Chapter 2

TRAP-BASED POSITRON BEAMS

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Abstract
The ability to accumulate large numbers of positrons in Penning traps and to manipulate them using nonneutral plasma techniques offers a completely new approach to creating high quality positron beams. This approach provides significant advantages over conventional positron beam technology with regard to beam brightness, flux, and system cost. The application of these techniques has already resulted in a new generation of bright, ultracold positron beams with state-of-the-art performance. These beams are currently being exploited in the area of atomic physics studies, but they also have the potential for uses in other areas of science and technology, such as materials science. The current status of trap-based positron beams is described and the potential for further development is discussed.

1. INTRODUCTION

Low-energy positron beams are used extensively in a variety of areas in science and technology, including materials science [1], atomic physics [2], plasma physics [3], and mass spectrometry [4]. These beams are generally derived from radioactive sources or LINACS and an extensive array of techniques has been developed for moderating the positrons to low energy, and focusing, pulsing and manipulating them in other ways [5, 6].

An important development in low-energy positron technology is the capability to accumulate large numbers of positrons in a modified Penning-Malmberg trap [7]. This technique has been extensively exploited
to study the interactions between positrons at room temperature and ordinary matter under the ideal conditions of two-body interactions [8, 9, 10, 11, 12]. More recently, it has been used to create low-energy positron beams with state-of-the-art beam parameters by releasing the positrons from the trap in a controlled manner [13]. These beams have been used to measure positron-atom and positron-molecule cross sections in the largely unexplored energy regime below 1 electron volt [14, 15].

In another recent experiment, significant brightness enhancement of the beam was achieved in a proof-of-principle experiment by compressing the positrons radially in the trap using a rotating electric field [16]. This development is an application of plasma physics techniques originally demonstrated in electron and ion plasmas in Penning traps [17, 18].

In this paper, we describe ways in which recently developed positron trapping technology can be used to create positron beams with qualitatively new capabilities, even using existing positron sources. The paper is organized as follows. Section 2 describes the trapping and accumulation of positrons in a modified Penning-Malmberg trap by collisions with nitrogen gas molecules. Section 3 describes the production of pulsed positron beams using stored positrons. In Sec. 4, brightness enhancement using non-neutral plasma techniques is described. Section 5 describes current and proposed developments in trap-based positron beams, and Sec. 6 summarizes the paper.

2. POSITRON TRAPPING

Positrons can be accumulated in Penning traps using a variety of techniques [3]. However, the only method that has been demonstrated to have sufficiently high efficiency for the applications under discussion is the buffer gas method [8, 19, 3]. For this method, moderated positrons from a radioactive source are accumulated in a modified Penning-Malmberg trap by means of inelastic collisions with a buffer gas such as nitrogen.

The electrode structure of the trap, illustrated in Fig. 1 forms three regions of successively lower pressure and electrostatic potential. A magnetic field (typically 1 kG) aligned with the axis of the trap provides radial confinement. Positrons accumulate in the region of lowest pressure (stage III) and cool to room temperature. The annihilation time on the residual nitrogen in this region (~100 s) is about two orders of magnitude longer than the cooling time (~1 s), so annihilation losses are minimal. Overall trapping efficiencies of 25–40% have been observed.

Positron traps offer a number of unique capabilities for high quality beam production [20].