50-Channel Charge Integrating Faraday Detector for Characterization of Ambient Ions

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Abstract— **Herein we present a novel 50 channel, charge integrating, Faraday plate detector system for the detection, characterization and imaging of charged particles emitted from an ambient ionization source. The detector is capable of spatial positioning of ion beams with sub nA current intensity, high linearity, large dynamic range and dark current noise <10 pA. Each channel is connected to its own calibrated amplifier for true simultaneous integration. To demonstrate the detector capability, 2-dimensional ion images are presented for ions emitted from a desorption atmospheric pressure chemical ionisation source with peak ion current of ~30μA. The novel detection system facilitates the characterization and optimization of ambient ionisation sources in terms of electrical and geometric conditions for improved ion generation and coupling with a mass spectrometer.**

Keywords— DAPCI, Ambient Ionization, Ion imaging, Pixelated Faraday Detector, Mass Spectrometry, Ion Mobility.

I. INTRODUCTION

Characterizing and optimizing ionization probes prior to deployment in mass analysis applications is important for building a framework to determine performance capability [1]. Prior knowledge of ion density and spread at the sample site allows optimal conditions to be generated to aid ion generation and transfer. Some previous studies [2-5] have used high resolution pixelated detectors to image ions both *in vacuo* and under ambient conditions. In this article, we describe the development of a segmented Faraday detector and associated electronics for the sensitive measurement of ion intensity and spatial positioning. This is demonstrated using a desorption atmospheric pressure chemical ionization (DAPCI) source operated under ambient conditions [6-8]. Our cost-effective design utilizes a 50-channel charge integrating circuit connected to a segmented Faraday plate fabricated on a Printed Circuit Board (PCB). This differs from micro-arrayed multi-channel Faraday detectors that offer enhanced spatial resolution [9]. The detector has been designed for ambient ionization source characterization to allow low-cost construction and flexible operation.

II. DETECTOR PLATE DESIGN

A. Sensor Design

Fabricating charge collecting surfaces on a PCB allows low-cost and rapid production of a variety of geometries (segment shapes and sizes). Each disc is 25mm diameter and plated with up to 50 individual surfaces for charge collection. Vias route the signal through the PCB to the back surface via FPC/FFC sockets and cabling to the integrator readout board. This flexible design allows detector plates to be readily interchanged. Figure 1 shows a photograph of four detector plates with different segment geometries. Each design accommodates an application, such as reducing and/or eliminating post image processing requirements. The resolution of the strip detector (a) is 400μm with a 150μm gap, corresponding to a coverage rate of ~72%. The ultimate limitation on resolution is the PCB fabrication technology chosen. A 50V suppressor grid (not shown) was placed in front of the sensor to reduce secondary emission.

B. Integrator Circuit

A dual switched integrator IC ACF2101 [10] was selected due to its low leakage current (<100 pA) and low noise (<10 μV_{RMS}). Each surface channel is connected to an input on 1 of 25 dual integrator ICs on the readout board. This differs from most other multi-array Faraday detectors where a single amplifier serves every channel and signals are multiplexed to the amplifier input. The transfer function between the ion beam current input and the output voltage is given by:
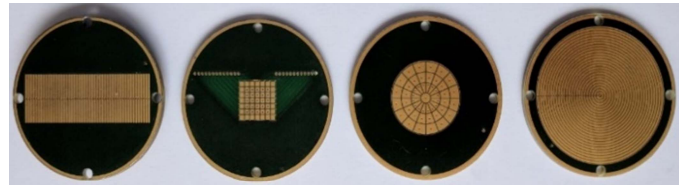

Figure 1. PCB Faraday detectors with various geometric designs: a) Strips, b) Pixels, c) Segmented concentric circles, d) Concentric circles

$$V_{OUT} = \frac{1}{C_{INT}} \int I_{IN} dt$$

Where C_{INT} is the integration capacitor, internally set to 100pF. By adjusting the integration time, it is possible to measure currents down to 10s of pAs within a time frame of ~100 milliseconds and larger beam currents of the order of µAs within a few microseconds. The ACF2010 employs true sample and hold topology, therefore synchronously clocking the results of integration onto the common data line allows the ADC (LTC1609) to sequentially digitize the analogue data. This adds to the dead time of the system but crucially simultaneous integration of each channel is assured. A simplified block diagram of the system is depicted below in Figure 2.

PCB layout techniques such as guarded inputs and separated ground returns are employed to ensure low noise operation. Each of the 50 input channels are individually calibrated and tested to ensure reliable operation and consistent measurement across all channels. The detector system is designed to operate in positive or negative ion mode. In negative mode, channels are pre-charged until a full scale reading is made. A negative beam impinging on the detector will then remove charge corresponding to the negative ion beam current.

III. EXPERIMENTAL

Experiments were performed by fixing the detector at set distances (4-14 mm) positioned directly under the DAPCI probe. A high potential (3kV) was applied to the needle generating a corona discharge at the needle tip. A high velocity carrier gas of compressed air (3 LPM) was directed over it to aid transfer of ions onto the detector. The needle is mounted concentrically within the probe nozzle and is surrounded by a copper grounded electrode at a distance of 4 mm from the needle tip. Figure 3 depicts the experimental set-up and the inset shows a photograph of the DAPCI electrode.
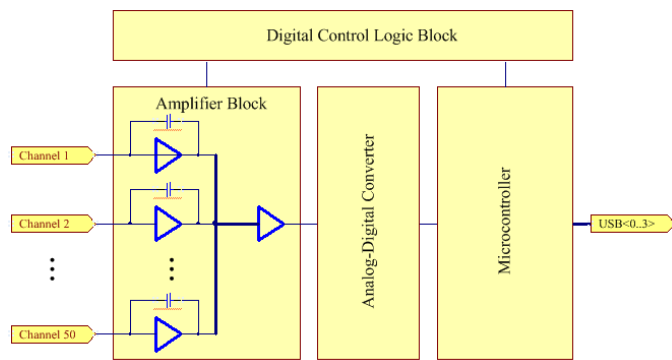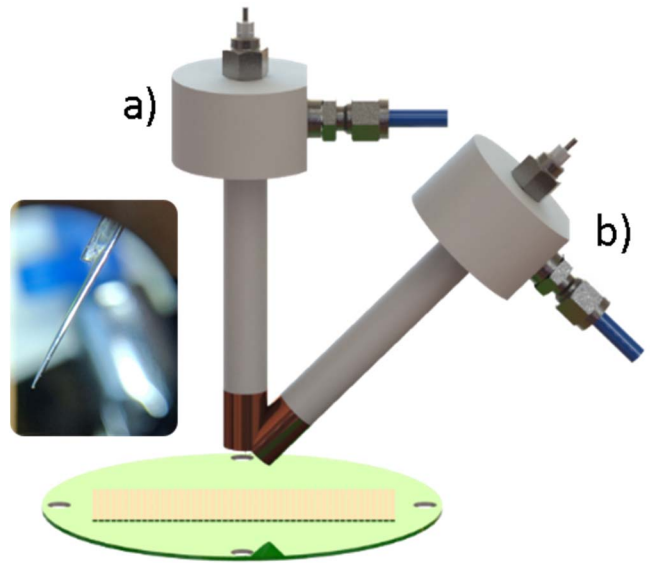

Figure 2. System Block Diagram

Figure 3. Experimental set-up showing ionization probe in proximity to segmented strip detector at a) 90° and b) 45° angles. Insert: Photograph of electrode.

IV. RESULTS

Figure 4 shows the results from a typical experiment. The graph on the left-hand side is the total ion current (summation of all channel currents). The chart on the right is the ion current collected on each strip. The software acquires data via a USB connection to a PIC32 microcontroller on the ADC and control board. Figure 5 shows an intensity map showing ion distribution produced in Matlab (Mathworks, MA, USA). Each distance measurement is an average of 100 data readings. The max reading was 5.08 µA. Dark blue zones represent ~10 nA of ion beam current.

Figures 5 shows the beam spread and density of the ion beam obtained by varying the distance of the probe to the detector. As expected, the beam becomes divergent and less intense as the distance increases, indicating that a distance of ~2-6mm from the sample under investigation is optimal.

Figure 4: Screenshot of software used to acquire data and display results of distance experiment
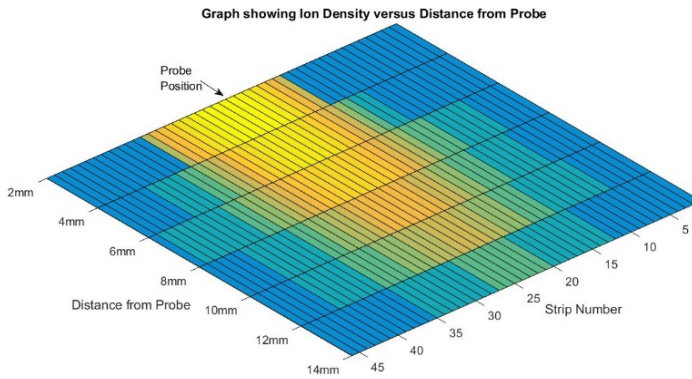
Figure 5. Ion image of DAPCI probe beam characterization at increasing distances with probe set to 90⁰.

Figure 6 shows the plots of ion distribution across the strips as the applied voltage is varied between 2.5 kV and 4.5 kV. Here the probe was set a fixed distance of 5mm orthogonal to the detector. The maximum current is 30.1 µA, with blue segments representing currents of ~10nA. As expected, a higher applied voltage generates a more intense beam. By lowering the applied voltage, a more focused beam is generated.

V. CONCLUSION

A multi-array integrating Faraday detector has been developed to enable characterization of ambient ion beams without requiring a mass spectrometer or ion mobility spectrometer. Ion intensity and spatial distribution have been demonstrated for a DAPCI source. This low cost and relatively simple approach can be used to optimize ion source parameters to maximize ion generation and ion transfer. Furthermore, this detector can also be used in a conventional manner, for example charged particle and ion optics applications where spatial information is required [11-12].
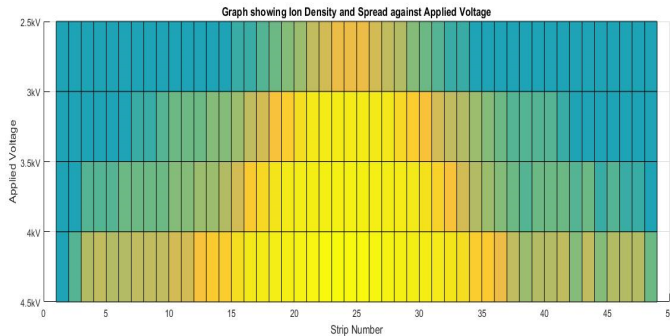

Figure 6: Ion spread emitted from DAPCI probe at 2.5-4.5kV @5mm distance

VI. ACKNOWLEDGMENTS

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