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An agency of Industry Canada

CA 2396925 A1 2001/07/19

(21) 2 396 925

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2000/11/24
(87) Date publication PCT/PCT Publication Date: 2001/07/19
(85) Entrée phase nationale/National Entry: 2002/07/10
(86) N° demande PCT/PCT Application No.: CA 2000/001405
(87) N° publication PCT/PCT Publication No.: 2001/051917
(30) Priorité/Priority: 2000/01/10 (60/175,305) US

(51) Cl.Int.^{7}/Int.Cl.^{7} H01J 49/42, H01J 49/40

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(54) Titre : APPAREIL ET PROCEDE DISCRIMINANTS CONTRE DES ESPECES IONISEES NON DESIREES EN SPECTROMETRIE DE MASSE AVEC DES DISPOSITIFS DE COLLISION ET DE REACTION

(54) Title: AN APPARATUS FOR AND METHOD OF DISCRIMINATING AGAINST UNWANTED IONIZED SPECIES IN MASS SPECTROMETRY WITH COLLISION AND REACTION DEVICES

(57) Abrégé/Abstract:
A spectrometer apparatus and method provides a modulated stream of ions which can be from the source that is inherently modulated, or a continuous source that is subject to some modulation or gating technique. The ions are then delivered as a pulse or a series of pulses of ions into a pressurized reaction cell, in which reaction and/or collision with gas in the cell occurs. The ions are then passed from the pressurized cell into a mass analyzer for detection. The mass analyzer, ion detector or ion induced signal processing system are operated in such a manner that only ions that arrive at the detector in a period of time set relatively to the time of release of pulses of ions are used for analysis. It has been found that by careful selection of this period, enhanced specificity can be achieved and the effect of interference ions can be reduced.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 July 2001 (19.07.2001)

PCT

(10) International Publication Number
WO 01/51917 A3

(51) International Patent Classification[7]: H01J 49/42, 49/40

(21) International Application Number: PCT/CA00/01405

(22) International Filing Date:
24 November 2000 (24.11.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/175,305 10 January 2000 (10.01.2000) US

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report:
4 April 2002

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 01/51917 A3

(54) Title: AN APPARATUS FOR AND METHOD OF DISCRIMINATING AGAINST UNWANTED IONIZED SPECIES IN MASS SPECTROMETRY WITH COLLISION AND REACTION DEVICES

(57) Abstract: A spectrometer apparatus and method provides a modulated stream of ions which can be from the source that is inherently modulated, or a continuous source that is subject to some modulation or gating technique. The ions are then delivered as a pulse or a series of pulses of ions into a pressurized reaction cell, in which reaction and/or collision with gas in the cell occurs. The ions are then passed from the pressurized cell into a mass analyzer for detection. The mass analyzer, ion detector or ion induced signal processing system are operated in such a manner that only ions that arrive at the detector in a period of time set relatively to the time of release of pulses of ions are used for analysis. It has been found that by careful selection of this period, enhanced specificity can be achieved and the effect of interference ions can be reduced.

Title: AN APPARATUS FOR AND METHOD OF DISCRIMINATING AGAINST UNWANTED IONIZED SPECIES IN MASS SPECTROMETRY WITH COLLISION AND REACTION DEVICES

FIELD OF THE INVENTION

This invention relates to an apparatus for and a method of detecting ions of interest in a mass spectrometry system while discriminating against ions unwanted for detection, in particular, isobaric interference ions.

BACKGROUND OF THE INVENTION

Pressurized ion transmission devices and collision cells are widely used in current mass spectrometry for collision induced dissociation (CID) of polyatomic ions, for reactive removal of unwanted species from the ion beam and for collisional and spatial focusing of an ion beam. For CID, the number of collisions can range from 1 to 10^6 (McLuckey, S. A., Principles of Collisional Activation in Analytical Mass Spectrometry, *Journal of American Society for Mass Spectrometry*, 1992, **3**, 599-614). For ion-molecule reactive removal of unwanted species, the efficiency is exponentially dependant on the number of collisions (Tanner, S.D., Baranov, V.I., A Dynamic reaction cell for Inductively Coupled Plasma Mass Spectrometry (ICP-DRC-MS). Part 2. Reduction of Interferences Produced Within the Cell, *Journal of American Society for Mass Spectrometry*, 1999, **10**, 1083). Collisional focusing, first described for linear RF pressurized devices by Douglas and French (Douglas, D.J., French, J.B., Collisional Focusing Effects in Radio Frequency Quadrupoles, *Journal of American Society for Mass Spectrometry*, 1992, **3**, 398) requires multiple collisions for the initial kinetic energy of the ions to be damped. Thus, for all the different functions, the preferred way of using pressurized ion transmission devices and collision cells in analytical mass spectrometry is to ensure that there are multiple collisions. A high number of collisions necessarily means that, not only the primary particles, but also the products of the collisions experience multiple subsequent collisions with target gas particles or other product particles. Those sequential multiple collisions can give rise to additional isobaric interference ions (the difference in m/z of which from the ions of interest is

beyond the resolving power of the mass spectrometer), produced in the cell by sequential reactive collisions. For CID cells, the dissociation of precursor ions in the cell can produce interferences to the analyte ions of interest, thus preventing use of collisional focusing in applications where no dissociation is required. An additional problem in pressurized cells is that, when ion kinetic energy is damped and the ions are cooled to nearly thermal translational energy, adducts and clusters can be formed in the cell, causing isobaric interferences.

One very effective way of discriminating against the new interfering species formed in a pressurized radio frequency multipole device, is operating it in a band pass mode, with the unwanted precursor sample ions and products of sequential reactions ejected from the cell by means of resolving RF and DC potentials applied to the rods, as described by Tanner and Baranov in PCT Patent Application No WO9856030A1. When the device is operated in such mode, only the ions of a selected m/z range are stable in the cell, all other ions including sample ions that are not measured being ejected. Most of the intermediate products are unstable in the cell so that the sequential reactive collisions chemistry is intercepted at the very first steps of the reaction chain, and in-cell production of interferences is suppressed.

In such a bandpass reaction cell, when the m/z of the analyte to be measured by the downstream quadrupole mass analyzer is changed, the band pass m/z range is changed in concert with the mass analyzer. This way for every m/z the sequential reaction chemistry in the cell is intercepted and production of new isobaric interferences is suppressed. The bandpass method is very efficient and does not affect duty cycle if a scanning analyzer is used downstream of pressurized cell, as such scanning analyzer is a m/z bandpass filter itself.

However, if the downstream analyzer is a simultaneous mass analyzer, for example a Time-of-Flight (TOF), Mattauch-Herzog with array detector or multi-collector magnetic sector analyzer, the bandpass interference reduction in the cell limits the mass range of the ions detected simultaneously by such analyzer. Therefore, this converts a simultaneous

analyzer into a sequential analyzer, diminishing the advantages of simultaneous detection.

Therefore, it is an object of the invention to provide an apparatus for and a method of discriminating between desired analyte ions and unwanted ions in a pressurized ion transmission device or a collision cell, which would allow transmission of sample ions of all masses.

For the bandpass rejection of interference ions, newly created in the cell, the bandpass should be sufficiently well defined so that the ions that potentially can form new interference ions via sequential ion-molecular gas-phase chemistry, would be unstable and quickly ejected from the cell. Among the RF multipole devices which are used as collision and reaction cells for mass spectrometry, the quadrupole has better defined boundaries of the stability region and provides the most suitable bandpass. The higher order multipoles, on the other hand, although not effective in providing a narrow bandpass, generally have larger acceptance ellipse and better transmission efficiency than the quadrupole. Widening the bandpass of a quadrupole cell improves transmission at the expense of poorer or lesser rejection of unwanted ions. The use of multipoles of higher order than a quadrupole as near-thermalized reaction cells is limited as they have less suitable bandpass and less effective means for intercepting the sequential reactive collisions that produce isobaric interferences. Therefore another, less effective way of discriminating against the ions produced in the pressurized cell must be used. For a non-thermal reaction multipole cell, the analyte ions which enter the cell, as described first by Rowan and Houk in 1989 [Rowan, J. T., Houk, R. S. Attenuation of Polyatomic Ion Interferences in Inductively Coupled Mass Spectrometry by Gas-Phase Collisions, *Applied Spectroscopy*, 1989,**43**,976], can retain some of their initial kinetic energy. A potential barrier placed downstream of the cell can allow some resolution of the analyte ions from the product ions, which do not have the residue of the initial kinetic energy the analyte ions have. This method can only work if the number of collisions the analyte ions experience is low, otherwise collisional energy damping will remove the difference in the energy distribution between the analyte ions and the product ions. As the efficiency of reactive removal of isobaric interferences depends on the

number of collisions, a compromise is required between the efficiency of interference removal and energy discrimination against product ions. Also, the advantage of collisional energy and spatial focusing is not obtained with a low number of collisions.

Thus, it is a further purpose or object of the present invention to provide an apparatus for and a method of discriminating against the unwanted ions produced in the pressurized device, which is not based on energy resolution and which would allow a high number of collisions to be used in the cell to ensure high reaction efficiency, collisional focusing or multi-collisional activation.

If the cell is near-thermal, none of the bandpass or energy discrimination methods can discriminate against the ions produced in the cell if they are identical in m/z and/or energy to the analyte ions. Such additional analyte ions can be produced by ion sputtering from the surface of the electrodes forming the cell, by ionization of the gas phase impurities in the cell or by collision induced dissociation of the sample ions. Thus it is yet another purpose or object of the present invention to provide a device and a method of discrimination against ions produced in the cells that are identical in m/z and/or energy to the analyte ions.

In a thermalized reaction cell, the ion-molecule reaction chemistry is predetermined by well-defined thermochemistry. If the processes are adiabatic, that is if there is no external supply of energy to the reaction participants, only thermodynamically favorable reactions with $\Delta_r H<0$ can take place, where $\Delta_r H$ is the enthalpy of reaction. A simple comparison of the first ionization potentials of the reaction participants can often give enough information on the probability of a particular reaction. If the reaction gas has a first ionization potential which is higher than that of the analyte but lower than the first ionization potential of the interfering ion, the reaction with the interfering ion will occur and therefore the interference removal by reaction will be effective. For many isobaric interferences in ICP MS it is easy to select a reaction gas as most of the interfering ions are argon-containing species that have high first ionization potential. However some polyatomic interfering ions can have a sufficiently low first ionization potential, so that the selection of a reaction pathway and

reaction gas is not straight forward. Some other polyatomic interference ions may have a bond strength sufficiently high so that their collision-induced dissociation requires the ion beam to be accelerated to a very high kinetic energy, thus being not very practical. Therefore it is a further goal of the present invention to provide a device and a method of discriminating against the isobaric interferences in the pressurized cell that can not be efficiently removed by ion-molecular reactions or collision-induced dissociation.

SUMMARY OF THE INVENTION

The basic concept developed by the present inventors is to separate, temporally, the sample ions that are to be detected from interference ions that are not to be detected. The ion beam extracted from the ion source, comprising sample ions and interference ions, is introduced into a pressurized cell in a pulsed or modulated manner, or any other time dependent manner, such that the ion beam current density or number density varies in time. At the exit of the pressurized cell, the signal produced by the ions to be detected has a different time dependence than the signal caused by the original interference ions from the ion source or the interference ions generated in the cell, both of which are not desirable for detection. The inventors have discovered that, if the detection is performed in a time-dependent manner, then discrimination between the desired sample ions and the interference ions can be effected.

In accordance with a first aspect of the present invention, there is provided a spectrometer apparatus comprising:

an ion generation means for generating a modulated stream of ions;

a pressurized cell for receiving ions from the modulated stream of ions generation means and including a reaction or collision gas whereby ions collide and/or react with the gas;

a mass analyzer and a detector for receiving ions from the pressurized reaction cell and for mass analyzing the ions; and

a control unit connected to the ion generation means and at least one of the mass analyzer and the detector, for controlling release of ions by

the ion generation means and for synchronizing detection of ions by the mass analyzer and the detector in a desired time period set relative to the release of ions by the ion generation means.

The ion induced signal detection and processing means may provide simply for timing of ion detection relative to the release of the pulse(s). Alternatively, all ions can be detected, and the ion signal detection and processing means then causes that only ion in a desired time period relative to the release of each pulse are used for spectrometry analysis.

Preferably, the ion generation means includes an ion gating means between the ion generation means and the pressurized reaction cell, and the control unit then includes a waveform generator connected to the ion gating means, for generating a series of pulses of ions.

The ion generation means can include an ion source operated in a pulsed manner to produce a series of pulses of ions, or alternatively a sample introduction system operated in a pulsed manner to produce a series of pulses of ions.

Preferably, the apparatus includes a time resolved detection means connected to the ion generation means and to at least one of the mass analyzer and the detector.

An axial field generation means can be provided, connected to the pressurized cell, for generating an axial field along the pressurized cell, for accelerating or decelerating ions.

More preferably, the ion generation means can include a sample introduction system, an ion beam forming and modulation means, and an interface provided between the sample introduction system and the ion beam forming and modulation means, for maintaining a pressure differential between the sample introduction system and the ion beam forming and modulation means, while permitting passage of ions through to the ion beam forming and modulation means.

The mass spectrometer can comprise a scanning mass spectrometer, for example a quadrupole mass filter or a mass analyzer including a magnetic sector, and wherein the detector is provided separately and is connected to the time resolved detection means.

Alternatively the mass analyzer and detector comprise a time-of-flight mass analyzer or other instrument capable of scanning and detecting a wide range of masses.

In accordance with another aspect of the present invention, there is provided a method of mass analyzing a stream of ions in a mass spectrometer apparatus, the method comprising:

(1) generating a stream of ions comprising desired analyte;

(2) providing stream of ions as a discrete pulse or discrete pulses of ions;

(3) passing each pulse of ions through a pressurized cell, including a reaction or collision gas whereby ions collide and/or react with the gas in the pressurized cell, wherein interference ions may be generated in the pressurized cell or may be present in the original stream of ions in step (1);

(4) mass analyzing and detecting ions that have passed through the reaction cell; and

(5) synchronizing detection of ions in step (4) with release of pulses in step (3), whereby ions are only detected in a time period set relative to the passage of each pulse.

For step (2), the method can include providing a continuous stream and controlling the ion stream with an ion gating means and controlling actuation of the ion gating means by a modulating waveform generator to form pulses of ions.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1 is a schematic diagram of a spectrometer apparatus in accordance with the present invention;

Figure 2 is a graph showing variation of an electric signal detected by a detector against time for two different samples, and also showing variation of a voltage applied to a lens;

Figure 3 is a graph showing the variation of signal to background noise for the data from Figure 2;

Figure 4 is a graph showing variation of the background equivalent concentration as a function of time from the start of a pulse applied to the lens;

Figure 5 is a graph showing variation of intensity detected for isobaric $CaO^+$and Fe^+ ions during different variations of time;

Figure 6a, 6b and 6c show variations of signals detected for isobaric $CaO^+$and Fe^+ ions with different electrical potential gradient along the axis of the pressurized cell.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A spectrometer system or apparatus of the present invention is shown schematically in Figure 1, and has a sample introduction system 1 connected to an inductively-coupled plasma (ICP) ion source 2, in which ions are generated. The ions are generated in a plasma of sustaining gases, and necessarily the plasma will include interference ions and ions to be detected. Other ion sources that operate at atmospheric pressure or at a pressure lower than atmospheric can be utilized in other implementations of the present invention, for example, Laser Ablation, Electrothermal Vaporization, Matrix Assisted Laser Desorption, Atmospheric Pressure Chemical Ionization, Electrospray Ionization, Glow Discharge ion sources.

In one example of the present invention, the ion source is producing ions in a continuous stream and connected by an interface 3 to an ion beam forming and modulation means 4 that operate at a low pressure suitable for electrostatic ion optics operation and comprise a stack of electrostatic ion – optical elements, one of which is shown as lens 9. The ion lens 9 functions in such example as an ion gate, permitting the ions to be transported through it only during a predetermined time and stopping a stream of ions from being transported through during other times, thus producing a modulated stream of ions.

In other embodiments of the present invention, the modulated stream of ions may be produced by appropriate time-dependant operation of the sample introduction system 1 (for example, by means of flow

injection), ion source 2 (for example, by ionization induced by a laser pulse) or interface 3 (for example, by using a vacuum shutter gate to interrupt the stream of ions). The main distinguishing feature of the present invention is that the stream of ions acquired a controlled time dependency of the ion current or ion density before being introduced into the pressurized cell 5. This controlled time dependency, as said above, can be acquired in the sample introduction system 1, the ion source 2, the interface 3 or the ion beam forming and modulation means 4, those modules thus carrying a common functionality of the means for generating a modulated stream of ions 15, shown by the dotted box on the Fig.1, and referred to in this specification as an ion generation means.

In known manner, the cell 5 can comprise a quadrupole rod set provided with a suitable reaction or collision gas for reactive removal of interferences, collisional focusing or collision induced dissociation. It is important to realize that the interference ions can be produced in the cell, not only in an ion source like ICP. So if the cell is used as a collision cell, i.e. for collision induced dissociation or collisional focusing, the interferences may be produced and need to be discriminated against. The pressurized cell 5 is connected to a mass analyzer 6, which can be for example, a scanning mass analyzer such as a quadrupole mass filter, a magnetic sector analyzer or an ion trap. This selects ions of a particular m/z ratio, and these ions are then passed to an ion detector 7 for detection.

It will also be appreciated that the mass analyzer 6 and detector 7 could be replaced by some other mass analysis instrument, for example a time-of-flight (TOF) or some other device capable of detecting all ions of a desired range of mass simultaneously or quasi-simultaneously as opposed to sequentially.

As noted above, with such a device, providing any sort of ions detected at a particular bandpass setting. To cover a wider mass range, the analysis would need to be repeated at a different bandpass setting, thus implementing sequential measurements and diminishing the advantages of a simultaneous analyzer.

In known manner, the different sections of the instrument would be provided with power supplies for RF and DC signals as required, the

pressurized cell 5 would be provided with a gas supply, and appropriate pumps would be provided to maintain the different sections at the desired pressures. By way of example, an axial field generating means 11 for the pressurized cell 5 is indicated.

In accordance with a given example of the present invention, a modulating waveform generator 10 is connected to the lens 9, for purposes detailed below. This generator 10 is connected to a time resolved detection means 8, which is connected to the detector 7 as indicated.

This detection means 8 ensures that only ions in a set time period are detected. For this purpose an ion induced signal detection and processing means then ensures that, for spectrometric analysis, only signals from a desired time period relative to the release of each pulse are used. The time detection means 8 forms a control unit.

In use of a given example a sequence of ion packets each of predetermined duration dt , is formed with a predetermined frequency f in the ion beam forming and modulation means 4 by supplying a time-dependent voltage of an appropriate waveform from the modulating waveform generator 10 to lens 9. The ion packets are then introduced into the pressurized cell 5 where the ion packets propagate and where new interference ions unwanted for detection may be generated.

In this preferred embodiment, a linear RF quadrupole with an axial field from the axial field generation means 11 is used as a pressurized cell 5, although in other embodiments other arrangements can be implemented. During the propagation through the pressurized cell 5, the ion packets are transformed in shape and duration, the properties of which transformation are made clear by the examples which follow.

After propagation through the cell 5, the sample ions to be measured, the accompanying interference ions from the ion source 1 and new interferences that might be generated in the pressurized cell 5 enter the mass analyzer 6. For the experiments detailed below, a quadrupole mass filter was used but any other analyzer such as magnetic sector, time-of-flight, ion trap or ICR mass analyzer can be used, i.e. it is not necessary to use a scanning-type analyzer. The mass analyzer 6 disperses or filters ions in accordance to their m/z values, and the detector 7 converts ion current

into electric signal that is then detected by the time resolved detection means 8.

Reference will now be made to Figure 2, where there is shown a typical example of measurements performed with the apparatus just described. The lens 9 is supplied with a voltage waveform 12 shown at the top of Figure 2, and whose value is indicated on the right hand scale. Signals measured by the time resolved detection means 8 for the sample of K at a concentration of 100 ng/mL and for a blank sample were as shown by lines 13 and 14 respectively, with the number of ions detected indicated on the left hand side (note that the left hand and horizontal scales are log scales, while the right hand scale for the lens voltage is a linear scale). The time resolved detection means 8 was operated in a pulse-counting mode, and the pulses produced by ions at the ion detector 7 were integrated in 5120 time-locked channels, each of 20.48 microseconds width, thus producing a record of 104.86 ms long. The presented data is an integral of 500 records collected consecutively but summed in a channel-by-channel manner, so that the given on figure 2 signals represent 5120 integrated time-locked channels. The mass analyzer 4 was set to transmit ions with m/z=39 and reject all other ions. The pulse duration dt =0.1 ms and pulses were supplied by the lens 9 at a frequency f =10 Hz. During a pulse the potential on the lens was set to 4 V that was approximately optimal for transmission of ions of m/z of about 40 from the plasma. Between the pulses, the potential of the lens 9 was kept at +20 V so that none of the ions extracted from plasma could enter the pressurized cell 5. The lens 9 thus acts as an ion gate which is open for the duration of the pulse dt and closed for the rest of the period of the waveform applied, that is for duration $t=1/f-dt$.

During a pulse, ions extracted from the plasma include analyte ($^{39}K^+$) and dominant plasma ions O^+, Ar^+ and ArH^+ and these ions entered the cell 5, which was pressurized with NH_3 reaction gas used for reactive removal of the Ar^+ and ArH^+ ions. In this experiment, the pressurized cell 5, which was contaminated by K and was operated under conditions known to produce inside the cell a relatively high amount of $^{39}K^+$ions and other ions at m/z=39, by keeping one of the elements forming the pressurized cell 5, the entrance aperture (not shown), at – 50 V. For a blank sample, most of

the ions detected at m/z=39 are those produced in the cell. When the sample of K is measured under identical conditions, same number of interference ions generated in the cell is detected together with the ions $^{39}K^{+}$ from the sample.

As clearly seen from the Figure 2, the base lines of the signals measured for blank sample and for K sample are similar and contain 5860 ions and 5270 ions respectively from 1.5 ms to 100 ms of the recorded scan. The segment of the scan from 0 to 1.5 ms contains different number of 46400 ions for K sample and 435 ions for the blank sample (all numbers are integrals of 500 records). That is, the interference ions produced in the cell, after the packet of ions extracted from plasma are introduced in the cell, are more evenly distributed in time than the ions of sample to be detected. It is obvious that during the first approximately 1.5 ms after the lens pulse, the signal-to-background ratio (Figure 3) and background equivalent concentration (Figure 4) are beneficial for determination of K in the sample. Therefore, if the time resolved detection means 8 detects ions only during the period of the first several milliseconds after the lens pulse, which can be arranged in several different ways, for example by deflecting the ions from the detector at all times except this period, or by setting a data acquisition system time window, the limit of detection of K in the sample is improved.

Another example of use of the preferred embodiment of Figure 1, is shown in Figures 5 and 6. This shows temporal resolving of ions of $^{56}Fe^{+}$ in presence of interfering ions of $^{40}Ca^{16}O^{+}$ formed in the plasma. In a first case, the axial field generation means 11 was switched off and the ions were introduced into the pressurized cell 5 at a relatively high kinetic energy, the signal caused by the ions of $^{40}Ca^{16}O^{+}$ for a sample containing 1000 ppm of Ca, is less broadened in time than the signal produced by the ions of $^{56}Fe^{+}$ for a sample of Fe at 20 ppm (Figure 5). Again Figure 5 shows levels detected after a pulse of ions is released into the pressurized cell 5, and here the time scale is a linear scale. Therefore, lower limits of detection of Fe in the presence of Ca in the sample could be achieved if the detection means 8 detect ions only during a time period, say, from 1 ms to 3 ms after the lens pulse. It is evident from Figure 5 that background equivalent concentration is lower during that time.

In another example, the axial field generation means 11 was operative to produce an axial electrostatic field along the axis of the pressurized cell 5 and the ions were introduced in the cell at a relatively low kinetic energy. Figures 6a, 6b and 6c indicate different potentials along the length of the pressurized collision cell 5.

Depending on the potential difference generated along the cell, the signals produced by isobaric ions of $^{56}Fe^{+}$ and $^{40}Ca^{16}O^{+}$ can either overlap in time (Figure 6a) or be partially resolved (Figure 6c) with Figure 6b indicating a lower level of resolution. Detection of $^{56}Fe^{+}$in the presence of 1000 ppm of Ca in the sample during the first 200 microseconds after the start of the lens pulse, for the case of 8 V potential difference along the cell, can give better limits of detection than if the detection was done continuously.

It will be clear to persons skilled in this technology that other embodiments of the invention are possible where the ion source produces ions in a pulsed manner such that further modulation of the ion beam extracted from the ion source is not required.

CLAIMS:

1. A spectrometer apparatus comprising:

an ion generation means for generating a modulated stream of ions;

a pressurized reaction cell for receiving ions from the modulated stream of ions generation means and including a reaction or collision gas where ions collide and/or react with the gas;

a mass analyzer and an ion detector for receiving ions from the pressurized reaction cell and for mass analyzing the ions;

an ion induced signal detection and processing means; and

a control unit connected to the said ion generation and to at least one of the said mass analyzer, the ion detector and the ion induced signals detection and processing means, wherein said control unit controls the release of ions by the ion generation means and synchronizes at least one of ion detection and processing of ion induced signals, whereby only ions arriving at a detector in a desired time period set relative to the release of ions by the ion generation means, are used for spectrometry analysis.

2. A spectrometer apparatus as claimed in claim 1, wherein the ion generation means includes an ion gating means and a waveform generator connected to the ion gating means, for generating a pulse of ions or a series of pulses of ions.

3. A spectrometer apparatus as claimed in claim 1, wherein the ion generation means includes an ion source operated in a pulsed manner to produce a pulse of ions or a series of pulses of ions.

4. A spectrometer apparatus as claimed in claim 1, wherein the ion generation means includes a sample introduction system operated in a pulsed manner to produce a pulse of ions or a series of pulses of ions.

5. A spectrometer apparatus as claimed in claim 1, wherein the control unit includes a time resolved detection means connected to the ion generation means and to at least one of the detector and mass analyzer.

6. A spectrometer apparatus as claimed in claim 1, 2, 3, 4 or 5, including axial field generation means connected to the pressurized cell, for generating an axial field along the pressurized cell, for accelerating or decelerating ions.

7. A spectrometer apparatus as claimed in claim 1, wherein the ion generation means comprises an inductively coupled plasma ion source.

8. A spectrometer apparatus as claimed in claim 7, wherein the mass spectrometer comprises a scanning mass analyzer and wherein the detector is provided separately and is connected to the time resolved detection means.

9. A spectrometer apparatus as claimed in claim 8, wherein the mass analyzer includes a quadrupole mass filter.

10. A spectrometer apparatus as claimed in claim 8, wherein the mass analyzer includes a magnetic sector.

11. A spectrometer apparatus as claimed in claim 8, wherein the mass analyzer includes an ion trap.

12. A spectrometer apparatus as claimed in claim 8, wherein the mass analyzer and detector comprise a time-of-flight mass analyzer.

13. A spectrometer apparatus as claimed in claim 8, which includes providing a mass analyzer with a vacuum region and the ion generation means with an interface connected to the vacuum region, the interface being operable in a pulsed manner to generate a stream of ion pulses.

14. A method of mass analyzing a stream of ions in a mass spectrometer apparatus, the method comprising :

(1) generating a stream of ions comprising desired analyte ions;

(2) providing the stream of ions as a discrete pulse or discrete pulses of ions;

(3) passing each pulse of ions through a pressurized cell, including a reaction or collision gas whereby ions collide and/or react with the gas in the pressurized cell, wherein interference ions may be generated in the pressurized well or may be present in the original stream of ions in step (1);

(4) mass analyzing and detecting ions that have passed through the reaction cell; and

(5) synchronizing detection of ions in step (4) with release of pulses in step (3), whereby ions are only detected in a time period set relative to the release of each pulse.

15. A method as claimed in claim 14, which includes providing the ions from the ion source operated in a pulsed manner.

16. A method as claimed in claim 14, which includes providing the ions from a sample introduction system operated in a pulsed manner.

17. A method as claimed in claim 14, which includes providing the ions into the vacuum region of a mass spectrometer apparatus by passing the stream of ions through an interface operated in a pulsed manner.

18. A method as claimed in claim 14, which includes, for step (2), providing a continuous ion stream and controlling the ion stream with an ion gating means by a modulating waveform generator to form pulses of ions.

19. A method as claimed in claim 14, 15, 16, 17 or 18, which includes providing an axial field along the pressurized cell to accelerate the ions.

20. A method as claimed in claim 14, which includes in step (1) generating the ions from an inductively coupled plasma ion source.

21. A method as claimed in claim 14, which includes analyzing the ions in step (4) with a quadrupole mass filter.

22. A method as claimed in claim 14, which includes analyzing the ions in step (4) with analyzer that include magnetic sector.

23. A method as claimed in claim 14, which includes analyzing the ions in step (4) with a time-of-flight analyzer.

24. A method as claimed in claim 14, which includes analyzing the ions in step (4) with an ion trap analyzer.

25. A method as claimed in claim 21, 22, 23 or 24, which includes passing the ions trough the pressurized cell in step (3) which cell comprises a quadrupole rod set.

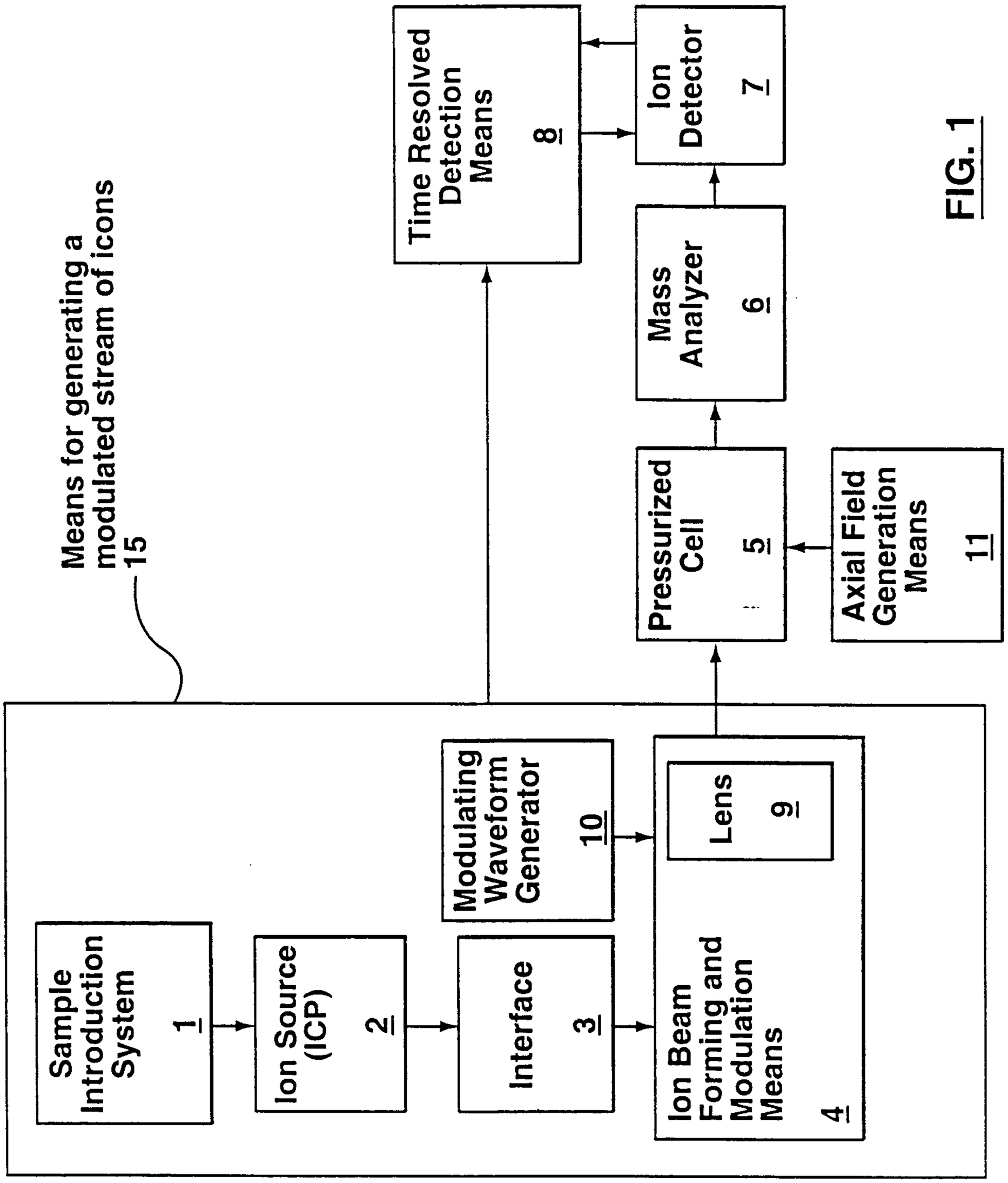

Means for generating a modulated stream of icons
15
Sample Introduction System
1
Ion Source (ICP)
2
Interface
3
Ion Beam Forming and Modulation Means
4
Modulating Waveform Generator
10
Lens
9
Pressurized Cell
5
Axial Field Generation Means
11
Mass Analyzer
6
Time Resolved Detection Means
8
Ion Detector
7

FIG. 1

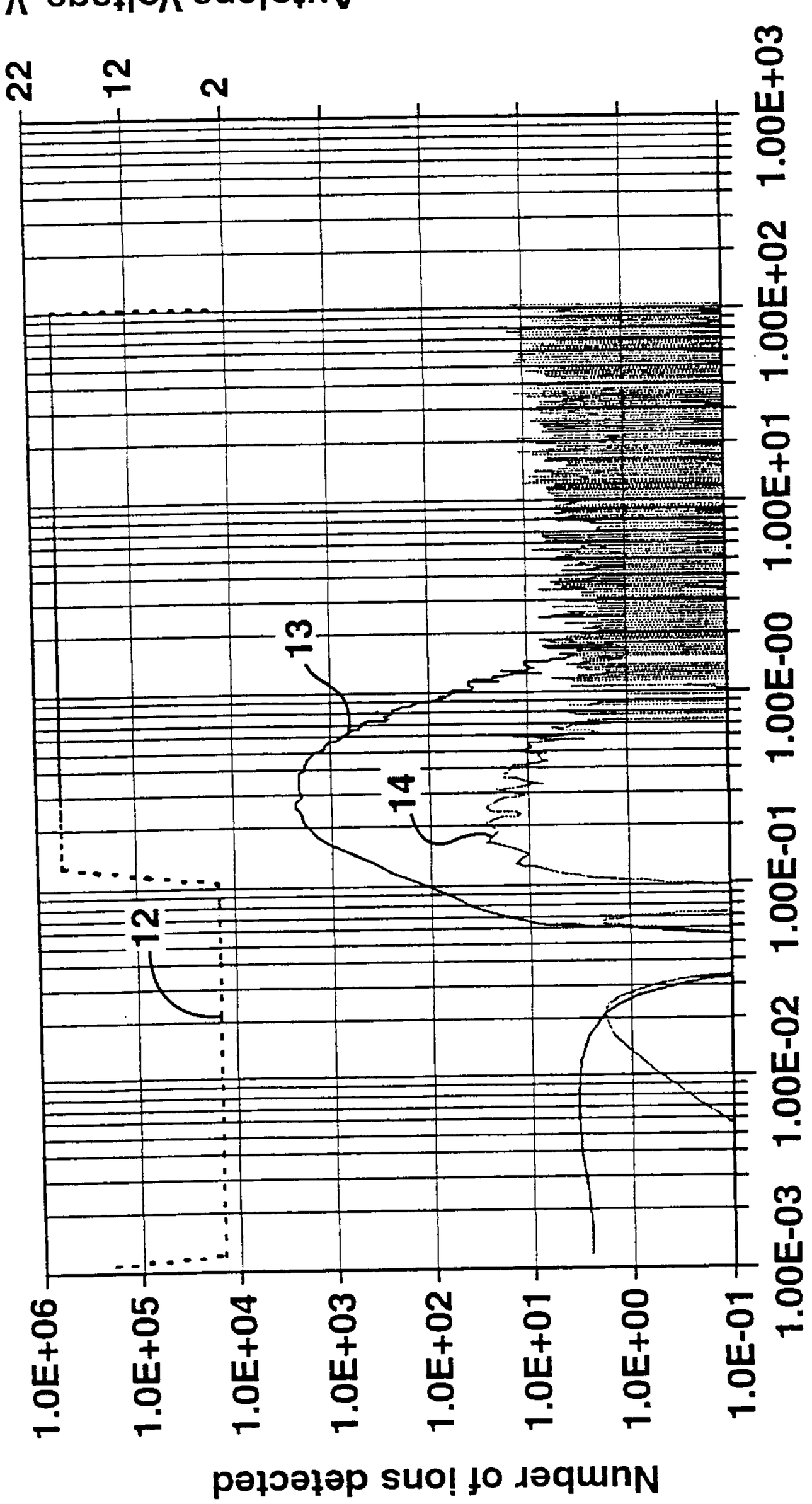

Autoions Voltage, V
22
12
2
13
12
14
1.00E-00
1.00E+01
1.00E+02
1.00E+0
Time, ms
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.00E-03
1.00E-02
1.00E-01
Number of ions detected

FIG. 2

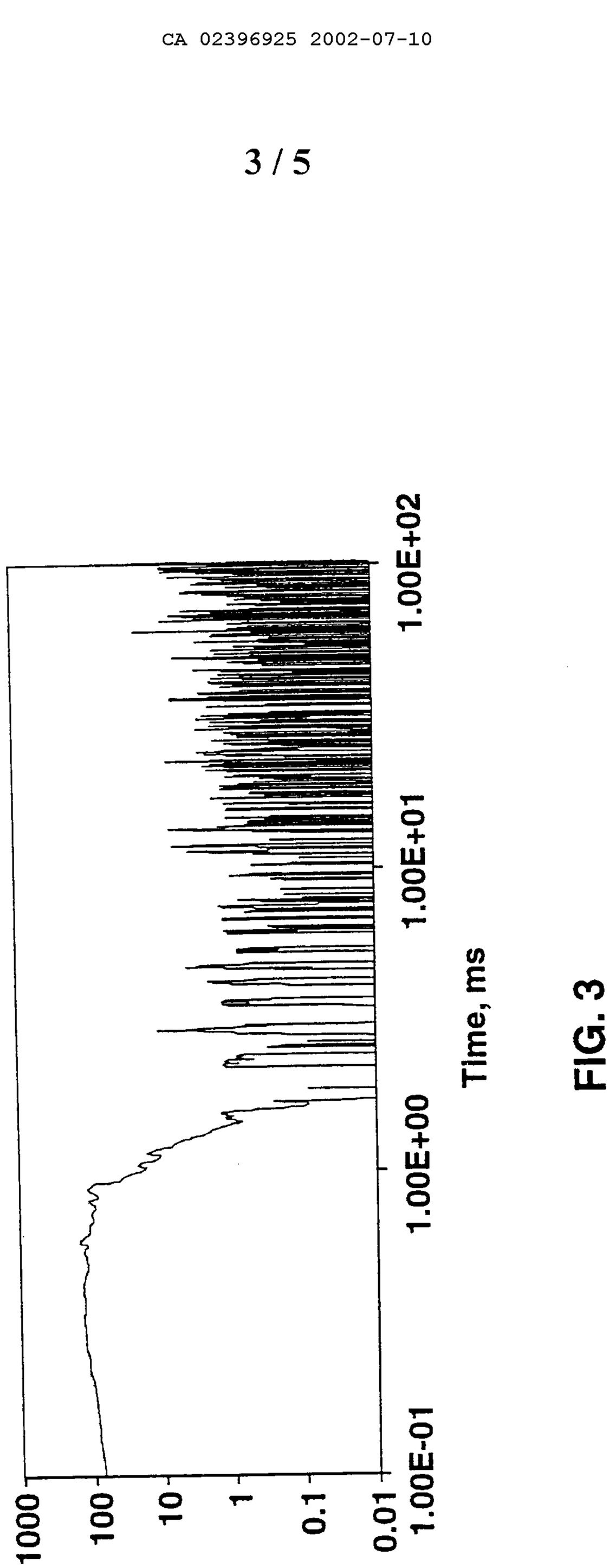

Signal-to-background, ions/ions
1000
100
10
1
0.1
0.01
1.0E-01
1.00E+00
1.00E+01
1.00E+02
Time, ms

FIG. 3

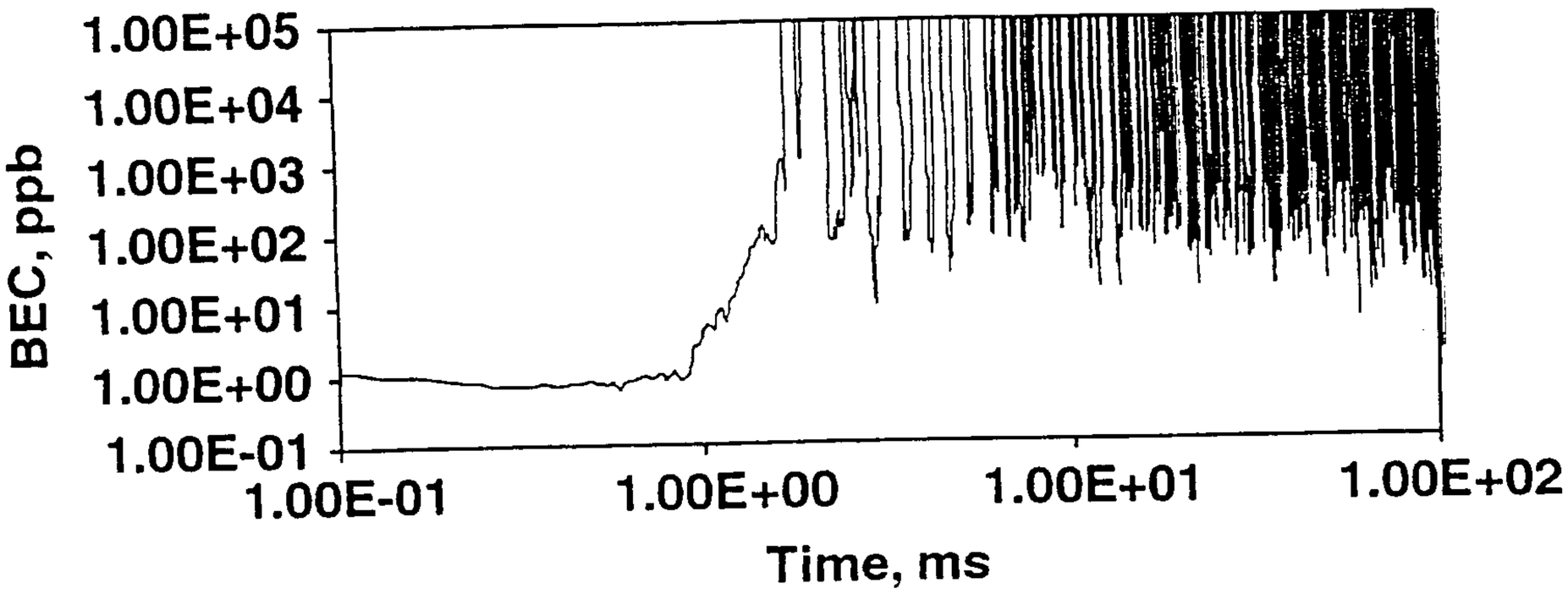

1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
BEC, ppb
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Time, ms

FIG. 4

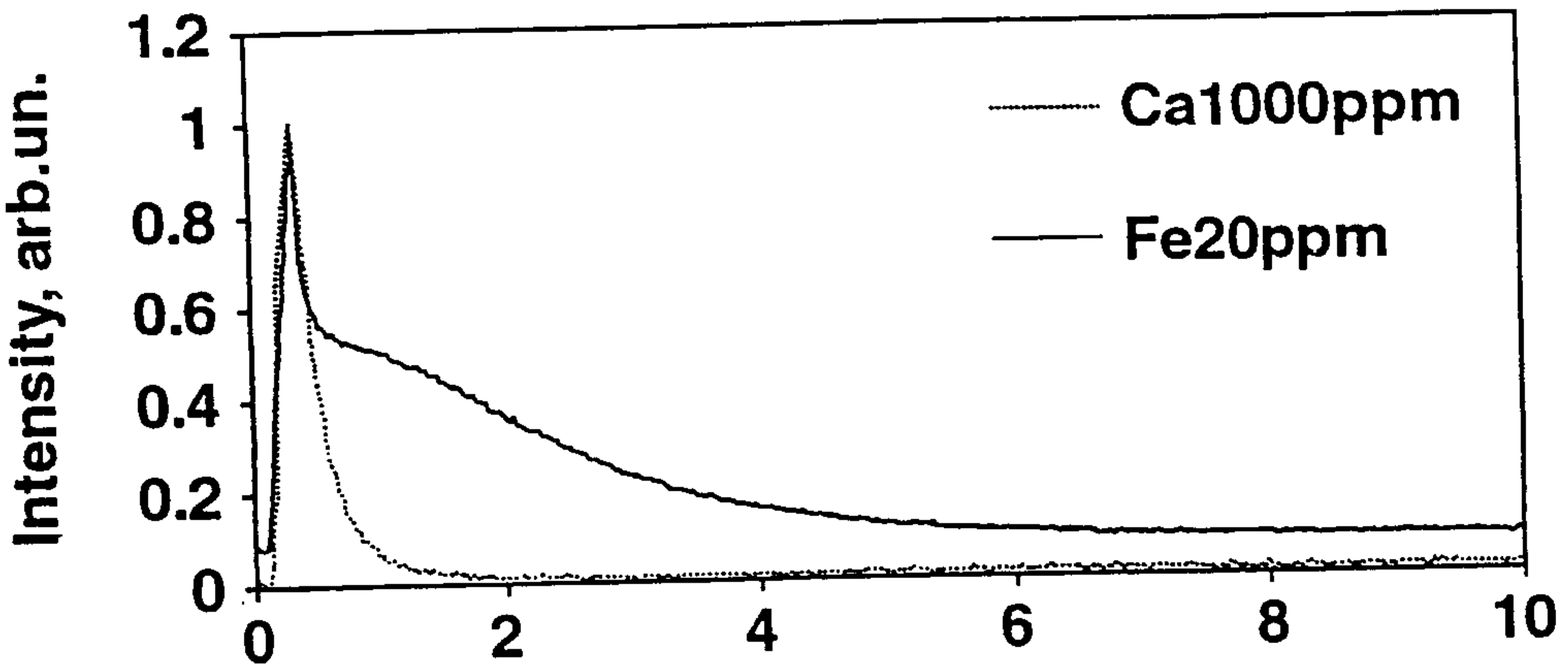
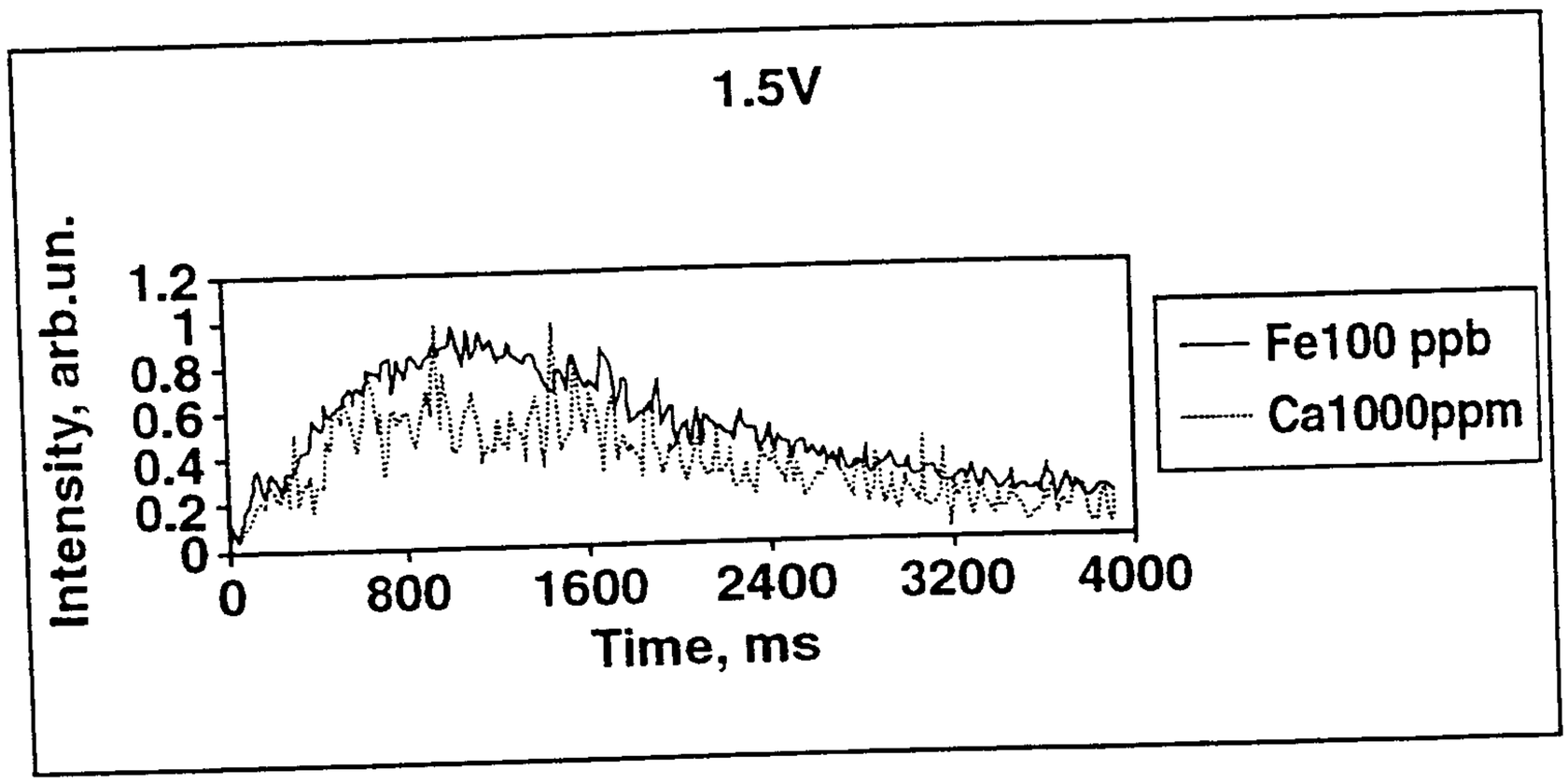
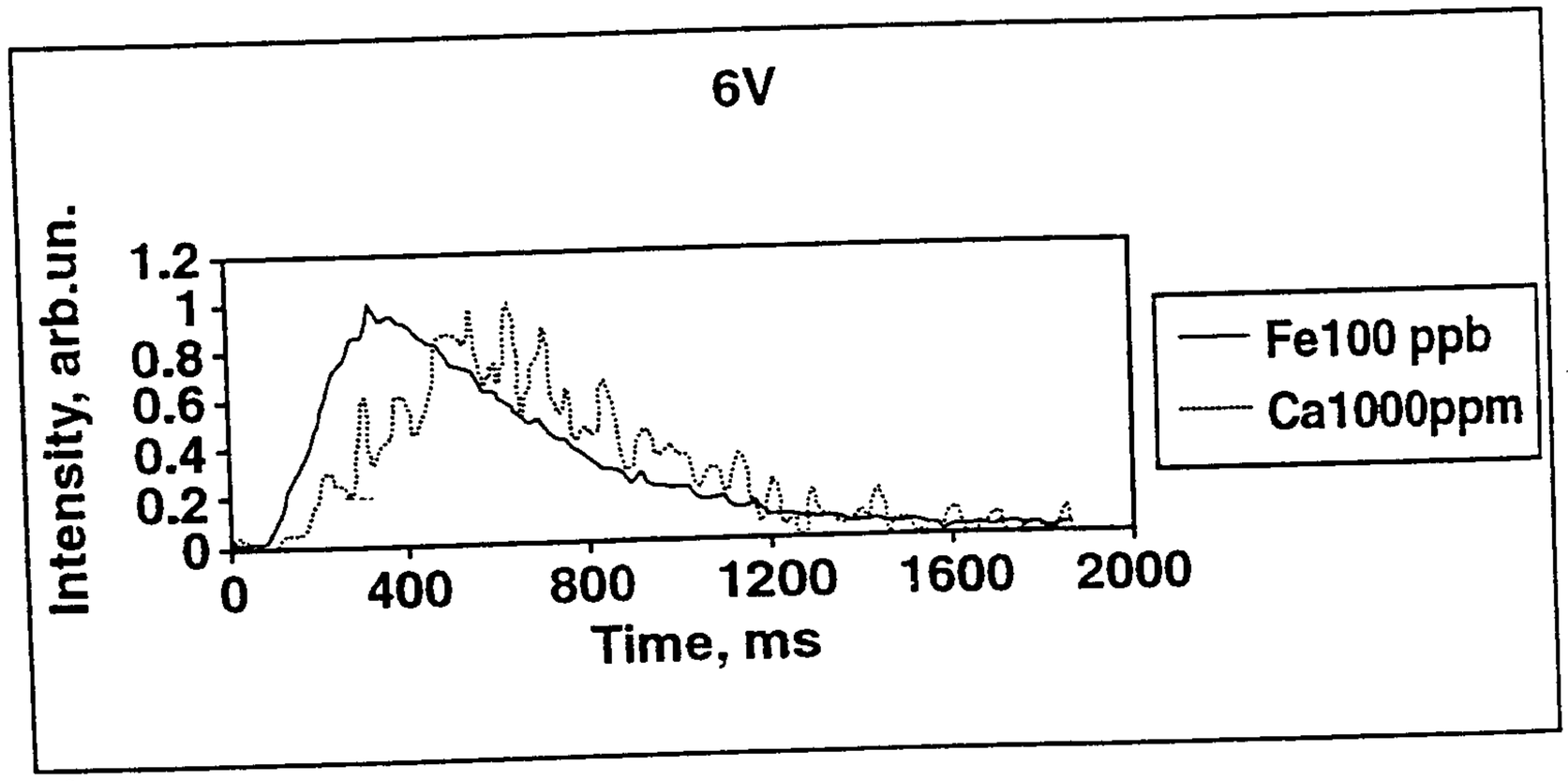

1.2
1
0.8
0.6
0.4
0.2
0
Intensity, arb.un.
Ca1000ppm
Fe20ppm
0
2
4
6
8
10
Time, ms

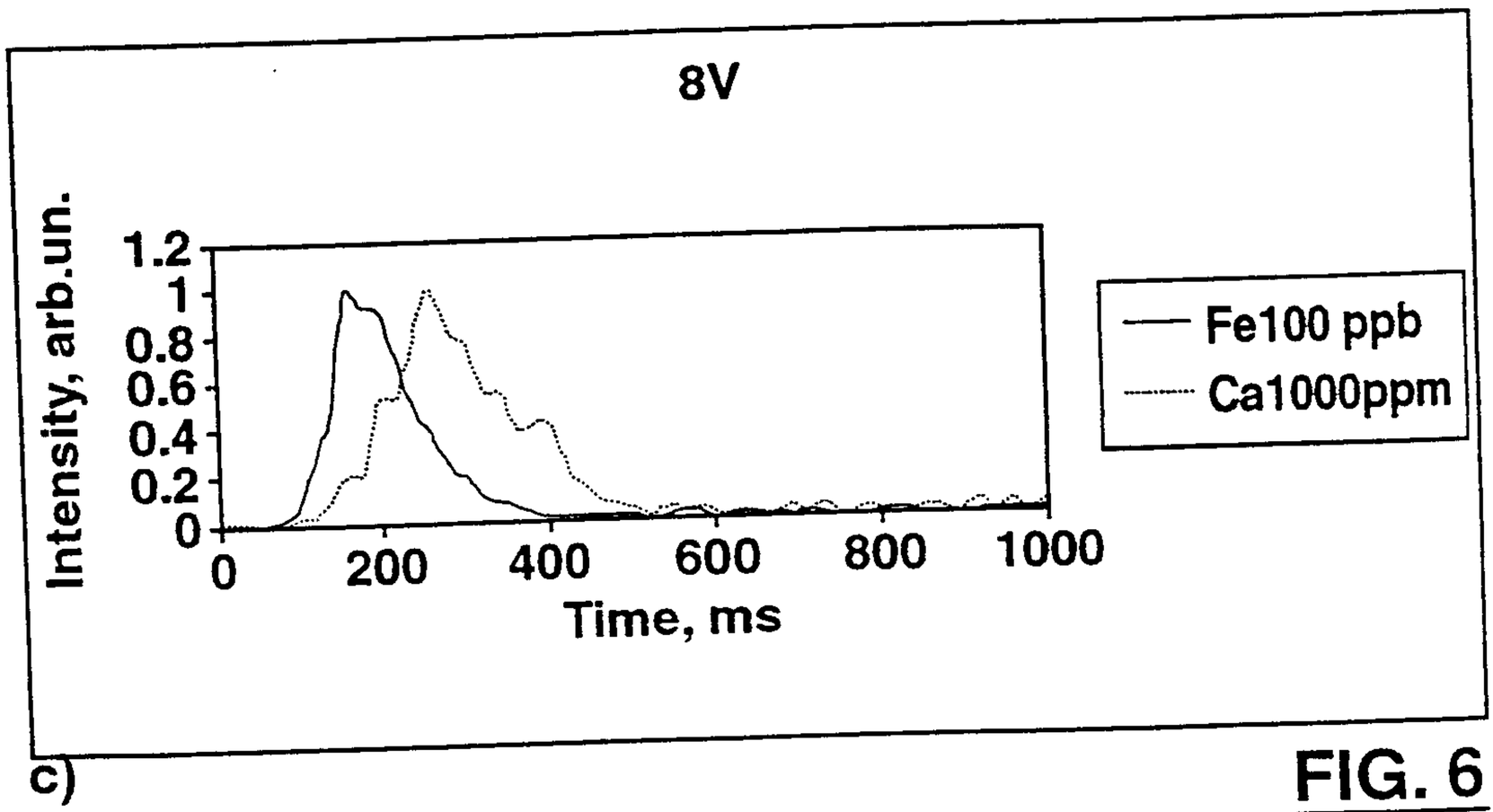
FIG. 5


1.5V
Intensity, arb.un.
1.2
1
0.8
0.6
0.4
0.2
0
0
800
1600
2400
3200
4000
Time, ms
Fe100 ppb
Ca1000ppm

a)


6V
Intensity, arb.un.
1.2
1
0.8
0.6
0.4
0.2
0
0
400
800
1200
1600
2000
Time, ms
Fe100 ppb
Ca1000ppm

b)


8V
Intensity, arb.un.
1.2
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
Time, ms
Fe100 ppb
Ca1000ppm

c)

FIG. 6