New experimental setup for boron isotopes separation by laser assisted retardation of condensation method

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1. Introduction

In this paper we present a new experimental setup design for boron isotope separation by the laser assisted retardation of condensation method (SILARC). Its parameters are calculated from our new static model based on the model given in [1,2]. Proposed static model corresponds to the two-cycle iterative scheme for boron isotopes separation. This rather simple model helps to understand combined action of all important parameters and relations between them on boron isotopes separation by SILARC method. These parameters include carrier gas choice, molar fraction at what BCl_3 gas is dissolved in carrier gas, laser intensity, providing minimum of energy expenses and the largest output, optimal gas pressure and temperature in backing and downstream chambers, optimal irradiation cell and skimmer chamber dimensions, optimal nozzle throughput. It was suggested a method for finding optimal values of these parameters based on global minimum or energy spent on production of unit of isotope, which is analog of Separative Work Unit (SWU). It was shown that the most optimal carrier gas, corresponding to this minimum, among other considered-N_2,NO_2,SF_6, is Ar. Restriction on the maximal irradiation chamber length, caused by dimerization rate [2], is also considered. Two types of industrial scale irradiation cells are compared. The first one has the only large throughput slit nozzle, while the second one has numerous small nozzles arranged in parallel arrays for better overlap with laser beam. It is shown that the last one outperforms the former one significantly.

2. Operational principles

Feed chamber is occupied by BCl_3 gas that is diluted at very small molar fraction (~2%) inside the carrier gas. Gas expands into irradiation cell (IC) across the slit nozzle as shown in the Figure 1. In order to prevent gas flow overexpansion and maintain rarefication degree (molar fraction) of BCl_3 in carrier gas after each enrichment iteration on the same level, background gas pressure inside IC is to be equal to the pressure inside the gas flow, and background gas should have the same components (BCl_3+CG) mixed at the same molar fraction. Enrichment process consists of fast and slow iterations cycles as shown in the Figure 2. Apparently the number of fast cycles proceeded until amount of BCl_3 accumulated in the product chamber achieves enrichment level, which is parameterized by the number of slow cycles k_0 already performed , can be calculated as: $x_{k_0} = x_i^2 \beta^{k_0},\ x_i = 0.188,\ k_0 = 1 \ldots n,\ n = \log_\beta \left(\frac{c_0}{x_i}\right)$

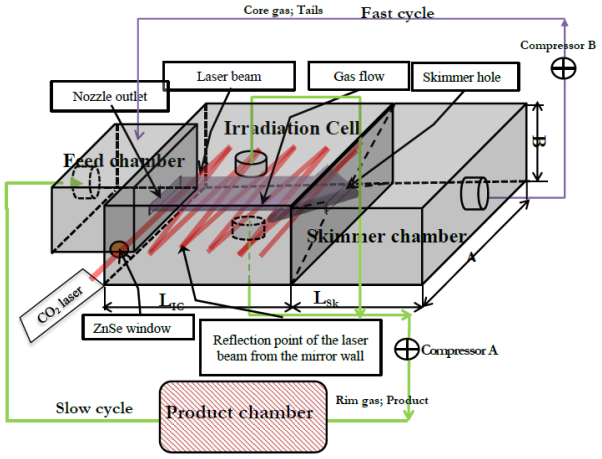

Fig. 1. Scheme of the experimental setup. Edges, links and details, which are invisible from the face surface, are displayed by dotted lines. Laser beam goes through semitransparent ZnSe window inside IC. Laser beam impinges gas flow under some optimal angle (laser beam is denoted by red line). Photons are reflected repeatedly by the mirror surface of IC interior. Optimal conditions inside the gas flow (pressure and temperature) are provided by preprogrammed compressor and specific nozzle design. Rim and tail gases are separated by skimmer blade. Rim gas is target isotope enriched.

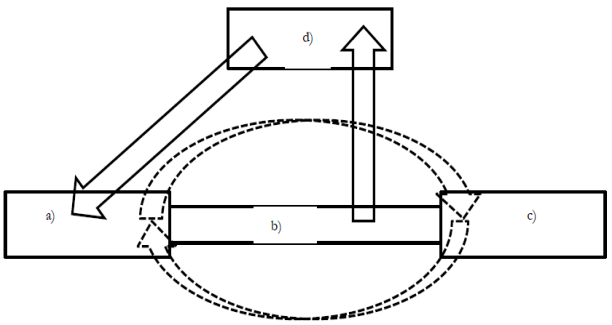

Fig. 2. Fast and slow enrichment cycles are denoted by dotted and solid arrows respectively. a)Feed chamber; b)Irradiation cell; c)Skimmer chamber; d)Product chamber.

Each slow cycle corresponds to enriched gas return from the product chamber to the feed chamber. This cyclic process goes on until BCl_3 enrichment in the product chamber gets achieves desired level, Ref.[3].

Enriched gas component separation principle can be formulated as follows. The most suitable skimmer geometry for cross-wise gas flow irradiation is wedge-like as shown in the Figure 3. Therefore, unexcited species can be thought occupying only space inside the rectangular parallepiped, which occupies the space between the nozzle outlet and hole of the skimmer. All other species we assume as excited. Gas flow is this scheme is continuous and irradiated by CW mode laser beam. Preprogrammed compressor compensates gradual pressure loss in the feed chamber caused by gas expansion across the nozzle. In order to prevent pressure building up near skimmer wall gas flow should be timely evacuated by action of separate compressors for rim and tail gases as shown in the Figure 1. Each compressor, in order to avoid contamination of recycled gas by evaporated compressor oil light fractions, should have magnetic bearing (the use of this bearings will also significantly reduce dissipative frictional losses). Laser intensity and setup characteristic dimensions are found from the requirement of minimum of energy consumption per unit of product as demonstrated in Ref.[3].

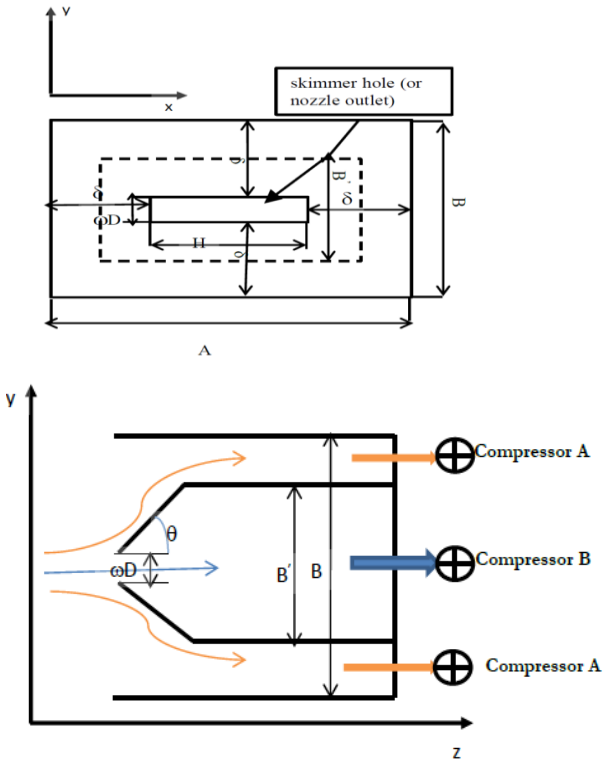

Fig. 3. Scheme of the skimmer chamber.

Slit nozzle is designed so that gas flow pressure and temperature at the nozzle outlet correspond to the optimal for enrichment values. Effects of low Reynolds number gas flow across the nozzle are taken into account within the boundary layer theory.

Efficiency of the use of laser energy is increased by fabricating the IC as a waveguide. IC size is constrained by waveguide optimal geometry and dimerization rate at the given pressure and distance, passed by target molecule from the nozzle outlet.

3. Results

We calculated that our experimental setup, provided argon is used as a carrier gas, can yield ~50mg/hr of boron-10. It is interesting to compare this production rate with traditional method of industrial boron isotopes separation by low temperature distillation, Ref.[4]. In this method production rate is practically the same, but energy expenses per separated isotope are substantially smaller: ~1eV/atom instead of ~10^3 eV/atom as for SILARC method. The largest fraction of energy expenses in our SILARC-based method comes from compressor operation. Apparently, by increasing the number of nozzles and irradiation cell length production rate can be made larger than for chemical exchange method, but consumed energy will rise proportionally to the number of nozzles used. However, we are planning to overcome this obstacle by using larger IC, more spacious skimmer chamber and pulsed gas flow. In such case requirements for pumping down rate will be weaken. Another popular optical method for isotopes separation that is being developed over last decades is AVLIS, Ref.[5]. In this method as well as in MOLIS method energy expenses are much higher ~10^5eV/atom, and ~10^4 eV/atom respectively, Ref.[6].

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