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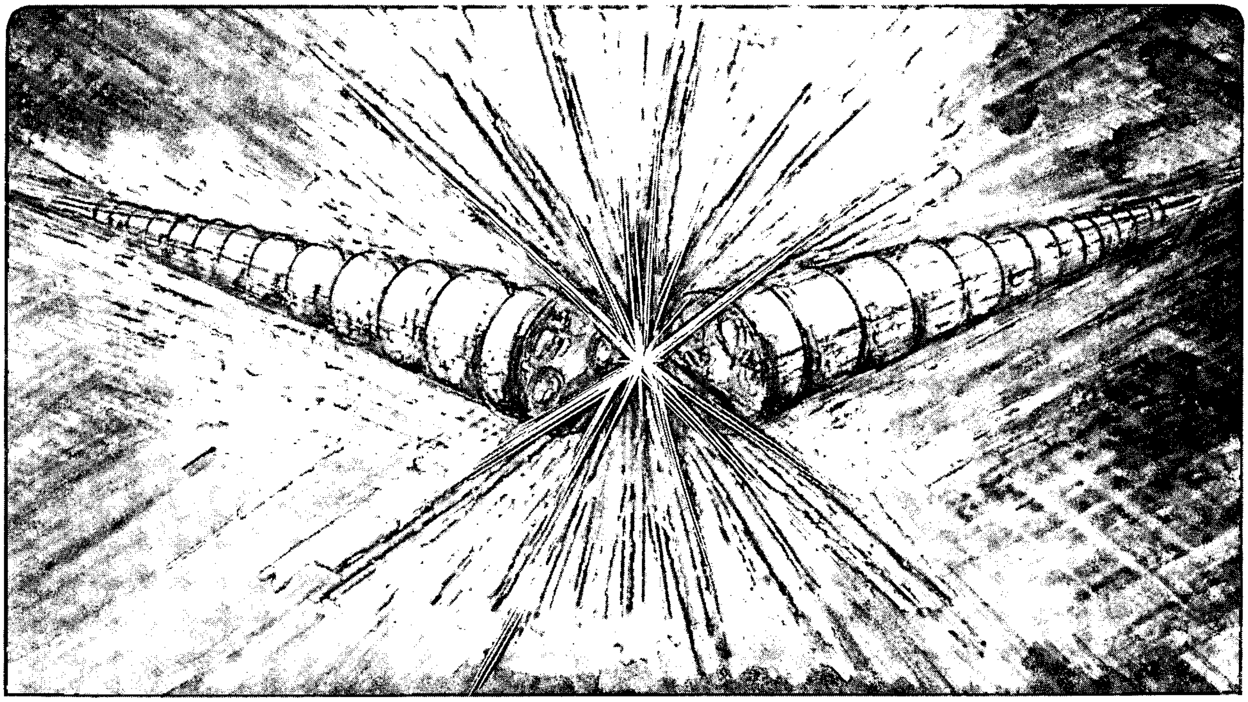

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# PERISTALTIC ION SOURCE*

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# PERISTALTIC ION SOURCE

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## Abstract

Conventional ion sources generate energetic ion beams by accelerating the plasma-produced ions through a voltage drop at the extractor, and since it is usual that the ion beam is to propagate in a space which is at ground potential, the plasma source is biased at extractor voltage. For high ion beam energy the plasma source and electrical systems need to be raised to high voltage, a task that adds considerable complexity and expense to the total ion source system. We have developed a system which though forming energetic ion beams at ground potential as usual, operates with the plasma source and electronics at ground potential also. Plasma produced by a nearby source streams into a grided chamber that is repetitively pulsed from ground to high positive potential, sequentially accepting plasma into its interior region and ejecting it energetically. We call the device a *peristaltic ion source*. In preliminary tests we've produced nitrogen and titanium ion beams at energies from 1 to 40 keV. Here we describe the philosophy behind the approach, the test embodiment that we have made, and some preliminary results.

# I. INTRODUCTION

Ion source science and technology has developed in pace with the use of ion beams throughout research and industry, and the performance of a wide range of ion sources is impressive. Plasma-based ion sources are composed of two primary parts – a plasma generating region and a beam formation region. The plasma is produced by any of a wide range of possible ways and confined, more or less, in a suitable geometry. A set of beam formation electrodes is located nearby and the plasma is guided from the production region to the beam formation region so as to present the electrodes with a plasma flux, or the beam formation region might be a part of the wall of the confinement region. Appropriate voltages are applied to the beam formation electrodes (the 'extractor') and the ions are accelerated by the extractor voltage drop.

For most ion beam applications, the region through which the post-extraction beam is transported and the beam target or final destination are at ground potential. Thus for the beam to propagate efficiently and for the full beam energy to be delivered to the target, the plasma from which the ions are formed is held at high positive potential and the extractor voltage drop is from this high voltage at which the plasma is held to ground. In this way the ions acquire the energy of the drop and propagate with this energy in the downstream space that is at ground potential. This is the way in which ion sources are routinely operated.

Provision of the extraction voltage is often a major part of the ion source investment. Voltages of tens to hundreds of kilovolts may be required, and the job of providing this power safely and floating the plasma source and associated power supplies and diagnostics to the high extractor potential can be a big mechanical and electrical undertaking that adds considerable complexity and expense. There could be advantage in some applications if an energetic ion beam could be formed from a device that was in essence at ground potential also.

Here we outline a technique for the production of energetic ion beams from a device that is, for the most part, at ground potential. We've constructed a first test device and carried out some preliminary investigations. The concept, test hardware embodiment, and experimental results are described in the following. Limitations and possible future developments are discussed.

## II. CONCEPT

Consider a plasma source that generates a steady state or pulsed plasma at ground potential that streams away from the source with a modest drift velocity toward another device that accepts the drifting plasma into its interior region. We would like the ions to be formed into an energetic beam by the second device, for example by an ion extractor at the far end of the device. We cannot do this on a steady-state basis; if the device is raised to high positive potential so as to set up the conditions necessary for beam formation at the far-end extractor grids, then the plasma would not be able to enter it, and in fact a discharge between the device and the plasma source would be likely. On a pulsed basis, however, the situation is different. One can then imagine a situation in which plasma drifts into a grided device, and after filling it (after drifting the length of the device) the interior region is raised to high positive potential so as to set up the beam formation conditions at the far end (extraction end); the device is then emptied of plasma as it is extracted as a beam, the potential is lowered to ground again, and the cycle repeated. We would have a way of forming a repetitively pulsed energetic ion beam by a device that accepts drifting plasma formed by a separate, nearby plasma source.

The ion motion is peristaltic. In a peristaltic pump, fluid is moved through a flexible tubing by a repeated squeezing motion along a length of the tubing. Peristaltic pumps are widely used in certain industries. Because of this resemblance we provisionally dub our device a *peristaltic ion* *source.* Another analogy is a linear accelerator, where drifting ions are accepted into a partially enclosed device (the drift tube) whose potential is raised while the ions are in the inside region; energy is added to the ions at exit and the process is repeated many times. There are many obvious differences too.

A simplified schematic of the peristaltic configuration is shown in Figure 1. Plasma is created in the plasma source (plasma gun in this context, perhaps, to stress that the plasma is born with a directed energy and streams away from the source) and drifts toward the peristaltic device with a drift velocity $v_d$. The peristaltic device has an inner chamber that can be pulsed to high voltage and an outer chamber that is held at ground potential. The ends of both the inner and the outer chambers are grided; that set of grids at the beam formation end (the 'far' end) is made with some care so as to be a good ion extractor, while that set of grids at the plasma entrance end (the 'near' end) is deliberately made so as to be a poor extractor. The length of the device from entrance grids to exit grids is $L_p$. The inner chamber and attached grids are held at ground potential while the chamber fills with plasma, a time given by $t_f = Lp/v_d$. When the inner chamber is full it is pulsed to high voltage, thus setting up conditions appropriate for ion beam formation at each end of the device, and an ion beam is formed until the chamber is emptied. Then the chamber is brought down to ground again and the cycle repeated.

Beam formation at the grids at both ends of the device is asymmetric. The exit (far) end is preferred, however, because of the plasma drift and because of the better extraction geometry there (grid spacing). The ion beam current that can be extracted from an ion source is given by the Child-Langmuir equation for ion current flow under space-charge-limited conditions [1,2]

$$I = \frac{4}{9}\varepsilon_o S\left(\frac{2q_i}{M_i}\right)^{1/2}\frac{V^{3/2}}{d^2} \tag{1}$$

where S is the open extractor area, $q_i = eQ_i$ the ion charge, $Q_i$ the ion charge state, $M_i = Am_{amu}$ the ion mass, A the atomic weight, V the extractor voltage, and d the extractor gap (separation between the main beam-forming electrodes). In the present situation this equation may not strictly apply because of the plasma drift. But it is clear that beam formation at the inlet end of the device can be minimized by having a large extractor gap; we deliberately introduce a poor extraction. As well as this, the plasma drift itself favors beam formation at the exit end of the device.

The drift velocity depends on the kind of plasma and plasma generator used, and can vary greatly. Typical might be in the range 0.1 – 10 cm/μs. For convenience the length of the peristaltic chamber might be a few tens of centimeters. Then the pulse width required is in the range a few to a few hundred microseconds and the pulse repetition rate is a few to a few hundred kHz.

## III. PRELIMINARY TESTS

A schematic of the device that we've tested is shown in Figure 2. The entrance grid set was made from open wire mesh and the gap was about 1 cm, while the exit set is precisely machined from carbon sheet with hole (beamlet) diameter 5 mm, about equal to the gap spacing; the extraction optics of the entrance grid is spoiled [2]. The middle grid was included in the design as an electron suppressor but for the work described here this grid was not used and was tied to ground. The length of the device was 30 cm and its internal diameter 15 cm. Both nitrogen plasma formed by a gaseous plasma source [3] as well as titanium plasma formed by a pulsed vacuum arc plasma gun [4,5] have been used to feed the device.

The combination of peristaltic pulsed extractor plus plasma source was mounted on a vacuum chamber, and the beam current monitored by a magnetically suppressed Faraday cup located 65 cm distant from the extractor grids. The vacuum vessel pressure was ~1 x $10^{-6}$ Torr when operating with the vacuum arc plasma gun and ~4 x $10^{-5}$ Torr when using the nitrogen plasma source. The pulser used to drive the peristaltic device was a commercial unit (Cober 605P) that could provide pulse bursts of maximum amplitude about 2.2 kV or by using a step-up transformer 22 kV.

Beams of both nitrogen ions and titanium ions were indeed formed. Maximum beam current was obtained with the vacuum-arc-produced titanium ion beam at the lower voltage (not because of better extraction but because of power availability from the pulser). Vacuum arc titanium plasma has a mean ion charge state of 2.1 [6,7], so the mean ion energy of the extracted beam at 2.2 kV was 4.6 keV. In all of these experiments the extraction was far from optimum: at high voltage (~20 kV here) the pulser power (and thus extractor current) was limited, while at low voltage (~2 kV) the extractor geometry (hole size and grid spacing) was inappropriate. Thus the beam formed was of high divergence and only a tiny fraction of the total extracted ion beam was measured by the small downstream Faraday cup. The plasma produced by the nitrogen plasma source was of considerably lower density that the vacuum arc produced plasma, limiting the ion current to yet lower levels. The nitrogen ion current measured to the Faraday cup was 20 μA. An oscillogram of the applied extractor voltage and the measured beam current is shown in Figure 3.

## IV. DISCUSSION

The ion beam formation technique presented here is new, and experimental results that we've obtained are limited and preliminary. We have nevertheless demonstrated that the method works. The value of the technique for actual ion beam application remains to be seen, and certainly the approach needs to be improved in many ways and its operation demonstrated over a much greater range of parameter space than has been done in the work described here.

To some extent, one technological concern, that of floating the source and its systems to high voltage, has been traded for another, that of the pulser. In some applications the pulser specifications could be severe – high voltage, high power, and fast – and such a pulser might be not easy or not possible to produce. But in other applications it could be that the peristaltic method is a convenient approach. By no means do we present this approach as an ion source panacea. We introduce the idea simply as a technique for the community's consideration.

## ACKNOWLEDGMENTS

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## Figure Captions

Fig. 1 Simplified schematic of a peristaltic ion source overall configuration.

Fig. 2 Schematic of the experimental device used.

Fig. 3 Oscillogram of applied extractor voltage (upper trace, 1 kV/cm) and nitrogen ion beam current measured by a downstream Faraday cup (lower trace, 10 μA/cm). Sweep speed is 100 μs/cm.

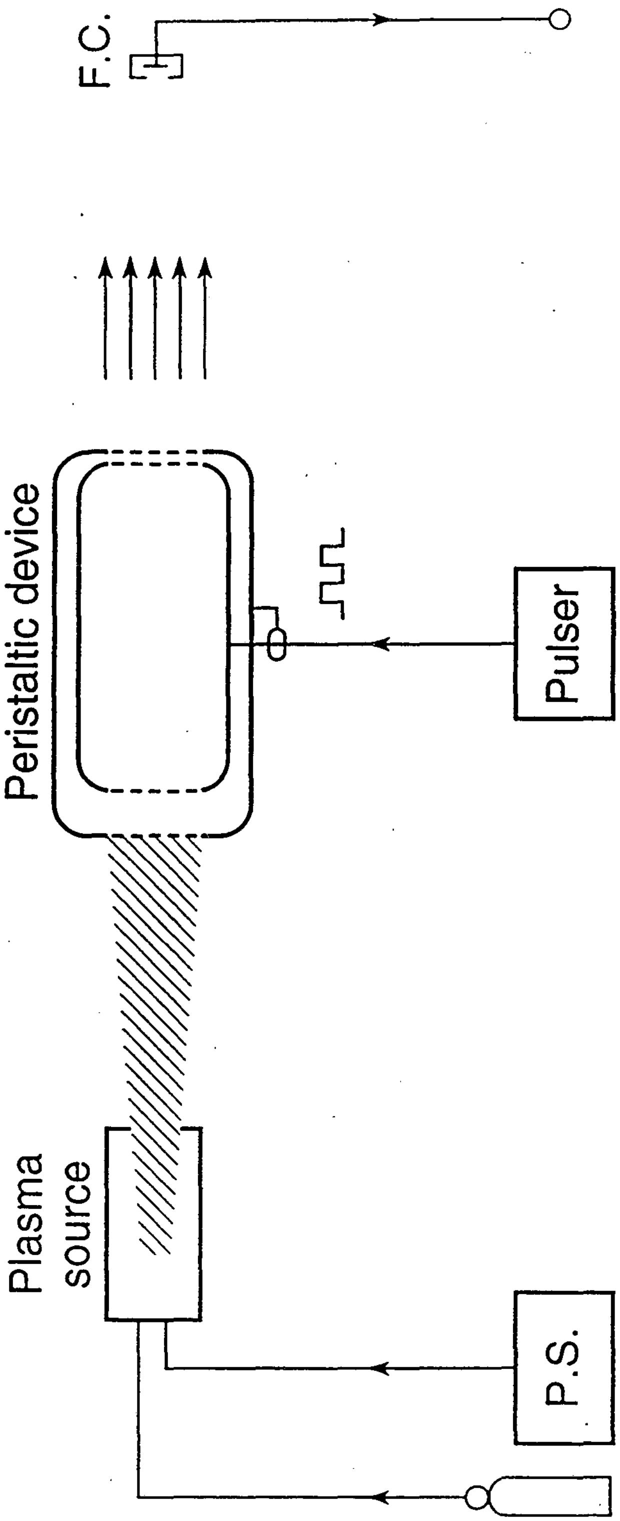

Fig. 1

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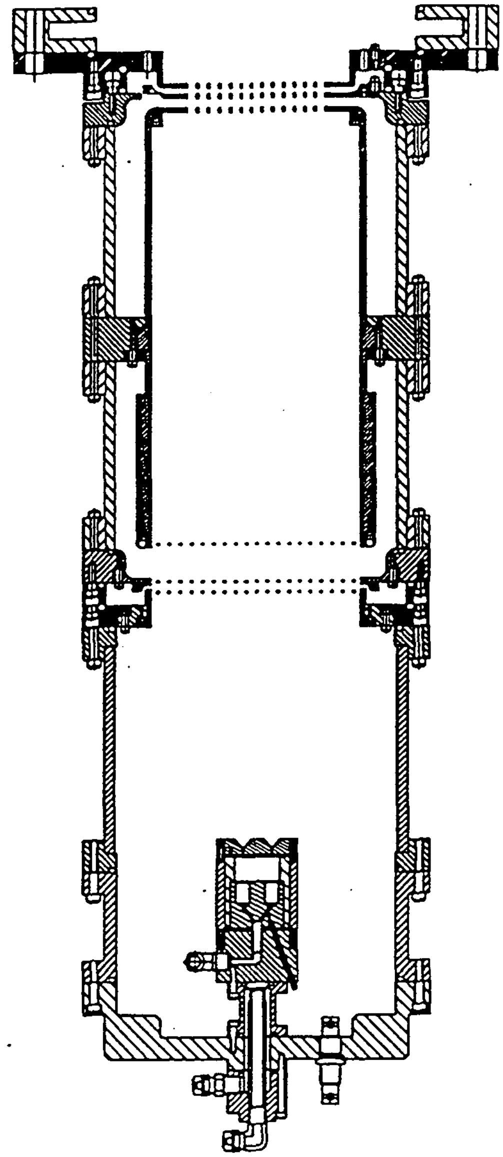

Fig. 2

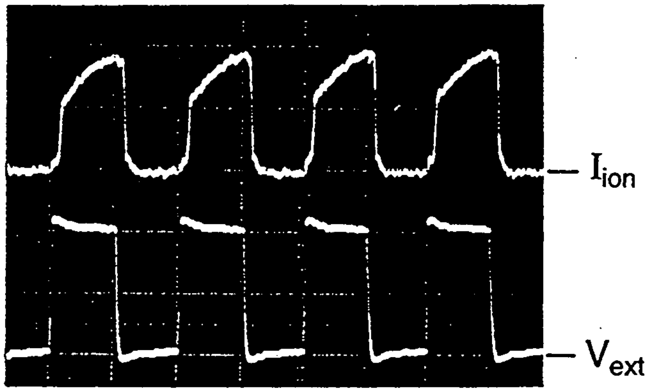

Fig. 3

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