22-inch Cryopump that Achieves Both Cost Reduction and Energy Saving

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The size of glass substrates in organic light emitting diode (OLED) vapor deposition equipment has increased, the mainstream has changed from conventional G6H devices to G8H devices, and the vapor deposition equipment itself has also become larger. Therefore, cryopumps used as high vacuums pumps will also be increased in size from 20 inches to 22 inches, and pumping speed will increase. In this paper, we introduce the history of 22-inch cryopump development and a technology that realizes both cost reduction and energy saving in a cryopump system that will be adopted in the G8H in the future.

1. Introduction

The size of glass substrates in organic light emitting diode (OLED) vapor deposition equipment has increased, with the mainstream evolving from the previous G6H (1500×900 mm) to G8H (2250×2500 mm), and the vapor deposition equipment itself has doubled in terms of volume ratio. For this reason, the cryopumps used for high vacuum pumping are also increasing in size, from the 20-inch to the 22-inch cryopump, which has a higher pumping speed. Since approximately 140 20-inch cryopumps are used in the G6H equipment, it is expected that approximately 200 cryopumps will be used in the G8H equipment. The requirements cryopump manufacturers must meet are performance, quality, cost, energy savings, and ease of procurement. Considering the number of units to be used, it is safe to assume that there will be strong requirements for not only pumping performance, but also cost reduction and energy saving. In this article, we introduce a technology to reduce costs and save energy while maintaining the pumping performance of our cryopumps.

2. Successive generations of our 22-inch cryopump

Successive generations of our 22-inch cryopump are shown in Fig. 1, the product specifications are shown in Table 1, and external drawings are shown in Figs. 2, 3, and 4.

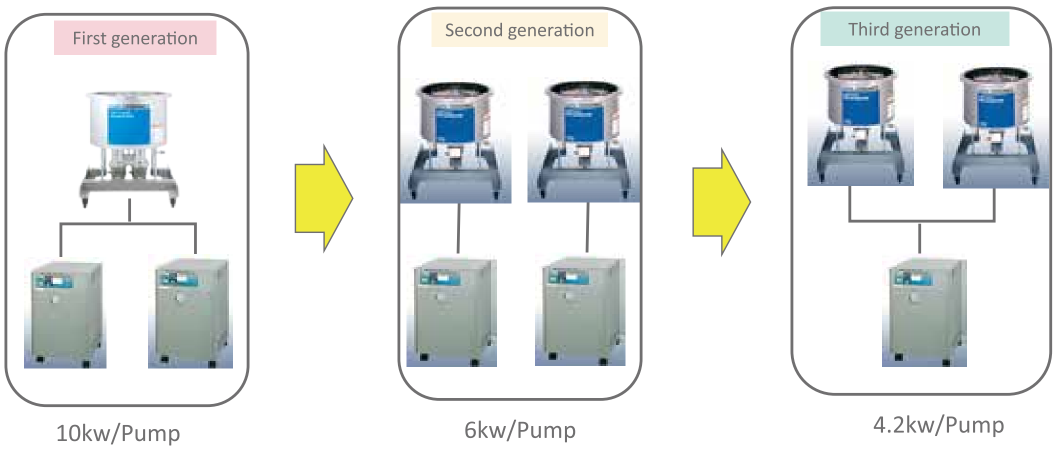

Fig. 1 Generations of 22-inch cryopumps

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Table 1 Specifications of 22-inch cryopump series

			First generation	Second generation		Third generation
Cryopump	Model		U22H	U22B	U22BL	U22BL
	Quantity		1	1	1	2
Refrigerator	Model		RM50T	RM120ET	RM120ET	RM150ET
	Quantity		2	1	1	2
Compressor	Model		C30VRT	C30PVRT	C30PVRT	C100L
	Quantity		2	1	1	1
Pumping speed		N_2	17000 L/s	13000 L/s	13000 L/s	13000 L/s
		Ar	14000 L/s	10000 L/s	10000 L/s	10000 L/s
		H_2	25000 L/s	15000 L/s	16000 L/s	16000 L/s
		H_2O	39000 L/s	39000 L/s	39000 L/s	39000 L/s
Maximum throughput (50 Hz)		Ar	4.1 Pa・m^3/s	3.0 Pa・m^3/s	3.0 Pa・m^3/s	Unmeasured
Pumping capacity		Ar	8.1 E+5 Pa・m^3	5.8 E+5 Pa・m^3	5.8 E+5 Pa・m^3	5.8 E+5 Pa・m^3
Cool down time (50 Hz)			150 min	170 min	230 min	Unmeasured
Power consumption (50 Hz)/pump			10.0 kW	6.0 kW	6.0 kW	4.2 kW

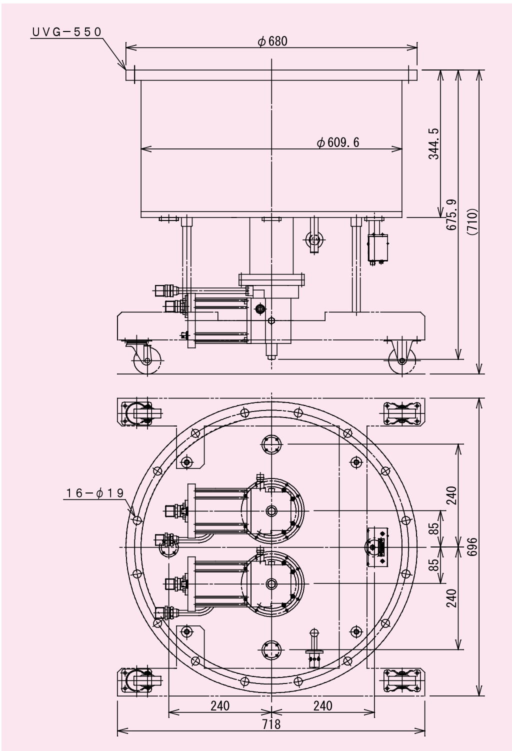

Fig.2 External drawing of CRYO-U22H

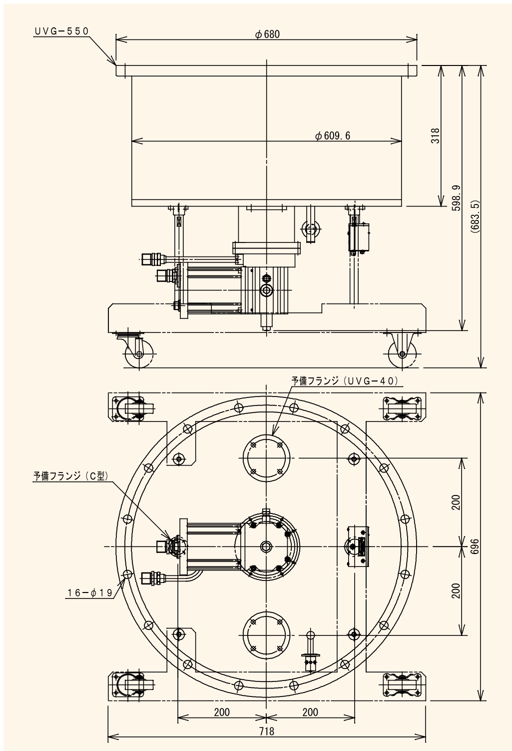

Fig.3 External drawing of CRYO-U22B

First generation

We developed the CRYO-U22H, which is used in optical applications and in vapor deposition equipment for electronic components, in 1988 by using a GM (Gifford-McMahon) refrigerator instead of the Stirling refrigerator made by Aisin. Even today, the pump still has the highest performance in the 22-inch series in terms of pumping performance and is produced and used in Japan to meet the needs of end users and set manufacturers.

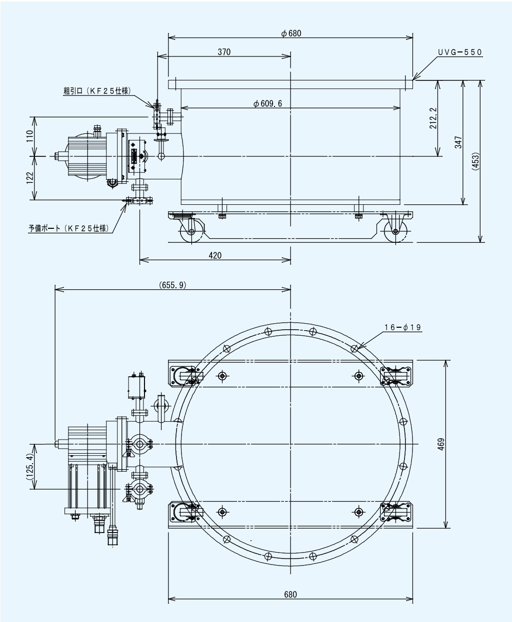

Fig. 4 External drawing of CRYO-U22BL

At that time, each pump was equipped with two R50 refrigerators, which have the highest performance among two-stage refrigerators, along with one C30 compressor per refrigerator. In other words, two refrigerators and two compressors were used for each pump.

Second generation

As the overall market for vapor deposition equipment for optical applications shifted overseas, security restrictions were imposed on exports from Japan.

The CRYO-U22H, which has a pumping speed of 15000 L/s or more for N_2, was classified as a product subject to security restrictions, overseas exports requiring permission from the Ministry of Economy, Trade and Industry. Considering the time required for export review and the short customer delivery time required, it became virtually impossible to ship the product. In order to meet the needs of overseas customers, it became necessary to develop a 22-inch cryopump with high performance and low maintenance costs that was not subject to export control.

In terms of the performance of the second-generation products, the H_2O pumping speed is the same as the CRYO-U22H, while the N_2 pumping speed is less than 15000 L/s. To reduce maintenance costs, we developed the RM120ET refrigerator, which has twice the performance of the conventional R50 refrigerator, thereby achieving a system with one pump, one refrigerator, and one compressor. In 2015, we developed the CRYO-U22B as a vertical type and the CRYO-U22BL as an L (horizontal) type cryopump...

Both models can be produced at our overseas subsidiaries. The CRYO-U22B is used in vapor deposition equipment for AR coating.

The CRYO-U22BL is the industry's first 22-inch horizontal cryopump. It can be installed in small spaces and led to cryopumps being adopted in OLED devices. Since there is only one refrigerator and one compressor per unit, power consumption is reduced by 40% compared to the CRYO-U22H.

Third generation

In 2016, we developed the CRYO-U20BL, a 20-inch cryopump for G6H OLED devices, in which the number of compressors is cut in half. This contributed to reducing energy consumption while the equipment is in use, while keeping selling costs down.

The CRYO-U20BL is a system that operates two cryopumps with one compressor, and uses the RM120ET refrigerator described above. Customer evaluations confirmed that the performance of the compressor was acceptable even when the helium flow rate supplied from the compressor is reduced by half.

Realizing that the same demands will inevitably force cryopumps for GH8 OLED devices to operate with half the number of compressors, we proactively began development of such a system. To halve the number of compressors, it is necessary to improve the efficiency and performance of the refrigerator. Simply increasing the volume of the expansion chamber of the refrigerator increases the refrigerating capacity proportionally. However, since this increases the helium flow rate required of the refrigerator, it is likely that the existing compressor will not be able to meet the requirements. Therefore, in parallel with the development of the refrigerator, it was necessary to develop a new compressor.

For the third generation, we decided to develop a two-unit multi-system (refrigerator and compressor) version of the 22-inch cryopump.

3. Refrigerator used for cryopump

The cryopump maintains the 80-K shield and 80-K baffle, which are thermally connected to the first stage, below

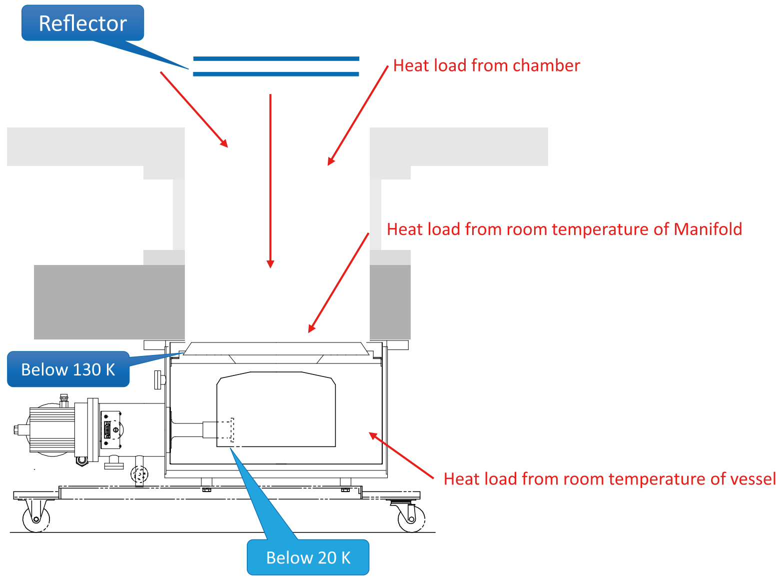

Fig. 5 Heat sources entering cryopump

130 K and maintains the 15-K cryopanel, which is thermally connected to the second stage, below 20 K in temperature. Molecules entering from the vacuum chamber are selectively pumped from gas at each location inside the cryopump.

The 80-K shield and 80-K baffle pump mainly H_2O, while the 15-K cryopanel pumps N_2, O_2, Ar, and H_2.

Sufficient refrigerating capacity is required to maintain the internal parts of the cryopump below the predetermined temperature. Heat input to the cryopump can be classified into two categories: radiant heat and heat transfer by gas. The main heat input in the vapor deposition equipment is radiant heat. The radiant heat is proportional to the fourth power of the emissivity, surface area, and temperature. Emissivity depends on surface conditions, and even with good surface finish on the equipment, large spaces will have a larger emissivity when viewed optically from the inlet of the cryopump. In addition, the temperature difference between the room temperature surface (300 K) and the cryocooled surface (20 K) is large at 280 K. Even if the facing surface is at room temperature, the heat load is large. In addition, the additional radiant heat from heating the substrate during the process can exceed the heat input that the refrigerator can handle, which is why multiple heat reflectors are usually placed in front of the cryopump to prevent heat buildup. The heat sources entering the cryopump are shown in Fig. 5.

Meanwhile, depending on the area of the heat reflectors relative to the opening area of the outlet and the distance between the outlet and the heat reflectors, conductance may drop, causing the pumping speed to decrease. There is therefore a trade-off between heat control and pumping speed. To maximize the performance of the cryopump, it is necessary to use a high-performance refrigerator and increase the conductance between the heat reflectors and the outlet opening.

Since the 80-K baffle and 80-K shield of the 22-inch cryopump have an even larger area in than the 20-inch cryopump, the heat input is also larger. In other words, the performance of the first stage of the refrigerator is important. What is needed is a refrigerator in which the temperature of the second stage does not rise even if a large amount of heat enters the first stage. In fact, at least 95% of the heat entering the cryopump is absorbed by the first stage, which has a high refrigerating capacity. The remaining 5% of the heat input is absorbed by the 15-K cryopanel (second stage), which has a relatively low refrigerating capacity compared to the first stage.

However, today's customers often set the second-stage temperature to a lower temperature of 17 K or 15 K instead of 20 K as the threshold to regenerate the cryopump. In terms of equipment operation, there is a tendency to regenerate earlier, and in order to maintain the regeneration cycle, it is necessary to increase the second-stage performance of the refrigerator.

4. Performance improvement goal for the refrigeration system

The refrigerating capacity of the combination (single system) of the RM120ET refrigerator and the C30 PVRT compressor fully meets the performance requirements of our second-generation CRYO-U22B and CRYO-U22BL 22-inch cryopumps, and they have been used without problems in actual equipment. We therefore set our development goal as ensuring that our two-unit multi-system has the same performance, in terms of refrigerating capacity per unit, as that of a single system: 120 W/80 K for the first stage and 15 W/20 K for the second stage.

5. Cryopump system design policy

Since the design of our 22-inch CRYO-U22B and CRYO-U22BL cryopumps is finalized, we decided not to change the basic structure of the 80-K baffle, 80-K shield, and 15-K cryopanel, which are essential pumping-related components, but rather to replace the existing refrigerator with the new refrigerator. As long as the cooling performance is maintained, in principle, the pumping speed and pumping capacity do not change. The factors that affect the performance of the cryopump when the refrigerator is changed are the cool down time, maximum flow rate, and crossover pressure. If the refrigerating capacity is the same, the above three factors do not change, so ideally the refrigerating capacity should be the same and the performance of the cryopump should not change.

6. Refrigerator design policy

6.1 Refrigerator expansion chamber

We made the second-stage expansion chamber about 34% larger than the current one, while keeping the first-stage expansion chamber as-is. Since the adoption of longer flexible hoses of 20 m or more in length and a larger compressor, which are used in larger equipment, is expected to affect the amount of helium gas used as a refrigerant, we assumed that we could maintain the current performance without changing the first-stage expansion chamber. We therefore decided to increase the volume of the second-stage expansion chamber to improve the performance of the second stage.

6.2 Sealing structure

The GM refrigerator maintains the temperature of each part by using seals so that the low temperature of the helium gas cooled by adiabatic expansion in both the first and second stages does not mix with the room temperature or the temperature of the first stage.

The sealing structure of the second stage of our conventional cryopump refrigerator uses a piston ring system in which the cylinder and displacer are physically sealed by pressing against the sealing ring at a constant surface pressure. However, since the new design has a larger expansion chamber, the circumference of the seal is greater if a piston ring system is adopted, which raises concerns about sealing performance. We therefore adopted the clearance seal system already used in our 4 K refrigerators, in which a narrow space is provided between the outer diameter of the displacer and the inner diameter of the cylinder, thereby reducing the conductance of this clearance area and restricting the flow of fluid. One advantage of this design is that even if the bore diameter specification is changed, sealing performance is assured as long as the clearance is designed within the specified range. Another advantage of this design is its long service lifetime. The disadvantage is the higher cost. Due to thermal shrinkage, the displacer must be made out of the same metal material as the cylinder to maintain a constant clearance even at low temperatures. The displacer is precisely manufactured from a metal material and then coated to prevent metal-to-metal contact. This inevitably increases the cost of the displacer, which traditionally is made of inexpensive resin.

6.3 Timing of valve opening and closing

The refrigerator incorporates mechanical valves for adiabatic expansion in the expansion chamber. It is equipped with an intake valve that takes in the gas supplied from the compressor and an exhaust valve that returns the gas to the compressor after adiabatic expansion. These are poppet type valves, which are synchronized with the motion timing of the displacer. The opening and closing timing of the valves is determined according to the position of the displacer. Factors such as pressure loss of the cold storage material exchanging heat inside the displacer and the size of the expansion chamber are taken into account to determine the opening and closing timing.

Since the amount of helium gas used in the expansion chamber is greater in the new model, the valve opening/closing timing should be set so that a large amount of helium gas can be supplied from the compressor to the refrigerator. However, through simulation, we found the valve timing that gives the maximum performance with the minimum opening time. This adjustment reduces the load on the compressor and reduces power consumption by providing cooling performance with an appropriate amount of gas.

6.4 New refrigerator test results

Table 2 compares the performance test results of the RM120ET refrigerator and the new RM150ET refrigerator. Performance was improved by 11% in the first stage and by 27% in the second stage.

Since the RM150ET has a larger second-stage expansion chamber, we anticipated that the flow rate of helium gas would be insufficient. We therefore set the standard operating frequency of the compressor to 60 Hz so that it can supply roughly 1.2 times more helium gas than at 50 Hz.

Table 2 Comparison of single refrigeration systems

	Conventional type	New Type	Ratio
Model	RM120ET	RM150ET	
1st 80 K	120 W	133 W	1.11
2nd 20 K	15 W	19 W	1.27
1st 0 W	34.0 K	37.5 K	—
2nd 0 W	7.1 K	6.0 K	—

7. Compressor design policy

Because the expansion chamber of the refrigerator is larger, a larger quantity of helium gas, the refrigerant, is required than before. This is even more necessary considering that two refrigerators are now operated by one compressor.

The performance of a refrigerator is basically determined by the differential pressure and the volume of the expansion chamber, from which various heat losses are subtracted.

If the amount of helium gas is small, the differential pressure, which determines the basic performance of the refrigerator, will be low and performance will not improve. We therefore enlarged the compressor to supply an even larger volume of helium gas to the refrigerator. The compressor we adopted for the new cryopump is, like our previous compressors, a scroll type helium compressor. However, the motor supports inverter drive as standard, which makes it possible to set a standard operating frequency of 60 Hz. The compressor we adopted is able to secure a maximum of twice the flow rate compared to the conventional model when the suction pressure of the compressor is increased by adjusting the lengths of the flexible hoses and the filling pressure. However, the compressor itself has an allowable operating pressure range, and the reliability of the compressor is not guaranteed unless it is operated within that range.

In other words, even if the suction pressure is increased, there is an upper limit to the discharge pressure, so it is necessary to operate the system within a range that does not reach the upper limit.

Table 3 compares the performance test results of the conventional single system cryopump versus our new cryopump, which features the combination of two new RM150ET refrigerators and one new C100L compressor.

The results for the new cryopump are indicated on a per-refrigerator basis. The first-stage performance is the same, and the second-stage performance is 14% inferior to the conventional single system. However, the energy consumption per cryopump was reduced by 30% to 4.2 kW.

Table 3 Comparison of new multiple refrigerator system and performance by refrigerator

	Conventional type Single	New Type Multiple	Ratio
Refrigerator Model	RM120ET	RM150E × 2	
Compressor Model	C30PVRT	C100L	
1st 80 K	120 W	120 W	1.00
2nd 20 K	15 W	12 W	0.86
1st 0 W	34.0 K	33.5 K	—
2nd 0 W	7.1 K	7.1 K	—
Consumption power/ Refrigerator	6.0 kW	4.2 kW	0.70

8. About the current results

When a multi-system cryopump system is used, the amount of helium gas supplied is reduced, so a reduction in refrigerating capacity is an unavoidable physical phenomenon. However, by upgrading to a newer model compressor, we were able to limit the degradation in performance to just 14%, and by adjusting the valve timing of the refrigerator, we were able to reduce the power consumption by 30%. In these terms, it can be said that the project was successful. Once again, to achieve our goals, we sought the optimal solution across each dimension of performance.