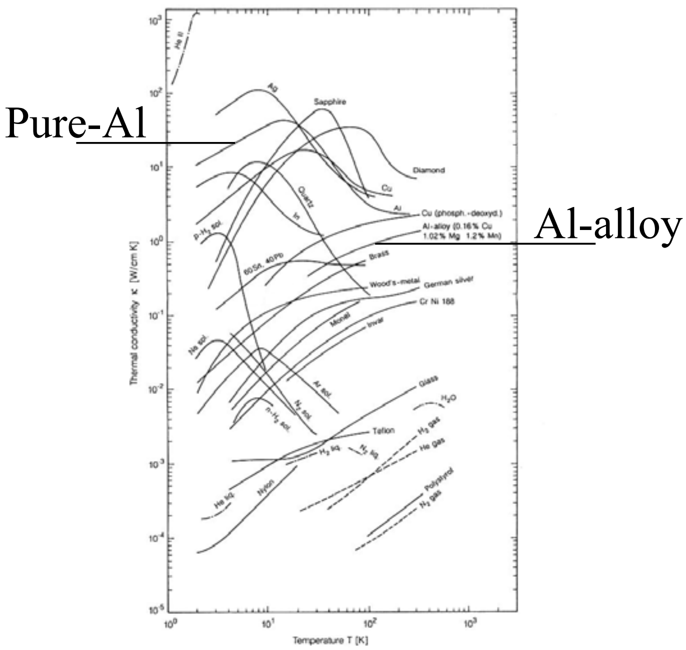

Fig.2. Thermal conductivities as a function of temperature for some materials. Pure-aluminium has high thermal conductivity at our operation temperature $\sim$10 K.

1.1.1 Target cell with the target pipe

A size of the target pipe is 1000 mm long, 65 mm and 61 mm for outer and inner diameters, respectively. A target cell with a thickness of 40 mm is located at the end of the target pipe, and the inner diameter of the cell is also 61 mm. The center of the cell is 920 mm downstream from the refrigerator.

Two 12.5 μm aramid films are epoxied upstream and downstream of the target cell to separate target region from vacuum. A pre-cooled pipe combines the cell with compressed H_2/D_2 gas cylinders. Because of a high cooling power of the refrigerator and good thermal conductivity of 4N pure-aluminium, achieving temperature of the target cell is 4.5 K.

1.2 Heat shield

The cryostat is protected from heat radiation by the heat shield having two components: a Cu shield and a cylindrical Al shield. The Cu shield, mounted on the top of the 1st stage of the refrigerator, is 4 mm thick and has high thermal conductivity. The cylindrical Al shield, connected to the Cu shield, surrounds the target pipe. The total length of the Al shield measures 1775 mm. The shield thickness is 0.5 mm around the target cell.

1.3 Vacuum chamber

The cryostat and the heat shield are placed in the vacuum chamber. The vacuum chamber comprises a vacuum cylinder and a vacuum duct made of carbon fiber reinforced plastic (CFRP) [3]. The target pipe and the Al shield are placed in the CFRP duct, which is employed to reduce the conversion rate of outgoing photons from the target cell. The CFRP has a disadvantage in the large emissivity of thermal radiation. Emissivity is about 1 for CFRP although that is about 0.1 for most of metals. The target pipe and the heat shield are surrounded with super insulation films (a 6.45 μm thick corrugated aluminized Mylar sheet: an aluminium deposited layer is 0.05–0.06 μm in thickness and a polyester sheet is 6.4 μm thick). They reduce the heat radiation from the CFRP to the heat shield and also from the heat shield to the target pipe.

§2. Gas Handling System

The gas flowing should be controlled finely at making, holding or vaporizing a cryogenic target by using some valves, vacuum gauges and vacuum pumps. Vacuum pumps are also used for vacuuming a chamber. Figure 3 shows schematic view of a gas handling system with a vacuum system.

The valve A and the scroll pump B (Edwards XDS5 Dry Pump) are used for purging an initial gas line with a target material. Valves B and C protect a purifier from vacuuming and air inflowing. The valve D which is a needle valve of a flow meter (Kofloc RK-1250) is mainly used for controlling gas pressure. Gas pressure in the gas line (nearly equal to in the cell) is measured by a vacuum gauge (MKS Baratron 122A) placed between the flow meter and the target cell.

A turbo molecular pump (Oerlikon Leybold Vacuum TURBO VAC 361) is combined with the vacuum chamber and the scroll pump A (Busch Fossa FO-0018B) is used for pre-vacuuming. The degree of vacuum in the chamber is measured by a Pirani gauge (ULVAC GP-1S with a sensor WPB-10) and a ionization vacuum gauge (ULVAC GI-M with a sensor M-13). The vacuum chamber is connected to a buffer tank (always evacuated) through a safety valve. If the pressure in the chamber is 0.05 atm higher than in the buffer tank, the safety valve automatically opens and the gas flowing from the chamber to the tank occurs. For discharging a target material gas, the scroll pump B and the valve G are used.

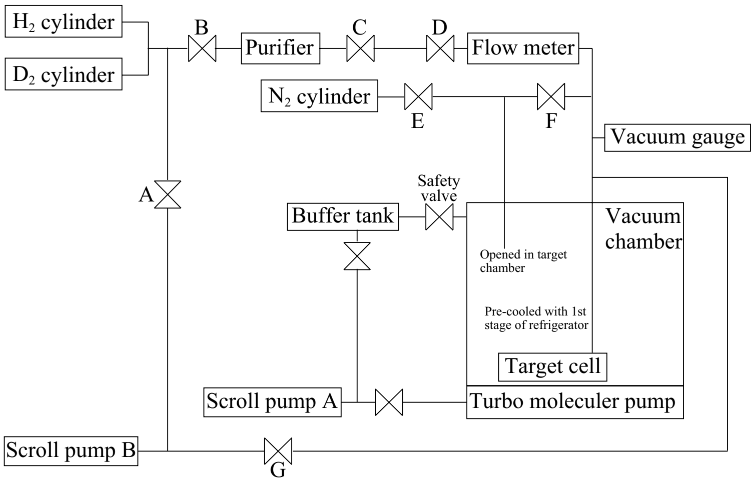

Fig.3. Gas handling system.

A compressed nitrogen cylinder is installed on the gas line between the flow meter and the vacuum gauge. It's used for breaking a vacuum in the chamber and the gas line. The nitrogen flowing is handled with valves E and F.

§3. Temperature Controlling System

It is important for safety operation to monitor and control temperatures of the target cell and the heat shield. A temperature controller (LakeShore model 331S), a temperature monitor (LakeShore model 218S), sensors (CX-1030-SDC, CX-1070-SD) and heaters (HTR-25) are used for a temperature controlling system. Figure 4 shows positions of temperature sensors and heaters. Sensors A and B are used as a reference point to maintain the cell temperature.

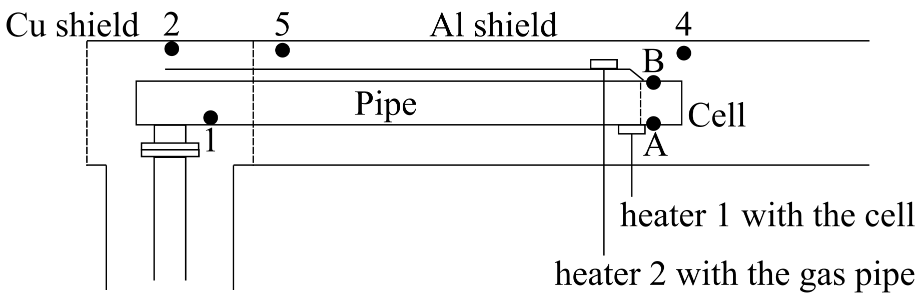

Fig.4. Positions of temperature sensors and heaters. To maintain the cell temperature, the sensors A and B are referred.

§4. Making and Holding a Cryogenic Target

Thanks to excellent thermal conductivity of 4N pure-aluminium, a cryogenic target can be made up quickly. Using a temperature control system, both the solid phase and the liquid are selectable. The gas pressure and the cell temperature are kept stable for a long time.

4.1 Making a cryogenic H_2/D_2 target

To make up solid hydrogen, a temperature of the target cell should be less than 10 K. Because of good thermal conductivity of 4N pure-aluminuium, the cell temperature is cooled down below 10 K after 3 hour-precooling, and it takes only 2 hours to make up solid hydrogen. We can easily change targets from hydrogen to empty or deuterium without changing the cooling system. Figure 5 shows a photo of the solid hydrogen target.

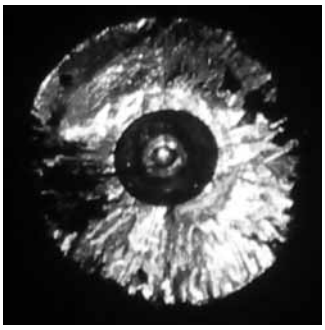

Fig.5. A photo of the solid hydrogen target.

It is important to keep the temperature of a gas-inlet above the triple point of the target material, 13.8 K for hydrogen and 18.7 K for deuterium, so that the gas flowing is not blocked by frozen H_2/D_2 in the gas-inlet. The gas pressure should be maintained at a proper value, which should be kept between the melting and the boiling point. The target material in the gas-inlet should be maintained in the liquid phase by using the temperature controller. For example we make a liquid target, operations are conducted at 14–15 K of temperature and about 240 torr of gas pressure for hydrogen, at 19–21 K and about 240 torr for deuterium. Figure 6 shows trends of the cell temperatures and the gas pressure during making the liquid hydrogen target. The temperatures of the cell and the gas pressure were well controlled.

4.2 Holding a cryogenic target

The cryogenic solid target is maintained for a long time because the cooling system has a sufficient power. The liquid H_2/D_2 target can be also kept in safety. Figure 7 shows trends of the temperatures and the gas pressure of the target cell with liquid deuterium during a week beam time. The heater power is controlled with the sensor A attached to a lower part of the target cell.

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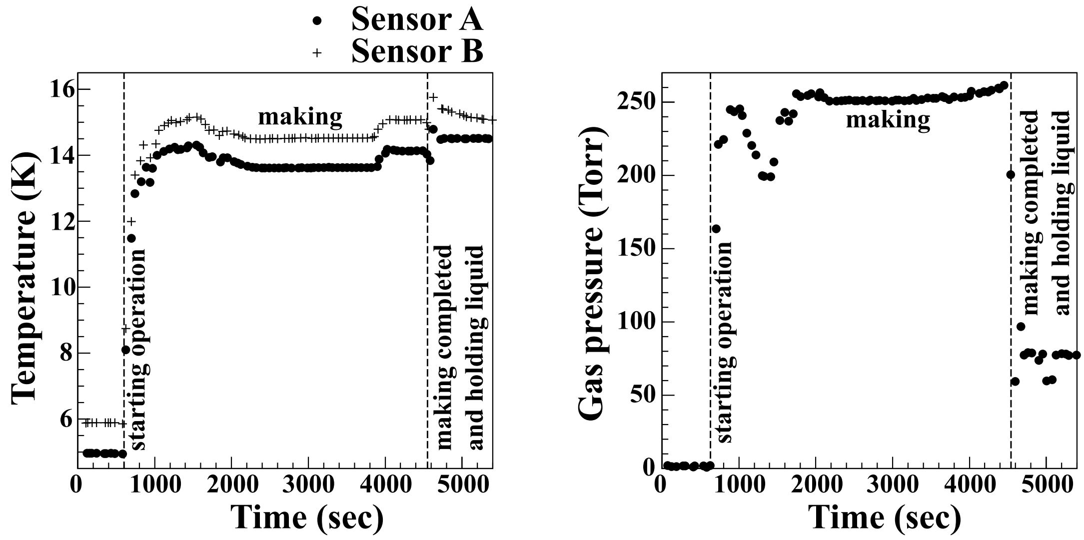

Fig.6. Trends of the cell temperatures and the gas pressure during making the liquid hydrogen target. It takes about 2 hours to make a liquid hydrogen target

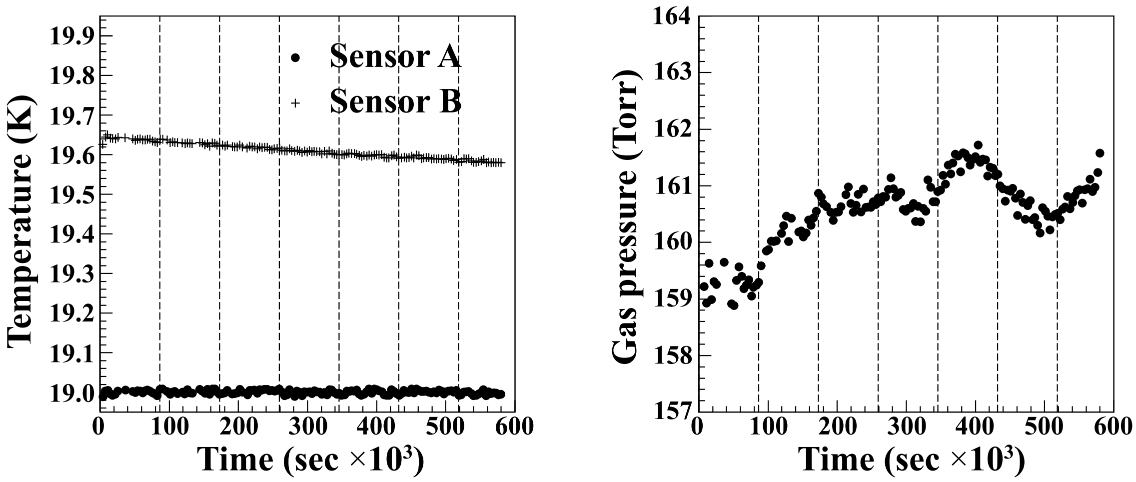

Fig.7. Trends of the temperatures and the gas pressure of the target cell with liquid D_2 in a week. The vertical broken lines are drawn every 24 hours. Each value is stable for a long time.

References

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