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Progress towards an intense beam of positrons created by a Van de Graaff accelerator

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ABSTRACT

A 4MV Van de Graaff accelerator was used to induce the nuclear reaction $^{12}C(d,n)^{13}N$ in order to produce an intense beam of positrons. The graphite target was heated so the radioactive ^{13}N would desorb from the bulk into the vacuum. This radioactive gas is frozen onto a cryogenic freezer where it decays to produce an antiparticle beam of positrons. This high current beam is then guided into a superconducting magnet with field strength up to 7 Tesla where the positrons will be stored in a newly designed Micro-Penning-Malmberg trap. Several source geometries have been experimented on and found a maximum antimatter beam with a positron flux of greater than $0.55 \pm 0.03 \times 10^6$ e^+s^{-1} was achieved. This beam was produced using a solid rare gas moderator composed of krypton (Kr) at a temperature of 25 ± 5 K. Due to geometric restrictions on this set up and other loss mechanisms, 10^7–10^8 e^+s^{-1} of the total number of positrons are lost. Simulations and preliminary experiments suggest a new geometry, currently under testing, will produce a beam of 10^7 e^+s^{-1} or more. The setup and preliminary results for the new geometry will be discussed as well.

1. Introduction

Moderate to low intensity beams of positrons have been used for a myriad of different materials analysis techniques [1]. Larger intensity beams of positrons would be advantageous to be used to produce positron induced Auger electron spectroscopy, positronium, Bose-Einstein condensates, and for energy purposes [2,3]. Positron beams commonly originate from four sources; radioactive elements such as ^{22}Na, pair production from high power LINACs, activated elements product from nuclear reactors, and by relatively small cyclotron or Van de Graaff type accelerators [4–6].

Each source of positrons has its advantages and disadvantages. High power LINACs and nuclear reactors have produced the most intense beams ($\approx 10^8$–10^{10} e^+ per sec) of positrons, but require large facilities to make these beams. Radioactive sources can be used in smaller set ups and have moderately intense beams ($\approx 10^6$–10^7 e^+ per sec), but radioactive sources require special handling and need to be replaced after it decays and the intensity is too low to be effective. Positron beams that originate from low energy accelerators ($\leq$30 MeV) are easy to turn off and on, relieving the problem of radioactive sources, and can be constructed in a smaller facility than of reactors and LINACs making it the cheaper alternative. However, low energy accelerator-based positron sources have only been able to produce low intensity beams on the order of 10^4–10^5 e^+ per sec.

The first accelerator-based positron beams used 11 MeV protons to induce the reaction $^{27}Al(p,n)$ ^{27}Si and were able to achieve an un-moderated beam to measure e^+e^- scattering [7]. Xie et al., were the first to use the $^{12}C(d,n)^{13}N$ reaction to produce a moderated beam of 10^2–10^3 e^+ per sec while the deuteron beam energy was between 1 and 2 MeV [8]. Since then, there has been a hand full of groups trying to increase the number of positrons produced with a relatively small accelerator and the $^{12}C(d,n)^{13}N$ reaction [2,3,9–12].

Diamond and graphite were used as the target material. Both targets were successfully used as a rotating source to produce a positron beam. The target would be irradiated with deuterons, and then rotated behind a tungsten foil moderator. At higher deuterium beam energies, these targets began to out gas the radioactive nitrogen and an upper limit of beam intensity was on the order of 10^5 e^+ per sec [12]. P. Decrock et al. found heating the graphite to a temperature of 2035 K will remove 50% of the ^{13}N atoms out of the target before they decay [13]. P. Decrock et al. intentionally heated their carbon targets to force the radioactive gas out and injected the gas into another accelerator to create a rare isotope beam of ^{13}N.

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In References 3, 10, and 12, Weber et al. have shown it is possible to use a similar method for out gassing carbon targets and freezing the radioactive gas on a cryogenic cold head. These efforts so far have produced a beam of roughly 10^4 e^+ per sec. In this design, the entire surface area of the cryogenic cold head was used to freeze the radioactive nitrogen was exposed to all of the gasses in the target chamber area. Because of this, radioactive gas that would have contributed to the positron count rate was able to freeze on undesired locations all over the cold head and only a small fraction of the frozen ^{13}N would contribute to the count rate.

In the following article, we discuss the results from a new design that aims to minimize the exposed surface area of the cryogenic cold head to freeze more radioactive gas to the desired location and produce larger count rates of accelerator-based moderated positrons. Two moderators composed of Kr and Ar are used and results are compared. A brief discussion and the preliminary results for a new set up that uses two separated vacuum chambers connected by a turbo molecular drag pump is presented at the end.

2. Experimental procedure

2.1. Accelerator set up

A KN4000 Van de Graaff accelerator was used to produce a beam of deuterons with energies up to 3 MeV and beam currents upwards of 300 μA. This belt driven single stage accelerator has a pressure tank filled with SF_6 at a pressure of 40–55 psig. The capacitively coupled RF plasma source is limited to approximately 500 μA of deuterons but stable beams of only 300 μA were achievable. The deuterons strike a graphite target manufactured by Schunk Graphite Technology isostaticly pressed and measured by Schunk to have a density of 1.94 g/cm3, porosity of 6%, and a mean grain size of 10 μm.

To raise the temperature of the graphite target to release more of the ^{13}N without increasing the deuteron beam current or energy, a thoriated tungsten filament was placed in front on the graphite target. The target was biased up to 10 kV and the electrons from the filament were accelerated to the target causing the graphite to heat up and desorb the ^{13}N nuclei. The base pressure of the target chamber was measured at 1×10^{-8} Torr; however, when the accelerator is running and the target is out gassing, the pressure rises to $1–10 \times 10^{-5}$ Torr.

After the radioactive gas is liberated from the graphite target, it will freeze to a thin foil of aluminum 10 μm thick that is attached to a cold finger. The copper cold finger is bolted to a two stage Cryodyne model 1020-C with indium foil to ensure good thermal contact. The temperature of the first stage is measured at 80 ± 5 K and used to shield the second stage used to freeze the moderator gas and the ^{13}N source at 25 ± 5 K. A Sapphire crystal is used to electrically isolate the freezing area so it can be biased to give the positrons their initial drift energy. A custom fabricated reducer flange made of 316 L stainless steel seals the bottom of the vacuum chamber from the top so the radioactive gas is only able to freeze on the upper surface area of the cold head. This custom flange is in thermal contact with the first stage cooling station of the Cryodyne to alleviate some of the heat transfer from the vacuum chamber to the colder second stage.

Tungsten foil, 0.5 μm thick, is sandwiched between two tungsten meshes and located 1–2 mm in front of the aluminum foil where the ^{13}N is frozen. This tungsten foil has been annealed according to the procedure produced by [14], then transported in air, and placed in the target chamber vacuum system. The tungsten foil is also the location where a rare gas solid moderator (RGSM) is to be frozen.

Inside the vacuum system, the positrons are axially guided by magnetic fields ranging between 50 and 100 G. After the positrons are emitted from the moderator, they cross a tungsten grid that can be biased to retard the positrons and measure the energy distribution. From here, the positrons enter a curved EXB energy filter with a plate separation of 1.3 cm, plate length of 28 cm, and total beam deflection of 2.5 cm, so only the slow positrons are delivered to the rest of the beam line, ultimately to arrive at the high magnetic field for trapping experiments (See Fig. 1). The positron beam is steered around the bends of the vacuum system by using custom-made quadrupole steering coils. The location of the four quadrupole coils was chosen based off of modeling performed in SIMION.

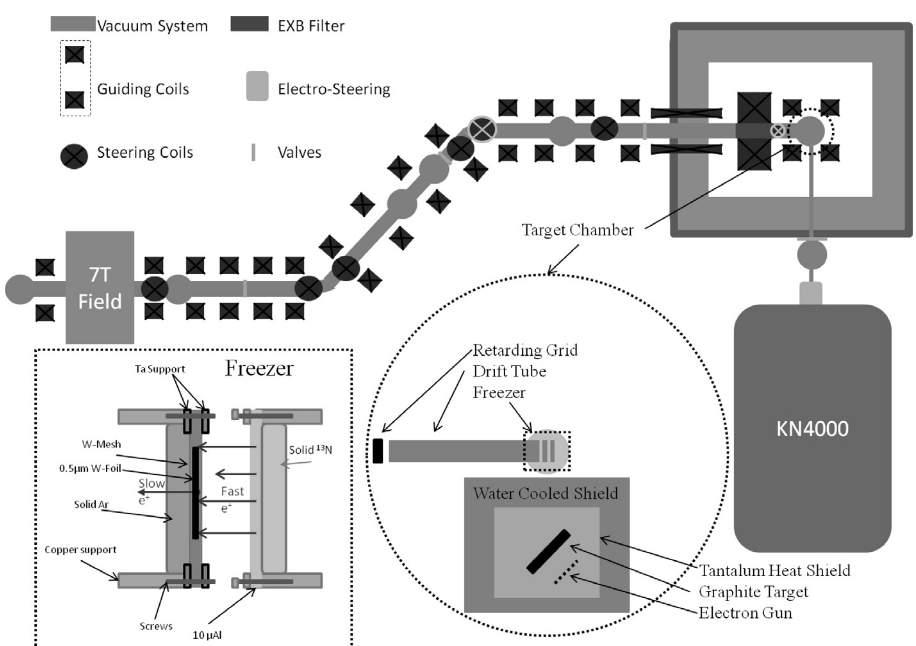

Fig. 1. Beam line, target chamber, and freezer diagram.