PLASMA DIAGNOSTICS
EQP APPLICATION NOTES

Application of the EQP and EQS mass spectrometers to time resolved studies in ion beam and plasma processes

EQP and EQS mass spectrometers can be used to study repetitive transients in ion beams or plasma afterglow. Mass and energy spectra of ions can be determined in a specified time window synchronised to the transients. Time windows can be as short as 1 microsecond. Applications include negative ion plasma analysis, time resolved measurements in pulsed plasmas and in the plume of laser ablation processes, and signal to noise ratio improvement in cyclical events.

Introduction

Many ion beam and plasma experiments, such as afterglow studies in a pulsed plasma, involve repeated transient signals. A mass spectrometer suitable for such studies must not only include energy and mass analysis of the ion population but also allow data to be acquired during a specific time gating period synchronised with the transient.

Hiden's EQP and EQS mass spectrometers have an electrostatic sector field energy analyser followed by a quadrupole mass filter and ion counting detector (Figure 1 shows the EQP analyser). The pulses from the detector can be electronically gated so that only ions detected during the gate time are counted in either the energy or mass spectrum.

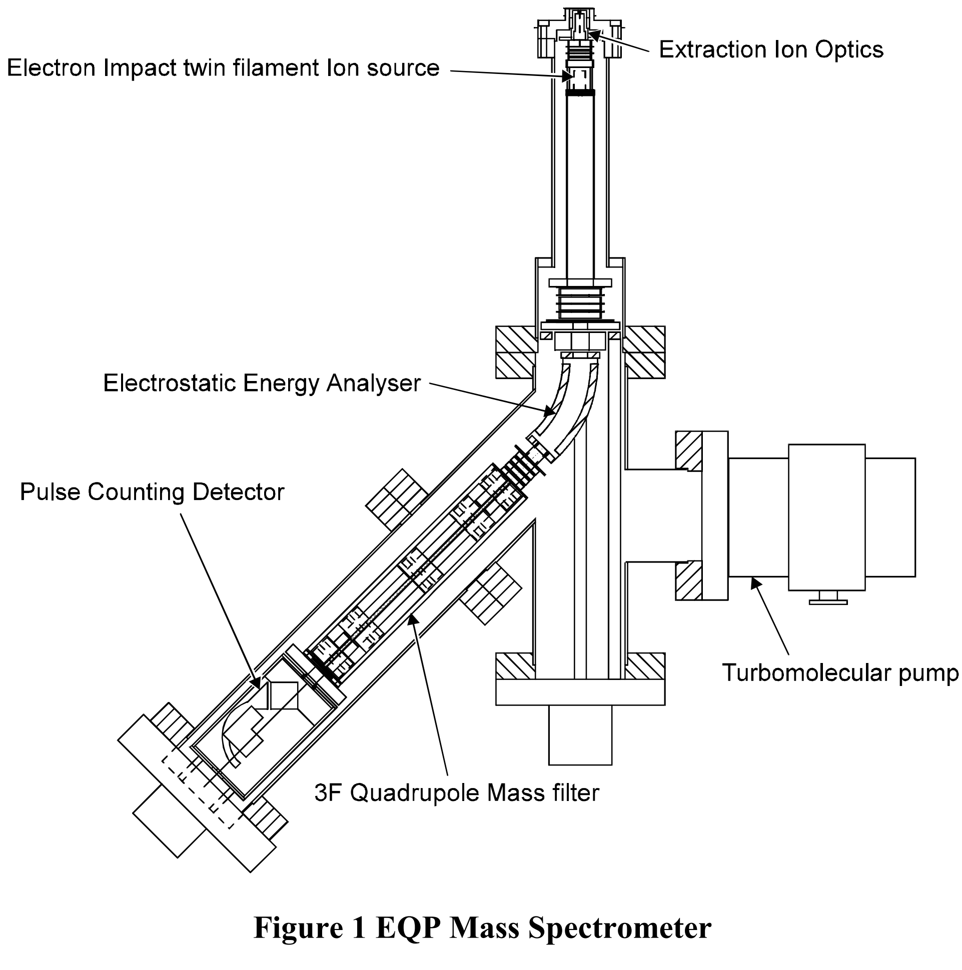

Figure 1 EQP Mass Spectrometer

Time Resolved Mass and Energy Spectra (TRMES)

TRMES allows data to be taken only from selected time slots in a cyclical event by controlling acquisition with a gating pulse synchronised to the event. Typical cyclical events occur in pulsed plasmas or laser ablation, which are normally controlled by a reference signal. This signal can be used to control the mass spectrometer and synchronise acquisition with the events.

As shown in figure 2 the event reference signal driving the experiment is used to trigger a variable delay generator, which in turn triggers the gating pulse generator. Since the mass spectrometer can only acquire data during the gating pulse "on" period, increasing the delay time moves the acquisition point through the event cycle, and decreasing the gate pulse width localises the values of the parameters monitored.

One of the user set control parameters in the mass spectrometer is the dwell time used to count the ions detected by the instrument at each point in the scan and derive the count rate. When time resolution gating is used, assuming the dwell time is longer than the gating pulses, the set dwell time is divided into segments by the gating pulses. Where the gate time is greater than the dwell time, acquisition of a point may complete in one or two gate pulses depending on the relative phase of the signals.

If a dwell time of 1 mS has been set and each gating pulse is 10 µS wide, the dwell gate will remain open for 100 gating pulses. If the gating pulses occur at 100 µS intervals, then the total time to acquire each point will be 10 mS. (See the Timings section below.)

TRMES can be used either to improve the signal to noise ratio of transient events or to monitor particular parts of the event cycle.

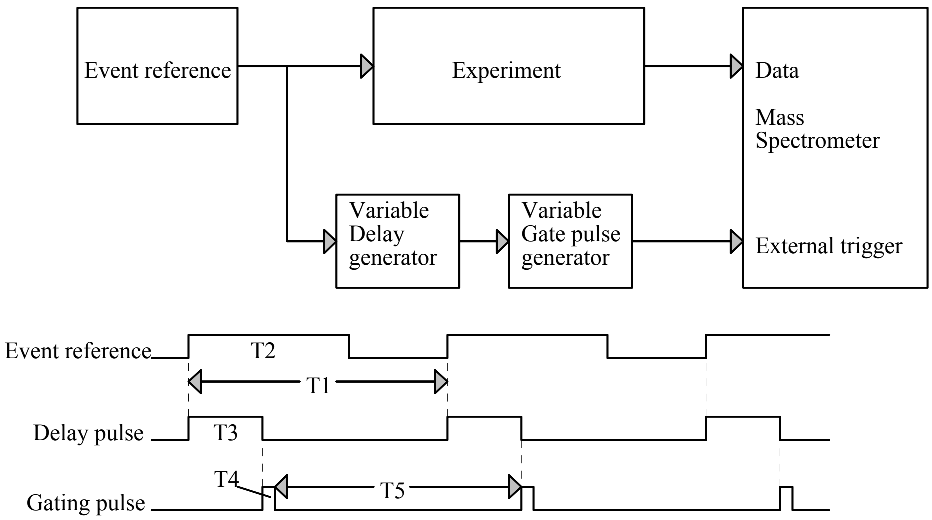

Figure 2 TRMES schematic

Signal to noise improvement

Time resolution sampling can improve the signal to noise ratio in experiments where the "on" to "off" time of the triggered event is small.

If no gating is used, acquisition will average the count rate over the dwell period, and effectively divide the "on" period total counts by the dwell time to obtain the rate. If the event "on" period is short compared to the dwell time and only one event occurs within it, this can result in an apparently very low count rate. For example, if the event "on" time is 10 μS and 10 ions are counted, the actual count rate is 10^6 c/s, but if one of these events is seen during a dwell time of 10 mS, the reported count rate will be 10^3 c/s (10 ions in 10 mS). Dwell time gating is also unlikely to be synchronised with the event rate, which can result in the dwell gate opening or closing part way through an event in some cycles and not others, thus increasing the apparent noise on the signal. In extreme cases there may be no event while the dwell gate is open, resulting in an apparently zero count rate.

Figure 3 gives an example of how to use TRMES to improve the signal to noise ratio in an experiment where the mass spectrometer is used to monitor the ablation plume created by a laser shot with a low repetition rate. The laser firing signal is used to trigger a delay which drives the gate generator. When the delay and gate timings are correctly adjusted the highest count rate will be seen. These timings may be set by using an oscilloscope or by using the mass spectrometer itself.

To use an oscilloscope, the display must be triggered by the laser trigger and the gating pulses and the external pulse output from the mass spectrometer monitored on the screen. Delay and gate timings can then be adjusted so that the gating pulse is seen to cover the time when the greatest concentration of ion pulses occur.

Using the mass spectrometer to set the timings is slightly more difficult, but does not require any other equipment. First a scan tree should be built to monitor the MID trend of the largest ion seen in the event. If this is not known, the instrument should first be used without external gating to acquire a mass scan, which can then be examined to find the largest peak. The MID scan should then be run and the monitored event cycle started. Initially the delay time should be set to zero and the gate time set to minimum or 1 μS whichever is the larger. Watching the MID trend display, increase the delay time until a signal is seen. If no signal is seen after the delay has passed through the point at which one would be expected, it may be that the actual count rate is too small to register with the minimum gate time, and the process should be repeated with a longer initial gate time. When a signal is seen, this is the delay to the start of the event reaction.

The gate time should now be increased until the count rate maximises. At this point both times are optimum and should be noted for future use. Once these are set, other scan trees can be built to monitor the required parameters, and, provided the experiment does not change, the noted times can be reused.

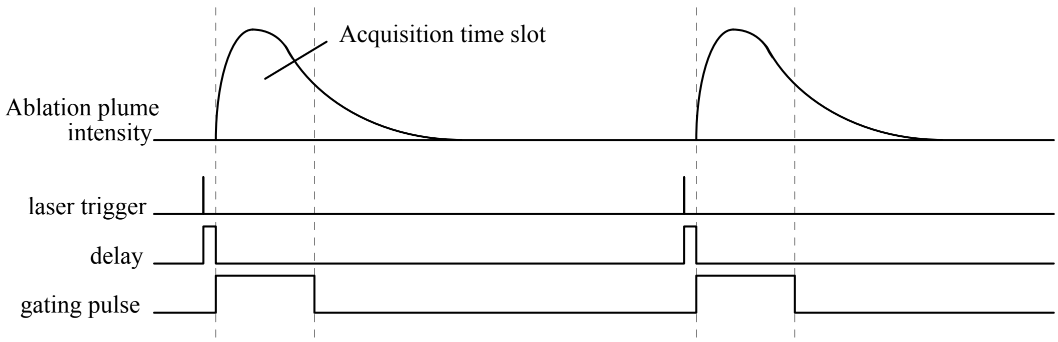

Figure 3 Improving the signal/noise ratio of a triggered event

Monitoring part of an event cycle.

Where the condition of the monitored system changes through the event cycle, for example the plasma in a pulsed plasma system, external gating can be used to look at the ions during a small part of the cycle. This method may also be used to monitor negative ions formed in the bulk plasma which cannot normally escape the plasma due to the confining effect of the sheaths (see example figs. 5 and 6).

Figure 4 shows the gating input used to monitor the afterglow in a pulsed plasma system. Here a fixed gate timing to look at the ions in a small part of the cycle. If the delay generator time is increased as data is acquired, the instrument will scan across the afterglow period.

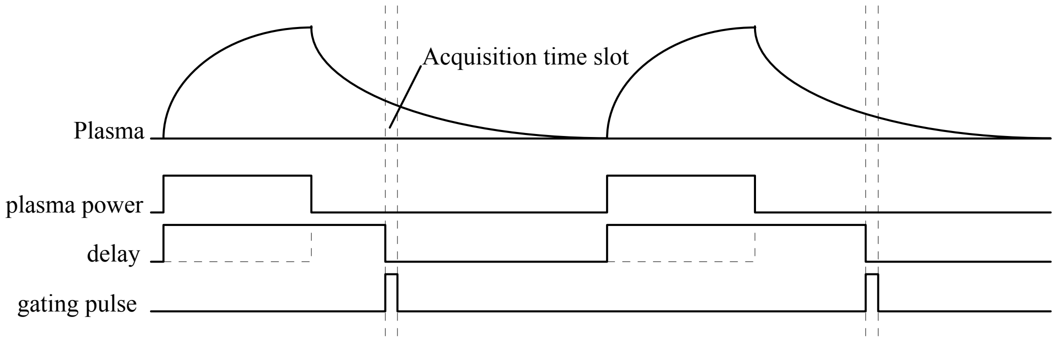

Figure 4 Pulsed plasma afterglow monitoring

Timings

Each point that the mass spectrometer acquires is read for the set dwell period. If external gating is used, the point is not read until the sum of the gating pulses equals the dwell time. Thus the time to acquire each point is longer than that where external gating is not used.

Referring also to Figure 2 above, if the set dwell time is T_d and the gating pulse width is $T4$, then the number of gating pulses required for each point, ng is:

$$n_g = \frac{T_d}{T4}$$

If the period of the gating pulses is $T1$ (i.e. the event reference period), then the total time to acquire each point (T_p) is:

$$T_p = n_g \times T1 = T1 \times \frac{T_d}{T4}$$

or

$$T_p = T_d \times \frac{T1}{T4} = \frac{T_d}{\textit{gating pulse duty cycle}}$$

If T_d = 100 mS, $T1$ = 400 µS, and $T4$ = 100 µS, each point requires 400 mS, and the total acquisition time for a 100 amu histogram spectrum is 40 seconds.

Example

Figures 5 and 6 show two energy selected negative ion mass spectra from an RF Carbon Tetrachloride discharge. The spectra were taken at 25 mTorr and 70 mTorr in an inductively coupled plasma pulsed at 1kHz.

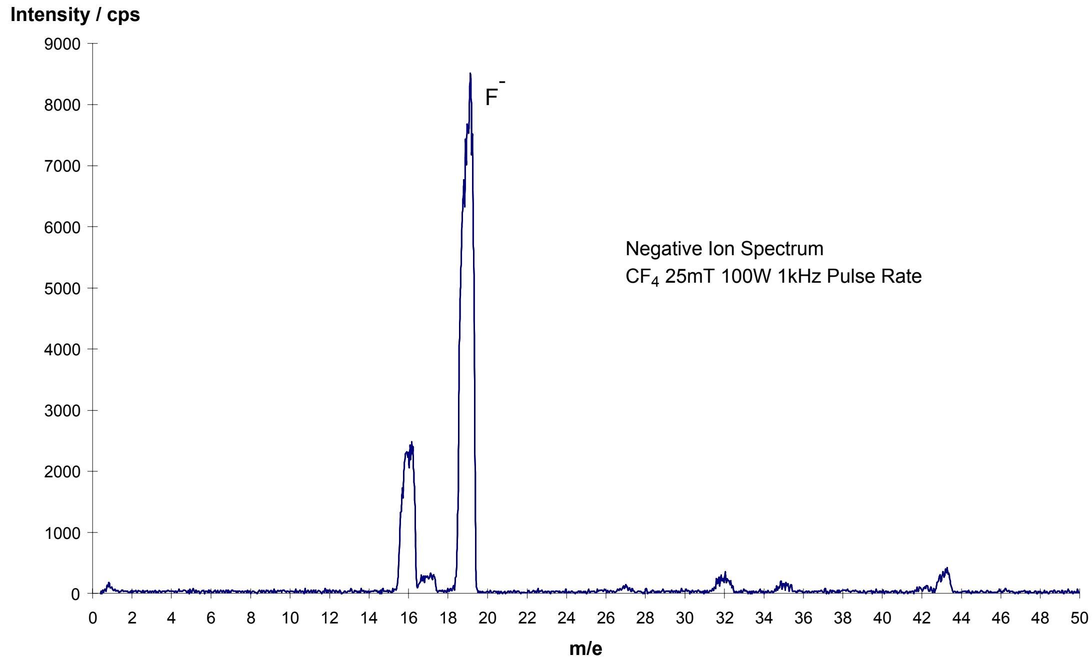

Figure 5 Mass Spectrum at 25 mTorr

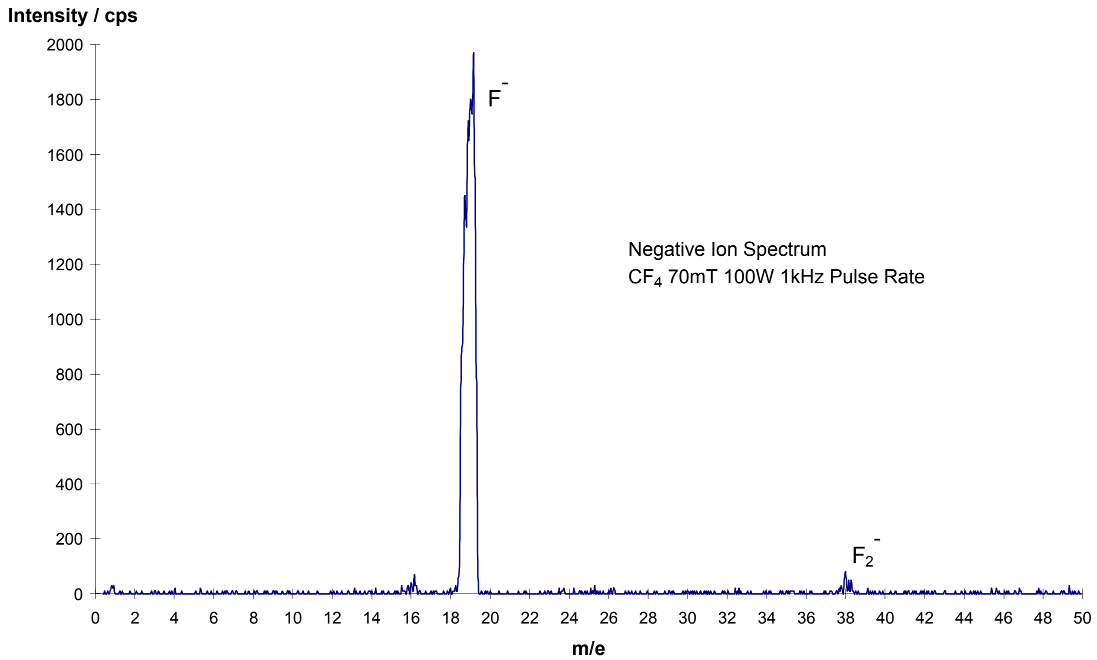

Figure 6 Mass Spectrum at 70 mTorr

Specifications

The Mass Spectrometer Interface Unit (MSIU) external gate input should be driven by a TTL level signal with the characteristics shown below. The instrument will operate with shorter T4 and T5 times, but this is not recommended as the gate signal is retimed to an internal clock, and shorter pulse widths increase the retiming uncertainty. Refer also to Figure 2 above.

Signal	Minimum	Maximum
Event reference period (T1)	> T3 + T4	-
Event reference pulse width (T2)	Depends on delay generator	< T1 - delay generator setup time
Delay period (T3)	Depends on delay generator	< T1 - T4
Gate "on" period (T4)	1 µS	-
Gate "off" period (T5)	1 µS	-
Gate signal rise/fall time	-	less than 50 ns

Table 1 Timing specifications for Time Resolved Mass and Energy Spectra signals

External gating signals are connected to the MSIU as follows:

Description	Signal	Common
Active high input	AC-05 pin 21	AC-05 pin 9
Active low input	AC-05 pin 8	AC-05 pin 9

Table 2 External gating signal connections

See also the EQP/EQS Analyser Operator's Manual HA-085-003 Chapter 8 Input/Output Subsystem

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