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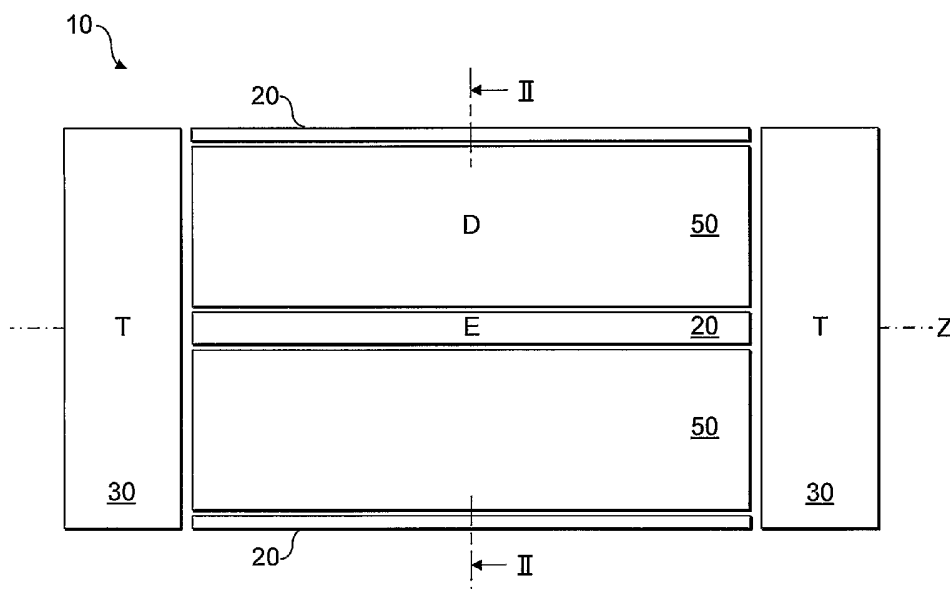
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(54) Title: MEASUREMENT CELL FOR ION CYCLOTRON RESONANCE SPECTROMETER



(57) Abstract: This invention relates to a measurement cell for a FTMS spectrometer. The measurement cell comprises a longitudinal axis and comprising five or more electrodes arranged about the longitudinal axis including two or more excitation electrodes operable to excite ions in the measurement cell into cyclotron motion and two or more dedicated detection electrodes operable to detect ions within the measurement cell, wherein a plane orthogonal to the longitudinal axis meets the five or more electrodes to define the perimeter of a cross-section, the two or more detection electrodes occupying at least 50% of that perimeter.



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.

MEASUREMENT CELL FOR ION CYCLOTRON RESONANCE SPECTROMETER

This invention relates to a measurement cell for an Ion Cyclotron Resonance (ICR) spectrometer.

5 Fourier Transform Ion Cyclotron Resonance is a technique for high resolution mass spectrometry which employs a cyclotron principle. An example of a FT-ICR spectrometer is shown in our co-pending Application No. GB 0305420.2 which is incorporated herein by reference in
10 its entirety. As is described in that application, ions generated in an ion source (usually at atmospheric pressure) are transmitted through a system of ion optics employing differential pumping and into an ion trap. Ions are ejected from the trap, through various ion
15 guides and into a measurement cell.

In the measurement cell, the field lines of a homogeneous magnetic field (generated by an external superconducting magnet, for example), extend along the cell in parallel with the cell's longitudinal axis. By
20 using excitation electrodes to generate a rf field perpendicular to the magnetic field, the ions can be excited so as to produce cyclotron resonance. Ions in the cell then orbit as coherent bunches along the same radial paths but at different frequencies. The frequency
25 of the circular motion (the cyclotron frequency) is proportional to the ion mass.

Detection electrodes are provided in the cell in which an image current is induced by the coherent orbiting ions. The amplitude and frequency of this
30 detected signal are indicative of the quantity and mass of the orbiting ions. A mass spectrum is obtainable by

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carrying out a Fourier Transform of the 'transient', i.e. the signal produced at the detection electrodes.

Figure 1a shows, highly schematically, a side sectional view of an arrangement of electrodes in a prior art measurement cell that may be used in a FTICR spectrometer. In particular, a section through cell 10 shows the longitudinal axis z of the cell 10 and that the cell 10 comprises a central excitation electrode 20 with outer trapping electrodes 30, 40 on either side. A rf voltage is applied to the excitation electrodes 20 so as to produce an excitation field, and a dc voltage is applied to the trapping electrodes 30, 40 to superimpose a trapping field.

Figures 1b and 1c correspond to central transverse sections through the cell 10 of Figure 1a that shows two possible arrangements of electrodes. In Figure 1b, four electrodes define a square perimeter of a cross-section through the measurement cell 10. In Figure 1c, four electrodes define a circular perimeter to the cross-section. As can be inferred from Figure 1a, the top and bottom electrodes of Figures 1b and 1c are the excitation electrodes 20. The left and right electrodes correspond to detection electrodes 50. The detection electrodes 50 and the excitation electrodes 20 have the same length and the same width, such that all four electrodes occupy the same length of the perimeter of the cross-sections shown in Figures 1b and 1c. The gaps 60 provided between electrodes mean that both the detection electrodes 50 and the excitation electrodes 20 occupy a little under 50% of the perimeter.

The equal-sized detection and excitation electrodes 20, 50 offer a good balance between the excitation function of the cell 10 on the one hand and the detection function on the other hand. However, it has been realised than an increase in the size of the detection electrodes 50 would be advantageous because the increase in active detection area will lead to a decrease in the signal-to-noise ratio of collected data. Merely increasing the size of the detection electrodes 50 would result in a corresponding decrease in the size of the excitation electrodes 20. This, in turn, would require even more power to be supplied to the excitation electrodes 20, leading to an undesirable need for expensive high-power amplifiers.

It is perhaps for this reason that a different approach has been followed to date: namely, to use shared electrodes that can be switched between excitation and detection modes of operation. However, this approach also has its disadvantages in that the electronics required to perform this switching are complex and expensive.

From a first aspect, the present invention resides in a measurement cell for a FTMS spectrometer, the measurement cell having a longitudinal axis and comprising five or more electrodes arranged about the longitudinal axis including two or more excitation electrodes operable to excite ions in the measurement cell into cyclotron motion and two or more dedicated detection electrodes operable to detect ions within the measurement cell; wherein a plane orthogonal to the longitudinal axis meets the five or more electrodes to

define the perimeter of a cross-section, the total circumferential extent of the dedicated detection electrodes exceeding the total circumferential extent of the excitation electrodes.

5 Thus, the present invention provides a measurement cell with dedicated detection electrodes, i.e. electrodes that are dedicated to detection rather than having to be switched between excitation and detection functions, and that occupy more of the measurement cell than the
10 excitation electrodes. This allows improved data collection.

Moreover, this arrangement of five or more electrodes requires at least three excitation electrodes or at least three detection electrodes. Either
15 possibility has distinct advantages.

The use of three or more excitation electrodes improves excitation as well as allowing other modes of excitation or de-excitation. Furthermore, the use of three or more excitation electrodes suppresses harmonics
20 that may otherwise be problematic when using two excitation electrodes, particularly in view of the fact that their width must be reduced to accommodate the wider detection electrodes.

The use of three or more detection electrodes allows
25 two different, desirable modes of operation: (a) direct detection of the phase of ions, improving the possibilities to suppress computationally unwanted harmonics, and (b) allowing calculation of absorption mode spectra with reduced requirements on phase
30 prediction or on an early start of the detection relative to the excitation.

Of course, the above arrangements may be combined to arrive at an arrangement of three or more excitation electrodes and three or more detection electrodes. Preferably, the measurement cell has four excitation
5 electrodes. It is also preferred for the measurement cell to have four detection electrodes. Thus, a measurement cell to have four detection electrodes and four detection electrodes is particularly preferred. Other preferred embodiments use two excite and four
10 detect electrodes or four excite electrodes and two detect electrodes.

Preferably, the two or more excitation electrodes and the two or more detection electrodes extend in the same direction as the longitudinal axis thereby forming a
15 volume of the measurement cell having a uniform cross-section, the two or more detection electrodes occupying at least 50% of the perimeter of the uniform cross-section. The cross-section may be a regular polygon, a circle or an ellipse. Although a circle is particularly
20 preferred, square, triangular, hexagonal and octagonal cross-sections are also contemplated. Moreover, cross-sections of regular polygons having truncated corners such as a square with bevelled edges at its corners are also contemplated. These short bevelled edges may
25 optionally be provided by excitation electrodes, the longer sides being provided by detection electrodes.

Optionally, the cross-section comprises a plurality of repeating segments that provide rotational symmetry, with each of the segments further comprising one of the
30 two or more excitation electrodes and one of the one or more detection electrodes, the detection electrode of

each segment occupying more than 50% of the perimeter of that segment. This may be accomplished by providing a detection electrode wider than the excitation electrode such that the detection electrode occupies more of the
5 perimeter. Arrangements that provide four-fold rotational symmetry are particularly preferred as this allows for a simpler distribution of rf potentials to the excitation electrodes and reduces "leakage" of the excite signal to the detection electrodes.

10 According to currently contemplated embodiments, the cell has a circular cross-section and comprises four 90° segments or six 60° segments or eight 45° segments such that the measurement cell comprises four, six or eight excitation electrodes respectively and four, six or
15 eight detection electrodes respectively. Within each segment of the latter arrangement, the detection electrode(s) optionally subtends an arc of substantially 65° to 80°. Thus, the excitation electrodes occupy around 10° to 25°, of course allowing for the necessary
20 gap between adjacent electrodes.

Although, the invention in its broadest sense requires the total circumferential extent of the detection electrodes to exceed that of the excitation electrodes, in a preferred embodiment the two or more
25 detection electrodes occupy at least 50% of the perimeter of the cross-section. Increasing preferred ranges of between 50% and 95% and of between 70% and 90% are in that case currently contemplated.

Optionally, the measurement cell may further
30 comprise two or more trapping electrodes positioned at axially separated locations about said longitudinal axis

and operable to trap ions longitudinally in the cell within a trapping region defined by the trapping electrodes; wherein at least one excitation electrode extends axially outwardly of the trapping region. This
5 increases the homogeneity of the field within the trapping region because, in effect, the excitation field is "pulled" out and away from the edges of the trapping region.

Each of the two or more excitation electrodes may
10 optionally comprise a central excitation electrode arranged about a central point along the longitudinal axis, and first and second outer excitation electrodes axially spaced from the central excitation electrode along the axis, and wherein the trapping electrodes are
15 located axially between the central excitation electrode and the first and second outer excitation electrodes respectively.

Alternatively, each of the two or more excitation electrodes may optionally include a unitary electrode
20 that extends substantially the whole of the trapping region of the cell and axially beyond the trapping region, and wherein the two or more trapping electrodes are circumferentially displaced from the unitary excitation electrode.

25 The present invention also extends to a FTMS spectrometer comprising a measurement cell as described above and a power supply including a power amplifier arranged to provide the two or more excitation electrodes of the measurement cell with a radio frequency signal,
30 wherein the power amplifier is substantially matched to the impedance of the measurement cell.

Such an arrangement is highly advantageous because it places a far reduced power requirement on the amplifier to produce a given field strength. For this invention, the advantage is exploited in that a given
5 field strength may be produced using a similar power delivered to excitation electrodes of much reduced width. This then allows the widths of the detection electrodes to be increased so that they may occupy the majority of the perimeter of the measurement cell's cross-section.

10 From a further aspect, the present invention resides in a method of operating a FTMS spectrometer comprising a measurement cell as described above, the method comprising: supplying a radio frequency signal to the two or more excitation electrodes to excite ions in the
15 measurement cell into cyclotron motion; and detecting ions within the measurement cell using the one or more detection electrodes. Preferably, the method further comprises supplying the radio frequency signal using a power amplifier substantially matched to the impedance of
20 the measurement cell.

In a further aspect of the invention, a measurement cell for a FTMS spectrometer is provided, the measurement cell having a longitudinal axis and comprising five or more electrodes arranged about the longitudinal axis
25 including two or more excitation electrodes operable to excite ions in the measurement cell into cyclotron motion and two or more dedicated detection electrodes operable to detect ions within the measurement cell; wherein a plane orthogonal to the longitudinal axis meets the five
30 or more electrodes to define the perimeter of a cross-section, and wherein, when the cell is notionally divided

into circumferential segments with at most one detection and one excitation electrode per segment, the detection electrode has at least a 50% circumferential share of each such notional segment.

5 Yet another aspect provides a measurement cell for a FTMS spectrometer, the measurement cell having a longitudinal axis and comprising five or more electrodes arranged about the longitudinal axis including two or more excitation electrodes operable to excite ions in the
10 measurement cell into cyclotron motion and two or more dedicated detection electrodes operable to detect ions within the measurement cell; wherein a plane orthogonal to the longitudinal axis meets the five or more electrodes to define the perimeter of a cross-section,
15 and wherein, where the cell is divided circumferentially into n segments of equal extent, and where n is the smaller of the number of excitation and detection electrodes, the excitation electrode(s) have the smaller share of the perimeter or angle in that segment.

20 In order that the invention can be more readily understood, reference will now be made by way of example only to the accompanying drawings, in which:

Figure 1 shows two embodiments of a measurement cell according to the prior art, Figure 1a corresponding to a
25 longitudinal section through either embodiment and Figures 1b and 1c corresponding to transverse sections through line I-I of Figure 1a for the first and second embodiments respectively;

Figure 2a is a side view of a measurement cell
30 according to a first embodiment of the present invention

and Figure 2b is a section through line II-II of Figure 2a;

Figure 3 shows excitation field lines for three measurement cells, Figure 3a corresponding to bipolar operation of the cell of Figure 1c, Figure 3b corresponding to bipolar operation of the cell of Figure 2b, and Figure 3c corresponding to quadrupolar operation of the cell of Figure 2b;

Figure 4 is a side view of a measurement cell according to a second embodiment of the present invention;

Figure 5 is a side view of a measurement cell according to a third embodiment of the present invention;

Figure 6 is a transverse section of a measurement cell according to a fourth embodiment of the present invention;

Figure 7 is a transverse section of a measurement cell according to a fifth embodiment of the present invention;

Figure 8 is a transverse section of a measurement cell according to a sixth embodiment of the present invention; and

Figure 9 is a schematic representation of a measurement cell with three excitation electrodes showing symmetric points P and P'.

An arrangement of electrodes in a measurement cell according to a first embodiment of the present invention is shown in Figures 2a and 2b. Only the electrodes are shown, with the associated power supplies and connections omitted for clarity. As can be seen, the measurement cell 10 of Figure 2a is of the cylindrical

open type with ends bounded by cylindrical trapping electrodes 30 that create an electric field component to trap ions injected into the cell 10 in a trapping region that extends therebetween.

5 The central section of the cell 10 between the pair of trapping electrodes 30 comprises eight electrodes that extend longitudinally, that is to say parallel to the z axis, the length of the central section. Thus, the cross-section of the cell 10 is uniform along its length.

10 The electrodes comprise four matching excitation electrodes 20 and four matching detection electrodes 50. The four electrodes of each type are arranged into two pairs of opposed electrodes, the pairs being orthogonally disposed. Thus, the type of electrode alternates around

15 the circumference to form four matching segments such that the cell has four-fold rotational symmetry. Although the excitation 20 and detection 50 electrodes have equal length, they differ in their respective widths. As can best be seen from Figure 2b, the

20 detection electrodes 50 occupy far more of the circumference of the cell 10 than the excitation electrodes 20.

 Thus, the measurement cell 10 has dedicated excitation electrodes 20 and dedicated detection

25 electrodes 50 rather than employing shared electrodes that must be switched between excitation and detection duties. Hence switching, and the associated complexity and expense of the necessary switching circuit, is avoided.

30 The inclusion of four detection electrodes 50 rather than just two as in the prior art of Figure 1c

advantageously assists reduction of the of harmonics.
For the same detecting area, the use of only two
detection electrodes 50 would mean that they occupy a
wide angle on the circumference and this would give rise
5 to more harmonics in the transient.

The provision of four excitation electrodes 20 in
the embodiment of Figures 2a and 2b also allows bipolar
excitation or quadrupolar excitation (i.e. using rf
potentials on the four excitation electrodes 20 with
10 phases of 0° , 90° , 180° and 270°). Figures 3a to 3c show
excitation fields arising from bipolar and quadrupolar
excitation of excitation electrodes 20 within measurement
cell 10. Figure 3a shows the excitation field obtained
with bipolar operation of the prior art measurement cell
15 10 of Figure 1c. As can be seen, the field lines extend
into the cell 10 to provide a large field gradient in the
centre of the cell 10. Figure 3b shows bipolar operation
of just two of the excitation electrodes 20 of the cell
10 of Figures 2a and 2b. Although the shape of the
20 resulting excitation field is good, the field strength at
the centre of the cell 10 is diminished. For this
reason, the use of all four excitation electrodes 20 is
preferred. This generates the excitation field shown in
Figure 3c, achieved using quadrupolar excitation with
25 phases of 0° , 90° , 180° and 270° .

In order to achieve sufficient field strength using
excitation electrodes 20 that occupy less than 50% of the
circumference of the cell 10, the excitation electrodes
20 are supplied with power from a matched power
30 amplifier. By employing power amplifiers matched to the
high impedance of the measurement cell 10, rather than

standard "off the shelf" amplifiers matched to a 50Ω output as at present, the power output necessary to achieve a given field strength is significantly reduced. This is taken advantage of by supplying a comparable
5 power to excitation electrodes of significantly smaller width. For example, a 100V excitation amplitude at 50Ω output impedance requires $V^2/Z = 200$ Watts of output power. At 250Ω output impedance, only 40 Watts of power is needed. Indeed, maintaining narrow excitation
10 electrodes 20 in such an arrangement proves to be desirable, since this avoids significant disturbance of the trapping field. In general terms, it is desirable to keep the width of the excitation electrodes 20 (i.e. the distance around the circumference of the measurement cell
15 10) below the length of the trapping electrodes 30 (in the z-axis direction of the cell 10) in order to minimize the effect of the disturbance on the trapping field.

Where only two detection electrodes are used, it is usual to feed the output signal from each detection
20 electrode to respective inputs (inverting and non-inverting) of a differential amplifier for the subsequent signal processing that is used to derive a mass spectrum from the transient. The situation is more complicated here where four detection electrodes 50 are used, and
25 many arrangements are possible although two arrangements are favoured in particular.

The first arrangement uses a single differential amplifier that receives two signals at each input, such that the output signals from a first pair of opposed
30 detection electrodes 50 are passed to one of the inverting or non-inverting inputs, and the output signals

from the second pair of detection electrodes 50 are passed to the other of the inverting and non-inverting inputs.

The second arrangement uses a pair of differential amplifiers, the output signals of one pair of opposed detection electrodes 50 being passed to the inverting and non-inverting inputs of one amplifier, and the output signals from the other pair of opposed detection electrodes 50 being passed to the inverting and non-inverting inputs of the other amplifier. The two outputs provided by the two differential amplifiers are provided to a two-channel A/D converter whose two outputs are in turn passed to a complex FFT filter that treats them as real and imaginary inputs. This second arrangement is preferred due to an improved signal-to-noise ratio. In particular, its use with quadrupolar excitation is favoured as this provides improved phase information that can be used to remove unwanted harmonics and, possibly, to reduce peak widths. Any mechanical deviations from the ideal detector electrode symmetry may be compensated by data processing.

Narrowed excitation electrodes 20 can be used with arrangements of electrodes other than those shown in Figures 2a and 2b. For example, our co-pending patent application PCT/EP04/010839, and that is incorporated herein in its entirety by reference, describes measurement cells 10 with novel arrangements of trapping and excitation electrodes that provide improved homogeneity of the field within the central section of the measurement cell 10. An example of such an arrangement is shown in Figure 4 as a side view, with the

transverse section through line V-V of Figure 4 corresponding to that shown in Figure 2b.

The cell 10 of Figure 4 comprises a first set of four central excitation electrodes 20 which are located about an axially central point of the cell 10. Axially outward of this central pair of excitation electrodes 20, on either side thereof, are two pairs of trapping electrodes 30. The trapping electrodes 30 of Figure 5 are located at the same, or similar, diameter as the first set of four excitation electrodes 20.

Axially outwardly of the pairs of trapping electrodes 30 are second and third sets of four outer excitation electrodes 20'. Again, these outer excitation electrodes 20' are located at the same diameter or similar as that of the trapping 30 and central excitation 20 electrodes. Thus, the outer excitation electrodes 20' and the central excitation electrodes 20 'sandwich' the trapping electrodes 30 between them.

A rf voltage supply is connected to each of the excitation electrodes 20, 20'. Although a single rf voltage supply (of a given voltage) may be attached to each of the excitation electrode pairs 20 and 20', different voltages and/or frequencies may instead be applied to each set by virtue of voltage and/or frequency divider(s) respectively, or by using separate rf voltage supplies. A dc voltage is applied to the trapping electrodes 30. Again, the same or different dc voltages may be applied to the two pairs of trapping electrodes 30.

The wider excitation electrode arrangement of Figure 4 "pulls" a non-linear region of the excitation

field outwards relative to the trapping electrodes 30 so that the excitation electric field is essentially homogeneous in the trapping region, i.e. between the trapping electrodes 30. It will also be noted that axial
5 barriers in the trapping field provided by the trapping electrodes 30 coincide with the homogeneous area of the magnetic field that extends along the z axis. Detection electrodes are not provided beyond the trapping electrodes 30 as the ions of interest are trapped only in
10 the trapping region between the trapping electrodes 30.

A further arrangement that provides a "pulled" excitation field resulting in improved homogeneity in the trapping region is shown in Figure 5 as a side view. The transverse section through line V-V of Figure 5
15 corresponds to that shown in Figure 2b. In this embodiment, a single set of four excitation electrodes 20 extend to span the length of the cell 10, with the detection electrodes 50 now being sandwiched between the trapping electrodes 30.

20 The arrangement of Figure 5 is based upon several principles. Firstly, the trapping field becomes distorted when the share of the trapping electrodes 30 on the circumference decreases. This in turn reduces the quality of the detect signal produced from the detection
25 electrodes 50. However it has been realized that the trapping electrodes 30 do not need to sandwich both the detection electrodes 50 and the excitation electrodes 20, and can instead sandwich the detection electrodes 50 only.

30 It will of course be evident that modifications may be made to the above embodiments without departing from

the inventive concept. The invention in its broadest aspect relates to the provision of detection electrodes occupying at least 50% of the perimeter of a measurement cell. Other details of the arrangement of electrodes are
5 subsidiary to this and so can be varied, interchanged, combined, etc. as desired without departing from the inventive concept as defined in the appended claims.

The choice of the number of excitation 20 and detection 50 electrodes may be varied from the examples
10 of four per type of electrode that are given above. Moreover, the number of excitation electrodes 20 need not necessarily equal the number of detection electrodes 50. Of course, whatever the numbers of excitation 20 and detection 50 electrodes, the total circumferential extent
15 of the detection electrodes 50 should be greater than that of the excitation electrodes, and, preferably, the detection electrodes should exceed 50% of the circumference of the measurement cell.

Whilst a measurement cell 10 of circular cross-
20 section is preferred, other cross-sectional shapes are possible. Examples of alternative shapes that are advantageous are shown in Figures 6 to 8.

A box-shaped measurement cell 10 is shown in Figure 6 as a transverse section through its trapping
25 region. The cross-section is square, each of the four corresponding sides containing a pair of longitudinally extending detection electrodes 50 separated by a narrow, central excitation electrode 20. Alternatively, only two of the sides need comprise excitation electrodes 20 with
30 the two remaining sides comprising single, larger detection electrodes 50.

Figure 7 shows a transverse section through the trapping region of yet another embodiment of a measurement cell 10 according to the present invention. The section is generally square, with four sides comprising detection electrodes 50. However, the corners of the square are truncated by angled excitation electrodes 20 that form short bevelled edges. The excitation electrodes 20 are far narrower than the detection electrodes 50 such that the detection electrodes 50 occupy far more than 50% of the perimeter of the section.

Figure 8 shows a transverse section through the trapping region of a further embodiment of a measurement cell 10 according to the present invention. The cell 10 of Figure 8 applies the bevelled corners of the square-shaped cell 10 of Figure 7 to a cell 10 with a triangular cross-section. Accordingly, the cell 10 comprises three long sides formed by three detection electrodes 50 and three short sides formed by three excitation electrodes 20. Preferably, the three excitation electrodes 20 are supplied with rf potentials with phases 120° separated, i.e. at 0° , 120° and 240° . This basic principle is preferably applied to however many excitation electrodes 20 are employed: for N electrodes, rf signals are supplied preferably to each electrode with $360^\circ/N$ phase separation.

All of the above embodiments describe measurement cells 10 that possess rotational symmetry (two-, three-, or four-fold symmetric). This is particularly convenient as it allows equal rf potentials to be applied to each of the excitation electrodes 20, albeit with varying phases,

to provide an excitation field that is approximately symmetric about the rotational symmetry axis of the measurement cell 10. Put another way, at a mirror pair of points P and P', the field potential should be of an equal magnitude but opposite polarity such that $U(P) = -U(P')$. This ensures that trapped ions are excited to rotate about the central axis of the cell 10 in the same sense at all locations. However, arrangements lacking rotational symmetry may be used although the rf potentials applied to the excitation electrodes 20 should be different to ensure the above equation is met. An example is shown in the section of Figure 9, where three narrow excitation electrodes 20 are shown along with an example of a pair of symmetric points P and P'.

Whilst the embodiments described above each have multiple operable excitation and detection electrodes, it is of course to be understood that at least some of the detection and/or at least some of the excitation electrodes may be non-functioning, e.g. grounded. For example, in the simple symmetrical example of Figures 2a and 2b, two (for example) of the four detection electrodes (for example, the top right and bottom left detection electrodes in Figure 2b) and two (for example) of the four excitation electrodes (for example, the centre right and centre left excitation electrodes in Figure 2b) could be grounded. In that case it will be noted that, although the total circumferential extent of the detection electrodes that are "wired up" is less than 180 degrees of arc of the cell circumference overall, the detection electrodes that are acting as such rather than

being grounded do nevertheless extend further around the circumference than do the excitation electrodes.

CLAIMS

1. A measurement cell for a FTMS spectrometer, the measurement cell having a longitudinal axis and
5 comprising:
five or more electrodes arranged about the longitudinal axis including two or more excitation electrodes operable to excite ions in the measurement cell into cyclotron motion and two or more dedicated
10 detection electrodes operable to detect ions within the measurement cell;
wherein a plane orthogonal to the longitudinal axis meets the five or more electrodes to define the perimeter of a cross-section, the total circumferential extent of
15 the dedicated detection electrodes exceeding the total circumferential extent of the excitation electrodes.
2. The measurement cell of claim 1, wherein the two or more detection electrodes occupy at least 50% of the
20 total perimeter of the cell.
3. The measurement cell of claim 2, wherein the two or more excitation electrodes and the one or more detection electrodes extend in the same direction as the
25 longitudinal axis thereby forming a volume of the measurement cell having a uniform cross-section, and
wherein the one or more detection electrodes occupy at least 50% of the perimeter of the uniform cross-section.
- 30 4. The measurement cell of claim 3, comprising exactly four excitation electrodes.

5. The measurement cell of claim 3 or claim 4, wherein the cross-section is a regular polygon, a circle or ellipse.

5

6. The measurement cell of claim 5, wherein the cross-section comprises a plurality of repeating segments that provide rotational symmetry, with each of the segments further comprising one of the two or more excitation
10 electrodes and one of the two or more detection electrodes, the detection electrode of each segment occupying more than 50% of the perimeter of that segment.

7. The measurement cell of claim 6, wherein the cross-
15 section is a circle and comprises four 90° segments such that the measurement cell comprises four excitation electrodes and four detection electrodes.

8. The measurement cell of claim 6, wherein the cross-
20 section is a circle and comprises six 60° segments such that the measurement cell comprises six excitation electrodes and six detection electrodes.

9. The measurement cell of claim 6, wherein the cross-
25 section is a circle and comprises eight 45° segments such that the measurement cell comprises eight excitation electrodes and eight detection electrodes.

10. The measurement cell of claim 7, wherein each
30 excitation electrode subtends an arc of substantially 10° to 25°.

11. The measurement cell of any of claims 2 to 10,
wherein the two or more detection electrodes occupy
between 50% and 95% of the perimeter of the cross-
5 section.

12. The measurement cell of claim 11, wherein the two or
more detection electrodes occupy between 70% and 90% of
the perimeter of the cross-section.

10

13. The measurement cell of any preceding claim, further
comprising two or more trapping electrodes positioned at
axially separated locations about said longitudinal axis
and operable to trap ions longitudinally in the cell
15 within a trapping region defined by the trapping
electrodes;

wherein at least one excitation electrode extends
axially outwardly of the trapping region.

20 14. The measurement cell of claim 13, wherein each of
the two or more excitation electrodes comprise a central
excitation electrode arranged about a central point along
the longitudinal axis, and first and second outer
excitation electrodes axially spaced from the central
25 excitation electrode along the axis, and wherein the
trapping electrodes are located axially between the
central excitation electrode and the first and second
outer excitation electrodes respectively.

30 15. The measurement cell of claim 13, wherein each of
the two or more excitation electrodes comprise a unitary

electrode that extends substantially the whole of the trapping region of the cell and axially beyond the trapping region, and wherein the two or more trapping electrodes are circumferentially displaced from the
5 unitary excitation electrode.

16. A FTMS spectrometer comprising the measurement cell of any preceding claim and a power supply including a power amplifier arranged to provide the two or more
10 excitation electrodes of the measurement cell with a radio frequency signal, wherein the power amplifier is substantially matched to the impedance of the measurement cell.

15 17. A method of operating a FTMS spectrometer comprising a measurement cell according to any of claims 1 to 15, the method comprising:

supplying a radio frequency signal to the two or more excitation electrodes to excite ions in the
20 measurement cell into cyclotron motion; and
detecting ions within the measurement cell using the one or more detection electrodes.

18. The method of claim 17, further comprising supplying
25 the radio frequency signal using a power amplifier substantially matched to the impedance of the measurement cell.

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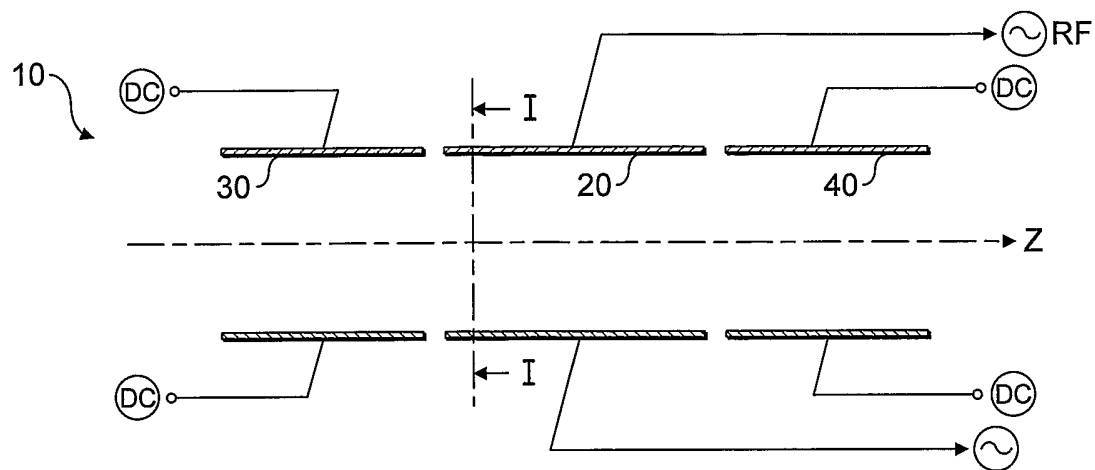


FIG. 1a
PRIOR ART

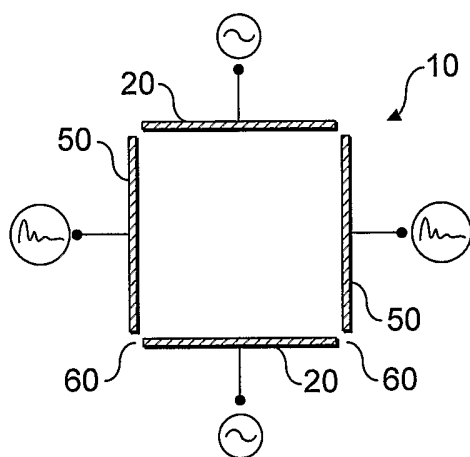


FIG. 1b

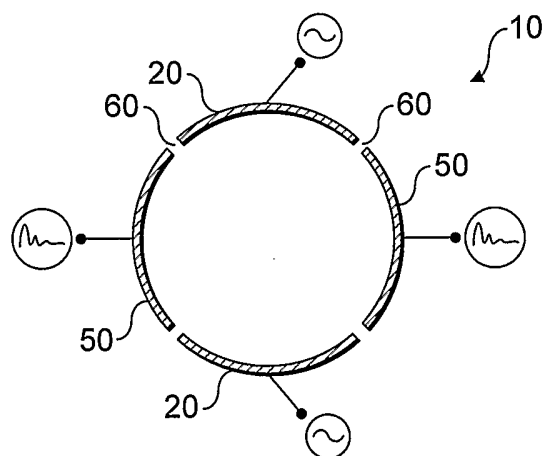


FIG. 1c

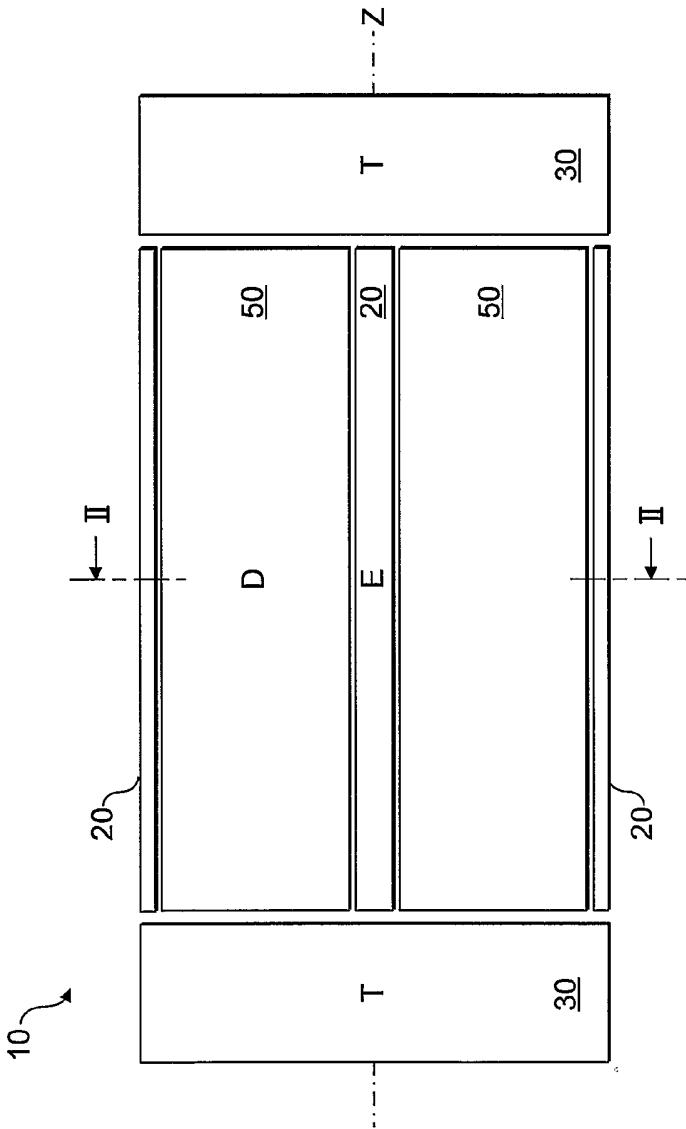


FIG. 2a

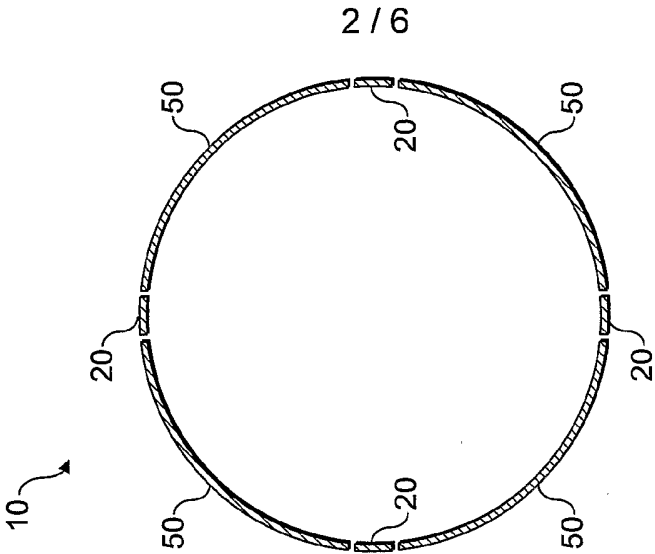


FIG. 2b

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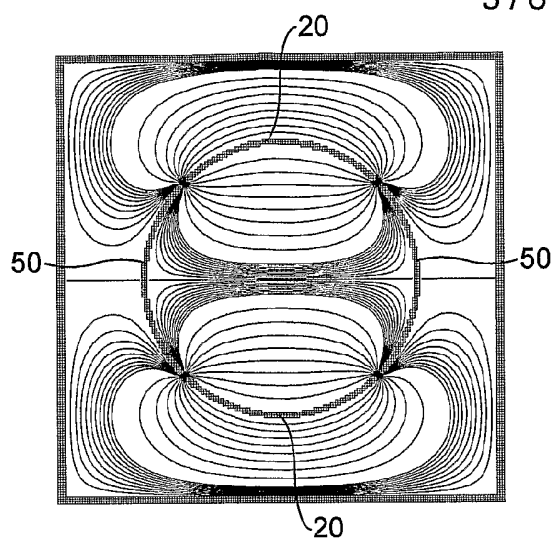


FIG. 3a

PRIOR ART

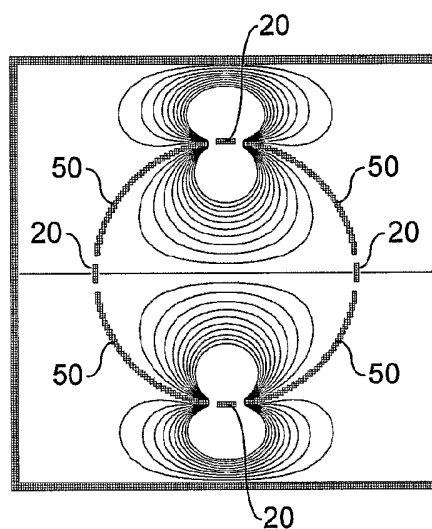


FIG. 3b

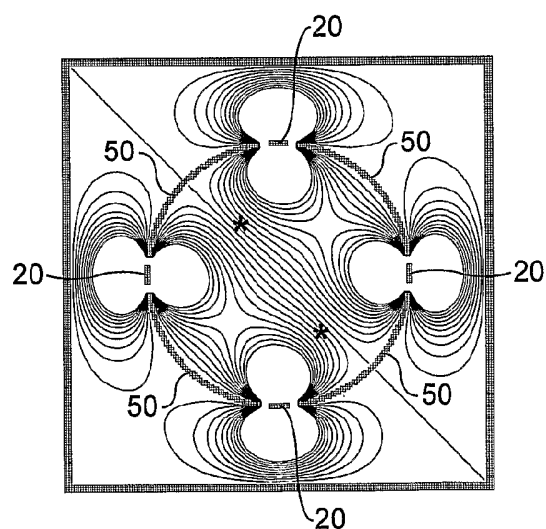


FIG. 3c

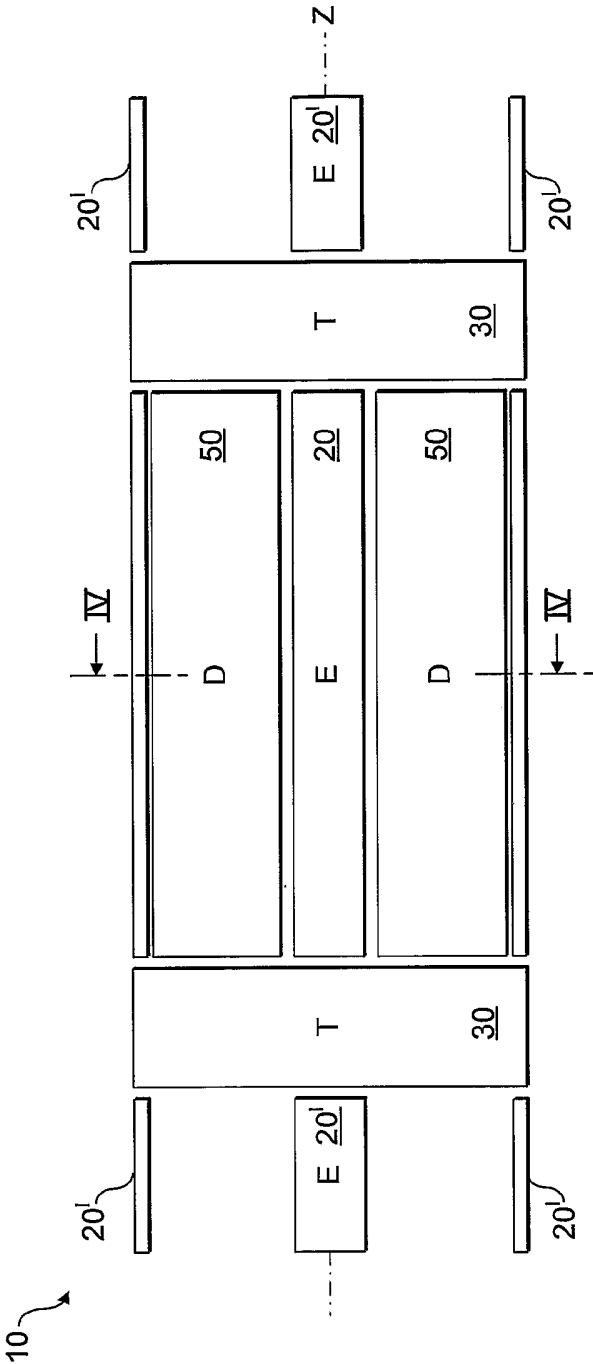


FIG. 4

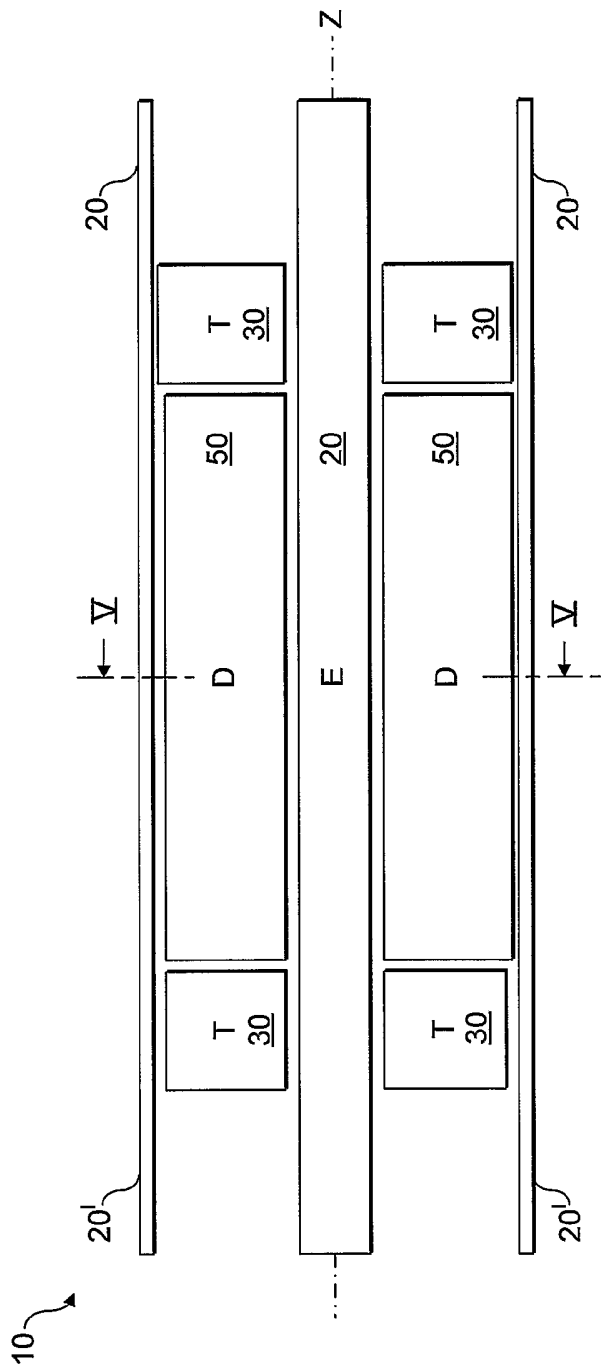


FIG. 5

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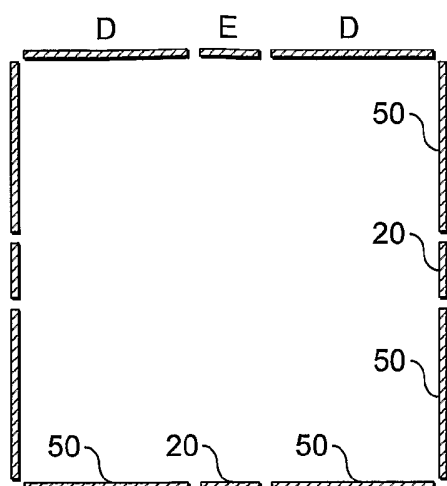


FIG. 6

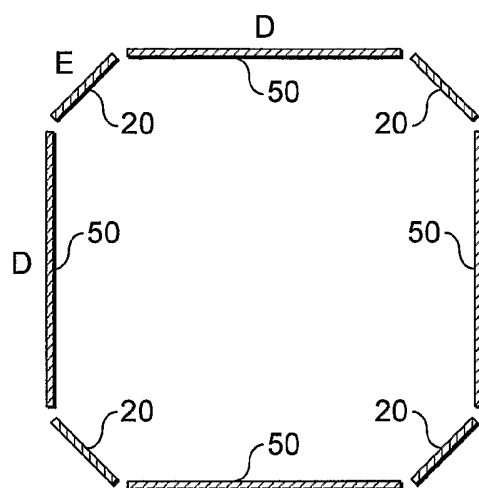


FIG. 7

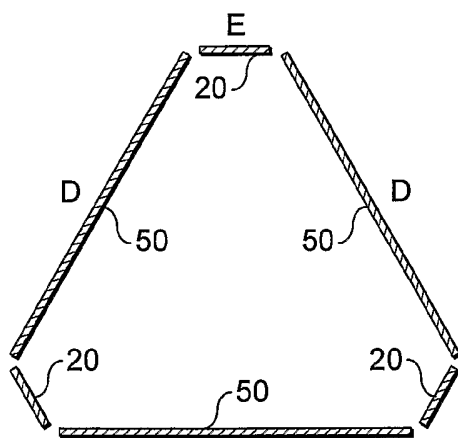


FIG. 8

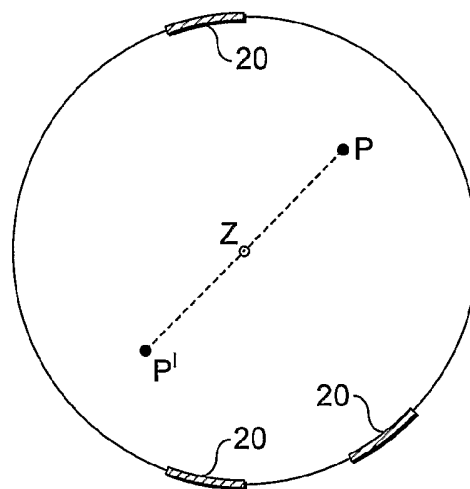


FIG. 9