HIGH CURRENT DENSITY LITHIUM ION SOURCE

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Abstract

Induction linear accelerators are featured in accelerator-based research currently supported by the Office of Fusion Energy Sciences. Over the next few years, the research will concentrate on developing intense ion sources and on studying the physics of spatial compression, neutralized transport, and focusing of the beam. The large diameter of lithium alumino-silicate ion emitters for large currents represents the current state of the art for emission densities of 1-1.5 mA/cm^2. Also, operating temperatures of the surface are limited by the temperature of alumina-potted heater packages. We propose a novel system for increasing the emission of lithium ions from β-eucryptite through modification of the surface morphology by sputter etching with argon plus other gases. The resulting local field enhancement will increase the ion emission over that of a microscopically flat surface. In addition, a free-standing graphite heater assembly will be used to increase the temperature of the surface of the emission source.

INTRODUCTION

In current Office of Fusion Energy Sciences programs, ion beams are produced using induction linear accelerators, in order to produce, accelerate, transport, and focus beams of required energy and intensity. Over the next few years, the research will concentrate on developing intense ion sources and on studying the physics of spatial compression, neutralized transport, and focusing of the beam. The large diameter of a thermionic lithium ion emitter for 100 mA is the result of the present state of the art for emission densities of 1-1.5 mA/cm^2. Operating temperatures of the surface are limited by the temperature of alumina potted heater packages.

The Neutralized Drift Compression eXperiment (NDCX-II) requires a compression in pulse length from ~500 ns at the source to 1 ns at the target. As a result of the low current density emitter, the diameter of the ion beam must go through approximately 100:1 compression to arrive at the final focal spot diameter of 1 mm. The NDCX-II ion source is currently configured as shown in Figure 1. With an increase in emission density, higher beam intensities may be achieved for a given radial and longitudinal compression.

TECHNICAL APPROACH

The proposed technical approach to achieving higher current densities will take two different tracks. The first track will be to increase the electric field at the surface of the emitter by producing a surface that has been etched to form field emission points. The second track will be to design a large diameter emitter source that can operate at

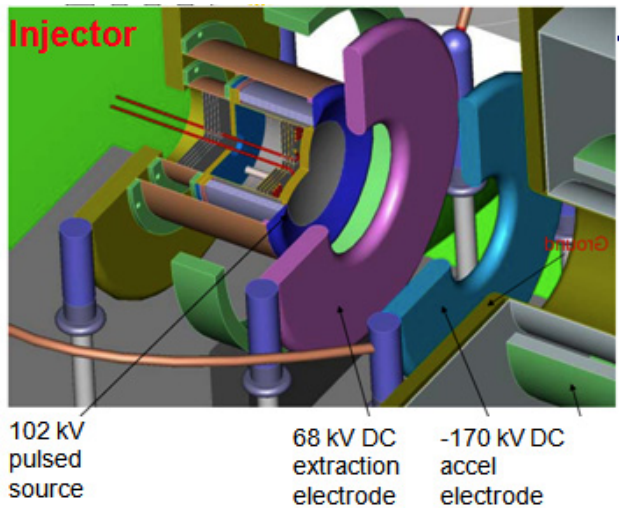

Figure 1. Cutaway view of lithium ion source proposed for NDCX-II [1]

temperatures close to the melting point of spodumene or β-eucryptite (1300 °C).

The ternary system of alumino-silicates, $Li_2O(x)Al_2O_3(y)SiO_2$, provides good lithium sources where the x=1, y=2, has the mineralogical name, β-eucryptite, and the x=1, y=4 mixture is spodumene [2]. The emission rate of lithium ions from thermionic emitters is controlled by the operating temperature of the emitter surface and the voltage gradient seen by the surface. Other high intensity sources of lithium ions are ionization processes such as modified duopigatrons (an arc discharge in a working gas that ionizes lithium vapors) with reported emission densities of 15 mA/cm^2 [3] and surface ionization processes producing 400 μA [4]. These sources produce higher extracted ion currents at the expense of hotter beam temperature, more complex hardware and limited source lifetimes [5]. The combination of ionization processes and thermionic emission was also experimented with, resulting in currents at the 100 μA level [6].

Thermionic emitters with sintered tungsten sponges as a substrate for the alumino-silicates were developed by Spectra-Mat [7] in 1968. Heatwave Labs, Inc purchased the rights and formulas for these ion emitters from Spectra-Mat, and are of the opinion many improvements have not been incorporated because there were few demands for higher emission densities and manufacturing volume for these type emitters did not provide a financial incentive for continued improvement [8]. As a result, the state of the art for thermionic emitters is 1-1.5 mA/cm^2 at operating temperatures 100-200 °C below the melting point of the alumino-silicates (1300-1350 °C) which is nearly identical to the reported data by Blewett and Jones in their 1936 experiments as reported in reference [2].

Lifetimes have been reported by most researchers as being in the low hundreds of hours. In addition, the lifetimes of thermionic emitters are not limited by evaporated neutrals, but by other processes which have not been well understood [9].

The most recent results from emission tests of small buttons (0.31 cm^2) suggest the breakthroughs in operating temperature and field enhancement may achieve the higher emission densities, if the engineering problems are solved for large diameter emitting surfaces.

P.K. Roy et. al. have performed some recent work on Li^+ from a fabricated b-eucryptite source [10].

Increasing the Operating Temperature

In order to increase the operating temperature of the emission surface close to the melting temperature of spodumene or β-eucryptite (1300 °C), we propose a new heater package design for a 10-cm diameter emitter, one that incorporates a free-standing graphite heater. Typically, to achieve 1300 °C operation at the emitter surface, the filament and its surrounding alumina potting operate 200-300 °C higher. At 1500 °C, the thermal expansion coefficients of the various materials used in the construction of the emitter do not match each other well, and the alumina potting material begins to break down. As a result, a free-standing heater is more desirable.

Free standing graphite heaters are thermally and mechanically stable and their electrical resistance does not change significantly as a function of temperature. This type of heater has been operated at 1400 °C for 10,000 hours without significant degradation in performance [11].

We propose that the geometrical form of the heater and support structure will be designed for thermal insulation, structural stability, and minimal thermal movement using thermal-mechanical finite-element codes such as ANSYS. The critical geometry for the heater and support for the emitter surface is shown in Figure 2.

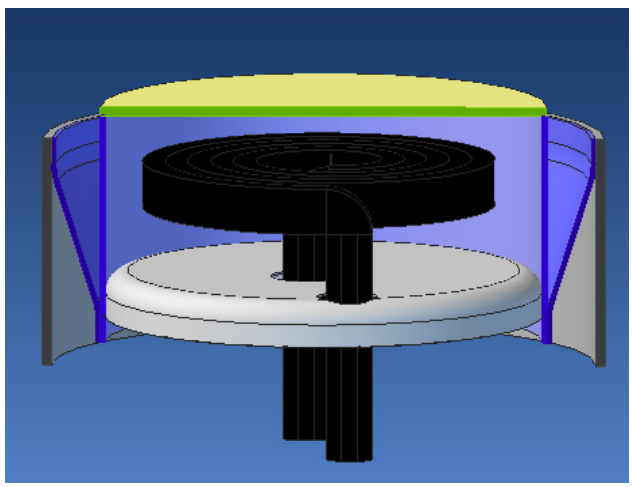

Figure 2. Critical elements of a high temperature emitter and filament package consist of the emitter surface (yellow), a wound graphite filament, a bottom heat shield (white), and multi-layer side heat shields.

The critical concept for a high temperature emitter package is sufficient conservation of heat such that the graphite filament runs at the coolest temperature possible. This is accomplished by optimizing the thickness of the inner support cylinder, the cone support cylinder, the heat shield and the outer support cylinder in order to minimize conducting the heat away from the emitter surface.

The second critical concept is to minimize the thermal movement of the emitter surface. This is accomplished by choosing the correct materials and dimensions, such that the thermal expansion of the inner and outer support is matched by the thermal expansion of the cone support. If this is done perfectly, then the emitter surface remains dimensionally stable throughout a wide range of operating temperatures. Examples of refractory metals that work well in this area are molybdenum alloys such as hastelloy B.

The third critical concept is the design of the filament and its support to maintain an even temperature on the emitter surface.

We propose all of these new design elements for an improved 10 cm diameter emitter.

Etching the Emitter Surface

Etching the surface of materials to create field emission sites has been done on many different materials for the purpose of enhancing electron emission. We propose the same types of processes to enhance the emission of lithium ions from the surface of the alumino-silicates. Etching rates of materials using different gas compositions and examination of surface roughness suggest the use of O_2 as a fraction of the composition along with other variables such as, source power, bias power, and pressure [13].

The use of Argon and Oxygen plasma sputtering has been used on lithium fluoride to remove contaminants [14], and it is proposed that a more rigorous etching will change the surface morphology of the alumino-silicates to provide localized field enhancement and higher emission densities.

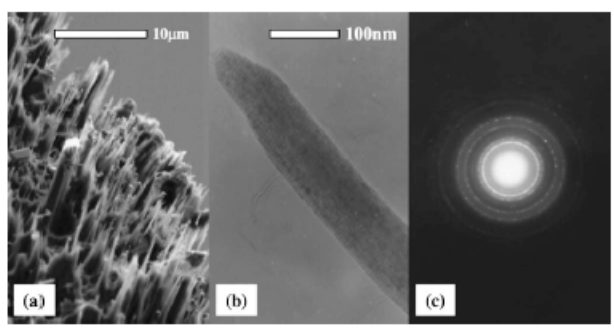

Figure 3. a) SEM image of a graphite rod surface after hydrogen plasma etching, b) TEM image of a single graphite nano-needle cathode, and c) electron diffraction pattern of a single graphite needle [12].

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