Progress in high-temperature-oven development for 28 GHz ECR ion source[†]

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We have been developing a high-temperature oven using UO_2 at the 28 GHz superconducting ECR ion source since 2013. Our high-temperature oven uses a tungsten crucible joule-heated with a DC current of 450–510 A. The crucible must be heated to a temperature higher than 2000°C to achieve a UO_2 vapor pressure of 0.1–1 Pa.[1] Some improvements have been made so far, and U^{35+} beams with a beam current of 100 μA could be continuously extracted from the 28 GHz ECR ion source for longer than two weeks. However, the high-temperature oven has not been used yet for providing U beams to the accelerators. This is because the use of the oven involves a higher trouble risk than the existing sputtering method, and it is not significantly superior to the sputtering method in the case of operation of a beam current of about 100 μA. However, the high-temperature oven cannot be expected to be more effective than the sputtering method in the stable operation of extracting U beams with a beam current higher than 200 μA.

Figure 1 shows shapes of the tested crucibles and Table 1 summarizes the test results. In the first test using the R34-type crucibles, the blockage of the vapor ejection hole by the UO_2 film often occurred. This was because the temperature of the cap and upper part of the crucible body is lower than that of the bottom part of the crucible according to the analysis by ANSYS.[2] In the next R41-type crucible, we decreased the thicknesses of the cap and the fitted section between the body and cap. In runs 5–7, the frequency at which the vapor ejection hole became blocked decreased. However, the oven voltage became unstable at high- temperature operations. This was presumed to be due to the local temperature rise in the upper and lower rods of the crucibles according to ANSYS. In the next R43-type crucible, the oven voltage was stabilized by increasing the diameter of the upper and lower rods from 2 mm to 2.2 mm. In run 10, we could increase the U^{35+} beam current by 20% by shifting the crucible position. Further, in the R435-type, we increased the diameter of the vapor ejection hole from 3 mm to 4 mm, and then we successfully operated the oven continuously for approximately 17 days without blockage of the vapor ejection hole.

In the next test, we are planning to approximately double the crucible size to increase the continuous operation period. Moreover, we are also planning to improve a thermal shield that was easy to break, and to connect the upper and lower support structures of the crucible to reduce the magnetic force acting on the crucible.

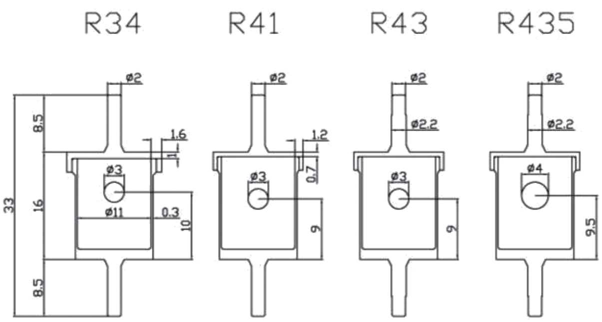

Fig. 1. Schematic of the tungsten crucibles used.

Table 1. Summary of the high-temperature oven operation results.

Run No.	Operation period	Crucible type	Oven power (W)	U^{35+} current (μA)	Operation time (h)	UO_2 Consumption rate (mg/h)	Comment
1	4/10-12/2013	R34	400-600	40-80	22	-	First test
2	7/8-16/2013, 7/22-27, 10/7-11	R34	550-650	60 (typ.)	291	2.5	Blockage of the ejection hole was observed directly by opening the ion source (7/10, 19)
3	11/5-15/2013, 11/19-22	R34	550-600	70-90	294	2.4	Blockage
4	12/10-13/2013	R34	550-600	60-80	77	0.6 (?)	
5	1/14-22/2014	R41	560-580	55-65	188	2.6	New type. No blockage
6	1/23-29/2014, 2/13-15, 2/25-28, 3/4-6	R41	480-510	55-70	283	1.7	Blockage removed by high-power (640 W) operation
7	3/11-26/2014	R41	530-660	40-70	311	1	Blockage. Unstable on high-power operation
8	6/24-7/6/2014	R43	570-660	70-100	257	4.7	Thick upper and lower rods. Oven current increased.
9	9/8-9/18/2014	R43	540-560	70-80	195	2.1	No blockage
10	2/5-3/11/2015	R43	560-630	80-100	326	2.6	Crucible moved forward by 25 mm. U^{35+} current increased by 20%. Blockage observed.
11	6/30-8/5/2015	R435	450-500	80-100	411	2.4	Ejection hole ϕ3 -> ϕ4. Thermal shield added. Oven power decreased. No blockage.

References
1) J. Ohnishi, et al.: Rev. Sci. Instr. 85, 02A941 (2014).
2) http://www.ansys.com/

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