Operation of high-temperature oven for 28-GHz superconducting ECR ion source

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Uranium beams, which are accelerated at the RI-beam Factory (RIBF), are extracted from a 28-GHz superconducting ECR ion source (SC-ECRIS)[1] by using a high-temperature oven (HTO). Our HTO uses a tungsten crucible, which is joule-heated with a DC current of 600–700 A. Figure 1 shows the dimensions of two types of crucibles. The crucible is heated to approximately 2000°C in order to achieve a UO_2 vapor pressure of 0.1–1 Pa. The HTO, which has been under development since 2013,[2] was first used to operate the ion source for the RIBF experiments in the autumn of 2016.

The HTO was also used to produce high-intensity vanadium beams in the 28-GHz SC-ECRIS. V^{13+} beams with a current of 100 μA or more were supplied to the beam time for experiments on super heavy element synthesis from 2018. For the production of vanadium beams, we placed a yttria crucible into a tungsten crucible and filled it with metal vanadium (vapor pressure: 1 Pa at 1827°C) because the metal vanadium should be electrically insulated from the crucible.

Table 1 lists a summary of the machine-time (MT), whose beams were supplied from the 28-GHz SC-ECRIS using the HTO. Four uranium-MT (U-MT) and three vanadium-MT have been performed so far. During normal operation, the average currents of U^{35+} and V^{13+} were both approximately 100–120 μA. The HTO can be operated continuously for at least three weeks because the fillable amount of the R692 type, which was used for these MTs, was approximately 2 and 4 g for vanadium and UO_2, respectively.

Figure 2 shows the trend of the beam current of U^{35+}, the electric current, and the power of heat generation of the crucible during the U-MT in the autumn of 2018. The beam current of U^{35+} was measured with a Faraday cup positioned down-stream of the analyzing magnet. The beam current can only be measured when the beams are not supplied to the accelerators and change according to the width of the slits located upstream. This trend shows that uranium beams of 120 μA or more could be supplied stably except during the last two weeks mentioned below. The power of heat generation of the crucible was obtained by subtracting the Joule loss on the support pipes from the total electric power. The operation of the ion source was interrupted because the crucible was changed to a new one for replenishment of UO_2 on Nov. 9. Although stable operation was performed, we had to increase the current and power of the HTO after the end of November, as can be seen in the figure. The reason was because a vapor-ejection hole of the crucible was blocked by a pileup of UO_2 and the beam intensity decreased. The first blockage that happened on December 6 was resolved naturally and the MT ended as scheduled even though the second blockage occurred. It was found that blockage tends to occur when the amount of vapor is large. This problem is serious, but it has not been solved yet. Details of this article are shown in Ref. 3).

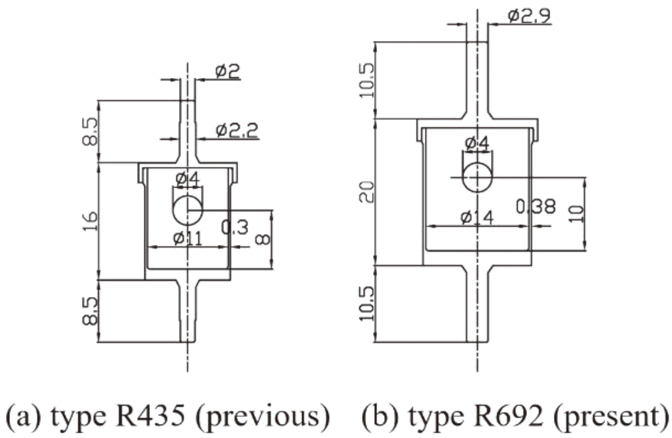

Fig. 1. Schematic of the tungsten crucibles.

Table 1. Summary of MT using HTO.

ion	period	beam current (μA)	operation time (d)	material	consumption rate (mg/h)
U^{35+}	10–11/2016	100–120	34	UO_2	2.4
U^{35+}	5–6/2017	60–120	35	UO_2	3.2
U^{35+}	10–11/2017	80–120	7 + 27 + 10	UO_2	4.0, 4.2, 12
U^{35+}	10–12/2018	110–140	27.5 + 30	UO_2	2.4, 2.4
V^{13+}	1–2/2018	100–210	20 + 13	metal V	2.2, 4.1
V^{13+}	6–7/2018	100–230	23 + 9	metal V	2.0, 3.8
V^{13+}	9/2018	90–110	10	metal V	2.4

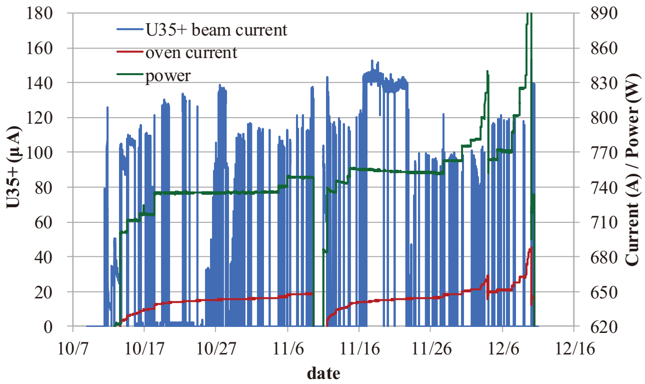

Fig. 2. Operational trend of HTO in U-MT of 2018.

References
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2) J. Ohnishi *et al.*, Rev. Sci. Instrum. **87**, 02A709 (2016).
3) J. Ohnishi *et al.*, Proc. 23rd Int. Workshop on ECR ion sources, Catania Italy, Sep. 2018, to be published in JACOW Web site.

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