Online Estimation of Photo-ion Collection Rate in Laser Isotope Separation Process

Dev Ranjan Das, S. P Dey, Biswajit Jana, Anupama Prabhala., Sanjay Sethi
ATLA-F, Beam Technology Development Group,
Bhabha Atomic Research Centre, Mumbai – 400 085
Email: drdas@barc.gov.in

Introduction

Atomic Vapour Laser Isotope Separation (AVLIS) method is successfully used for the isotopic enrichment of lanthanides used in medical and other applications[1]. AVLIS consists of several processes like generation of atomic vapour and its collimation to form an atomic beam, selective excitation and ionization of targeted isotope to produce its photoions, collection of the photoions on the collector plate with minimal non-selective isotope pickups. A DC electric field[2] is applied to extract and collect the photoions from the laser-atom interaction region to the product collector plate. When the photoions are collected on the plate, it creates a current signal in the electrical circuit. Since the pulsed lasers having high repetition rate are used for the ionization process, the ion current signal is pulsed in nature. The area under Current-Time (CT) plot of the photo-ion signal averaged over a number of pulses gives the ion collection rate on the product collector plate. Its real time plot indicates the overall performance of various sub-systems, monitors the ion collection rate and checks for any deviation from specified system parameters. A boxcar averager is generally used to estimate the real-time ion collection rate by gating the ion-collection peak. Here, we introduce a novel methodology of processing and integrating the gated waveform of photo-ion signal recorded on an oscilloscope using a computer algorithm. The captured data is processed to obtain real time rate of photo-ion collection on the collector plate as well as its cumulative value over the time of experiment.

Methodology

Figure-1 shows the typical arrangement and the electrical circuit to measure the photo-ion current signal in a Laser Isotope Separation (LIS) experiment. The ion-current is passed through shunt resistor of 1000 ohms and the voltage drop across the resistor is given to an oscilloscope through a DC blocking capacitor. A typical waveform of the ion-collection signal of the collector plate captured on the oscilloscope is shown in Figure-2. The noise at the beginning of the rising edge of the pulse is characteristic of Copper Vapour Laser (CVL) that originates due to CVL discharge[3]. The same waveform of Figure-2 is captured into a personal computer using Standard Commands for Programmable Instruments (SCPI) protocol over Ethernet[4, 5, 6]. The captured waveforms consists of 1000 data points over the full time scale. The full time scale of the waveform in Figure-2 is 40 micro-seconds. Figure-3 shows the representative ion collection signal after it is averaged over 25 data points to show only one data point per micro-second. The voltage signal from oscilloscope is converted to equivalent current by dividing the data by a factor of 1000 to account for the shunt resistor discussed above.

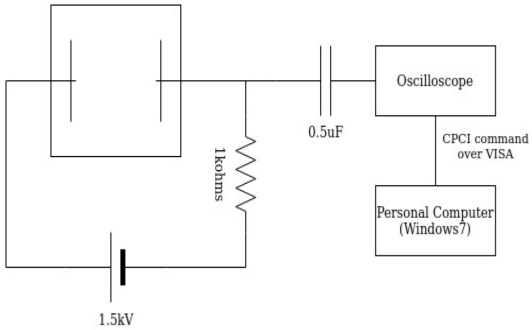

Figure-1: Electrical circuit used to measure photo-ion current signal.

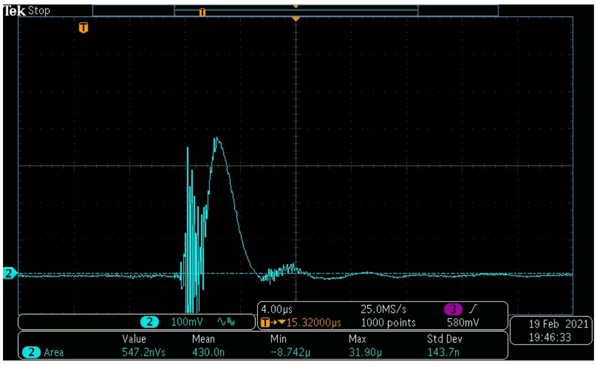

Figure-2: Typical waveform of the ion-collection signal of collector plate captured in the oscilloscope.

(X axis: 4us per div, Y axis: 100mV per div)

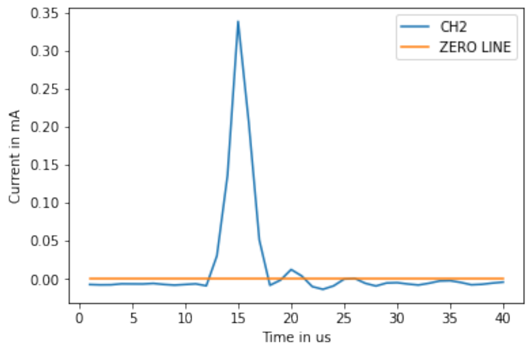

Figure-3: Representative image of Captured photo-ion current signal on a PC with 1000 data points reduced to 40 data points; one data point every one micro-second

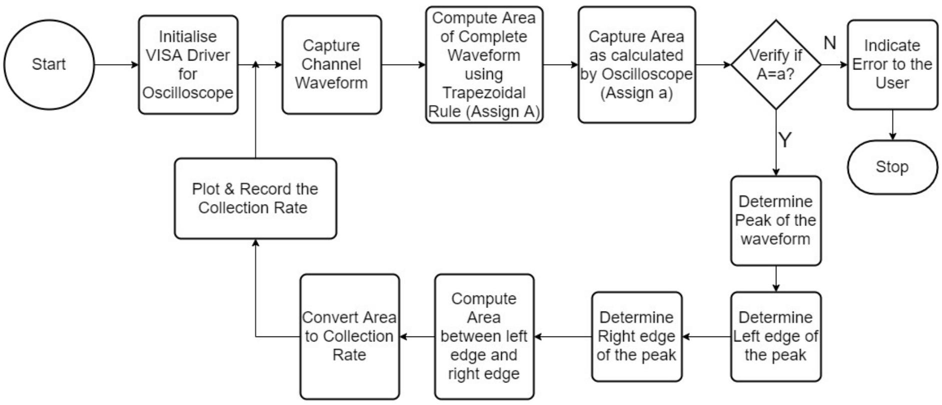

Figure-4: Software Algorithm used to compute the collection rate

The data of captured waveform is processed, integrated and the instantaneous ion-collection rate is derived. The algorithm used for computing the area of ion current pulse and ion collection rate on the product collector plate is shown in Figure-4. Processing of the waveform mainly consists of software gating which is done by catching the zero crossing of the waveform on both sides of the peak which provides the time duration of the peak. As this software gating is automatic, delay and width parameters are dispensed with. The area of ion current signal is estimated by integrating the gated waveform using trapezoidal rule and area is used to compute the ion collection rate using Equation 1 below. The collection rate (g/h) of photo-ions is captured and recorded every one second. The oscilloscope and Python based computer program with SCPI commands satisfactorily replicates the function of a boxcar averager for this application.

The total mass ('g/h') of photo-ion collected on the collector plate is computed as

$$M \text{ (ion in g/h)} = [(area\_ct/C) \times (A/N_A) \times rep \times 3600] \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (1)$$

Where 'rep' is the Laser Pulse Repetition Frequency i.e., PRF (Hz), '*area_ct*' is the area under the ion current curve in amp-sec, '*A*' is the mass number of the atom from which ion is generated (g), '*C*' is the charge of one ion i.e. 1.6×10^{-19}C, and 'N_A' is Avogadro's number.

For an example, if the estimated area of ion current signal is $2\text{x}10^{-8}$ amp-sec; the computed ion collection rate is ~ 1.02 mg /h in the LIS experiment of Samarium (A=152) with 9 KHz laser pulse repetition rate.

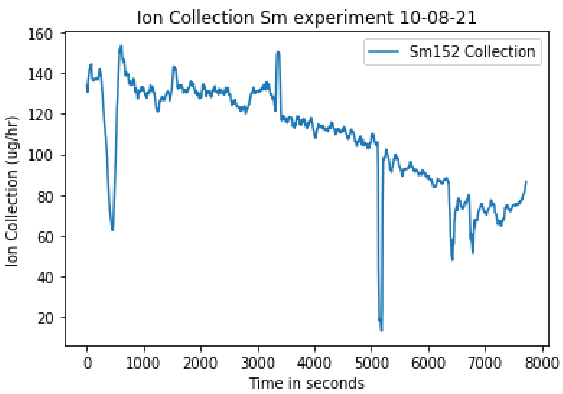

Figure-5: Trend of photo-ion collection rate of during an LIS experiment

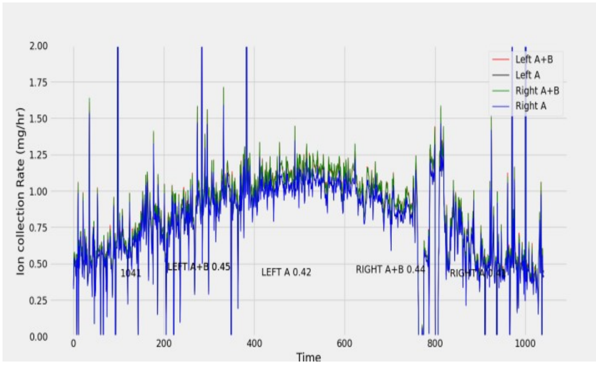

Figure-6: Ion-collection rate during systematic detuning of the laser wavelength

Results and Discussion

Fig. 5 depicts the real time plot of photo-ion collection rate during the laser isotope separation experiment. It shows the trend of ion collection rate over more than two hours of experiment. The dips, peaks and the trend are expected. Its variation is due to changes in the various parameters of the separator and lasers during the experiment. Hence it is useful for the post analysis of the experiment and to understand the performance of various sub systems. Fig. 6 provides a trend of change of the rate of photo-ion collection when the laser wavelengths are deliberately detuned in order to study its effect on the photoionization process. The fluctuation in this plot is due to the fluctuations in the measured ion current signal.

Conclusion:

A technique of monitoring the photo-ion collection rate in AVLIS using processed signal of the oscilloscope has been developed and successfuly tested during the LIS experiment of Yb and Sm. The algorithm and the programme is generic and can be used for any LIS system to monitor the real time ion collection data. Validation of the technique discussed in this paper, based on the product quantification using suitable laboratory based procedures, will result in a quality control tool for the isotope separation experiments.

Acknowledgments

The authors acknowledge the support and encouragement of Director BTDG, BARC and also for facilitating the work. The entire group of ATLA-F, BTDG is acknowledged for the LIS experiments during which the technique is tested and ion collection rates was estimated.

References

1. Biswaranjan Dikshit and Archana Sharma, *IEEE Transactions on Nuclear Science*, **67(12)**,2465, (2020).
2. Takemasa S. et al. "*Journal of Nuclear Science and Technology*", **33:11**, 834, DOI: 10.1080/18811248.1996.9732017
3. Deepak Naphade et al. "*National Laser Symposium (NLS 24)*", RRCAT Indore, (2015)
4. National Instruments Virtual Instrument Software Architecture (VISA), https://www.ni.com/visa/
5. SCPI-1999 Specification, S. Consortium (1999).
6. SCPI & VISA: A valuable combination, John M. Pieper, http://www.hit.bme.hu/~papay/ edu/Lab/ SCPIandVISA.pdf