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Devices for mass spectrometry on a chip

Synonyms

Mass spectrometer, mass analyser

Definition

A mass spectrometer is a vacuum analytical instrument that uses electric or magnetic fields or a mixture of the two to separate ions based on the ratio of their mass m to their charge q. A distinction is made between mass spectrometers, which produce a serially scanned output, and mass spectrographs, which produce a parallel (and sometimes graphical) output. The mass-to charge ratio is often written as m/z, where $q = ze$, $e = 1.6 \times 10^{-19}$ C is the electronic charge and z is the charge number. The ions are created from analyte molecules by processes that give rise to a characteristic pattern of fragments, in addition to the molecular ion itself, allowing a mass spectrometer to be used for chemical identification, compositional quantification and structural analysis. Performance is characterized in terms of the mass range (defined by the maximum mass $m_{\max}$ that can be measured), the mass resolution (defined as $m/\Delta m$, where Δm is the uncertainty in the mass being measured) and the sensitivity. Applications include analytical chemistry, process and pollution monitoring, forensic science, the detection of drugs, chemical and biochemical weapons, and space exploration. In some cases, high performance is essential, while in others, low cost, small size, and portability are more desirable. Increasingly, key components are being constructed on chip, to allow overall system miniaturization.

Overview

A complete mass spectrometer normally contains an ion source, a mass filter and one or more ion detectors. In addition, the system will require a vacuum chamber, a method of sample introduction, vacuum pumps (usually a roughing pump and a main pump), a vacuum gauge, control electronics and a data acquisition, display and storage system.

A variety of different operating principles can be used for each component. The most common methods of ionization in miniaturised devices are:

- Electron impact ionization, for gaseous analytes
- Electrospray ionization, for liquid analytes

Similarly, the most common variants of miniaturised mass filter are:

- Time-of-flight filters
- Magnetic field and crossed-field filters
- Electrostatic quadrupole filters and quadrupole ion traps

Finally, ion detectors may be single elements or arrays of

- Faraday cup
- Electron multiplier

The main factor dominating the size, weight and the cost of the overall system is the pump set. Pumping requirements are largely determined by the size of the vacuum chamber, which is in turn controlled by the size of the components therein. Consequently, there is a drive to use planar processing or microelectromechanical systems (MEMS) technology to construct miniature ion sources, mass filters and detectors. Other drivers include the use of cold cathode field emission electron sources as low power ion sources (for example, for space applications), nanospray capillaries as low-flow-rate sources for liquid analytes (for example, in drug discovery) and arrayed detectors in high-resolution mass spectrographs.

Because of the reduced ion flight path, miniature mass spectrometers can operate at higher pressures than conventional systems. However, size-scaling laws and limitations on achievable features affect the performance of microfabricated devices. Although many MEMS mass spectrometers now exist, and are producing increasingly realistic data, their designs have not yet reached the sophistication of conventional systems, where cascaded or double-focusing analyzers are common.

Basic Methodology

The operation of all types of mass spectrometer is subject to simple size scaling laws, which become very significant as devices are miniaturized.

- Mean free path

According to the kinetic theory of gases, the mean free path λ in a gas with a molecular collision diameter d at an absolute temperature T and pressure P is:

$$\lambda = kT/(\surd 2\pi d^2 P) \tag{1}$$

Here, $k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant. Since the overall flight path L in a mass spectrometer must be smaller than the mean free path if the ions are to transit successfully, the operating pressure must be:

$$P < kT/(\sqrt{2}\pi d^2 L) \tag{2}$$

This result implies that operating pressures can vary inversely with the dimensions of the system. Assuming the typical value of $d = 3.7 \times 10^{-10}$ m for the collision diameter (for N_2), at $T = 300$ K we obtain $P = 6.8 \times 10^{-1}/L$ N/m^2, where L is in cm. Since the dimensions of microengineered mass spectrometers are typically one or two orders of magnitude smaller than conventional systems, operating pressures can in principle be up to two orders higher. However, the need to avoid discharges often tends to negate this advantage.

- Electron impact ionisation

Electron impact ionization (EI) is primarily suitable for gaseous analytes. In an EI source, electrons are produced by either thermionic emission from a hot filament or by field-induced tunneling from a cold surface. They are accelerated into an ionization region, where they encounter the analyte. At low energies (< 20 eV), there is insufficient energy for ionization. At higher energies (in a broad range near 70 eV), the de Broglie wavelength of the electrons matches the length of typical molecular bonds, and ionization and molecular fragmentation rates are both maximised. At higher energies, the electron wavelength reduces and the ionization efficiency decreases. Typical ionization efficiencies (i.e., the number of ions produced per electron) are extremely low, around 1 in a 1000.

In thermionic emission, the current density J obtained from the electrically heated filament in the presence of an electric field E obeys the modified Richardson-Dushman equation:

$$J = AT^2 \exp\{-(\phi - \Delta\phi)/kT\} \tag{3}$$

Here ϕ is the work function of the filament material, and A is Richardson's constant, given by $A = 4\pi m_e k^2 e/h^3$, where m_e is the electron mass and $h = 6.62 \text{ x } 10^{-34}$ J s is Planck's constant. The field-induced term is $\Delta\phi = (eE/4\pi\varepsilon_0)^{1/2}$, where $\varepsilon_0 = 8.85 \text{ x } 10^{-12}$ F/m is the vacuum permittivity. Because of the exponential variation above, materials such as tungsten that can survive operation at very high temperatures are required. Difficulties in fabrication and thermal management have hindered the development of integrated hot filament sources.

This drawback has led to a focus on cold-cathode sources, which operate by tunelling from a surface in the presence of a strong electric field. The current density obtained is given in this case by the Fowler-Nordheim equation:

$$J = AE^2 \exp(-B\phi^{3/2}/\mathrm{E}) \tag{4}$$

Here A and B are different constants. In this case, the dominant factor is the electric field. Suitable fields can be obtained at voltages of ≈ 100 V from tips with radii of ≈ 1 nm, which can be made by microfabrication. Since $\log_e(J/AE^2\} = -B\phi^{3/2}/E$, a plot of $\log_e(I/V^2)$ versus $1/V$ (where I is the emission current and V is the voltage) should be a straight line with a negative slope. The reduction in operating temperature and the elimination of a heater current makes cold-cathode sources a strong candidate for low-power portable systems.

- Electrospray ionization

Electrospray ionization (ESI) is primarily suitable for liquid analytes. In ESI, a voltage is applied between an electrode and a capillary containing the analyte. Liquid is extracted from the tip and drawn into a Taylor cone, from which large charged droplets are emitted. The droplets are accelerated to supersonic speed, evaporating as they travel. Coulomb repulsion of the charges in the shrinking droplet results in fragmentation to ions when the Rayleigh stability limit is reached. The resulting ions can be multiply charged. In a conventional electrospray system, with capillaries of ≈100 μm internal diameter, flow rates are of the order of 1 μl min^{-1}, and extraction voltages lie in the range 2.5 kV – 4 kV. Flow rates and voltages are reduced in so-called "nanospray systems", based on capillaries having internal diameters down to ≈10 μm. Decreasing the capillary diameter and lowering the flow rate also tends to create ions with higher mass-to-charge ratio, extending the applicability further towards biomolecules.

- Forces

An ion of mass m and charge q travelling with a velocity $\underline{v}$ in an electric field with strength $\underline{E}$ and a magnetic field with flux density $\underline{B}$ experiences a force $\underline{F}$ defined by the Lorentz force law. This equation can be combined with Newton's laws to yield the acceleration $\underline{a}$ as:

$$\underline{F} = q\{\underline{E} + \underline{v} \times \underline{B}\} = m\underline{a} \tag{5}$$

Many combinations of electric and magnetic field are exploited in mass spectrometry.

- Ion velocity

For example, in an electric field E that acts only in the x-direction, we obtain:

$$F = qE = m\, \mathrm{d}^2x/\mathrm{d}t^2 \tag{6}$$

Here t is time, and $E = \mathrm{d}V/\mathrm{d}x$, where $V(x)$ is the potential variation that gives rise to the field. Integrating from zero potential at the origin to V_a at x we obtain the ion velocity v as:

$$1/2\, mv^2 = qV_a \qquad \text{so that} \qquad v = \sqrt{(2qV_a/m)} \tag{7}$$

This result implies that ions accelerated through a common potential will acquire a velocity that varies as the inverse square root of their mass.

- Filtering by time-of-flight

A simple method of constructing a mass spectrometer is based on time-of-flight (TOF), first described by Cameron in 1948. A pulse of ions of mass m entering an analyser of length L at zero time will exit at time τ, given by:

$$\tau = L/v \qquad \text{so that:} \qquad (m/q) = 2V_a\tau^2/L^2 \tag{8}$$

This result implies that the time-of-flight τ is a direct measure of the mass-to-charge ratio m/q. However, the time-scale is non-linear, and flight times reduce linearly with the characteristic dimension L of the system. Consequently, very short ion pulses and fast detector electronics are required in miniaturised TOF-MS.

- Magnetic filtering

An alternative method of filtering is based on the use of a magnetic field. Magnetic mass spectrometers were developed and improved by the fathers of mass spectrometry, Thompson, Aston and Bainbridge, in the early part of the 20th century. An ion with velocity v travelling in a perpendicular magnetic field of flux density B will follow a circular trajectory of radius r, found from a balance between the magnetic and centrifugal forces as:

$$qvB = mv^2/r \qquad \text{so that} \qquad r = (m/q)\,(v/B) \tag{9}$$

This result may be combined with the earlier expression for velocity to obtain:

$$(m/q) = B^2r^2/2V_a \tag{10}$$

These two results imply that a magnetic field will disperse ions into trajectories of different radius, depending on their mass. Greater dispersion can be obtained by reducing the ion energy V_a; however, V_a cannot be reduced arbitrarily, and must typically be significantly larger than the thermal energy of the ion. A small radius (and hence a compact instrument) is only obtained with a powerful magnet. Consequently, magnetic filtering is difficult to scale into the MEMS size domain.

- Crossed field filtering

Consider now the case when an additional electrostatic field E is introduced, perpendicular to both the ion velocity and the magnetic field. This field will generate an additional force, which can compensate for the magnetic force, partially straightenening the ion trajectories in a magnetic mass spectrograph. The two forces can balance exactly if:

$$qvB = qE \qquad \text{so that} \qquad v = E/B \tag{11}$$

In this case, the trajectory is exactly a straight line. An arrangement of crossed fields, with a pair of co-linear apertures allowing only line-of-sight path, will therefore act as a filter (first demonstrated in 1898 by Wien) for ions with the velocity given above. If the exit aperture in a Wien filter is replaced with a detector array, ions will be dispersed across the array so that the device acts as a mass spectrograph. In this case, the mass resolution is:

$$m/\Delta m = EL^2/2V_a\Delta w \tag{12}$$

Here L is the length of the filter and Δw is the spacing of the detector array.

- Quadrupole filtering

Filtering may be carried out in an entirely different way using a method invented by Paul and Steinwedel in 1953 and based on a time-varying hyperbolic electrostatic field. Four parallel electrodes with suitable cross-sections are used to establish the two-dimensional potential $\phi(x, y) = \phi_0 (x^2 - y^2) / 2r_0^2$. Here r_0 is the radius of an inscribed circle that just touches the electrodes, where the potential $\phi = \pm \phi_0/2$. The field will exert forces in both the x- and y-directions on an ion moving in the z-direction. For a singly charged ion, the equations of motion are:

$$m\, \mathrm{d}^2x/\mathrm{d}t^2 = -e\, \partial\phi/\partial x = -e\phi_0 x/r_0^2 \qquad m\, \mathrm{d}^2y/\mathrm{d}t^2 = +e\phi_0 y/r_0^2 \tag{13}$$

When the time variation of the potential is $\phi_0(t) = U - V\cos[\omega(t - t_0)]$, where $\omega = 2\pi f$ is the angular frequency, ωt_0 is the starting phase and U and V are constant potentials, we obtain:

$$\mathrm{d}^2u/\mathrm{d}\zeta^2 + \{a_\mathrm{u} - 2q_\mathrm{u} \cos[2(\zeta - \zeta_0)]\}\, u = 0 \tag{14}$$

Here, the normalised parameters used are $\zeta = \omega t/2$, $\zeta_0 = \omega t_0/2$, $a = 4eU/(m\omega^2 r_0^2)$ and $q = 2eV/(m\omega^2 r_0^2)$, u is x or y, and $a = a_\mathrm{x} = -a_\mathrm{y}$ and $q = q_\mathrm{x} = -q_\mathrm{y}$.

Solution of the equations shows that the nature of the trajectory depends almost entirely on a and q, varying little with the initial conditions ζ_0, $u(0)$ and $u'(0)$ of the ion. There are a several regions on the q-a plane that give rise to stable solutions. The so-called “lower stability region”, most commonly used for mass filtering, is an approximately triangular region, bounded by the loci:

$$\begin{aligned} a_0(q) &= q^2/2 - 7q^4/128 + 29q^6/2304 \;\ldots. \\ b_1(q) &= 1 - q - q^2/8 + q^3/64 - q^4/1536 \;\ldots. \end{aligned} \tag{15}$$

The locus a_0 defines the limit for trajectories that are stable in the y-direction, while b_1 is the limit for trajectories in the x-direction. Between the two, trajectories are stable in both directions. The apex of the stable region lies at $a = 0.237$, $q = 0.706$, so that $a/2q = U/V = 0.168$. In a quadrupole mass spectrometer, U and V are normally ramped together, following a line passing just below the apex of the lower stability region. Stable trajectories are only obtained for a narrow mass range, so that the device acts as a tuneable mass filter. An attractive feature of miniaturisation is that U and V scale with r_0^2, so that decreasing the linear dimension of an instrument by (say) 10 will reduce both potentials 100-fold.

The mass resolution varies as $m/\Delta m \approx n^2/20$, where n is the number of cycles of the RF field experienced by an ion. Ions are normally injected with a constant axial energy V_a. The number of cycles is $n \approx fL/v$, where L is the quadrupole length, so the uncertainty in mass is:

$$\Delta m \approx 40eV_a/(f^2L^2) \tag{16}$$

Thus, the uncertainty in mass increases as the quadrupole is reduced in size. Compensation can be provided, by increasing the frequency, but this in turn requires an increase in voltage.

Quadrupoles are attractive candidates for miniaturisation, since they do not require either a magnetic field or very fast electronics. However, the challenge in miniaturising a quadrupole is generally to achieve a suitably high mechanical precision, since the accuracy of the hyperbolic field determines the ultimate resolution. One important aspect is electrode mounting, which requires precise assembly. Another is the shape of the electrodes. Hyperbolic electrode cross-sections are normally too complex to machine, and are replaced by cylinders, with the ratio of the cylinder radius r_e to r_0 being chosen to give the best approximation to a hyperbolic potential variation.

- Ion trap filtering

The ion trap is a variant of the quadrupole mass spectrometer, which was first described by Paul and Steinwedel in 1960. It consists of a circular hyperbolic electrode, with spherical electrode caps at the top and bottom, and can be conceived as a quadrupole bent round in a circle. The three electrodes correspond to three of the rods of the bent quadrupole, while the fourth (inner) rod is reduced to a vanishingly small point.

As with the quadrupole spectrometer, a potential $+\phi_0$ consisting of both DC and radio frequency AC components is applied to the end caps, while a potential $-\phi_0$ is applied to the ring electrode. Ions of all masses are then trapped by the resulting three-dimensional, time-varying electrostatic field, and follow stable, closed trajectories, that are shaped approximately like the figure "eight".

In a quadrupole, ions are injected continually, and the potentials are adjusted so that only ions of a particular mass can transit successfully. In the ion trap, however, the method of obtaining a mass spectrum is rather different. The different masses are held together inside the trap, and are expelled in sequence by applying a further voltage at a particular resonant frequency to obtain the spectrum. Consequently, the sensitivity of a miniaturized ion trap is limited by the amount of charge that can be stored inside a small volume in the face of charge repulsion effects. A general problem with miniaturisation is therefore loss of sensitivity, but this may be overcome to some extent by using a two-dimensional array of traps. Ion traps are also attractive candidates for miniaturisation. Once again, exactly shaped electrodes are generally too complex to machine, and structures with optimised combinations of cylindrical ring and planar end-cap electrodes are normally used.

Key Research Findings

We now give a few examples of miniaturised mass spectrometer systems, restricting the discussion to cases where planar technology has clearly been employed.

- Ion sources

Most of the results from microfabricated mass filters to date have been obtained from hybrid systems fitted with conventional ion sources, and only limited work appears to have been carried out on planar sources. Consequently, the ideal of a fully integrated chip-based mass spectrometer still appears some way off.

Yoon et al. of Ajou University have successfully fabricated a tungsten filament with an extraction grid and other electrodes formed in nickel on a silicon substrate, as shown in Figure 1a [1]. To allow its very high operating temperature to be reached, the filament was suspended over a pit formed by anisotropic wet chemical etching. Emission currents up to 7 nA were obtained with an applied voltage of 35 V.

Considerably more attention has been paid to cold cathode sources, due to intensive industrial efforts to develop field emission displays. Emitters are constructed in the classical Spindt geometry, in which a sharp tip with a radius of 1 - 10 nm is fabricated by isotropic dry etching of silicon in a SF_6 plasma. Self-aligned anodes and focusing electrodes have been demonstrated, emission currents have been stabilised, and current densities and lifetimes have been improved using coatings of thin film diamond-like carbon. Figure 1b shows the cross-section and emission characteristic of a source fabricated by Huq of Rutherford Appleton Laboratory, which follows the Fowler-Nordheim relation given earlier [2]. Cold cathode sources have been used extensively with ion traps, because the geometry allows electrons to be injected directly into the trap as shown in Figure 1c.

Müller of the Technische Universität Hamburg-Harburg has demonstrated an interesting plasma ion source [3]. The source is a small chamber operating at higher pressure than the mass analyser, within which a discharge is excited. Figure 1d shows the source, which uses a three-layer stack of etched Pyrex wafers containing a plasma chamber beneath a DC extraction grid. Ionisation is accomplished with electrons extracted from inert gas plasma. The plasma is ignited by a piezoelectric spark discharge and sustained by microwave excitation. Electron currents of 100's of μA have been obtained using RF powers of 350 mW at pressures of 80 Pa, with accelerating voltages as low as 100V.

Considerably more work has been carried out on chip-based electrospray ionisation sources. Ramsey et al. of Oak Ridge National Laboratory were the first to show that a spray could be drawn from the edge of a glass chip containing an etched capillary [4]. Since then, integrated capillaries have been demonstrated in many materials and geometries. Nozzles have been combined with a sample and buffer reservoirs in glass substrates, and additional channels have been provided for sheath flow. More complicated devices combine sample inlet ports, preconcentration sample loops, separation channels and pneumatic nebilizers. One issue with all glass substrates is their hydrophilic nature, which allows the Taylor cone to spread laterally over the edge of the chip as the flow rate increases, reducing the separation of mass peaks. This problem has been overcome using plastics and a wide variety of coatings and substrate materials have been investigated. Other geometries suitable for planar integration, including open channels and nibs, have also been demonstrated.

- Mass filters

Many of the ‘classical’ variants of mass filter have been demonstrated using planar technology. A recent review by can be found in [5].

The best example of a chip-based time-of-flight filter is the previously mentioned example developed by Yoon [1], which uses electroplated metal electrodes for ion coupling and detection. Using a 1 cm^2 chip, the flight times were up to 5 μS for masses up to 100 atomic mass usnits (a.m.u.). Despite the small size of the chip, mass filtering has been convincingly demonstrated.

Figure 2a shows the mass spectrum of acetone, which was however obtained using a Q-switched Nd-YAG laser for ionization rather than the hot-filament source.

A novel microengineered instrument with a rather different planar electrode layout has been proposed by Müller [3]. Figure 1d shows the device, which uses the microwave ion source described earlier and electrostatic filtering. This time, however, mass selection is based on the filtering action provided by the interaction between the ion beam and a three-phase travelling electrical field, which is created by a periodic electrode structure fed by suitably phased drive signals.

Syms of Imperial College London and and Taylor of Liverpool University have demonstrated microfabricated quadrupole filters using a pair of etched silicon substrates separated by glass rods [6]. Each substrate carried two of the four cylindrical electrodes, and the glass rods spaced the assembly apart by the distance needed to achieve the quadrupole geometry. Mass spectra were demonstrated early on, but various aspects of performance (particularly, the mass range, which was restricted to 100 a.m.u.) were limited by RF heating caused by capacitative coupling through the substrates.

Geear et al. of Microsaic Systems [7] has demonstrated a more advanced MEMS quadrupole. The device is formed from two bonded silicon-on-insulator substrates, which are attached together to form a monolithic block. Deep etched features and springs formed in the outer silicon layers are used to locate cylindrical metal electrode rods, while similar features formed in the inner silicon layers are used to define integrated ion entrance and exit optics. Mass filtering has been demonstrated, with a mass range of $\approx$ 400 a.m.u. and a resolution of 1 a.m.u. at a mass of 219 a.m.u., using quadrupoles with rods of 500 μm diameter and 30 mm length, operating at 6 MHz RF frequency. Figure 2b shows the device itself and the mass spectrum of perfluorotributylamine (PFTBA).

Many groups have fabricated ion traps, using the cylindrical approximation to the ideal hyperbolic geometry shown earlier in Figure 1c. Ramsey and Whitten at Oak Ridge National Laboratory have constructed traps, with 1/1000th the volume of conventional devices [8]. A mass range from 40 to 400 a.m.u. has been demonstrated, with peak widths less than 0.2 a.m.u. for single scans. The device has been operated with a frequency quadrupled Nd-YAG laser photo-ionization source, and both hot cathode and cold-cathode electrode impact ionization sources.

Freidhoff, et.al. of Northrop Grumman has developed a microfabricated Wien filter mass spectrometer [9]. The device is a mass spectrograph based on a continuous ion source, fixed, crossed magnetic and electric fields, and an ion detector array, as shown in Figure 3a. The whole analyser is formed in a shallow cavity etched into a single silicon substrate a few cm long. Because of the near-planar geometry of the cavity, it is difficult to establish a uniform, fixed electric field, and a discontinuous field approximating the desired field is derived from a set of parallel coplanar electrodes biassed by a resistor chain. Despite these difficulties, preliminary data has been obtained for a mass range of 40-200 amu with a peak width of 1 amu at 60 amu.

- Ion detectors

Most miniature mass spectrometers have used a single detector such as a channeltron, which allows spectra to be obtained in serial form by scanning the filter passband. For example, in a magnetic separator, the magnetic field can be ramped, and in a quadrupole, the two components of the electric field can be varied in a fixed ratio. This method has the disadvantage that ions of a given mass are only observed for a fraction of the time available. Improved sensitivity is obtained by parallel detection, which allows continual observation.

The most advanced chip-based ion detectors are the microfabricated Faraday cup arrays fabricated by Darling of Washington University [10], for use with a compact linear dispersion magnetic mass spectrograph. Deep reactive ion etching of silicon was used to form high aspect ratio trenches, which were then oxidised and metallised to form an array of independently addressable MOS capacitors as shown in Figure 3c. Detector arrays were constructed with up to 256 elements and with pitches down to 150 μm, and the arrays have been combined with an electronic multiplexer to allow serial readout.

Future Directions for Research

The overall goal of miniaturizing mass spectrometers – to allow wider access to the most versatile method of chemical analysis yet developed – is an important one. Particularly, the availability of portable systems could allow the use of accurate identification methods outside the laboratory. The key goals of future work are to improve mass range and mass resolution of miniaturized mass filters, and the reliability and efficiency of compatible ion sources.

Cross-References

Mass spectrometry, Detection using mass spectrometry; Interfaces between microfluidics and mass spectrometry; Microfabrication techniques; Silicon micromachining

Definitions

Title

Ion source

Synonyms

Ion source, ionization source

Definition

A device for generating a flux of ionized molecules. Examples include hot- and cold-cathode electron impact ion sources, photoionization ion sources and electrospray ion sources.

Cross-references

Mass spectrometry, Interfaces between microfluidics and mass spectrometry.

Title

Mass filter

Synonyms

Mass filter, mass analyzer

Definition

A device for separating ions based on their mass-to-charge ratio. Many different types of mass filter exist, exploiting different combinations of static and time varying electric and magnetic fields for ion separation.

Cross-references

Mass spectrometry

Title

Time-of-flight filter

Synonyms

Time-of-flight filter, time-of-flight mass spectrometer, TOF-MS

Definition

A mass filter that separates ions according to their time of flight through a fixed distance, following their acceleration through a common potential. Requires a pulsed ion source, fast electronics and sufficient flight path for ion separation.

Cross-references

Mass spectrometry

Title

Magnetic filter

Synonyms

Magnetic filter, magnetic mass spectrometer

Definition

A mass filter that separates ions according to their trajectories in a magnetic field. A device with a fixed magnetic field normally acts as a mass spectrograph, whereas a device with a variable field acts as a mass spectrometer.

Cross-references

Mass spectrometry

Title

Crossed field filter

Synonyms

Crossed field filter, Wien filter, crossed-field mass spectrometer

Definition

A mass filter that separates ions according to their trajectories in a combined field consisting of perpendicular magnetic and electrostatic fields. Can also be used as a velocity filter.

Cross-references

Mass spectrometry

Title

Quadrupole filter

Synonyms

Quadrupole filter, electrostatic quadrupole, quadrupole mass spectrometer

Definition

A mass filter that separates ions according to their trajectories in a two-dimensional hyperbolic electrostatic field with DC and radiofrequency AC components. Ions with stable trajectories transit the filter, while other ions discharge on the electrodes. Unlike a quadrupole ion trap, the quadrupole filter operates continuously.

Cross-references

Mass spectrometry

Title

Quadrupole ion trap

Synonyms

Quadrupole ion trap, ion trap mass spectrometer

Definition

A mass filter that separates ions according to their trajectories in a three-dimensional hyperbolic electrostatic field with DC and radiofrequency AC components. Unlike a quadrupole filter, the ion trap does not operate continuously, but on batches of ions that are trapped, stored and then detected in sequence.

Cross-references

Mass spectrometry

Title

Ion detector

Synonyms

Ion detector, ion counter

Definition

A device for detecting ions that operates by converting the ion back into a neutral molecule, the resulting electron motion generating a flow of current in a detection circuit. Examples include Faraday cups and electron multipliers. For singly charged ions, Faraday cups yield one electron per ion, whereas multipliers provide a typical amplification factor of $10^6 – 10^7$.

Cross-references

Detection using mass spectrometry

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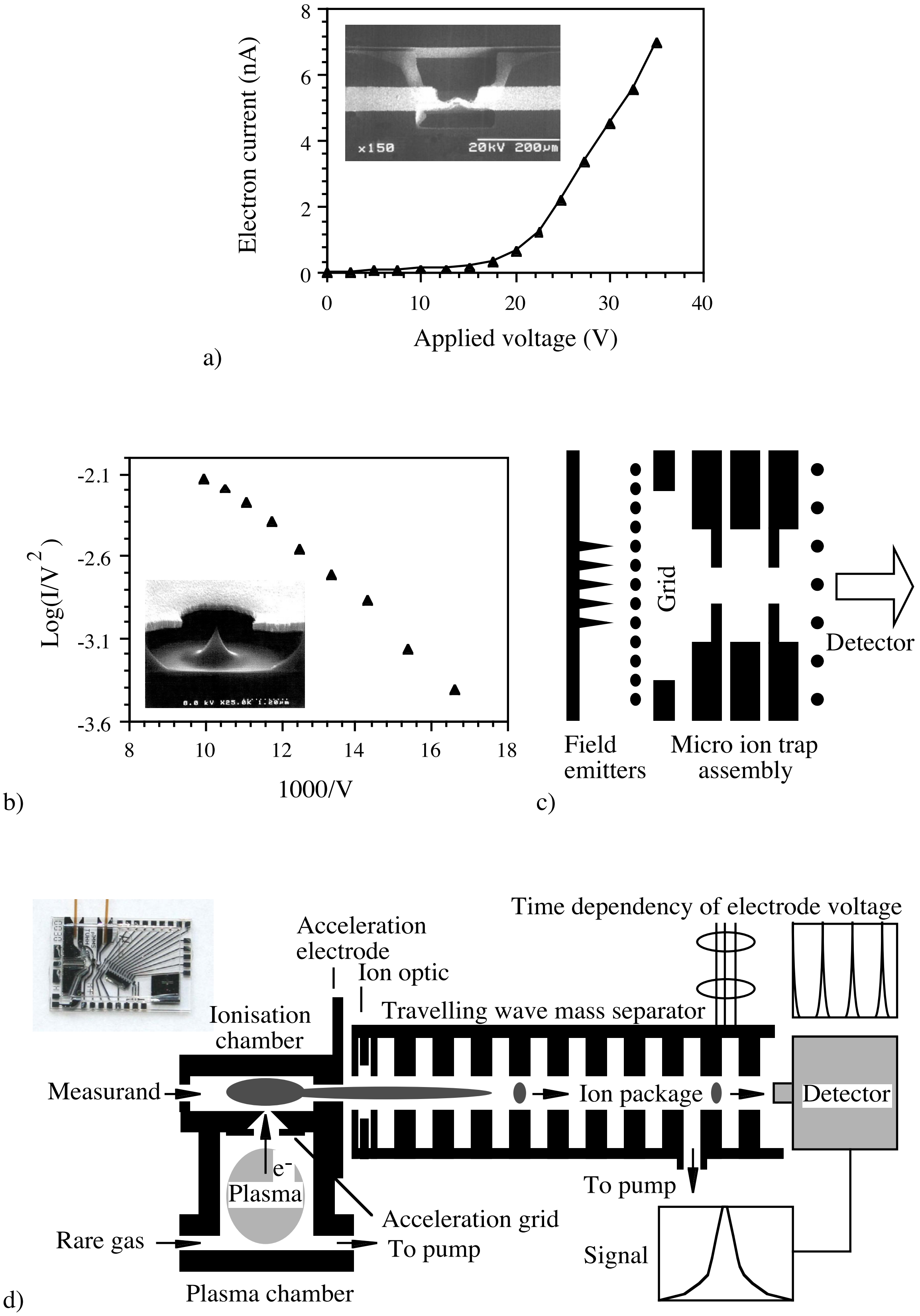
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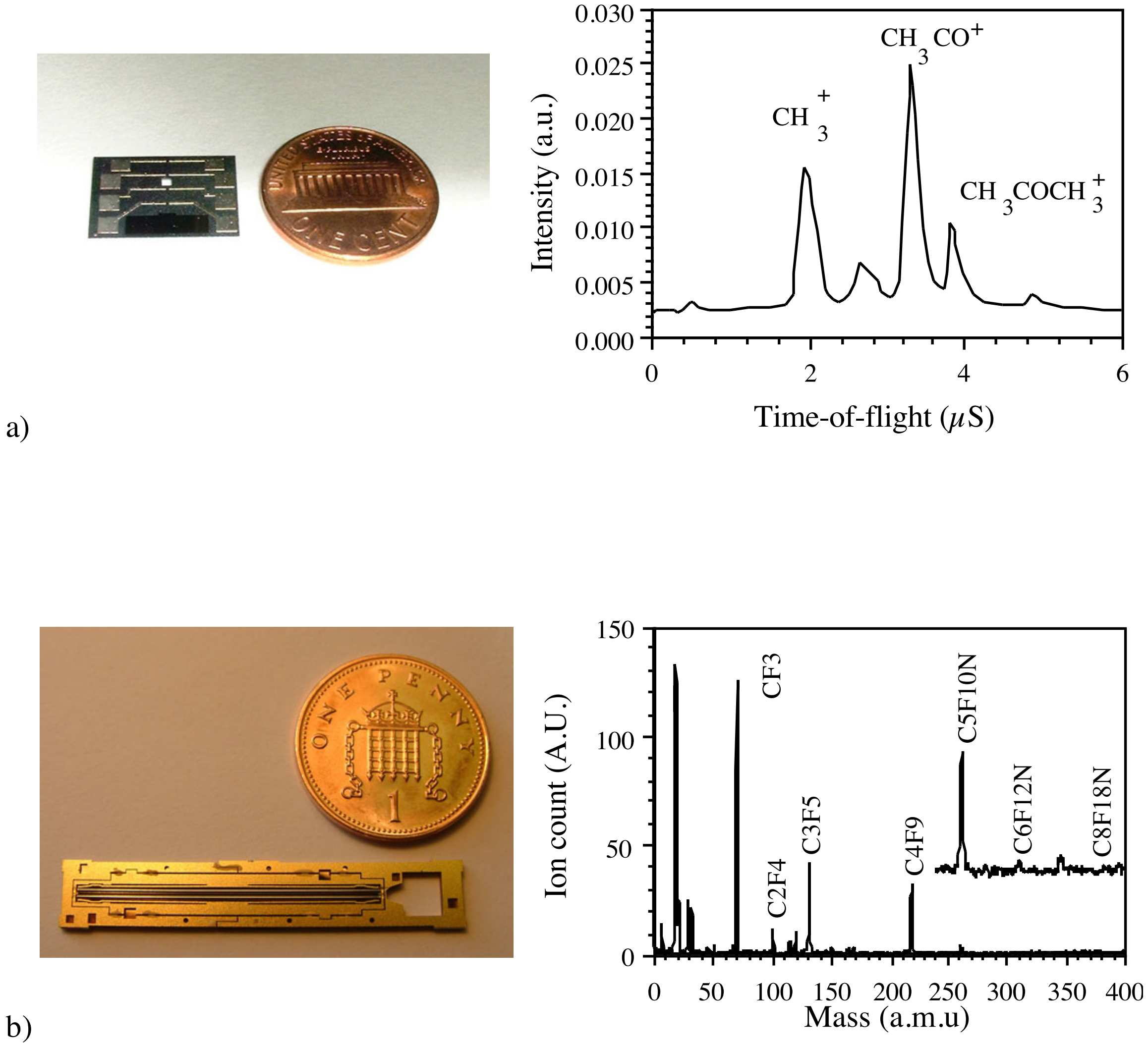
6
4
2
0
0
10
20
30
40
Applied voltage (V)
x150
20kV 200µm
a)
Log(I/V^2)
-2.1
-2.6
-3.1
-3.6
8
10
12
14
16
18
1000/V
b)
Grid
Detector
Field emitters
Micro ion trap assembly
c)
Time dependency of electrode voltage
Acceleration electrode
Ion optic
Ionisation chamber
Travelling wave mass separator
Measurand
Ion package
Detector
e$^-$
Plasma
To pump
Acceleration grid
Rare gas
To pump
Signal
Plasma chamber
d)

Figure 1.


a)
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0.025
0.020
0.015
0.010
0.005
0.000
Intensity (a.u.)
CH_3^+
CH_3CO^+
$CH_3COCH_3^+$
0
2
4
6
Time-of-flight (μS)
b)
150
100
50
0
Ion count (A.U.)
CF3
C2F4
C3F5
C4F9
C5F10N
C6F12N
C8F18N
0
50
100
150
200
250
300
350
400
Mass (a.m.u)

Figure 2.

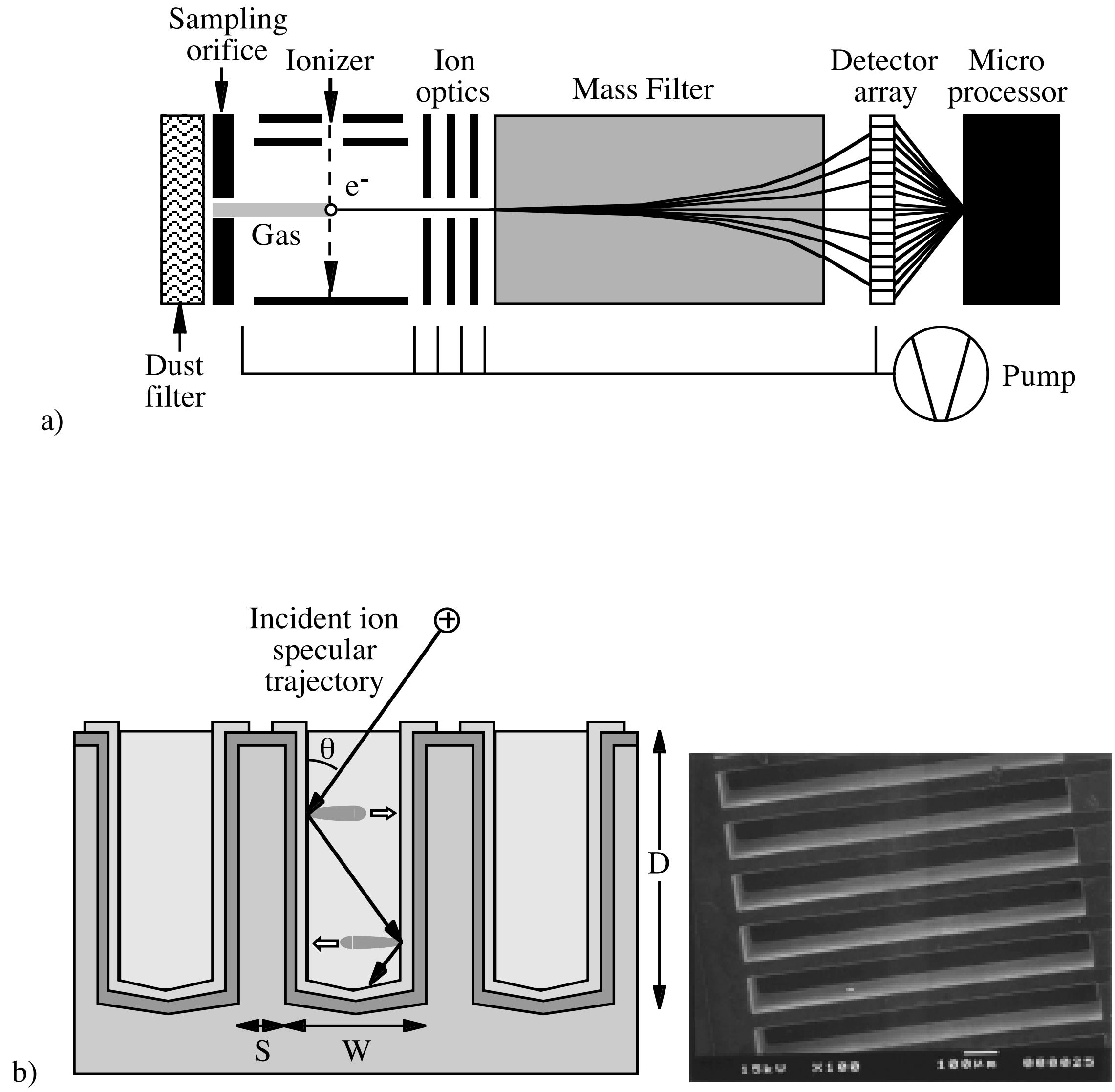
Sampling orifice
Ionizer
Ion optics
Mass Filter
Detector array
Micro processor
e-
Gas
Dust filter
Pump
a)
Incident ion specular trajectory
θ
D
S
W
b)
15kV ×100 100μm 000025

Figure 3.