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Rare-earth neutral metal injection into an electron beam ion trap plasma[a)]

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We have designed and implemented a neutral metal vapor injector on the SuperEBIT high-energy electron beam ion trap at the Lawrence Livermore National Laboratory. A horizontally directed vapor of a europium metal is created using a thermal evaporation technique. The metal vapor is then spatially collimated prior to injection into the trap. The source's form and quantity constraints are significantly reduced making plasmas out of metal with vapor pressures ≤ 10^{-7} torr at ≤1000 C more obtainable. A long pulsed or constant feed metal vapor injection method adds new flexibility by varying the timing of injection and rate of material being introduced into the trap.

I. INTRODUCTION

Introducing elements into magnetically confined plasmas in general and into an electron-beam ion trap in particular is not a new endeavor. Since the advent of the electron-beam ion trap (EBIT) [1] many methods have been developed: The metal-vapor vacuum arc (MeVVA) ion source [2], wire probe [3], laser ablation injectors [4], Knudsen cell [5], and organometallic injection, e.g., $W(CO)_6$ [6]. The system we describe here allowed us to inject neutral metal elements, specifically the rare-earth europium (Eu=Z 63), which is difficult to inject by the other available methods.

Lawrence Livermore National Laboratory's electron beam ion traps EBIT-1 and SuperEBIT, in operation since the mid 1980's [7], have been used for the investigation of radiation emitted by a large variety of highly charged ion species and as test beds for spectrometers and spectroscopic techniques used in high temperature plasma research [8]. Plasmas produced by an EBIT have incorporated a majority of elements in the periodic table with the desire to easily add more. In brief, an EBIT consists of an electron gun where the electron beam is created, a superconducting magnet for beam compression, an electrostatic trap where the beam and target elements interact, an electron beam collector, and an injector system for introducing target material into the trap.

There are two basic trajectories available to inject material into an EBIT. They are constrained by access ports and magnetic fields. The trajectory parallel to the magnetic field lines allows the injection of ions, e.g., via a MeVVA. Perpendicular to the magnetic field injection must be with neutrals such as a gas. Because obtaining large enough quantities of Eu and machining an air-reactive metal to make a MeVVA cathode cannot be readily done, we opted to develop a method to inject Eu as an atomic vapor that crosses the magnetic field. The new injector we have designed and implemented combines desired characteristics of both, the gas-injector and Knudsen-cell injections methods, with some advantages over other methods especially for Eu.

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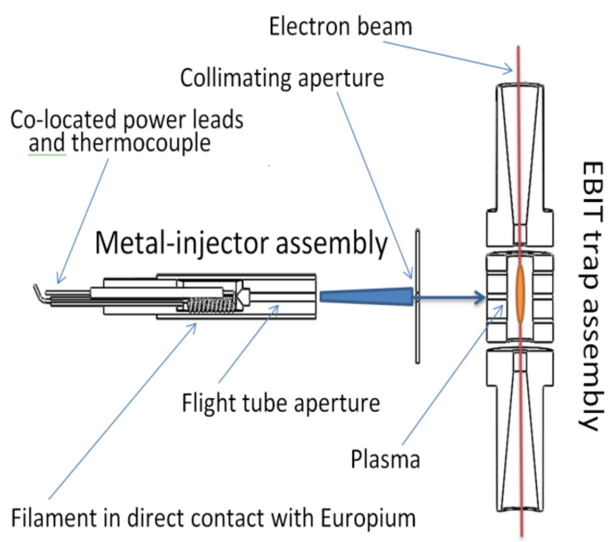
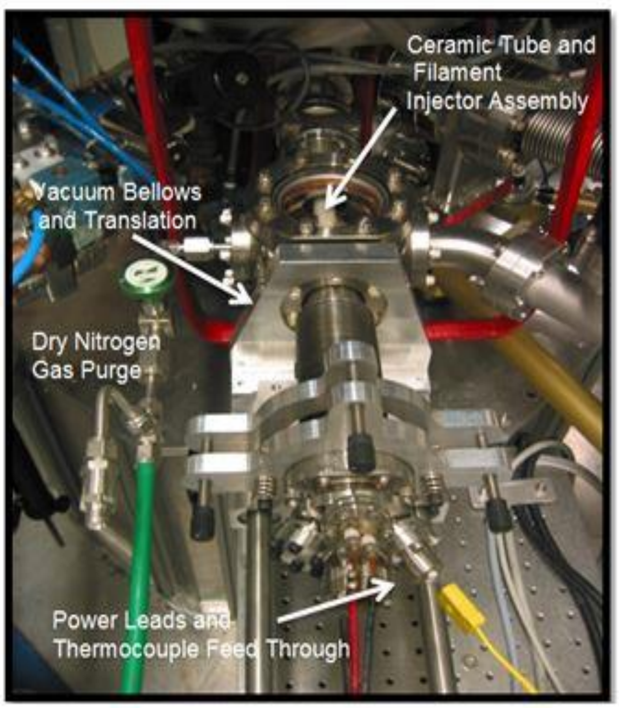
II. EXPERIMENTAL SETUP

The principle for this injector is to quickly heat a small quantity (1gram) of europium, mesh 40 shot, high enough that the vapor pressure is sufficient for the metal to be directionally injected. This design separates itself from the Knudsen cell by the way that the material is heated. Heating is accomplished by direct contact with a wound .25mm tungsten filament inside a vacuum. Once the vapor is generated the injection is accomplished by collimating the vapor with concentric openings.



Cut away schematic of the injector, collimator and EBIT trap region.
FIG. 1

As illustrated in Fig. 1 the metal vapor is allowed to leave through the open 3mm aperture in the ceramic enclosure then pass through a second 3mm aperture aligned with the plasma trap. The container is made out of ceramic aluminum oxide and thus is capable of withstanding high temperatures (<1000 C). The back end of the ceramic container has the two filament power leads and a thermocouple. Fig. 2 shows the injector assembly mounted on a horizontal view port looking directly into the machine. The injector can be extended or retracted on a linear bearing and rod track. The injector vacuum chamber has a view port that is removable to access and load the Eu into the injector when retracted. We flow dry nitrogen gas through the chamber when opened to prevent oxidation of the Eu metal power. An 81 l/s turbo pump keeps the pressures at 5 x10-8 torr. A type K thermocouple is collocated with the filament and Eu to monitor the temperature. The filament's maximum power was capped well below the 826 °C melting point of the Eu. Because we only need miniscule quantities of material to feed the plasma, a vapor pressure of ≤10-7 torr is needed. As a result we operated the heater at ≤320 C. At these temperatures the europium does not become ionized and the neutral atoms passed freely through the magnetic field and into the plasma trap. The current supply for the filament was switched on and off via a timing signal from the EBIT cycle timing program. The timing of the heating filament could thus be set for both start and stop time during a measurement cycle. For the experiment the assembly is translated to the position closest to EBIT. Upon completion of the experiment, the ceramic tube, europium, thermocouple and filament assembly is retracted into the vacuum bellows, closed off behind a valve and protected under vacuum until it is needed again.

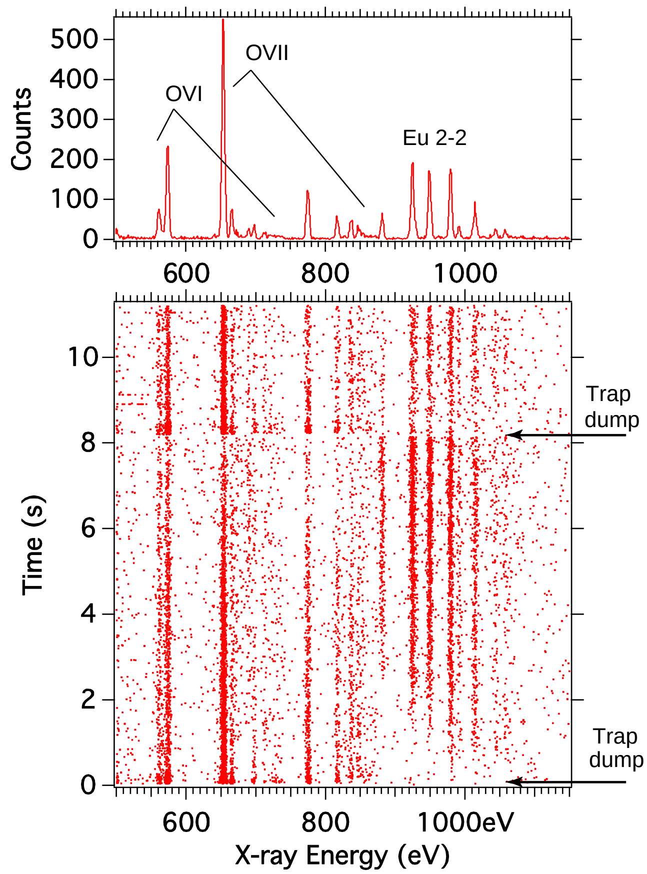


Complete injector assembly and vacuum housing mounted on the EBIT view port.

FIG. 2

III. RESULTS

When the coiled filament is turned on heat is transferred through conduction to the Eu , and the temperature of the Europium rises to where it begins to emit sufficient metal vapor. Injection was confirmed by detecting characteristic (n=2 to n=2) x-rays from very highly charged Eu^{57+} through Eu^{60+} using an x-ray micro-calorimeter [9]. Fig. 3 shows an 11 second measurement cycle where the trap is dumped in the beginning and the injector is turned on (i.e, power is supplied to the filament) for two seconds. The 2-2 lines of Eu are seen on the micro-calorimeter spectrum as the material enters the trap and is ionized to higher charge states as time increases. A second trap dump is shown at the 8 second mark followed by additional europium injection. The injector was used for two weeks with no visual signs of source material depletion. Because Eu's vapor pressure at room temperature is negligible, when the injector was turned off the Eu did not linger in the trap or vacuum chamber and thus did not appear in subsequent measurements.



The 2-2 lines of Eu are seen on the micro-calorimeter spectrum as the material enters the trap and is ionized to higher charge states as time increases.

FIG. 3

IV. SUMMARY

We have successfully demonstrated a neutral metal vapor injector using the rare-earth europium on the SuperEBIT electron beam ion trap at the Lawrence Livermore National Laboratory.

This method allowed us to use readily available small (gram) quantities of Eu for study. This new injector also gives us the opportunity to further explore other elements that have vapor pressures $\geq 10^{-7}$ torr at $\leq$ 1000 C. This type of injector has the potential for use on other types of plasma generating devices.

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