Development of high-temperature oven for 28-GHz ECR ion source

J. Ohnishi,[*1] Y. Higurashi,[*1] M. Kidera,[*1] K. Ozeki,[*1] A. Uchiyama,[*1] and T. Nakagawa[*1]

U^{35+} ions extracted from the 28-GHz superconducting ECR ion source[1)] are used to supply uranium beams to the RIBF. Although we have thus far used the sputtering method, in which uranium is supplied in the ion source plasma by directly inserting a metal uranium rod, we began developing a high-temperature oven[2)] with the aim of increasing and stabilizing the beams. Because the oven method uses UO_2, a crucible must be heated to a temperature higher than 1900°C to supply an appropriate amount of UO_2 vapor to the inside of the ion source.

Figures 1 and 2 show the dimensions of the crucible and illustrate the oven in its entirety. The crucible is joule-heated with a large DC electric current. The crucible, made by machining a tungsten rod, is supported with upper and lower water-cooled copper blocks. The electric current and cooling water are supplied through brass double pipes. The crucible was designed by performing the electric, thermal, and structural analyses simultaneously using ANSYS.[3)] Figure 3 shows the temperature distribution of the oven, calculated by ANSYS. The boundary conditions are as follows: The temperature of the cooling water is 27°C, the heat transfer coefficient from the water to the copper block is 5000 $W/m^2/K$, and the voltage between the upper and lower copper blocks is 1.25 V. The radiation coefficient of tungsten was assumed to be 0.25. The electric current was calculated to be 439 A. The maximum temperature of the body is 2041°C, and the temperatures of the bottom and the cap are 1960–2000°C.

The oven is placed in a solenoid magnetic field of approximately 3.3 T, which is orthogonal to the axis of the crucible. Therefore, if an electric current of 450 A flows through the crucible, the crucible is subjected to an electromagnetic force of approximately 40 N. According to the ANSYS calculation, a maximum stress of 160 MPa is generated around the tapered parts on the crucible body sides of the upper and lower rods. Since the temperature of these tapered parts increases to higher than 1800°C, it was expected that this stress level could result in the deformation and destruction of the crucible with the decrease in the tungsten's strength. In fact, bends in the upper and lower rods were observed after operation.

We installed the oven loaded with UO_2 in the 28 ECR ion source and tested the generation of uranium beams in April 2013 after a temperature rise test and temperature measurement in a test chamber. In the first test, the oven was operated for 42h and a U^{35+} beam current of 140 μA was successfully obtained at an RF power of approximately 3 kW. After the first test, operation tests of the oven were executed intermittently from July to December. The operation time was a total of 29 days. Although we could maintain a U^{35+} beam current of 50–80 μA at an RF power of 1.5 kW for a maximum of one week, the beam currents often decreased to less than half in 7–8h. This decrease resulted from UO_2 blocking the crucible ejection hole. Since the cause of the ejection hole's blockage was assumed to be that the temperatures of the cap of the crucible and the upper part of the hole are lower than the temperature of the bottom, we reduced the thicknesses of the cap and brim by 0.2 mm. Figure 1 shows the schematic after this reduction. Presently, we have just started to test the crucible of the new design. We are also investigating the use of rhenium instead of tungsten, which has better creep characteristic strength at high temperature for solving the bends and fracture of the rods of the crucible.

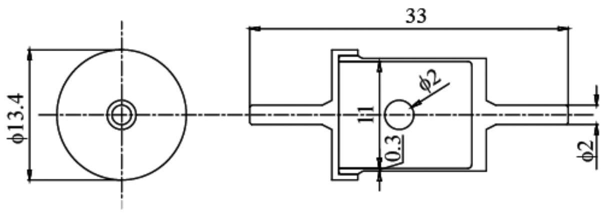

Fig. 1. Schematic of the tungsten crucible. The axis of the crucible is oriented vertically.

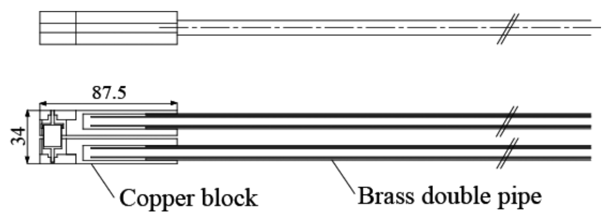

Fig. 2. Schematic of the crucible and support.

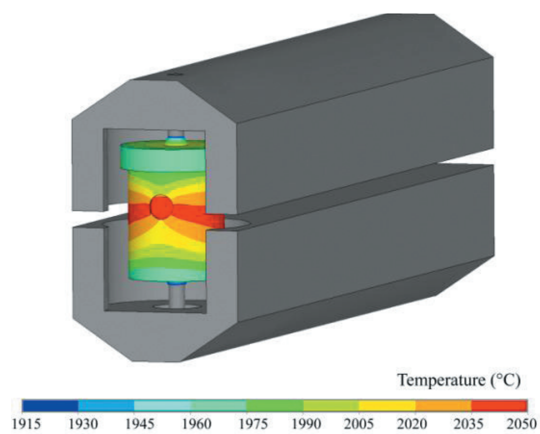

Fig. 3. Temperature distribution of the oven calculated by ANSYS.

References
1) Y. Higurashi, et al., Rev. Sci. Instr. 83, 02A308 (2012).
2) J. Ohnishi, et al., Rev. Sci. Instr. 85, 02A941 (2014).
3) http://www.ansys.com/

*1 RIKEN Nishina Center