Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 90 (2017) 136 – 142

Physics Procedia

Conference on the Application of Accelerators in Research and Industry, CAARI 2016, 30 October — 4 November 2016, Ft. Worth, TX, USA

Staging of RF-accelerating units in a MEMS-based ion accelerator

A. Persaud[a,*], P. A. Seidl[a], Q. Ji[a], E. Feinberg[a,1], W. L. Waldron[a], T. Schenkel[a], S. Ardanuc[b], K. B. Vinayakumar[b], A. Lal[b]

[a]*Accelerator Technology & Applied Physics, E. O. Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley CA 94720, United States*
[b]*School of Electrical and Computer Engineering, Cornell University, 120 Phillips Hall, Ithaca NY 14853, United States*

Abstract

Multiple Electrostatic Quadrupole Array Linear Accelerators (MEQALACs) provide an opportunity to realize compact radio-frequency (RF) accelerator structures that can deliver very high beam currents. MEQALACs have been previously realized with acceleration gap distances and beam aperture sizes of the order of centimeters. Through advances in Micro-Electro-Mechanical Systems (MEMS) fabrication, MEQALACs can now be scaled down to the sub-millimeter regime and batch processed on wafer substrates. In this paper we show first results from using three RF stages in a compact MEMS-based ion accelerator. The results presented show proof-of-concept with accelerator structures formed from printed circuit boards using a 3×3 beamlet arrangement and noble gas ions at 10 keV. We present a simple model to describe the measured results. We also discuss some of the scaling behaviour of a compact MEQALAC. The MEMS-based approach enables a low-cost, highly versatile accelerator covering a wide range of currents (10 μA to 100 mA) and beam energies (100 keV to several MeV). Applications include ion-beam analysis, mass spectrometry, materials processing, and at very high beam powers, plasma heating.

Keywords: accelerators; radio-frequency; MEMS; simulations

1. Introduction

A driving force in the development of new accelerators for applications in research and industry is reducing the cost and the size of the instrument while at the same time achieving higher beam intensity. In Persaud et al. (2016), we proposed a new concept to achieve high beam intensities using a very compact multi-beamlet accelerator structure. The concept is based on earlier work on Multiple Electrostatic Quadrupole Array Linear Accelerators (MEQALACs) in the 1980s by Maschke (1979) and has been implemented by, for example, Urbanus et al. (1989) using beamlet apertures on the order of centimeters. We propose to reduce the size by greater than an order of magnitude by implementing the MEQALAC concept using micro-electro-mechanical systems (MEMS) structures, reducing the

* Corresponding author. Tel.: +1-510-495-2529
[1] Now XTD-IDA, Los Alamos National Laboratory, Los Alamos, NM 87545
E-mail address: apersaud@lbl.gov

doi:10.1016/j.phpro.2017.09.040

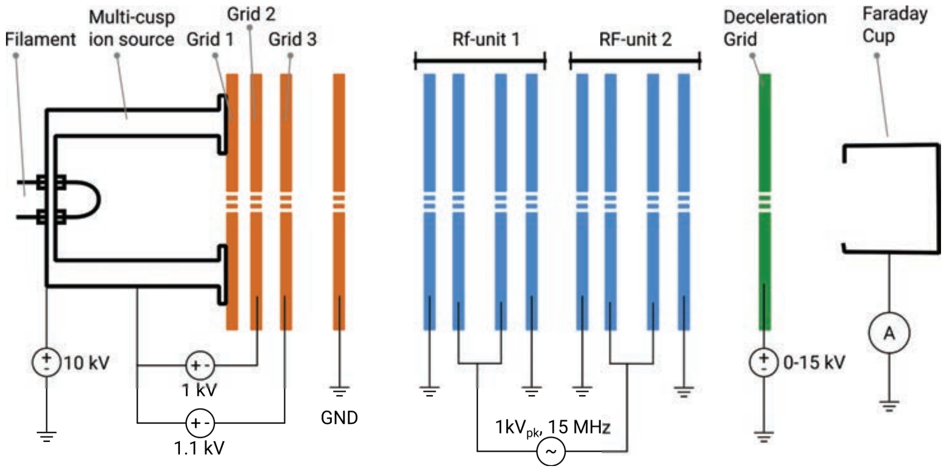

Fig. 1. The experimental setup consists of an ion source at high potential, an extraction grid system, the RF units, a retarding-potential analyzer, and a Faraday cup.

aperture size to the (sub-) millimeter scale and possibly to the scale of tens of micrometers. The MEQALAC is based on the fact that decreasing the beam aperture size in the electrostatic quadrupoles (ESQs), which supply the needed beam focusing, leads to higher transportable beam current densities. Therefore, it is advantageous to replace a large aperture and its focusing quadrupoles with multiple small apertures and quadrupoles closely packed in the transverse plane. The smallest achievable size is determined by fabrication errors. For example, fabrication errors will lead to the displacement of quadrupole centers from the desired beamline axis, leading to beam centroid oscillations and particle loss. Using MEMS technology will push these fabrication errors into the micrometer range and therefore allow better alignment and high beam intensities. Using multiple apertures in parallel will then allow to increase the total transported beam current compared to single aperture accelerators.

The accelerator structure contains two elements: electrostatic quadrupole lenses to focus the beam and transport it along the beam line, and radio-frequency (RF) acceleration. Compared to non-RF accelerators, one of the advantages of a MEQALAC structure is the use of relatively small voltages (< 10 kV) to achieve high beam energies (up to MeV). All elements are to be implemented in a silicon wafer structure, so that they can be easily fabricated using MEMS technology. For the initial proof-of-concepts experiment, both RF and ESQ structures have been implemented in circuit boards (FR-4) using millimeter-scale structures and a 3×3 array of beamlets. The FR-4 boards are fabricated by laser cutting, see Persaud et al. (2016) for details on the fabrication procedure. In this paper we will focus on experiments using two and three RF units that have been realized in FR-4. We will show results from staging these RF units and compare these measurements with a simple 1D-model.

2. Experimental Setup

To demonstrate the staging of several RF units, the setup shown in Fig. 1 was used. A multi-cusp ion source driven by a filament discharge, as described in Ji et al. (2016), is used to create the injected ion beam. The flow of argon gas is set to achieve a pressure of 7 mTorr inside the source body. The filament operates at 3.5 V and 36 A for 7.5 seconds. After 6 seconds of filament heating an arc-pulse of -100 V is applied for 300 μs between the filament and the source housing to ignite the plasma. The ion beams (a 3×3 array with a pitch of 5 mm) are then extracted between two aligned hole plates (grids 1&2 in Fig. 1) by floating grid 1 and biasing grid 2 to -1 kV. A third hole plate (grid 3 in Fig. 1) is available at the source to enable fast beam pulsing, but this feature was not utilized in the experiments described in this paper and the plate was instead biased at a constant -1.1 kV. To be able to operate the RF and quadrupole wafers at ground potential, the ion source and the source grid power supplies are floating on high voltage (< 12 kV). This voltage will accelerate the ions to a grounded electrode that marks the end of the source setup. Afterwards the ions