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Thermal and plasma modeling of a hot cavity ion source for radioactive ion beam production at ISOL@MYRRHA

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ISOL@MYRRHA, under construction at the Belgian Nuclear Research Centre, SCK CEN [1], will be an isotope separation facility producing radioactive ion beams (RIBs) using 100-MeV protons at beam intensities of up to 500 µA. These RIBs support applications in fundamental research, medical science, and materials science. A key component is the 'hot cavity' ion source, which relies on surface and/or resonant laser ionization to ionize radioactive isotopes. Our work aims to optimize the current ion source design by integrating experimental studies with computational modeling to achieve higher efficiencies at increased ion loads.

During operation, the ion source is resistively heated above 2000 ℃. Thermionic electrons from the cavity walls form a confining plasma potential that enhances ion survival. However, the accumulation of positive ions can generate a counteracting potential that overrides this confinement, causing significant ion losses and reduced extraction efficiency. To characterize this environment, thermal-electrical simulations using Ansys [2] provide the temperature profile and voltage drop along the length of the ion source, which serve as input for Particle-In-Cell (PIC) plasma simulations in Starfish [3]. These simulations provide insights into ionization behavior, plasma dynamics, beam shape, and the time that laser/surface ions spend in the system. Additionally, molecular flow simulations using MolFlow+ [4] evaluate collision rates, pressure, and the sticking times of neutrals in the system.

In parallel, using a fabricated prototype, experimental measurements reveal the temperature distribution, ionization efficiency, and the extraction time of laser ions leaving the hot cavity, all of which serve as validation for the computational models [5,6]. Using this experimental and computational approach, the geometry and operating conditions of the ion source design can be optimized to find the best configuration for ISOL@MYRRHA's operating requirements.

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