A Finite Element Calculation of Temperature Distribution on the Target Cell

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Abstract

We calculated the temperature distribution on the ^{3}He target using finite element method. We were able to impose various conditions on the target cell, such as forced convective cooling and metal coating, hoping to find a configuration that allows us to boost the beam current from 12 μA to 30 μA, while maintaining a reasonably low temperature for the glass cell.

Due to the relative complex shape of the helium-3 target cell, an analytic calculation of the temperature distribution on the surface is very difficult, even approximately. Therefore we use a finite element approach with the help of COMSOL multiphysics software to obtain the distribution in a realistic environment.

To begin with, we set the ambient temperature to 20 °C. The geometry of the system in question is shown in Figure 1. At the beam window, the thickness of the cell reduces significantly. This feature is presented in Figure 2, a cross section of the end region of the target cell. The target contains Helium-3 gas of 8 Amagats, and nitrogen of 0.5 Amagats. The energy loss of an electron in media is calculated using the Bethe-Bloch formula, whose results are shown in table 1. In the finite element calculation, the heat source is set to be a cylindrical region along the beam direction, with radius of 1.5 mm, in order to simulate the beam raster. Temperature of the pumping cell is fixed at 200 °C.

We first calculated the temperature distribution with a 12 μA, 6 GeV electron beam. To match the reality, various power of forced convective cooling imposed around the beam window are tested, whose results are shown in Figure 3. We found that a heat flux density of 100 W m^{-2} K^{-1} best matches the experimental data, and therefore was used in all the following calculations. An overview of the calculation result is shown in Figure 4. We are interested in the region

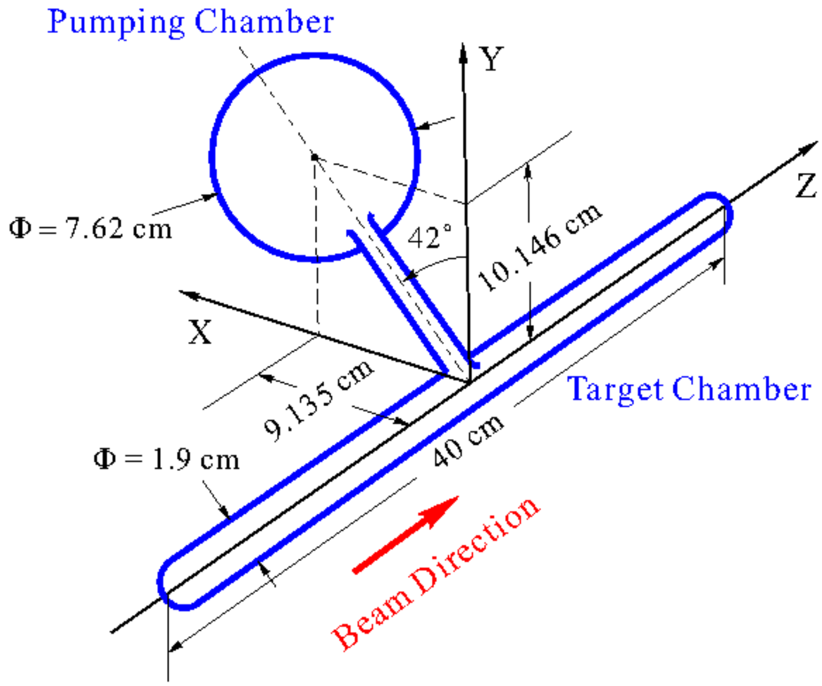

Figure 1 The geometry of the target system

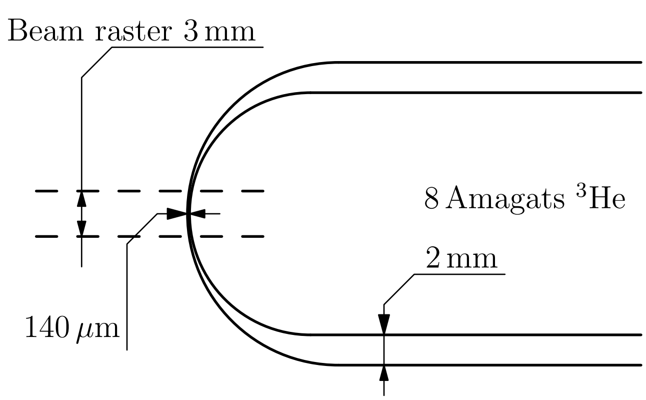

Figure 2 Target cell, near the beam window

near the beam window, where the temperature is supposed to be the highest. A cross section of that region is presented in Figure 5. Note that the maximum temperature in this configuration is 683 K.

Beam current	Media		
	Gas (^{3}He and N_2)	GE180 glass	Copper
12 μA	11.3	7310	
30 μA	28.2	1.83×10^4	5.25×10^4

Table 1 Power loss (in W/m) of the electron beam as a whole in media

We also acquired the temperature on the surface of the target cell at points 8.5 cm and 17 cm away from the center of the target cell, as well as at the center. These temperatures are gathered in table 2, and they agree with experimental data.

To be written: agree to what level.

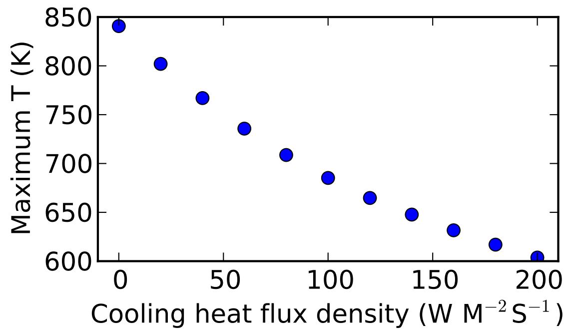

Figure 3 Maximum temperature versus cooling power

Distance from center	0	8.5 cm	17 cm
Temperature (K)	328	322	328

Table 2 Temperature at specific locations on the target cell, 12 μA

We then increased the beam current to 30 μA while keeping other conditions unchanged, and calculated the temperature distribution (Figure 6). In this configuration, the highest temperature raises to 1101 K. Trying to lower this

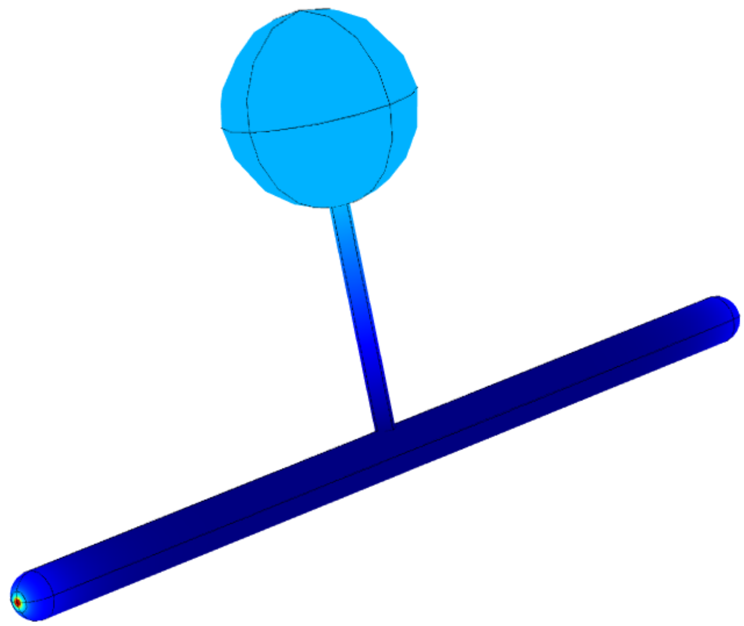

Figure 4 Temperature distribution with 12 μA beam current

temperature, we put a layer of copper coating outside the target cell that covers the whole target cell. We varied the thickness of the coating, hoping to acquire a similar highest temperature as with 12 μA beam current. Figure 7 displays the temperature distributions with a number of values of the thickness labeled under each picture. Also, the maximum temperatures for different thickness are summarized in table 3.

Among these settings, copper coating of 5 μm thickness has a highest temperature closest to that with 12 μA beam current. We suggest this configuration as a good candidate for a long-lasting target cell under 30 μA beam current.

Reference

[1] W. Korsch, "Summary of the He Cell Beam Test at TJNAF", 1997

[2] C. Dutta, Ph.D. Thesis, University of Kentucky, 2010

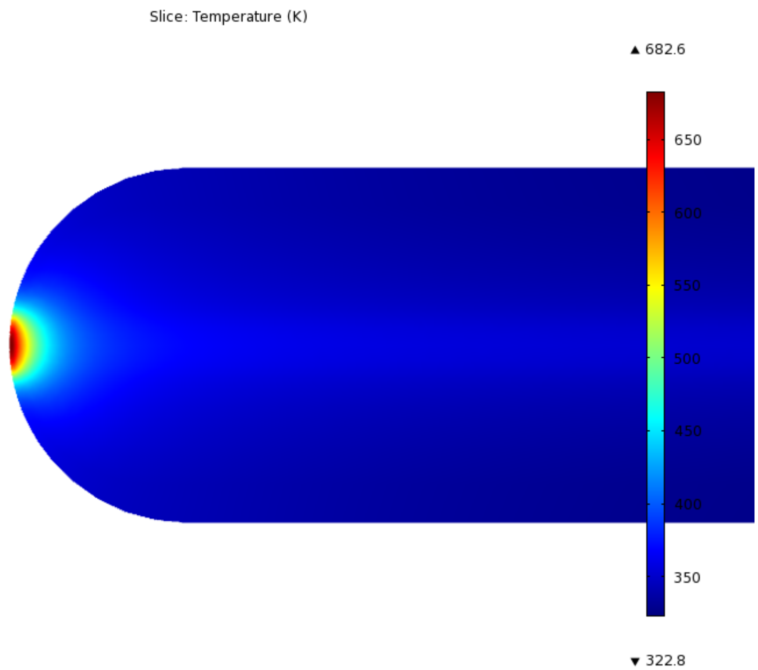

Figure 5 Temperature distribution with 12 μA beam current

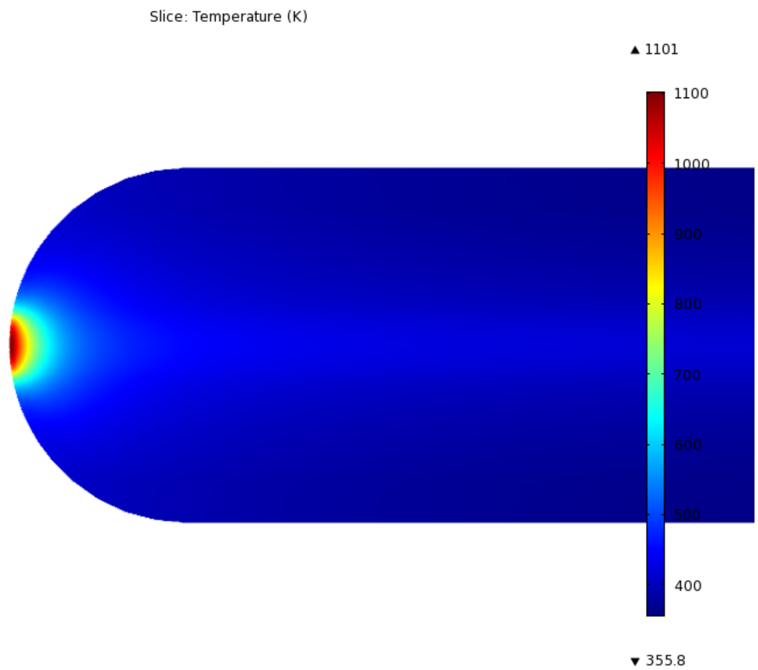

Figure 6 Temperature distribution with 30 μA beam current

Thickness (μm)	1	2	5	10	20	40	80
Max. T (K)	927.8	840.7	706.3	622	557	514.9	488.9

Table 3 Highest temperature with various coating thickness

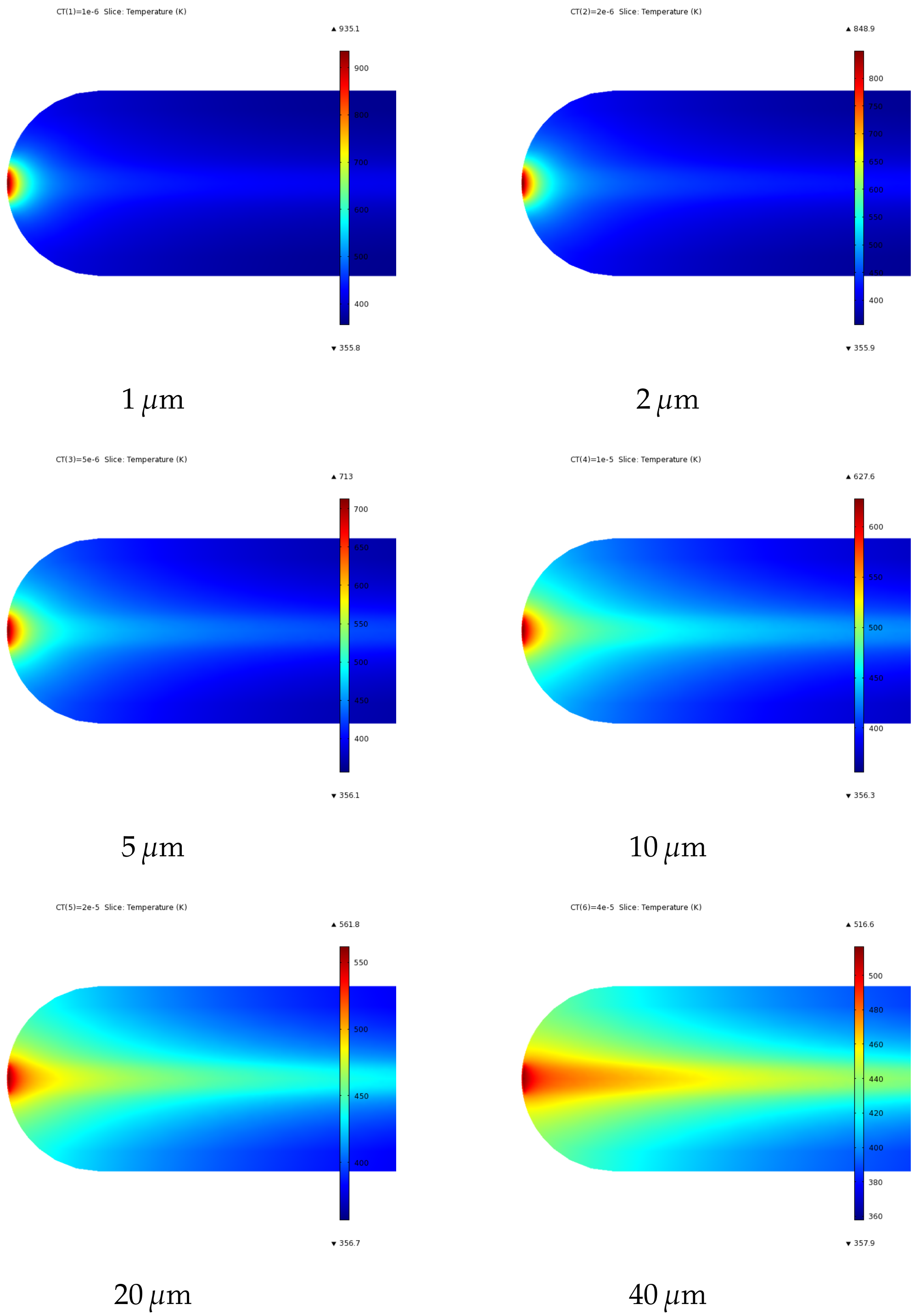

Figure 7 Temperature distributions with copper coating, 30 μA

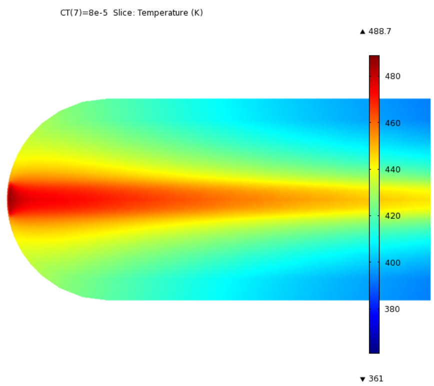

Figure 8 . . .continues from Figure 7, 80 μm