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(71) Applicant: **THE UNIVERSITY OF MANCHESTER**
[GB/GB]; Oxford Road, Manchester M13 9PL (GB).(72) Inventors: **FLANAGAN, Kieran**; 7 Shirebrook Drive,
Glossop Derbyshire SK13 8RF (GB). **FLUERAS, Andra-**
da; 4A Miron Costin, Cluj-Napoca, 400169 Cluj (RO).
BINNERSLEY, Cory; Apartment 62, 1 Isaac Way, Man-
chester Greater Manchester M4 7ED (GB).(74) Agent: **HGF LIMITED**; 4th Floor, Merchant Exchange,
17-19 Whitworth Street West, Manchester Greater Man-
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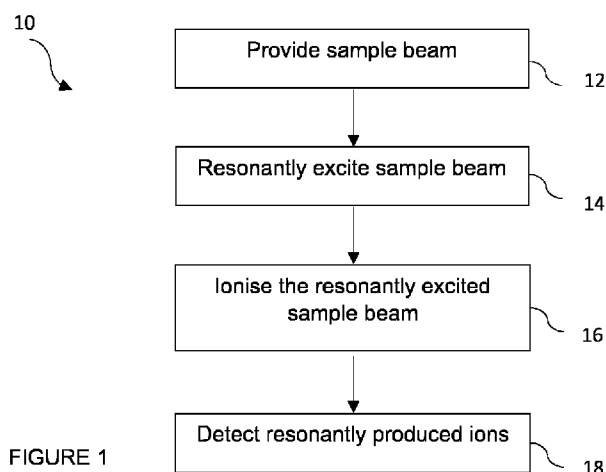


FIGURE 1

(57) Abstract: A method of determining the presence of ions in a sample, comprising providing a beam containing the sample, and using a first laser excitation means to resonantly excite the sample beam, wherein the first excitation means includes at least one continuous wave laser beam, and wherein resonant excitation of the sample beam by the first laser excitation means forms a resonantly excited sample beam. The method further comprises using a second laser excitation means to ionise the resonantly excited sample beam to form resonantly produced ions and resonantly produced electrons, wherein the second excitation means includes a continuous wave laser beam substantially perpendicular to the sample beam, and detecting the resonantly produced ions.



METHOD AND APPARATUS FOR DETERMINING THE PRESENCE OF IONS IN A SAMPLE

[0001] This invention relates to a method and apparatus for determining the presence of ions in a sample.

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BACKGROUND

[0002] It is known that laser spectroscopy can be used for the study of isotopes.

Conventional approaches use a sample beam containing the isotope of interest and a pulsed laser beam to excite and/or ionise the sample. The sample beam is typically a bunched beam, where the bunching of a beam is achieved using ion traps.

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[0003] The study of exotic isotopes of light elements, such as carbon and oxygen, presents major challenges to the established techniques used in laser spectroscopy. These elements are highly reactive making the trapping and manipulation of the ions of these elements particularly difficult. Additionally, the ionic and atomic transitions from the ground states of these elements are in the extreme ultra-violet range which is not accessible to conventional lasers in laser spectroscopy. As such, the study of light elements using bunched sample beams and conventional pulsed lasers is challenging.

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[0004] It is an object of the present invention to provide a method for determining the presence of ions in a sample that overcomes at least some of the disadvantages associated with the prior art. The identification of ions may facilitate the identification of isotopes.

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BRIEF SUMMARY OF THE DISCLOSURE

[0005] In accordance with the present invention there is provided a method of determining the presence of ions in a sample, comprising:

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providing a beam containing the sample;

using a first laser excitation means to resonantly excite the sample beam, wherein the first excitation means includes at least one continuous wave laser beam, and wherein resonant excitation of the sample beam by the first laser excitation means forms a resonantly excited sample beam;

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using a second laser excitation means to ionise the resonantly excited sample beam to form resonantly produced ions and resonantly produced electrons, wherein the second excitation means includes a continuous wave laser beam substantially perpendicular to the sample beam; and

detecting the resonantly produced ions.

[0006] The step of using the first laser excitation means to resonantly excite the sample beam may include using at least one continuous wave laser beam arranged substantially collinearly with the sample beam.

[0007] The step of using the first laser excitation means to resonantly excite the sample beam may include using at least one continuous wave laser beam arranged substantially perpendicular to the sample beam.

[0008] Additionally or alternatively, the step of using the first laser excitation means to resonantly excite the sample beam may include using at least one continuous wave laser beam arranged substantially perpendicular to the sample beam to excite the sample beam in a two photon excitation process.

[0009] The step of using the first laser excitation means to resonantly excite the sample beam may include passing the sample beam through a first optical cavity arranged in the optical path of the at least one continuous laser beam arranged substantially perpendicularly with the sample beam. In such embodiments, the first optical cavity may be a standard bow-tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

[0010] In certain embodiments, using the second laser excitation means may include using a continuous wave laser arranged substantially perpendicularly with the sample beam to excite the sample beam to a Rydberg level.

[0011] The step of using a second laser excitation means to ionise the resonantly excited sample beam may include passing the sample beam through a second optical cavity arranged in the optical path of the second laser excitation means. In such embodiments, the second optical cavity may be a standard bow-tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

[0012] In certain embodiments, detecting the resonantly produced ions may comprise:

- detecting ions produced from the resonantly excited sample beam;
- obtaining data relating to the resonantly produced electrons resulting from the resonant ionisation of the sample beam; and
- determining the presence of resonantly produced ions in the detected ions using the data relating to resonant electrons.

[0013] The step of determining the presence of resonantly produced ions in the sample may comprise:

- producing an ion signal relating to ions resulting from the resonant ionisation of the sample beam; and
- processing the ion signal using the data relating to the resonantly produced electrons.

[0014] In certain embodiments, detecting the resonantly produced ions may comprise determining a resonance time period using the data relating to the resonantly produced electrons, wherein processing the ion signal may comprise excluding parts of the ion signal that are not associated with the determined resonance time period.

5 [0015] In certain embodiments, obtaining data relating to the resonantly produced electrons may comprise detecting resonantly produced electrons. The method may comprise extracting resonantly produced electrons using a penetrating field extractor prior to the step of detecting resonantly produced electrons.

10 [0016] Additionally or alternatively, detecting resonantly produced electrons may include rejecting collisional electrons. In such embodiments, rejecting collisional electrons may comprise deflecting collisional electrons away from resonantly produced electrons. A cylindrical deflector analyser may be used to deflect collisional electrons away from resonantly produced electrons.

15 [0017] In certain preferable embodiments, the method may comprise a step of using data relating to the detected resonantly produced ions to identify isotopes present in the sample.

[0018] The sample beam may be an ion, molecule or atom beam.

20 [0019] In such embodiments where the sample beam is an ion beam, and the method may comprise neutralising the ion beam prior to using the first laser excitation means to resonantly excite the sample beam. In certain embodiments, neutralising the ion beam may comprise forming a sample beam containing meta-stable atoms. Additionally or alternatively, the step of neutralising the ion beam may comprise passing the ion beam through a charge exchange cell.

[0020] In such embodiments where the sample beam is an ion beam, the ion beam may be accelerated prior to using the first laser excitation means to resonantly excite the sample beam.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 shows a method according to an embodiment of the present invention;

30 Figure 2 shows steps of a method according to a specific embodiment of the present invention; and

Figure 3 schematically shows an apparatus according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0022] Figure 1 illustrates a method 10 for determining the presence of ions in a sample according to an embodiment of the present invention. The identification of ions may facilitate the identification of isotopes. An apparatus 30 for performing the method in accordance with a non-limiting embodiment of the present invention is illustrated in Figure 3.

[0023] The method comprises an initial step 12 of providing a beam containing the sample. As shown in Figure 3, a sample source 32 may provide a sample beam 34.

[0024] In certain embodiments, the sample source 32 may be an atom, molecule or ion source. In embodiments in which the sample source 32 is an atom or molecule source, an energetic beam may be provided (i.e. accelerated) which may then be neutralised into an atom or neutral molecule beam. Examples of suitable ion sources include, but are not limited to, a plasma ion source, a sputter ion source, and a laser ion source. In certain embodiments, the sample source 32 may be held at a high voltage e.g. between 1 kV and 50 kV, however, accelerating voltages outside of this range may be used to accelerate the sample beam 34.

[0025] The sample source 32 may provide a sample beam 34 comprising atoms, molecules or ions. The sample beam 34 may be a continuous beam. In embodiments in which the sample beam comprises ions, the sample beam 32 may be neutralised. The neutralisation process may comprise passing the sample beam through a charge exchange cell. The neutralisation process may be used to populate meta-stable states of the sample. The population of meta-stable states of the sample is advantageous in the study of light elements, including but not limited to oxygen, fluorine, and the noble gases. The transitions of electrons from the ground states of these elements to excited or ionised states are in the extreme ultra-violet range. The wavelengths required for a laser beam to achieve such excitation are less than 90 nm.

Wavelengths in this range are not accessible with conventional lasers. However, the transition of electrons from the meta-stable states of these elements to excited states or ionised states is possible using laser beams with wavelengths greater than 200 nm. Wavelengths in this range are accessible with conventional lasers. As such, the ionisation of light elements is possible with conventional lasers once the elements have been excited to meta-stable states. In an alternative embodiment the neutralisation process may be used to populate the ground state of the sample. The ground state may be preferred for the study of some elements, including but not limited to calcium.

[0026] Once the sample beam 34 has been provided and neutralisation of the sample beam 32, if required, has occurred, a first laser excitation means is used to resonantly excite the sample beam in step 14 of the method. The first laser excitation means includes at least one

continuous wave laser beam. The resonant excitation of the sample beam 34 by the first laser excitation means forms a resonantly excited sample beam 34. In certain embodiments, the first laser excitation means may be operated at a plurality of frequencies. The frequency may be chosen depending on the sample to be studied. Different frequencies may be used to excite the sample to different atomic states. A range of frequencies may be scanned to find the frequency which corresponds to an atomic transition in the sample and resonantly excite the sample.

[0027] A second laser excitation means is then used to ionise the resonantly excited sample beam 34 to form resonantly produced ions and resonantly produced electrons according to step 16 of the method. The second laser excitation means includes a continuous wave laser beam arranged substantially perpendicular to the sample beam 34. The sample beam 34 is arranged to pass through the laser beam of the second laser excitation means. Ionisation of the sample by the second laser excitation means is possible because the sample has been excited by the first laser excitation means.

[0028] The first and second laser excitation means comprise continuous wave lasers. Suitable continuous wave lasers include, without limitation, ring dye lasers, TiSA lasers, diode lasers and fiber lasers. The use of continuous wave lasers allows a continuous sample beam to be used. This removes the need for the sample beam 34 to be bunched. A continuous sample 34 beam is advantageous for the study of light elements such as oxygen, carbon and elements with similar atomic numbers because such elements are highly reactive making bunched sample beams difficult to produce. For example, ions of light elements can easily be neutralised by collisions with a gas or form nuclear compounds with impurities which may be present in an ion trap. The arrangement of lasers disclosed above provides a more versatile method of laser spectroscopy in which light elements, as well as heavier elements, can be studied.

[0029] The second laser excitation means may comprise a broadband laser. The atoms, molecules or ions in the sample beam 34 may have a range of velocities in the direction perpendicular to the sample beam. Therefore, a broadband laser may be used to provide a range of energies to ionise the sample beam. In an embodiment, the energy density of the second laser excitation means may be increased by the use of an optical cavity. The second laser excitation means may include an optical cavity arranged in the optical path of the continuous wave laser beam which is arranged substantially perpendicular to the sample beam. The optical cavity may be positioned such that the sample beam passes through the optical cavity. The optical cavity may increase the energy density of the laser in the region of the sample beam. The optical cavity may be a high-finesse optical cavity. The optical cavity

may be any suitable type, such as a standard bow-tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

[0030] The second laser excitation means may be chosen such that the interaction region is small. The interaction region is the region of overlap between the sample beam and the second laser excitation means in which the resonantly produced ions and resonantly produced electrons are produced. The interaction region may be defined by the diameter of the laser beam. In certain embodiments, the diameter of the laser beam may be less than 0.1 mm.

[0031] Different combinations of lasers may be used to form the first laser excitation means and the second laser excitation means when performing method steps 14 and 16. The combinations of lasers offer alternative ways to create the resonantly produced ions and resonantly produced electrons and are described with reference to different embodiments below. The lasers may be chosen depending on the sample which is being studied and how the excitation and ionisation may be achieved.

[0032] In the embodiment shown in Figure 3, the first laser excitation means may include a resonant laser 35 arranged to produce a laser beam 31 that is substantially collinear with the sample beam 34. Throughout the present specification, the term “collinear” means coaxial, i.e. parallel and axially aligned. The second laser excitation means may include a non-resonant laser 36 arranged to produce a laser beam 32 that is substantially perpendicular to the sample beam 34.

[0033] The embodiment of Figure 3 may be modified such that the first laser excitation means includes more than one laser beam 31 arranged substantially collinearly with the sample beam 34. As such, the sample beam 34 may be excited by a combination of the collinear laser beams. In addition to the one or more collinear laser beams in this embodiment, the first laser excitation means may include one or more resonant lasers arranged to produce a laser beam that is substantially perpendicular to the sample beam 34. As such, the sample beam 34 may be excited by the combination of laser beams arranged collinearly with and perpendicular to the sample beam 34.

[0034] In an alternative embodiment, the first laser excitation means may include one or more laser beams arranged substantially collinearly with the sample beam 34 and the second laser excitation means may include a resonant laser beam arranged substantially perpendicular to the sample beam. The second laser may be configured to excite the atoms, molecules or ions in the sample beam to a Rydberg level.

[0035] In another embodiment, the first laser excitation means may include a resonant two-photon laser arranged to produce a laser beam substantially perpendicular to the sample

beam 34 and the second laser excitation means may include a non-resonant laser arranged to produce a laser beam substantially perpendicular to the sample beam 34. An optical cavity may be arranged in the optical path of the two-photon laser beam. The sample beam 34 may pass through the optical cavity. A two-photon laser provides two photons that couple in the optical cavity to excite the atom. The momenta of the two photons in the direction parallel to the laser beam cancel out as the photons couple. This reduces the Doppler broadening in the sample beam. The first laser excitation means may additionally include one or more resonant lasers arranged to produce a laser beam substantially collinearly with the sample beam 34. As such, the sample beam 34 may be excited by a combination of the two-photon laser and the one or more collinear lasers.

[0036] In embodiments in which the first laser excitation means includes a resonant laser collinearly arranged with the sample beam 34, the collinear laser may be a narrowband laser. The ions, atoms or molecules in the sample beam may have similar kinetic energies in the direction parallel to the sample beam. Therefore, a narrowband laser beam may be sufficient to excite the sample.

[0037] In embodiments in which the first laser excitation means includes a laser beam arranged in a direction substantially perpendicular to the sample beam, the perpendicular laser may comprise a broadband laser. Additionally, an optical cavity may be arranged in the path of the laser which is substantially perpendicular to the sample beam. The sample beam may pass through the optical cavity. The optical cavity may be any suitable type, such as a standard bow-tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

[0038] The ionisation of the sample beam 34 by the second laser excitation means in step 16 of the method produces ions and additionally liberates electrons as part of the ionisation process. Once the sample beam has been ionised, the resonantly produced ions (resulting from the ionisation of the resonantly excited sample beam 34) are then detected in step 18 of the method 10. The resonantly produced electrons (resulting from the ionisation of the resonantly excited sample beam 34) may be used in the detection of the resonantly produced ions.

[0039] During the ionisation step 16, all ions, atoms or molecules in the sample beam 34 may not interact with the second laser excitation means. In an embodiment, electrostatic deflector plates may be used to separate non-interacting ions, atoms or molecules in the sample beam from the ions and electrons produced. With reference to the apparatus 30 illustrated in Figure 3, the electrons may be extracted as an electron beam 40 for detection by an electron detector 39 and the ions may be extracted as an ion beam 41 for detection by an ion detector 38. However, the ion beam 41 will include resonantly produced ions and ions that arise due to

collisions within the sample beam (i.e. collisional ions). Similarly, the electron beam 40 will include resonantly produced electrons and electrons resulting from collisions within the sample beam (i.e. collisional electrons). The process of non-resonant collisional ionisation ordinarily results in large isobaric contamination that will contribute to the recorded background signal (i.e. noise) in an ion detection process.

[0040] The resonantly produced electrons will have an energy in the rest frame of the atom/molecule/ion (from which it was liberated) that is dependent on the difference between a final ionising energy of the laser 36 and the ionisation potential of the atom/molecule/ion. In preferable embodiments, this difference is minimized as far as possible. The second laser excitation means may be chosen such a resonantly produced electron may be detected in coincidence with the corresponding resonantly produced ion. The coincidence detection of the resonantly produced electrons and ions reduces the background because collisional electrons will not be detected in coincidence with collisional ions.

[0041] The background is further reduced by the second laser excitation means, as discussed above, overlapping the sample beam 34 in a small region. Therefore, the sample beam 34 travels a short distance from the sample source 32 to the interaction region, where the second laser excitation means overlaps the sample beam 34 and ionisation occurs. The short distance enables the background to be kept low because there is little opportunity for collisions to occur.

[0042] In one embodiment, step 18 for detecting the resonantly produced ions may comprise the method steps illustrated in Figure 2. These steps provide a detection method for the resonantly produced ions which helps to reduce the background from collisional ions.

[0043] The first step 20 in the method is the detection of ions produced from the resonantly excited sample beam. As discussed above, in the embodiment illustrated in Figure 2, the ions may be extracted as an ion beam 41 for detection by an ion detector 38.

[0044] Then, at step 22, data relating to resonantly produced electrons resulting from the ionisation of the sample beam may be obtained, and subsequently, at step 24, the presence of resonantly produced ions in the sample may be determined using the data relating to resonant electrons. As discussed above with reference to the apparatus 30 illustrated in Figure 2, the step 22 of obtaining data relating to resonantly produced electrons may comprise detecting the electron beam 40 using the electron detector 39. A guide magnetic field that is arranged parallel to the electron beam 40 may be used to aid the transport of resonantly produced electrons. As the resonantly produced ions and electrons leave the interaction region (where ionisation takes place), the electrons may be extracted using a penetrating field and, further, may be injected into an electrostatic lens before detection by the electron detector 39. In

certain embodiments, the electron detector 39 may comprise an electron spectrometer such as a hemispherical electron spectrometer.

[0045] Since the electron beam 40 may include resonantly produced and collisional produced electrons, some filtering or processing may be performed so that an electron signal

predominately relating to resonantly produced electrons may be obtained. For example, electrons having energies outside of a predetermined range (or ranges) may be rejected (or not detected in the first place). Such electrons may be considered to not result from the ionisation processes and may therefore be ignored in the interest of reducing the noise caused by non-resonant electrons in the electron signal. Similarly, at least some of the collisional electrons may be deflected away from the electron detector 39 (e.g. using a cylindrical deflector analyser) so as to not contribute to the electron signal.

[0046] In a particular embodiment, the step 24 of determining the presence of resonantly produced ions in the sample using the data relating to resonant electrons comprises first producing an ion signal relating to ions resulting from the ionisation of the sample beam 34.

With reference to the apparatus 30 shown in Figure 3, the step of producing the ion signal may comprise detecting the ion beam 41 with the ion detector 38. Secondly, the ion signal may be processed using the data relating to the resonantly produced electrons.

[0047] In particular embodiments, the method 24 may further comprise determining a resonance time period using the data relating to the resonantly produced electrons, and the ion signal may be processed to exclude parts of the ion signal that are not associated with the determined resonance time period. That is, the data relating to the resonantly produced electrons may be used to indicate when resonance was taking place and the time period associated with this resonance may be determined. The determined resonance time period may then be used (e.g. using coincidence logic) to process the ion signal, e.g. by truncating the ion signal to only include data that corresponds to the resonance time period. In this manner, the ion signal may be processed to reduce data contained therein that relates to non-resonantly produced ions. In doing so, the signal to noise ratio in respect of detection of resonant ions is greatly reduced. Indeed, an electron-ion coincidence signal can be used to reduce random background signals in both the electron detector 39 and the ion detector 40.

[0048] The apparatus 30 may further comprise processing means, e.g. as part of a computer or controller, that are communicably coupled so as to receive data from the electron detector 39 and receive data from the ion detector 38. The processing means may be configured to process the data received from the ion detector 38 using the data received from the electron detector 39 to determine the presence of ions in the sample (e.g. by performing coincidence logic).

[0049] In certain preferable embodiments, the above-described method step 18 may further determine the presence of isotopes using the determination of the presence of ions in the sample. In particular, the determination of a particular resonantly produced ion may permit an isotope contained within the sample to be identified.

5 **[0050]** Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification
10 is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0051] Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described
15 herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel
20 one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0052] The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which
25 are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

CLAIMS

1. A method of determining the presence of ions in a sample, comprising:
providing a beam containing the sample;
using a first laser excitation means to resonantly excite the sample beam,
5 wherein the first excitation means includes at least one continuous wave laser beam, and
wherein resonant excitation of the sample beam by the first laser excitation means forms a
resonantly excited sample beam;
using a second laser excitation means to ionise the resonantly excited sample
beam to form resonantly produced ions and resonantly produced electrons, wherein the
10 second excitation means includes a continuous wave laser beam substantially
perpendicular to the sample beam; and
detecting the resonantly produced ions.
2. A method according to claim 1, wherein using the first laser excitation means to
15 resonantly excite the sample beam includes using at least one continuous wave laser
beam arranged substantially collinearly with the sample beam.
3. A method according to claim 2, wherein using the first laser excitation means to
20 resonantly excite the sample beam includes using at least one continuous wave laser
beam arranged substantially perpendicular to the sample beam.
4. A method according to claim 1 or 2, wherein using the first laser excitation means
to resonantly excite the sample beam includes using at least one continuous wave laser
beam arranged substantially perpendicular to the sample beam to excite the sample beam
25 in a two photon excitation process.
5. A method according to claim 3 or 4, wherein using the first laser excitation means
to resonantly excite the sample beam includes passing the sample beam through a first
optical cavity arranged in the optical path of the at least one continuous laser beam
30 arranged substantially perpendicularly with the sample beam.
6. A method according to claim 5, wherein the first optical cavity is a standard bow-
tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

7. A method according to claim 2, wherein using the second laser excitation means includes using a continuous wave laser arranged substantially perpendicularly with the sample beam to excite the sample beam to a Rydberg level.

5 8. A method according to any preceding claim, wherein using a second laser excitation means to ionise the resonantly excited sample beam includes passing the sample beam through a second optical cavity arranged in the optical path of the second laser excitation means.

10 9. A method according to claim 8, wherein the second optical cavity is a standard bow-tie (SBT) cavity, Fabry Perot type cavity or a delta cavity.

10. A method according to any preceding claim, wherein the step of detecting the resonantly produced ions comprises:

15 detecting ions produced from the resonantly excited sample beam;
obtaining data relating to the resonantly produced electrons resulting from the resonant ionisation of the sample beam; and
determining the presence of resonantly produced ions in the detected ions using the data relating to resonant electrons.

20 11. A method according to claim 10, wherein determining the presence of resonantly produced ions in the sample comprises:
producing an ion signal relating to ions resulting from the resonant ionisation of the sample beam; and
25 processing the ion signal using the data relating to the resonantly produced electrons.

12. A method according to claim 11, further comprising determining a resonance time period using the data relating to the resonantly produced electrons, wherein processing
30 the ion signal comprises excluding parts of the ion signal that are not associated with the determined resonance time period.

13. A method according to any of claims 10 to 12, wherein obtaining data relating to the resonantly produced electrons comprises detecting resonantly produced electrons.

14. A method according to claim 13, comprising extracting resonantly produced electrons using a penetrating field extractor prior to the step of detecting resonantly produced electrons.

5 15. A method according to claim 13 or 14, wherein detecting resonantly produced electrons includes rejecting collisional electrons.

16. A method according to claim 15, wherein rejecting collisional electrons comprises deflecting collisional electrons away from resonantly produced electrons.

10 17. A method according to claim 16, comprising using a cylindrical deflector analyser to deflect collisional electrons away from resonantly produced electrons.

18. A method according to any preceding claim, comprising a step of using data
15 relating to the detected resonantly produced ions to identify isotopes present in the sample.

19. A method according to any preceding claim, wherein the sample beam is an ion, molecule or atom beam.

20 20. A method according to claim 19, wherein the sample beam is an ion beam, and the method comprises neutralising the ion beam prior to using the first laser excitation means to resonantly excite the sample beam.

25 21. A method according to claim 20, wherein neutralising the ion beam comprises forming a sample beam containing meta-stable atoms.

22. A method according to claim 20 or 21, wherein the step of neutralising the ion beam comprises passing the ion beam through a charge exchange cell.

30 23. A method according to any preceding claim, wherein the sample beam is an ion beam, and the method comprises accelerating the ion beam prior to using the first laser excitation means to resonantly excite the sample beam.

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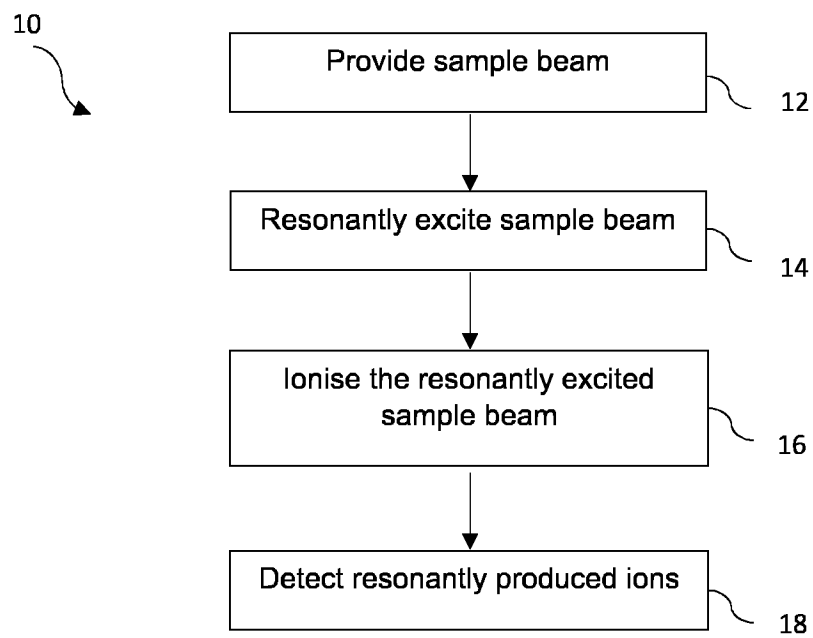


FIGURE 1

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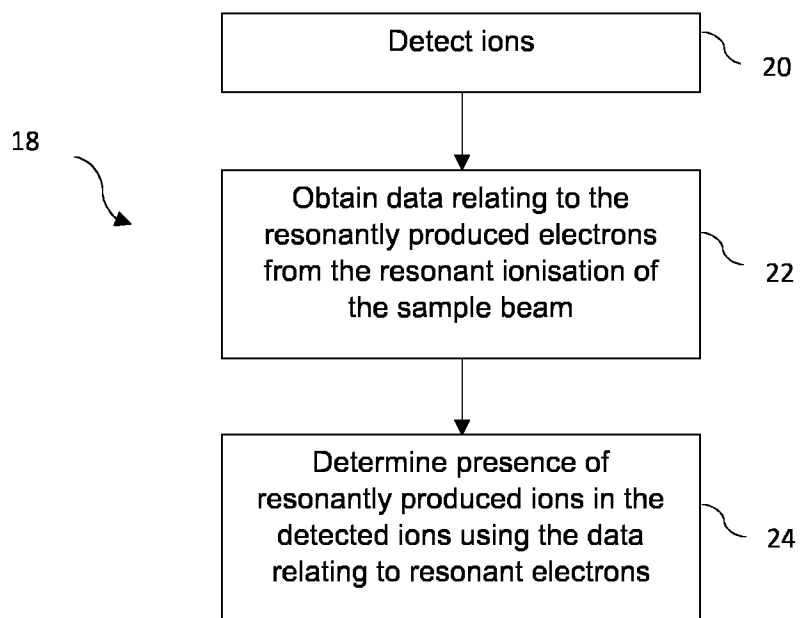


FIGURE 2

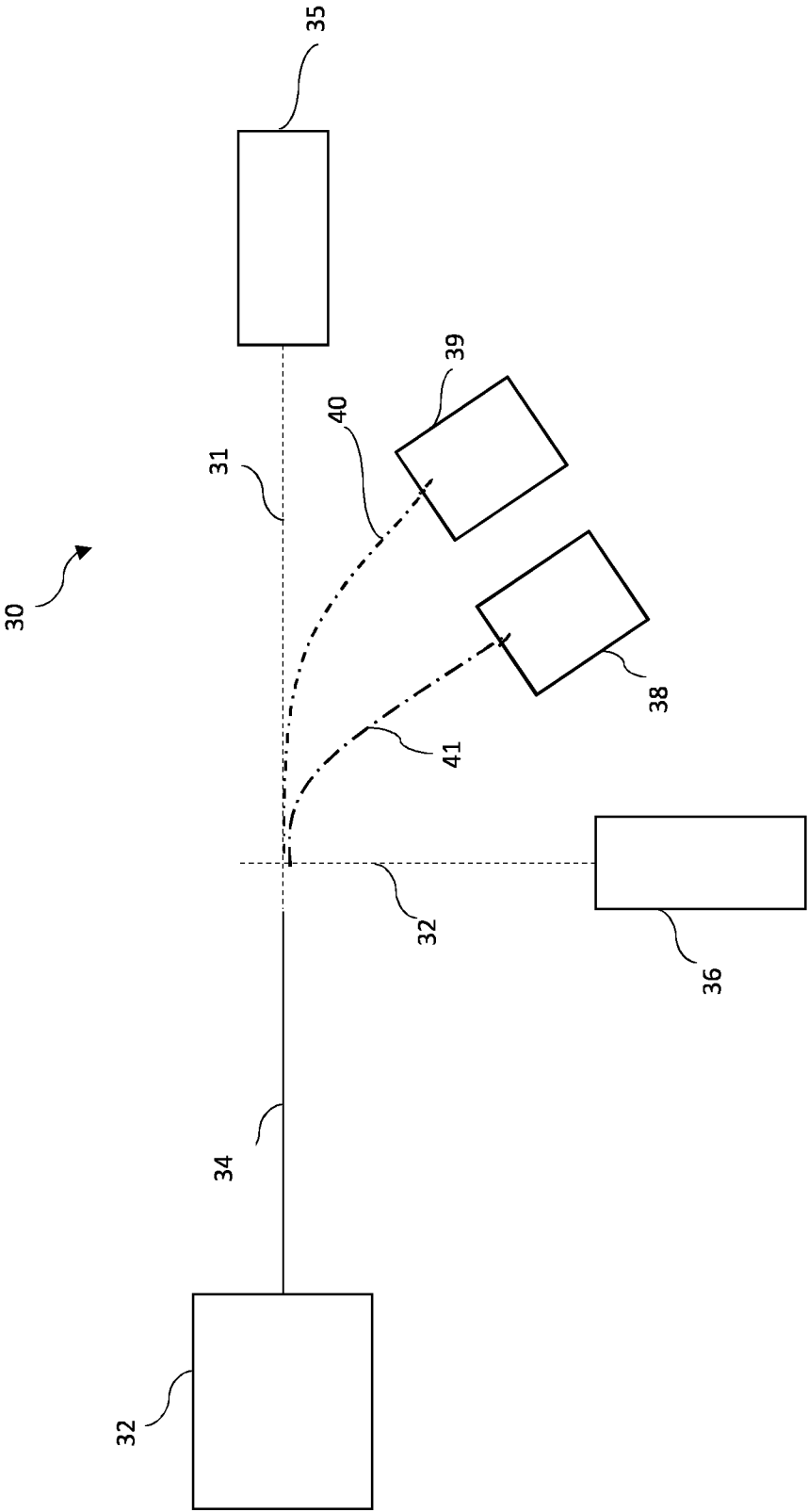


FIGURE 3

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N27/62 H01J49/16 H01J27/24 G01N27/64
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TEN HAAF G ET AL: "Cavity-enhanced photoionization of an ultracold rubidium beam for application in focused ion beams", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 6 August 2017 (2017-08-06), XP081294673, DOI: 10.1103/PHYSREVA.96.053412 page 2; figure 1 -----	1-9,18, 19
X	WO 2018/073570 A1 (UNIV MANCHESTER [GB]) 26 April 2018 (2018-04-26)	1-4,7,19
A	paragraphs [0009], [0033], [0045] - [0054]; figure 2 -----	5,8,9
A	EP 0 722 180 A2 (MITSUBISHI ELECTRIC CORP [JP]) 17 July 1996 (1996-07-17) figures 6,7 -----	5,6,8,9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 December 2019

Date of mailing of the international search report

17/02/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Rutsch, Gerald

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2019/052850

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of Item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-9, 18(completely); 19(partially)

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9, 18(completely); 19(partially)

A method of determining the presence of ions in a sample, comprising:
 providing a beam containing the sample; using a first laser excitation means to resonantly excite the sample beam, wherein the first excitation means includes at least one continuous wave laser beam, and wherein resonant excitation of the sample beam by the first laser excitation means forms a resonantly excited sample beam; using a second laser excitation means to ionise the resonantly excited sample beam to form resonantly produced ions and resonantly produced electrons, wherein the second excitation means includes a continuous wave laser beam substantially perpendicular to the sample beam; and detecting the resonantly produced ions wherein using the first laser excitation means to resonantly excite the sample beam includes using at least one continuous wave laser beam arranged substantially collinearly with the sample beam. wherein using the first laser excitation means to resonantly excite the sample beam includes passing the sample beam through a first optical cavity arranged in the optical path of the at least one continuous laser beam arranged substantially perpendicularly with the sample beam.

2. claims: 10-18(completely); 19(partially)

A method of determining the presence of ions in a sample, comprising:
 providing a beam containing the sample; using a first laser excitation means to resonantly excite the sample beam, wherein the first excitation means includes at least one continuous wave laser beam, and wherein resonant excitation of the sample beam by the first laser excitation means forms a resonantly excited sample beam; using a second laser excitation means to ionise the resonantly excited sample beam to form resonantly produced ions and resonantly produced electrons, wherein the second excitation means includes a continuous wave laser beam substantially perpendicular to the sample beam; and detecting the resonantly produced ions;
 wherein the step of detecting the resonantly produced ions comprises:
 detecting ions produced from the resonantly excited sample beam; obtaining data relating to the resonantly produced electrons resulting from the resonant ionisation of the sample beam; and determining the presence of resonantly produced ions in the detected ions using the data relating to resonant electrons.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

3. claims: 18, 20-23(completely); 19(partially)

A method of determining the presence of ions in a sample, comprising: providing a beam containing the sample; using a first laser excitation means to resonantly excite the sample beam, wherein the first excitation means includes at least one continuous wave laser beam, and wherein resonant excitation of the sample beam by the first laser excitation means forms a resonantly excited sample beam; using a second laser excitation means to ionise the resonantly excited sample beam to form resonantly produced ions and resonantly produced electrons, wherein the second excitation means includes a continuous wave laser beam substantially perpendicular to the sample beam; and detecting the resonantly produced ions; wherein the sample beam is an ion beam.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2019/052850

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
W0 2018073570	A1	26-04-2018	EP 3529605 A1	28-08-2019
			US 2019244797 A1	08-08-2019
			W0 2018073570 A1	26-04-2018

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			EP 0722180 A2	17-07-1996
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