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(54) **FLY-THROUGH INDUCTIVE CHARGE DETECTOR**

(57) The invention provides an integrated small-input-capacitance detector for nondestructive induced charge measurement, comprising a loop-shaped sensing electrode and an amplifier device, wherein the loop-shaped sensing electrode is assembled physically and directly on the amplifier device, or in close proximity to the amplifier device.

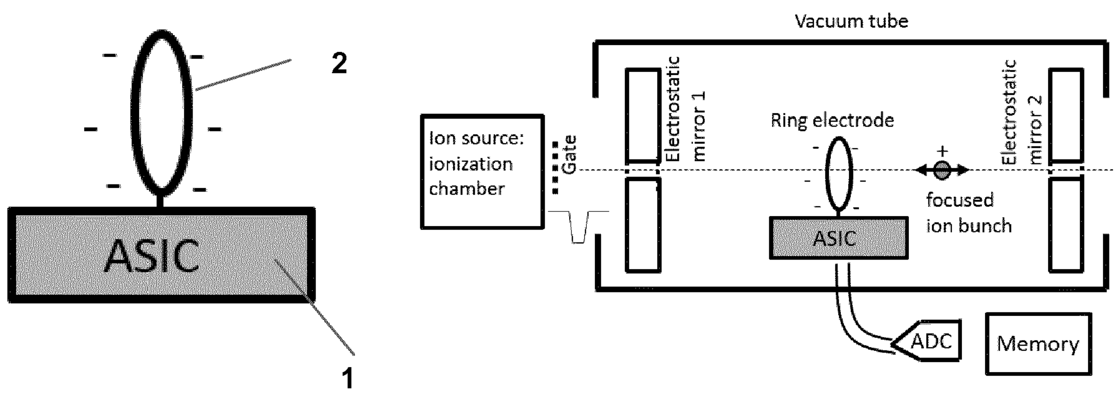

FIG. 2

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Description

Field of the invention

[0001] The invention is in the field of non-destructive charge measurement, with application for example in the field of mass spectrometry or ion mobility spectrometry.

State of the Art

[0002] The analytical method of mass spectrometry (MS) is capable of quantitatively detecting a large diversity of chemically and biologically relevant molecules, with uniquely high sensitivity and selectivity. For this reason, MS has become the reference method for chemical analysis, and large efforts are being undertaken to make it faster, more affordable and more transportable, without compromising either the sensitivity or the selectivity of the method.

[0003] Separation of ions with different mass-to-charge ratio is performed in a mass analyzer either with magnetic or with electric forces. Because of the relative simplicity with which electric forces can be created and precisely controlled, this method is of particular interest for practical applications.

[0004] The detector in mass spectrometers records either the charge induced or the current produced when an ion passes by or hits a surface. Typically, some type of electron multiplier is used, though other detectors including Faraday cups and ion-to-photon detectors are also used. Because for mass spectrometers having the detector placed after the analyzer, the number of ions leaving the mass analyzer at a particular instant is typically quite small, considerable amplification is often necessary to get a signal. Microchannel plate (MCP) detectors are commonly used in modern commercial instruments. In other types of mass spectrometers, where the detector is placed inside the analyzer, such as FTMS and Orbitraps, the detector consists of a pair of metal surfaces within the mass analyzer/ion trap region, which the ions only pass near as they oscillate. No direct current is produced, only a weak AC image current is produced in a circuit between the electrodes.

[0005] Linear electrostatic ion trap (LEIT) type mass spectrometers however, e.g., Ring 2000, Zajfman 2003, Greenwood 2011, feature a passive pick-up ring placed on the ion-optical axis, connected to charge amplification outside of the vacuum chamber. Figure 1 schematically illustrates an ion beam trap according to prior art from Zajfman 2003. The ion beam trap features a central pick-up electrode in the essentially field free center region of the ion beam trap cavity. An ion beam is for example injected through a left side of the trap indicated by an arrow labeled *ENTRANCE.* The ions then form a cloud which oscillates essentially back and forth, inducing repeatedly mirror charges on the pick-up electrode. The mirror charges are amplified and subsequently visualized as pulses on a digital oscilloscope.

[0006] Current detectors, such as microchannel plate detectors (MCPs), lack the ability to measure charges nondestructively, others, like simple rings connected to non-vacuum qualified amplifiers, lack sensitivity due to a long feedline across vacuum-tight feedthroughs leading to large effective input capacitance.

[0007] Hereafter, a brief overview is given of drawbacks known from prior art devices, such as the microchannel plate and the pick-up ring connected to a commercial preamplifier outside the vacuum chamber.

- Drawbacks of MCPs comprise:
    - o destructive detection: ions are lost after single measurement;
    - o high vacuum requirements (e.g., <1e-6 mbar);
    - o channels get saturated/are blocked after each incident for further charge detection (~ms);
    - o detection efficiency dependent on ion velocity (to the fourth power);
    - o detect also neutral species, that are accelerated fast enough (e.g., in linear MALDI-TOF systems); and
    - o cost of goods depend on detector size.
- Drawbacks of pick-up ring connected to commercial preamplifier outside vacuum chamber comprise:
    - o long feed line creating large noise due to big effective input capacitance, limiting the sensitivity;
    - o bulky amplifier setup with need for active cooling; and

o increased power consumption.

[0008] Accordingly, it is an object of the invention to address the various shortcomings encountered in prior art.

[0009] It is thus an object of the invention to provide a means for inductive sensing of the ion clouds drifting in a field-free region, e.g., a region of a linear electrostatic ion trap, whereby the means for inductive sensing must be designed so as to reduce the noise of the induced charge sensing signals and to increase the sensitivity.

[0010] Another object of the invention is to provide a sensor which as a whole is vacuum compatible, small and consuming low power.

Summary of the invention

[0011] In a first aspect, the invention provides an integrated small-input-capacitance detector for nondestructive induced charge measurement, comprising a loop-shaped sensing electrode and an amplifier device, wherein the loop-shaped sensing electrode is assembled physically and directly on the amplifier device, or in close proximity to the amplifier device.

[0012] In a preferred embodiment, the detector further comprises a plurality of further loop-shaped sensing electrodes, wherein the further loop-shaped sensing electrodes are assembled physically and directly on the amplifier device, such that openings of the loops of every loop-shaped sensing electrodes may be traversed by a charge in a single straight line, or any curved line.

[0013] In a further preferred embodiment the loop-sensing electrode is shaped as an open loop.

[0014] In a further preferred embodiment the loop-sensing electrode comprises a plate.

[0015] In a further preferred embodiment the loop-shaped sensing electrode comprises a circular opening.

[0016] In a further preferred embodiment the loop-shaped sensing electrode comprises metal, or electric conductor.

[0017] In a further preferred embodiment the loop-shaped sensing electrode is assembled physically and directly on the amplifier device in an electrically conducting manner.

[0018] In a further preferred embodiment the amplifier circuit is configured to maintain a potential of the loop shaped sensing electrode at a determined constant potential.

[0019] In a further preferred embodiment the amplifier circuit comprises means to provide a charge to the loop-shaped sensing electrode such to maintain the potential at the determined constant potential, an amplifier to amplify the charge provided, a band-pass filter configured to filter the output of the amplifier, and to output a voltage signal at an output of the amplifier circuit.

[0020] In a further preferred embodiment the amplifier circuit comprises an application specific integrated circuit, and the loop-shaped sensing circuit is assembled on the application specific integrated circuit.

[0021] In a further preferred embodiment the amplifier circuit further comprises means for observation of the output of the amplifier configured to detect a saturation of the amplifier circuit, and a reset switch configured to reset an input charge of the amplifier circuit when the saturation of the amplifier circuit is detected.

[0022] In a further preferred embodiment the amplifier is configured such that the gain of the amplifier is changed by a switch of the capacitors and resistors in its feedback whereby this change leads to an increased dynamic range.

[0023] In a further preferred embodiment the amplifier circuit contains ESD structures that protect the circuit from electrostatic discharges with the ESD structures designed in a way such as not to increase the input capacitance of the amplifier.

[0024] In a second aspect the invention provides an ion trap chamber for mass spectrometry measurements comprising an integrated small-capacitance detector as described herein above, wherein the ion trap chamber comprises a first electrostatic mirror and a second electrostatic mirror configured together as a resonator for bunches of ions entering the ion trap chamber, whereby the one or plurality of loop-shaped sensing electrodes are positioned substantially in a middle between the first electrostatic mirror and the second electrostatic mirror such that the bunches of ions pass through the opening of the one or plurality of loop-shaped sensing electrodes when traveling back and forth between the first electrostatic mirror and the second electrostatic mirror.

[0025] In a further preferred embodiment, the ion trap chamber further comprises an analog to digital converter and processing means, whereby the output of the one or the plurality of amplifier circuits is connected to an input of the analog to digital converted, and the processing means process data received from the analog to digital converter, whereby the processing means are enabled to determine a mass of the ions in the bunch of ions.

[0026] In a further preferred embodiment, when intended ions of the bunch of ions oscillate they do so at a specific frequency according to their mass-to-charge ratio, governed by

$$f = k \cdot \sqrt{q/m}$$

with f being the specific oscillation frequency, q the charge and m the mass of the ion and k being a proportionality factor entirely defined by the resonator geometry, ion optics and ion energy, stating that the oscillation time is inversely proportional to the square-root of the mass-to-charge ratio.

[0027] The invention hence provides an electronic charge sensing circuit which is in close contact with the means for inductive charge sensing/inductive sensing electrode, for example also when the means for inductive charge sensing in mounted in an ion trap. The charge sensing circuit is optimized to the charge measurement task, resulting in charge sensing signals with an effective noise, in the root mean sense, of the order of a few tens electrons only.

[0028] The invention further provides sensing electrodes that are mounted directly on the charge detection circuits, i.e., on a pad directly connected to the front-end amplifier to best reduce input capacitance and increase sensitivity. Since signal noise is a product of input-referred noise of the front-end amplifier times input capacitance of the front-end amplifier, both are minimized for optimum performance.

[0029] The invention further provides a sensor comprising a pick-up ring and electronics circuits which are vacuum compatible.

Brief description of the figures

[0030] The invention will be better understood through the description of preferred embodiments and in view of the drawings, wherein

figure 1 contains a schematic view of an ion beam trap with central pick-up electrode in the essentially field free center region according to prior art;

figure 2 illustrates on its left a sensor comprising charge detection ASIC and pick-up ring mounted directly on top of it, and on its right a typical implementation of the sensor in an electrostatic ion resonator according to a preferred embodiment of the invention;

figure 3 contains schematics of an input charge amplifier according to a preferred embodiment of the invention;

figure 4 contains schematics of an input stage of a charge amplifier together with an ESD protection according to a preferred embodiment of the invention;

figure 5 contains a graph relation to internal reset activation according to an example embodiment of the invention;

figure 6 (former figure 7) contains a picture of an example embodiment of a sensor according to the invention comprising 4 pick-up rings mounted in succession;

figure 7 (former figure 8) represent a detector circuit that was implemented as application specific integrated circuit (ASIC), whereby the left shows the architecture of the circuit and the right the shift register;

figure 8 shows a picture of a PCB (printed circuit board) with a mounted ASIC and a 4 mm diameter pick-up ring assembled directly on the ASIC;

figure 9 contains graphs of measurement made with a ASIC detector circuit: measurement of Ar^{+} and Ar^{++} ions in an electrostatic ion resonator. The top part show a full measurement, and the bottom part a zoom-in to a few peaks; and

figure 10 contains graphics illustrating a bonding procedure for pick-up electrodes on ASICs.

Detailed description of preferred embodiments of the invention

[0031] In a preferred embodiment, the invention provides an integrated small-capacitance detector for nondestructive induced charge measurement. The detector may be deployed individually or as an array of single detectors, whereby each detector includes its own ultra-low-noise intelligent amplifier and small metal pick-up ring physically directly assembled on top of the circuit of the amplifier, for use, e.g., in a compact electrostatic ion resonator for mass spectrometry with signal processing algorithms in time or frequency domain or a combination of both.

[0032] The charge pick-up detectors may measure ions without disturbing their flight trajectories and allow to generate mass spectra with high mass resolving power, high dynamic range, high sensitivity at high mass range.

[0033] Figure 2 illustrates an example embodiment of a sensor according to the invention. Figure 2 is divided in two parts.

[0034] On the left side part, figure 2 schematically represents a sensor that comprises a charge detection ASIC 1 and the pick-up ring 2 mounted directly on top of the charge detection ASIC 1. The charge detection ASIC 1 may be embodied for example by a printed circuit board, or a casing containing a circuit (both not represented in figure 2). The charge detection ASIC 1 is the ultra-low-noise intelligent amplifier of the signal providing from the pick-up ring 2. The pick-up ring 2 may be made out of metal.

[0035] While figure 2 shows a pick-up ring 2 as loop-sensing electrode, various other types of electrodes may be used, such as for example a loop-sensing electrode shaped as an open loop, or a loop-sensing electrode comprising a plate, straight or bent.

[0036] On the right side part of figure 2, a typical implementation of the sensor in an electrostatic ion resonator is shown. A vacuum tube enables ions from an ion source, i.e., an ionization chamber to enter the vacuum cavity by firstly passing through a first electrostatic mirror. The ions are represented as a focused ion bunch. The focused ion bunch continues its path until it reaches a second electrostatic mirror where it is decelerated and accelerated in opposite direction, effectively mirrored back towards the first electrostatic mirror, which meanwhile has been set to also mirror the focused ion bunch back in direction of the second electrostatic mirror. While travelling back and forth between the two electrostatic mirrors, the focused ion bunch passes through the pick-up ring of the sensor, which is positioned halfway between the electrostatic mirrors. The signal output by the ASIC amplifier as a result of the focused ion bunch passing through the pick-up ring in converted into a digital signal by an analog digital converter ADC and subsequently stored in a memory for further processing.

[0037] The inventive setup of figure 2, right side part, effectively enables nondestructive sensing of charged particles-singly charged monatomic ions to multiply charged nanoparticles-with high sensitivity, as required in particular by mass spectrometry according to the time-of-flight principle.

[0038] Moreover specifically, this invention enables the realization of miniaturized integrated detectors for mass spectrometers with much reduced geometrical size and fabrication cost than in prior art, that do not need forced cooling and can be placed directly around the ion-optical axis in a vacuum recipient.

[0039] The invention may also be used in other fields, e.g., as a bacteria detector (bacteria are always negatively electrically charged) in a microfluidic setup.

Sensing principle

[0040] Ion bunches pass through the center of the pick-up ring, i.e., a ring-formed sensing electrode attached to the detector circuit, realized as the application specific integrated circuit (ASIC). The sensing electrode is electrically biased at a constant potential versus system ground, and is supposed not to disturb trajectories of flying ions from the ion bunches.

[0041] Keeping the ring-formed sensing electrode at a constant potential requires that, when charged particles pass through the ring, there will be an extra amount of charge at the ring-formed sensing electrode induced by rules of electrostatics. That extra amount of charge is amplified, band-pass-filtered and delivered to the output of the ASIC as a differential, continuous-time voltage signal for off-chip analog-to-digital conversion and data post-processing in order to extract information about the ion bunches traveling through the ring electrode: ion mass and number of ions in each bunch.

[0042] A first stage of the abovementioned signal processing is a low-noise charge-to-voltage converter as shown in figure 3. High gain of the amplifier causes the induced charge on the electrode Q to be converted into voltage on the feedback capacitance C_f. Feedback resistor R_f provides DC biasing to the input and also, together with C_f provides a high-pass filter function for electrode signal. In order to extend dynamic range, it is possible to select different feedback capacitors C_f: for high sensitivity and small charges Q, small C_f is chosen, while for large Q, large C_f can be selected. Selection between different C_f and R_f value may be done by connecting MOS transistors-switches in series with different C_f or R_f elements and turning them on or off by controlling their gate potentials.

[0043] Hence the selectable feedback capacitor / resistor around the input amplifier enables larger dynamic range of the system.

[0044] Since detection noise Q_n of the amplifier is:

$$Q_n = V_n \cdot C_{in} \qquad \text{Equation 1}$$

[0045] V_n is input referred noise voltage and C_{in} is input capacitance of the amplifier; both V_n and C_{in} have to be minimized for optimum performance of the system. V_n is minimized by using a single-input-transistor amplifier as shown in figure 4 driven at a possibly large bias current (M1 with current 11) to achieve high transconductance of that transistor. Transistor M1 can also be a cascade transistor. Minimization of C_{in}, like already mentioned, is achieved by fabricating the electrode directly on top of the IC, keeping the pad size small and using top metal layers for the pad, as well as using only small-size ESD structures - preferably only diodes. Diode D1 handling negative strikes is connected to GND. Diode

D2, handling positive strikes is connected to a replica node, whose potential is the same as V_{in}, if M2 and I2 are scaled replicas of M1 and I1. ESD current flows through D1 and D2. This arrangement minimizes capacitance at V_{in} as well as leakage current, avoids input coupling to VDD supply and at the same time provides enough ESD protection level.

[0046] The amplifier accepts both negatively and positively charged particles. If very large ion packets pass through the ring-formed sensing electrode, the charge amplifier might get and stay saturated. Such an event happens if the input node collects extra charge during bunch passing, for example from ions colliding with the ring-formed sensing electrode, or from opening parasitic diodes at the ring-formed sensing electrode, when its potential drifts too much from nominal. If that happens, extra measures have to be implemented to restore normal operation; otherwise, the charge amplifier will stay saturated for long time. One possibility is to externally apply a reset to the charge amplifier. Another possibility is to internally detect saturation of the charge amplifier and automatically activate the reset of the charge amplifier. Referring now to the graph of figure 5, the internal activation of reset is based on observation of output of an amplifier (y-axis in the graph): differential, or single-ended that changes its state from saturation-high to saturation-low, or vice-versa. If such an event is detected, reset switch across input charge amplifier is activated.

[0047] The pick-up ring or ring-formed sensing electrode may be a metal tube. In a preferred embodiment the metal is Aluminum. The pick-up ring is dimensioned with an internal diameter large enough in order to let the ion bunch of beam pass through. In a preferred embodiment the internal diameter is in the range of 1-5 mm. The pick-up ring is further dimensioned such that its length measured in the direction in which the ion bunch travels, is optimized to the ion energy. In a preferred embodiment the length in in the range of 0.1-1 mm. Furthermore the pick-up ring is directly connected to the ASIC. The ions of the ion bunch fly through the pick-up ring while generating mirror-charges on the ring surface of the pick-up ring.

[0048] The pick-up ring has to be connected directly to the ASIC in the shortest way, i.e., it is assembled on top of it, to the input pad. An integration of the charge pick-up ring directly on the ASIC, which works as a charge detection circuit chip, may be realized either by bonding techniques or by additive manufacturing directly on the ASIC. The bonding of the electrode directly onto the ASIC may be solved by using a dielectric interposer.

[0049] In case more than 1 ring-formed sensing detector is used, it is possible to do a separate processing of the signal of each detector for its different charge signal shape, due to the ion cloud dispersion of the multi-reflection system.

[0050] A combination of the different signals after separate processing enables an ultra-low-noise measurement of the sample's mass spectrum.

Advantages of the invention

[0051] The following lists a number of advantages inherent to the invention, in an non-exhaustive manner.

- With the pick-up rings mounted directly on the integrated ultra-low-noise charge detection circuit, the limit of detection in nondestructive charge detection is reduced to as few as tens of electrons (compared with external prior art pre-amplifiers).
- No vacuum requirement (compared with prior art MCPs).
- Low-cost, vacuum-compatible preamplifier (compared with external amplifier stages).
- Detection efficiency independent of ion velocity (compared with MCPs).
- Detector does not get stuck (compared with MCPs, in which channels get blocked for ms).
- Dynamic range enhancement by using multiple measurements with different gain settings.
- Insensitive to neutral species (compared with MCPs).

Examples of further preferred Implementations

[0052] Referring to figure 6, this contains pictures of a preferred embodiment of the sensor. The sensor comprises 4 independent pick-up ring detectors, which are implemented as a discrete circuit. The 4 independent pick-up electrodes are mounted on a charge detection circuit board. The left side part of figure 6 contains a side-view with the ion flight-axis showing out of the picture plane. The charge detection circuit board is visible at the upper side of the picture. The ruler allows to estimate a length of the board at about 8 cm.

[0053] The right side part of figure 6 is a bottom-view of the 4 pick-up ring electrodes.

[0054] Referring to figure 8, this contains a picture of a PCB (printed circuit board) with a mounted ASIC and a 4 mm diameter pick-up ring assembled directly on the ASIC. The configuration of figure 8 may for example be used with the electrostatic ion resonator mass spectrometer of figure 2 for testing and characterization. An example layout for the ASIC detection circuit of figure 8 is shown in figure 7. The detector circuit is thus implemented as an application specific integrated circuit (ASIC) in TSMC 65 nm CMOS technology using 1.2 V and 2.5 V transistors. The left part of figure 7 shows the ASIC architecture, while the right part illustrates a shift register

Ions with a certain kinetic energy E_i from a pulsed ion source enter the resonator at the left side as illustrated in figure

2, therefore the voltages on the left mirror electrodes (electrostatic mirror 1) are lowered by means of fast HV-switches (not shown in figure 2). Once the ions are inside the resonator the voltages are set back to their nominal value and the "gate" is closed. The ions are being reflected at the right mirror (electrostatic mirror 2), fly back to the left mirror and are being reflected again, thus they start oscillating with specific frequencies according to their mass-to-charge ratio, governed by Equation 2, with f being the oscillation frequency, q the charge and m the mass of the ion and k being a proportionality factor entirely defined by the resonator geometry, ion optics and ion energy, stating that the oscillation time is inversely proportional to the square-root of the mass-to-charge ratio.

$$f = k \cdot \sqrt{q/m} \quad or \quad m = q/(f \cdot k)^2 \qquad \text{Equation 2}$$

[0055] The pick-up electrodes in the middle of the resonator-any embodiment of pick-up electrode discussed herein-may be used to induce mirror charges every time a packet of ions of the same mass-to-charge ratio flies through them. This charge is detected, converted into voltage, amplified and sent to analog to digital converter in the data acquisition system. In the latter the pulses detected this way in the time domain are processed both in time and frequency domain to generate a mass-to-charge spectrum of the trapped ions.

[0056] The pick-up rings may be fabricated with laser cutting of an aluminum sheet.

[0057] In a preferred embodiment, the pick-up ring is bonded per ASIC, onto a special pad directly connected to the front-end amplifier input with adhesive means.

Results of measurements

[0058] Referring to figure 9, this contains graphs of measurement made with an ASIC detector circuit: measurement of Ar+ and Ar++ ions in an electrostatic ion resonator. The top part of figure 9 shows the full measurement, while the bottom part zooms in to a few peaks only.

Manufacturing topics

[0059] In addition to explanation about manufacturing already given herein above, the pick-up ring may be fabricated according to at least the following non-exhaustive list of fabrication methods:

- machining from a metal sheet;
- stamping from a metal sheet;
- laser cutting from a metal sheet;
- electroplating; and
- 3D-printing (both conductive polymer and metal pre-cursor that is sintered).

[0060] Various assembly procedures of the pick-up ring to the circuit may be realized as explained herein below in a non-exhaustive manner:

- gluing with conductive glue using a dielectric interposer (for instance, glass or ceramic substrate) to increase the stability, as shown in figure 10. The idea is to glue a dielectric interposer around the ASIC pad. Such interposer is shown as an example under the name *Glass chip (borosilicate).* The electrode tip-illustrated at the left of figure 10, for a *large electrode* and for a *small electrode,* both tips appear have slightly different lengths, and belonging to the electrodes illustrate at a whole at the bottom of figure 10, with the same name-is then inserted in a central hole of the interposer and conductively coupled to the ASIC pad using a conductive adhesive (not shown in figure 10). The use of the interposer allows to massively increase the stability of the bonding of the electrode;
- thermocompression bonding: the electrode and substrate can be heated up and brought into contact under a given pressure to achieve diffusion bonding (not illustrated in the figures);
- soldering; and
- 3D-printing of the rings directly onto the contact pads.

References

[0061]

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Claims

1. An integrated small-input-capacitance detector for nondestructive induced charge measurement, comprising a loop-shaped sensing electrode and an amplifier device, wherein the loop-shaped sensing electrode is assembled physically and directly on the amplifier device, or in close proximity to the amplifier device.

2. The detector of claim 1, further comprising a plurality of further loop-shaped sensing electrodes, wherein the further loop-shaped sensing electrodes are assembled physically and directly on the amplifier device, such that openings of the loops of every loop-shaped sensing electrodes may be traversed by a charge in a single straight line, or a curved line.

3. The detector of claim 1, wherein the loop-sensing electrode is shaped as an open loop.

4. The detector of claim 1, wherein the loop-sensing electrode comprises a plate.

5. The detector of claim 1, wherein the loop-shaped sensing electrode comprises a circular opening.

6. The detector according to any one of claims 1 to 5, wherein the loop-shaped sensing electrode comprises metal, or electric conductor.

7. The detector according to any one of claims 1 to 6, wherein the loop-shaped sensing electrode is assembled physically and directly on the amplifier device in an electrically conducting manner.

8. The detector according to any one of claims 1 to 7, wherein the amplifier circuit is configured to maintain a potential of the loop shaped sensing electrode at a determined constant potential.

9. The detector according to claim 8, wherein the amplifier circuit comprises means to provide a charge to the loop-shaped sensing electrode such to maintain the potential at the determined constant potential, an amplifier to amplify the charge provided, a band-pass filter configured to filter the output of the amplifier, and to output a voltage signal at an output of the amplifier circuit.

10. The detector according to any one of claims 8 or 9, wherein the amplifier circuit comprises an application specific integrated circuit, and the loop-shaped sensing circuit is assembled on the application specific integrated circuit.

11. The detector according to any one of claims 8 to 10, wherein the amplifier circuit further comprises means for observation of the output of the amplifier configured to detect a saturation of the amplifier circuit, and a reset switch configured to reset an input charge of the amplifier circuit when the saturation of the amplifier circuit is detected.

12. The detector according to any one of claims 8 to 11, wherein the amplifier is configured such that the gain of the amplifier is changed by a switch of the capacitors and resistors in its feedback whereby this change leads to an increased dynamic range.

13. The detector according to any one of claims 8 to 12, wherein the amplifier circuit contains ESD structures that protect the circuit from electrostatic discharges with the ESD structures designed in a way such as not to increase the input capacitance of the amplifier.

14. An ion trap chamber for mass spectrometry measurements comprising an integrated small-capacitance detector of any one of claims 1 to 13, wherein the ion trap chamber comprises a first electrostatic mirror and a second electrostatic mirror configured together as a resonator for bunches of ions entering the ion trap chamber, whereby the one or plurality of loop-shaped sensing electrodes are positioned substantially in a middle between the first electrostatic mirror and the second electrostatic mirror such that the bunches of ions pass through the openings of the one or the plurality of loop-shaped sensing electrodes when traveling back and forth between the first electrostatic mirror and the second electrostatic mirror.

15. The ion trap chamber of claim 14, further comprising an analog to digital converter and processing means, whereby the output of the one or the plurality of amplifier circuits are connected to one or multiple inputs of the analog to digital converted, and the processing means process data received from the analog to digital converter, whereby the processing means are enabled to determine a mass of the ions in the bunches of ions.

16. The ion trap chamber of claim 15, wherein when intended ions of the bunches of ions oscillate they do so at a specific frequency according to their mass-to-charge ratio, governed by

$$f = k \cdot \sqrt{q/m}$$

with f being the specific oscillation frequency, q the charge and m the mass of the ion and k being a proportionality factor entirely defined by the resonator geometry, ion optics and ion energy, stating that the oscillation time is inversely proportional to the square-root of the mass-to-charge ratio.

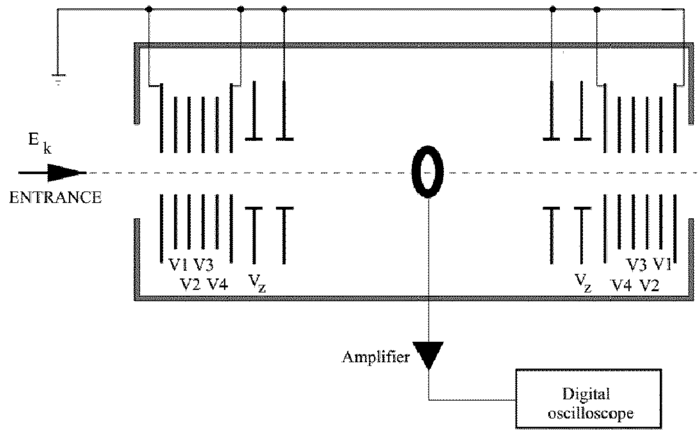


FIG. 1 — PRIOR ART

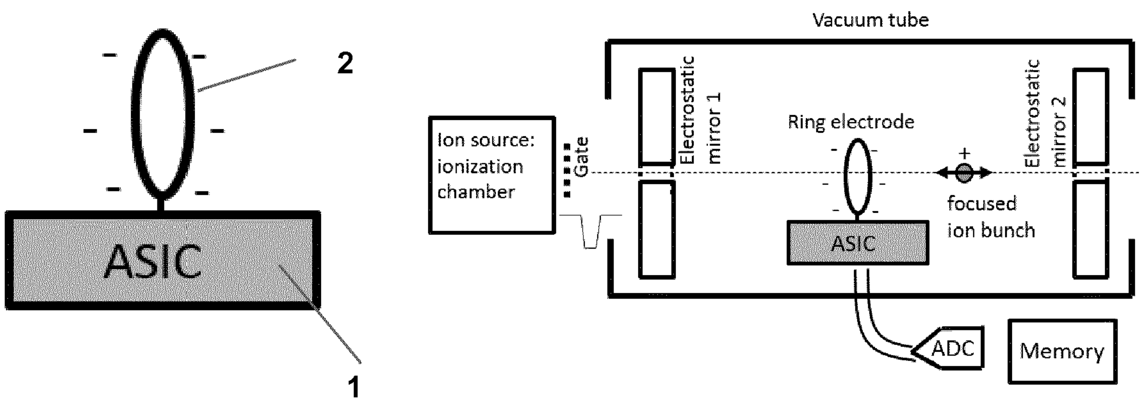


FIG. 2

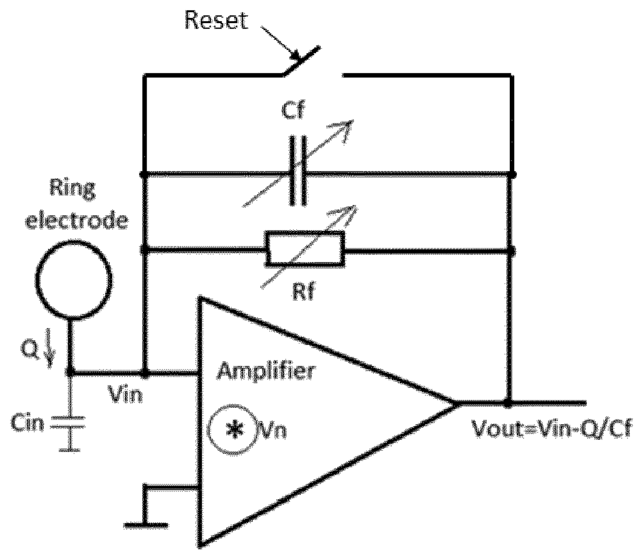

Reset
Cf
Ring
electrode
Rf
Q
Amplifier
Vin
Cin
Vn
Vout=Vin-Q/Cf

FIG. 3

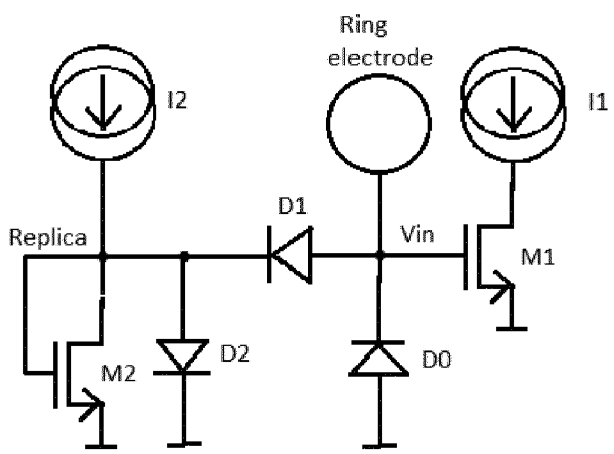

Ring
electrode
I2
I1
D1
Replica
Vin
M1
D2
D0
M2

FIG. 4

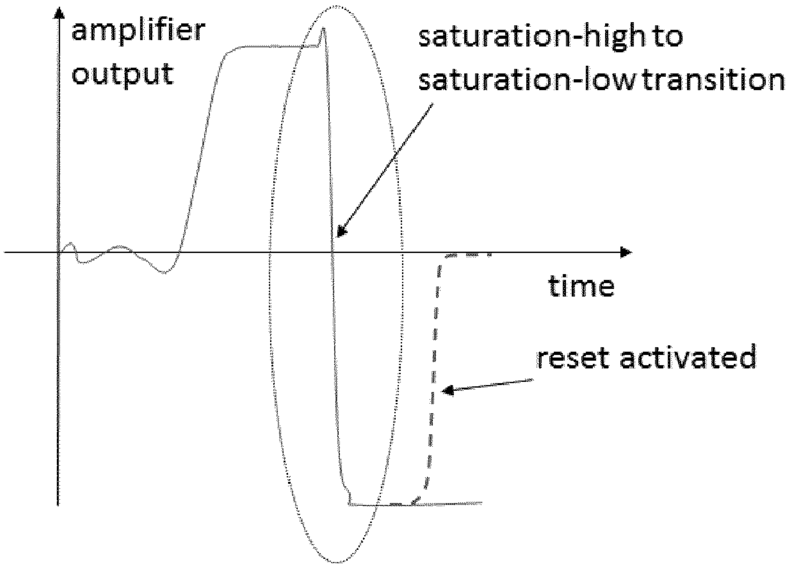

amplifier
output
saturation-high to
saturation-low transition
time
reset activated

FIG: 5

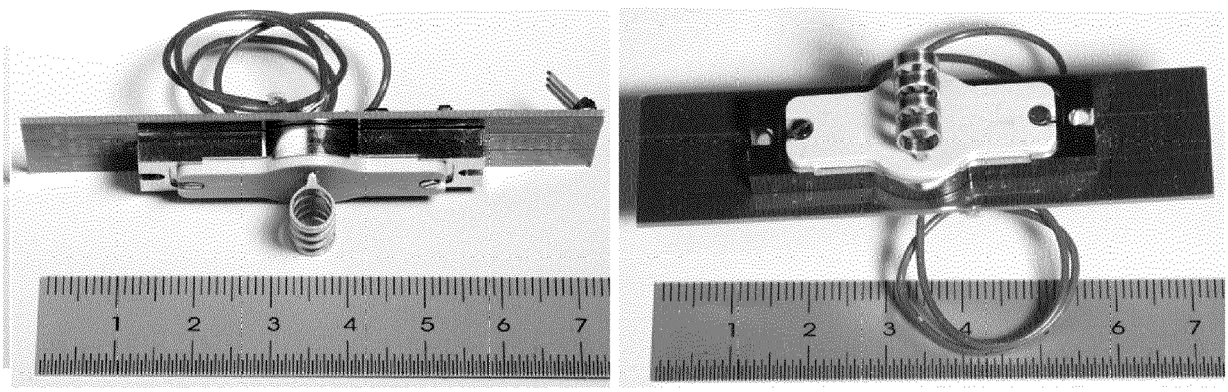


FIG: 6

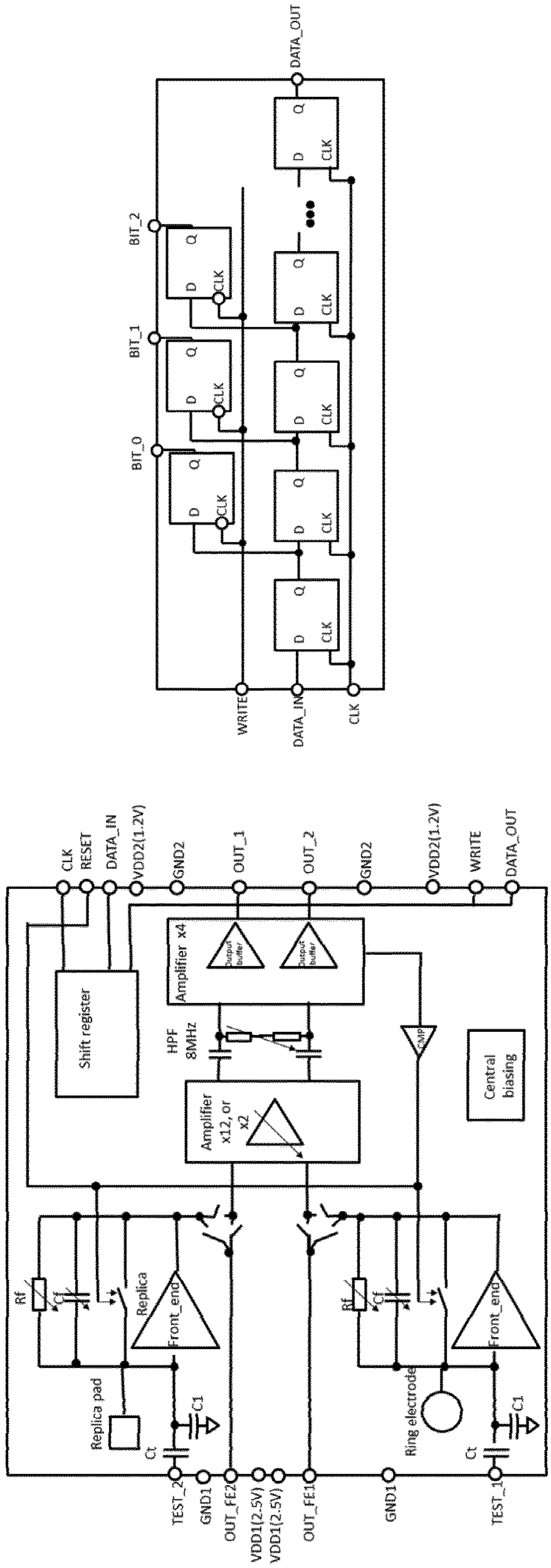

DATA_OUT
BIT_0
BIT_1
BIT_2
D
Q
CLK
WRITE
DATA_IN
CLK
RESET
DATA_IN
VDD2(1.2V)
GND2
OUT_1
OUT_2
GND2
VDD2(1.2V)
WRITE
DATA_OUT
Shift register
Amplifier x4
Output buffer
HPF 8MHz
Amplifier x12, or x2
CMP
Central biasing
Rf
Cf
Replica
Front_end
Replica pad
Ring electrode
Ct
C1
TEST_2
GND1
OUT_FE2
VDD1(2.5V)
VDD1(2.5V)
OUT_FE1
GND1
TEST_1

FIG. 7

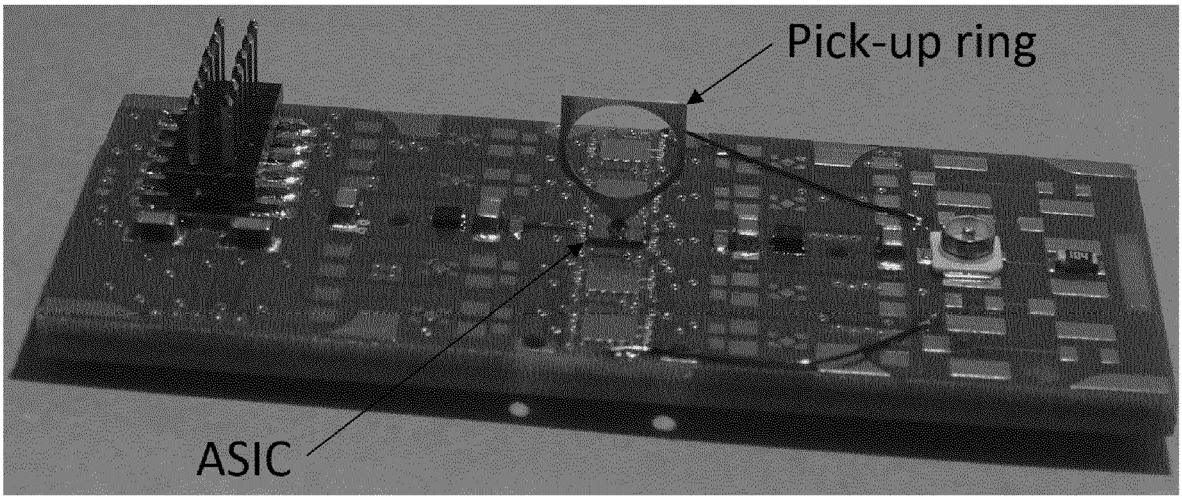
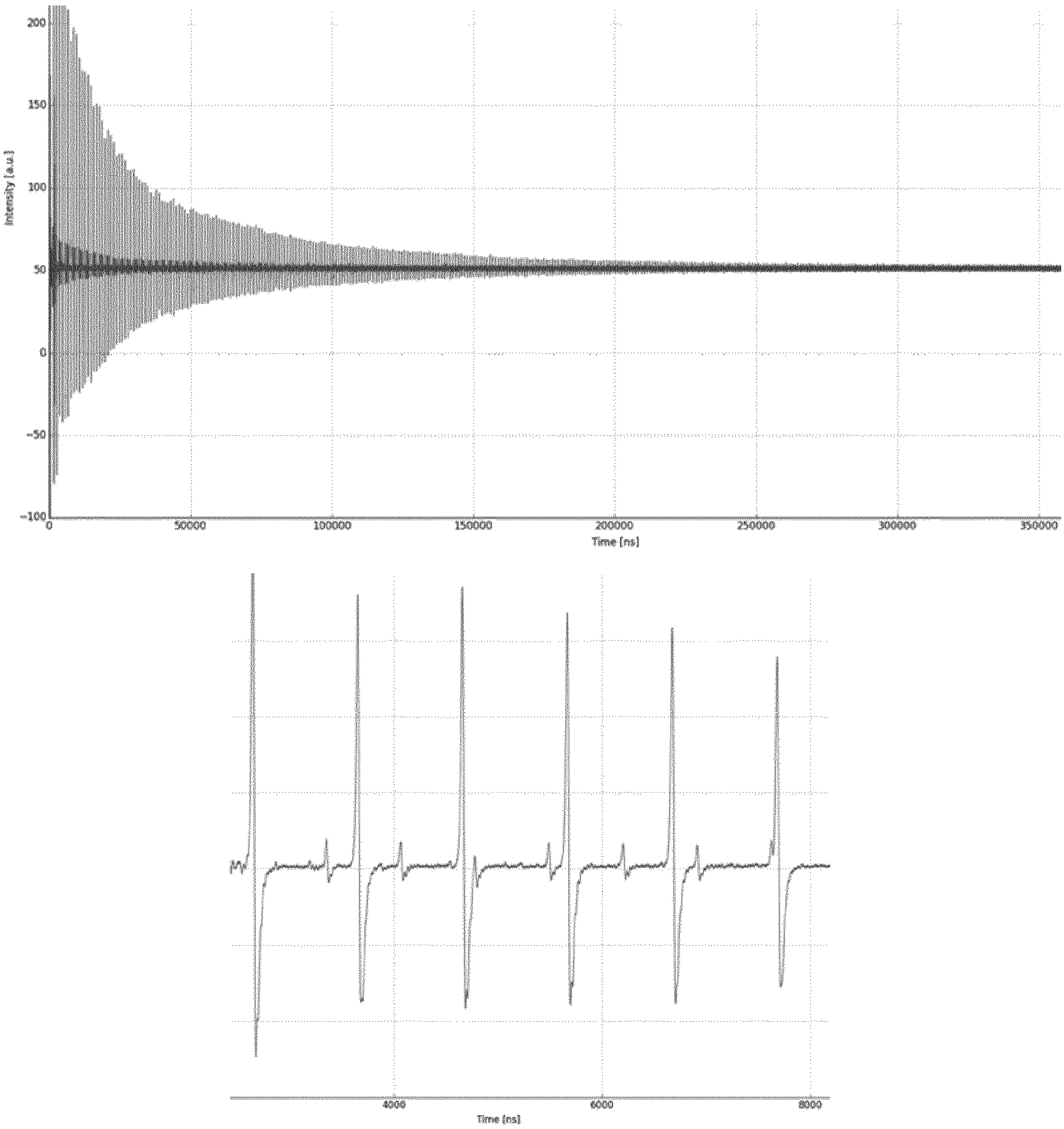


FIG. 8



200
150
100
50
0
−50
−100
Intensity [a.u.]
0
50000
100000
150000
200000
250000
300000
350000
Time [ns]
4000
6000
8000
Time [ns]

FIG. 9

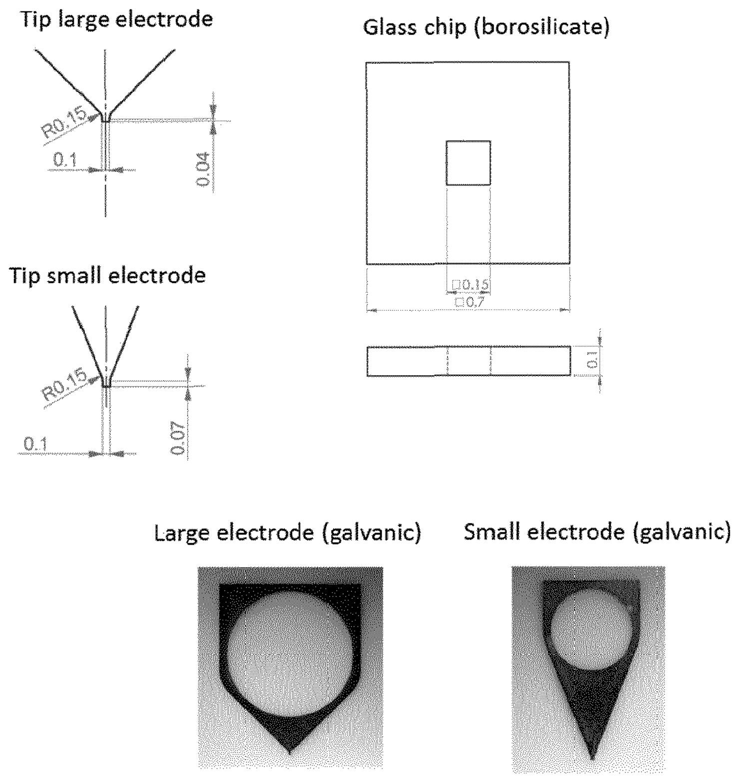

Tip large electrode
R0.15
0.1
0.04
Tip small electrode
R0.15
0.1
0.07
Glass chip (borosilicate)
□0.15
□0.7
0.1
Large electrode (galvanic)
Small electrode (galvanic)

FIG. 10

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EUROPEAN SEARCH REPORT

Application Number
EP 16 20 5943

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	N/a: "CSEM - Scientific and Technical Report 2014", , 27 January 2015 (2015-01-27), XP055383460, Retrieved from the Internet: URL:http://csem.swiss/Doc.aspx?id=31628 [retrieved on 2017-06-21] * page 16 * -----	1-16	INV. H01J49/02 H01J49/42 H01J49/00
A	US 5 880 466 A (BENNER W HENRY [US]) 9 March 1999 (1999-03-09) * abstract * * figure 2 * * column 5, lines 20-39 * * column 6, lines 12-45 * -----	1-16	
A	WO 2012/083031 A1 (UNIV INDIANA RES & TECH CORP [US]; SMITH JONATHAN [US]; JARROLD MARTIN) 21 June 2012 (2012-06-21) * abstract * * figure 8 * * paragraphs [0034], [0080], [0082] * -----	1-16	TECHNICAL FIELDS SEARCHED (IPC)
A	BRANDON L. BARNEY ET AL: "A multi-stage image charge detector made from printed circuit boards", REVIEW OF SCIENTIFIC INSTRUMENTS., vol. 84, no. 11, 30 November 2013 (2013-11-30), page 114101, XP055383209, US ISSN: 0034-6748, DOI: 10.1063/1.4828668 * abstract * * figure 3 * * Section "II. Experimental Setup" on pages 3-4 * ----- -/--	1-16	H01J

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	21 June 2017	Dietsche, Rainer

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)

1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	21 June 2017	Dietsche, Rainer

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21-06-2017

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