UCRL-JC—110792

DE92 017257

Ion Microtomography using Ion Time-of-Flight *

M.L. Roberts, D.W. Heikkinen, and I.D. Proctor
Lawrence Livermore National Laboratory
Livermore, CA 94551

and

A.E. Pontau, G.T. Olona, T.E. Felter, D.H. Morse, and B.V. Hess
Sandia National Laboratories
Livermore, CA 94551

June 8, 1992

Abstract

We have developed and are in the process of testing an ion time-of-flight (TOF) detector system for use in our ion microtomography measurements. Using TOF, ion energy is determined by measurement of the ion's flight time over a certain path length. For ion microtomography, the principle advantage of TOF analysis is that ion count rates of several hundred thousand counts per second can be achieved as compared to a limit of about ten thousand ions per second when using a solid-state silicon surface barrier detector and associated electronics. This greater than 10 fold increase in count rate correspondingly shortens sample analysis time or increases the amount of data that can be collected on a given sample. Details of the system and progress to date are described.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.

Introduction

In general, ion microtomography measurements are count rate limited (i.e., limited by the maximum rate at which data can be acquired)[1]. In most cases, the limiting factor has been the silicon surface barrier detector and its associated electronics. Due to the shaping constant applied to the pulse from our surface barrier detectors and the even slower conversion time of the associated analog to digital converter, count rates were limited to about ten thousand ions per second. To overcome this limitation, we have built and are in the process of testing a time-of-flight (TOF) detector system.

The TOF detector system utilizes two chevron type microchannel plate (MCP) detectors to measure the TOF of ions over a known path length. This measurement of ion TOF over a given path length is in essence a measurement of ion velocity and hence ion energy. In ion microtomography, TOF analysis is advantageous in that, due to the fast response times of the MCP's and associated electronics, ion count rates of several hundred thousand counts per second can be achieved while maintaining an energy resolution comparable to or better than that of a typical solid state silicon surface barrier detector. Another advantage of the TOF system is its relative immunity to radiation damage. Silicon surface barrier detectors often suffer localized radiation damage when used in ion microtomography. The resulting loss of charge collection efficiency in the damaged areas causes an apparent shift in the energy spectrum which in turn can cause artifacts in acquired data.

Design and Operation

The TOF detector system is schematically shown in Figure 1. Our system utilizes both a start and a stop detector. The start detector is shown schematically in Figure 2 and pictorially in Figure 3. The design of this detector is similar to that of D'Erasmo *et al.*[2] and Starzecki *et al.*[3]. This design was chosen in part because of its simplicity. Particles to be detected pass through a thin carbon foil mounted perpendicular to the particle trajectory. Secondary electrons emitted from the foil are accelerated to approximately 1 keV by the electric field between the foil and an acceleration grid mounted on the front of the block. An additional grid is mounted in front of the carbon foil and kept at the same potential as the block in order to prevent carbon foil deformation and/or breakage due to the electrostatic force. After acceleration, the electrons drift in a field free region inside the block and then enter an electrostatic mirror. The electrostatic mirror consists of two parallel grids mounted 45° to the ion path. The electrostatic field existing between these two grids deflects the electrons through 90° towards a chevron type fast MCP detector which is housed outside of the ion beam.

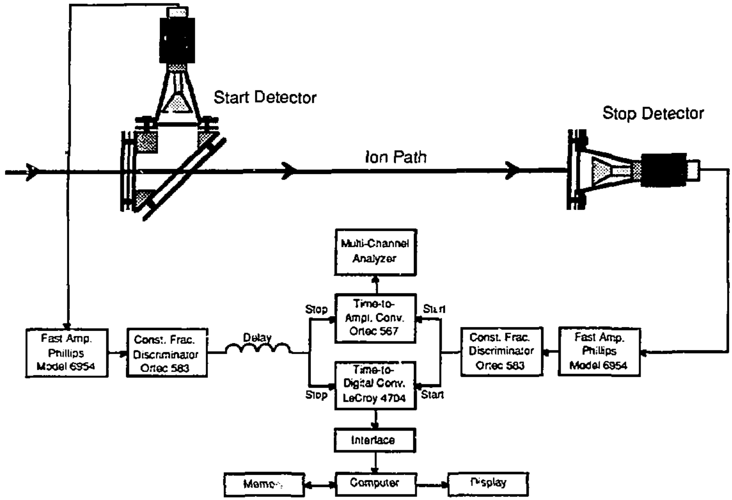

Figure 1. Schematic overview of the time-of-flight detector system showing the start and stop detector and a block diagram of the electronics.

All grids are made of 25 μm diameter Be-Cu wire with an average wire spacing of 1.25 mm. This choice gives a calculated transparency of 98% for each grid or a total transmissivity of greater than 92% for all four grids. An important reason for choosing this detector design is that the transport of electrons is to first order isochronous. That is, the total electron path length to the MCP, and hence the electron TOF, is independent of the point of origin on the start foil. Using the following formula:

$$t(ns) \cong 72 \left(\frac{m(amu)}{E(MeV)}\right)^{\frac{1}{2}} \cdot l(m) \qquad (1)$$

we estimate this electron TOF time to be approximately 3 ns for 1 keV electrons.

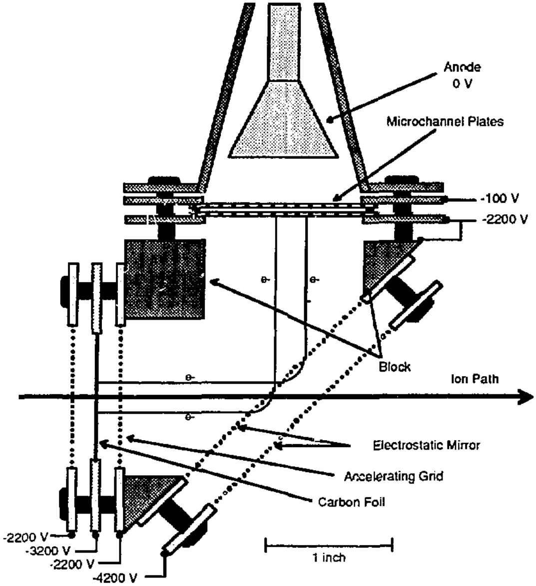

Figure 2. Schematic view of the start detector showing path of the emitted secondary electrons and typical voltages.

After passing through the first or start detector, the ion beam is incident upon the second or stop detector. This stop detector is placed perpendicular to and is centered on the incoming beam. The detector consists of a negatively biased nickel foil mounted on the front of another chevron type MCP detector. Secondary electrons emitted from the back surface of the nickel foil are accelerated towards the MCP where they are amplified and collected to form the stop pulse.

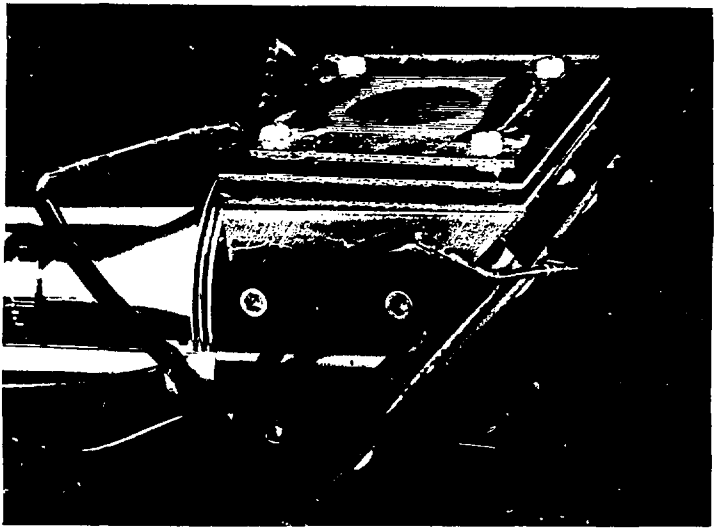

Figure 3. Photograph of the start detector.

A block diagram of the electronics used is also shown in Figure 1. Anode signals from each of the MCP detectors were amplified using a Phillips Model 6954 fast amplifier and fed into an Ortec Model 583 constant fraction discriminator. A constant fraction discriminator is used to prevent amplitude dependent time walk (i.e., time variations in timing pulses due to amplitude variations of the signal). Discriminator outputs were then fed into a time-to-amplitude converter (TAC) for display on a multichannel analyzer and into a time-to-digital converter (TDC) that is part of the data analysis system. As is often the custom in time-of-flight work, outputs from the stop detector were fed into the "start" of both the TAC and TDC while outputs from the start detector were delayed and fed into the "stop" of both the TAC and TDC. Reversing the start and stop pulses is done for two reasons: First, due to the less than 100% transmittance of the start or first detector, the ion count rate in the stop detector is in principle less than in the "start" detector and having a "start" pulse without a corresponding "stop" pulse causes time overflow in the TAC and TDC which can generate significant dead time at high count rates. Second, reversing the "start" and "stop" pulses produces the purely aesthetic result that signals with shorter flight times (i.e., higher energy) have larger analog and digital outputs.

Results

As an initial test of the TOF detector system, four square silicon pillars were analyzed using a 3 μm diameter 8 MeV proton beam. The tomographic image resulting from this ion analysis is shown in Figure 4. For the analysis, approximately 90 million ions (19 ions per ray or pixel, 389 rays per slice, 20 tomographic slices, and 611 projections) were analyzed in a period of about 45 minutes. This gives an average count rate of approximately 33 thousand ions per second using the TOF system. Using a surface barrier detector counting at 10 thousand ions per second, it would have taken almost 2.5 hours to acquire the same image. Time resolution for the TOF system during the analysis was better than 350 ps over a flight path of about 2 m giving an energy resolution of better than 110 keV at 8 MeV. To determine overall system efficiency, a solid state detector was periodically inserted in front of the first or start detector and ratios of timing peak counts per unit time over solid state detector energy counts per unit time were obtained. Overall system efficiency averaged approximately 20%.

Future Plans

Our future plans center around two obvious aspects: Improving the time resolution of the system and increasing the detection efficiency. The current time resolution of approximately 350 ps fwhm is larger than the 120 to 225 ps fwhm achieved by others[2,3,4]. Whether this time resolution difference is due to some mechanical difference between our system and theirs, problems with our MCP's, or poor electronics is unknown and needs to be studied. Note however, that a time resolution of 125 ps would produce an energy resolution of less than 40 keV for 8 MeV protons over a flight path of 2 m.

Efforts to improve the efficiency of the detector system are presently underway. Most of our efforts have focused on the start or first MCP detector. Ion detection efficiency in the first detector is currently about 25% for 8 MeV protons and 50% for 5 MeV alphas. Different carbon foil thicknesses of 5 and

20 μg/cm^2 have been tried with little if any effect. A thin coating of MgO on the back of the carbon foil, however, did increase detector efficiency from 10% to its current 25%. Clearly, further effort in the area of enhancing secondary electron emission is warranted.

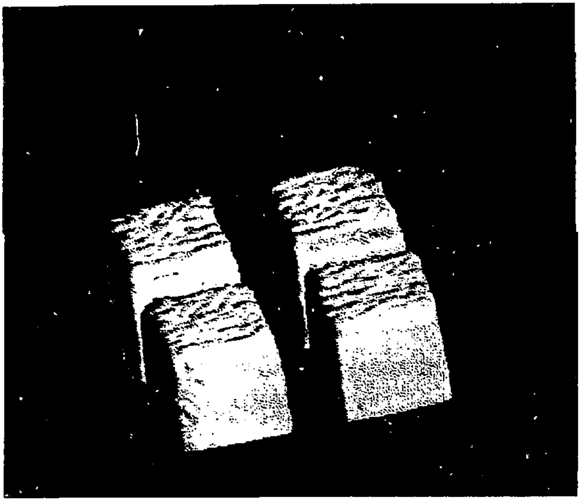

Figure 4. Ion microanalysis of four 100 micron by 100 micron square silicon pillars using a 3 μm diameter 8 MeV proton beam. This analysis was our first test of the ion time-of-flight technique to measure ion energy loss.

Conclusions

We have developed and are in the process of testing an ion time-of-flight detector system for use in our ion microtomography measurements. While we are hopeful that further improvements in time/energy resolution and detector efficiency can be made, the system has already allowed us to acquire a test tomograph at a rate approximately 3.5 times as fast as could have been acquired using a solid state detector system. It is anticipated that ion time-of-flight will become a routine tool in our laboratory for collection of ion microtomography data.

References

[1] A.E. Pontau, A.J. Antolak, and D.H. Morse, "Some Practical Considerations for Ion Microtomography", Nuclear Instruments and Methods in Physics Research, **B454** (1990) 503-507.

[2] G. D'Erasmo, V. Paticchio, and A. Pantaleo, "A Transmission Time Detector for Low Energy Light Ions", Nuclear Instruments and Methods in Physics Research, **A234** (1985) 91-96.

[3] W. Starzecki, A.M. Stefanini, S. Lunardi, and C. Signorini, "A Compact Time-Zero Detector for Mass Identification of Heavy Ions", Nuclear Instruments and Methods, **193** (1982) 499-505.

[4] J. Girard and M. Bolore, "Heavy Ion Timing with Channel-Plates", Nuclear Instruments and Methods, **140** (1977) 279-282.