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3,505,516

ION CYCLOTRON RESONANCE SPECTROMETER EMPLOYING AN
OPTICALLY TRANSPARENT ION COLLECTING ELECTRODE

Filed Aug. 4, 1967

2 Sheets-Sheet 1

FIG. 1

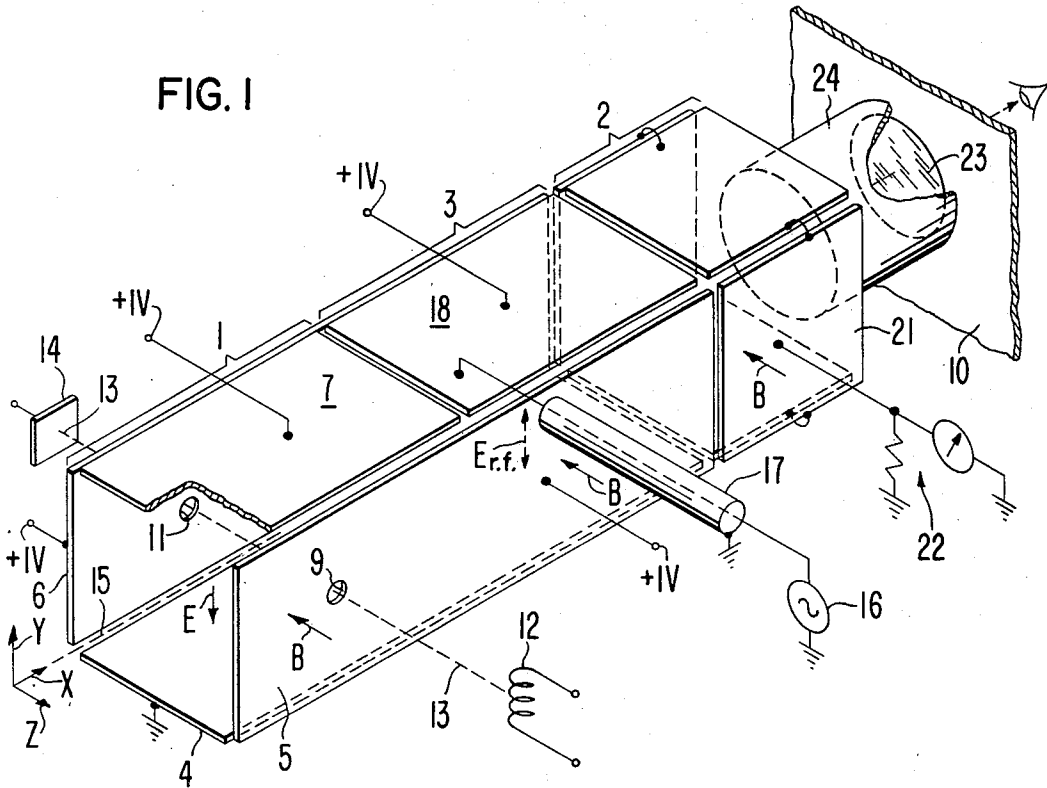


FIG. 2

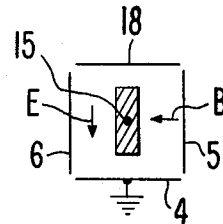
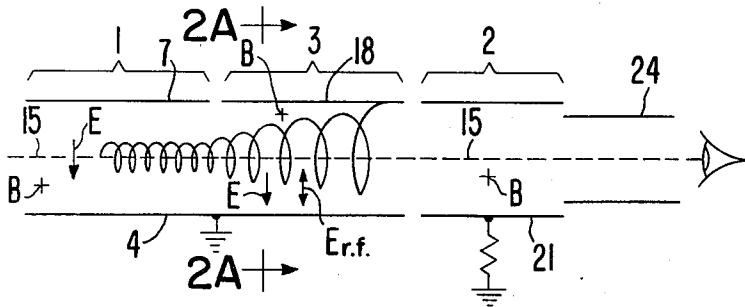


FIG. 2A

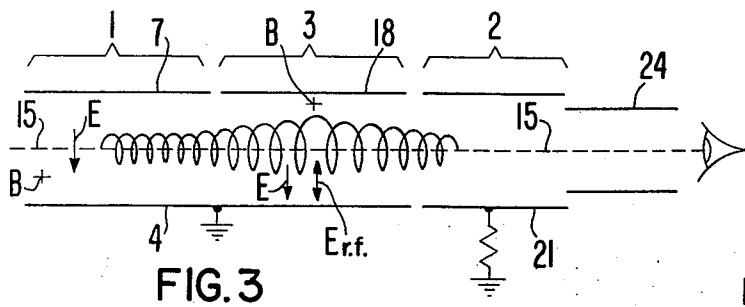


FIG. 3

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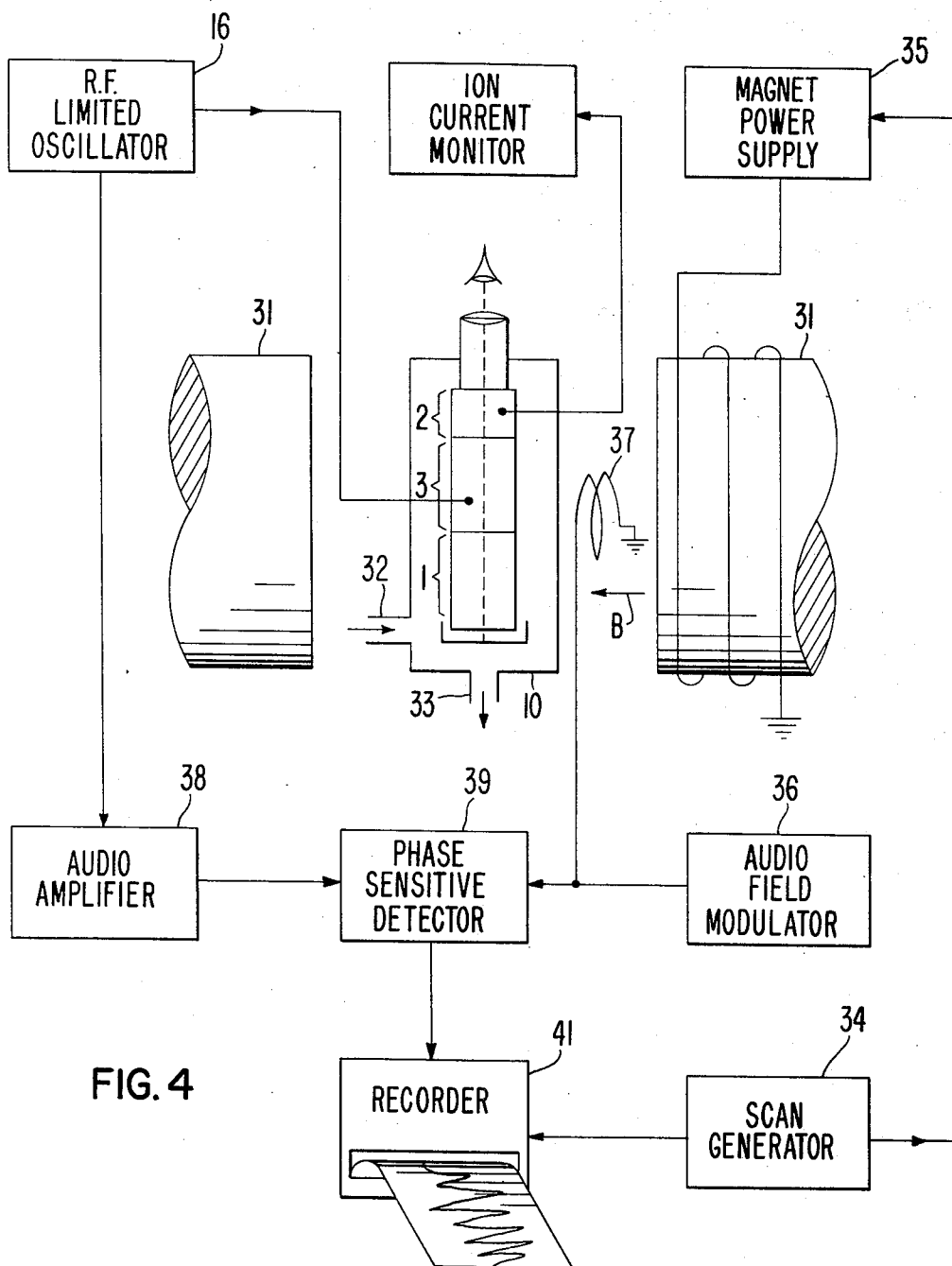
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ION CYCLOTRON RESONANCE SPECTROMETER EMPLOYING AN OPTICALLY TRANSPARENT ION COLLECTING ELECTRODE

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8 Claims

ABSTRACT OF THE DISCLOSURE

An ion cyclotron resonance MASS spectrometer which is provided with a transparent ion collecting electrode such that optical radiation may be passed through the ion collector to or from the ion analyzing region. The ion cyclotron resonance MASS spectrometer includes a vacuum envelope containing an ion source wherein gases to be analyzed are ionized by an electron beam. The ions generated in the source are beamed through a separate analyzing section to an ion collector electrode. The analyzing section comprises an open ended hollow rectangular electrode structure with the ions beamed axially thereof. A D.C. magnetic field is applied to the analyzing region perpendicularly to an applied radio frequency electric field. At the cyclotron resonance of the ions, the ions of the beam absorb energy from the applied R.F. field causing the resonant ions to follow an expanding spiral trajectory and to be collected on the electrodes forming the analyzing section. Non-resonant ions pass through the analyzer to a separate ion collector electrode structure. The ion collector structure comprises a hollow rectangular open ended structure coaxially aligned with the ion beam path. A gas tight window is provided in the vacuum envelope in alignment with the open ended ion collector and ion beam path to permit observation of any optical radiation emitted by the ions in the analyzing region and to permit application of optical radiation to the gas in the analyzer section. In a preferred embodiment, a light shield surrounds the optical path between the window and the ion collector to shield out stray light originating in the ion source region.

DESCRIPTION OF THE PRIOR ART

Heretofore, ion cyclotron resonance MASS spectrometers have been built which included a source region for generating an ion beam in one embodiment. The ion beam was projected through the crossed R.F. electric and D.C. magnetic fields of an analyzer region to an ion collector structure. However, in the prior art MASS spectrometer the ion collector blocked the beam path at the end of the device and prevented optical radiation from being passed out of or into the analyzer region through the ion collector. As a result it was difficult to observe the optical radiation emitted by the ions in the analyzer region or to apply light to the ions in the analyzer region to observe the effect of the light upon resonance of the ions.

In addition, the prior ion collector design produced a substantial perturbation of the electric fields in the analyzer region. More specifically, the R.F. electric fields in the analyzer instead of passing between the plates of the analyzer in a uniform manner fringed over to the end closing in collector plate. As a result, the uniformity of the applied R.F. electric field was adversely affected.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved ion cyclotron resonance spectrometer.

One feature of the present invention is the provision, in an ion cyclotron resonance spectrometer, of an ion beam collecting electrode structure which is optically transparent, whereby optical radiation may be transmitted to or from the ion analyzer region through the ion beam collector structure.

Another feature of the present invention is the same as the preceding feature wherein the ion collector structure is apertured in axial alignment with the ion beam path.

Another feature of the present invention is the same as any one or more of the preceding features wherein the ion beam collector has generally the same transverse dimensions and form as the analyzing electrode structure, whereby the R.F. electric fields in the analyzing region are not excessively perturbed by the ion collecting structure.

Another feature of the present invention is the same as any one or more of the preceding features including the provision of a vacuum envelope enclosing the MASS spectrometer with an optically transparent gas tight window therein in axial alignment with the ion beam path.

Another feature of the present invention is the same as the preceding features including the provision of an opaque shield surrounding the light path from the ion collector to the window to prevent stray light generated within the vacuum tight chamber from being observed through the window.

Other features and advantages of the present invention will become apparent upon the perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic perspective view of the electrode structure of the ion cyclotron spectrometer of the present invention,

FIG. 2 is a schematic line diagram depicting ion trajectories for a resonant ion,

FIG. 2A is a sectional view of FIG. 2 taken along line A—A in the direction of the arrows,

FIG. 3 is a schematic line diagram depicting trajectories for non-resonant ions, and

FIG. 4 is a schematic block diagram of an ion cyclotron MASS spectrometer of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown the electrode structure of an ion cyclotron resonance spectrometer incorporating features of the present invention. The electrode structure is generally of an elongated hollow rectangular shape and is contained in an evacuated envelope 10 at 10^{-7} torr. An ion source region 1 is disposed at one end of the structure. An ion collector region 2 is disposed at the other end of the structure and an analyzing cyclotron resonance region 3 is disposed between the source 1 and the collector 2.

The source region 1 comprises a grounded base plate 4 forming the bottom wall of the rectangular structure. Two opposed rectangular side plates 5 and 6 are operated at a small positive potential, as of +1 v., relative to the bottom grounded plate 4. A top plate 7 is also operated at the +1 v. relative to the ground. A magnetic field B, as of 3000 gauss, is directed through the entire electrode structure in a direction perpendicular to the side plates 5 and 6. The plates are affixed to four insulative rods, not shown, disposed at the four corners of the rectangular electrode structure and running the length thereof.

A pair of apertures 9 and 11 are placed in plates 5 and 6, respectively in alignment with the direction of the

magnetic field B. A filamentary electron thermionic emitter 12 is disposed to project a beam of electrons 13 through the aligned apertures 9 and 11 to an electron collector electrode 14.

The electron beam 13 serves to ionize gas to be analyzed which finds its way into the source region 1. The positive ions, under the influence of the small static electric field E which is directed in the -Y direction and the strong magnetic field B in the -Z direction, are caused to drift in tight cycloidal trajectories along a beam path 15 which is axially directed of the rectangular electrode structure in the X direction.

In the mass analyzing region 3, the ion beam is subjected to a radio frequency (R.F.) electric field $E_{r.f.}$ at the cyclotron resonance frequency of the ions to be analyzed. The electric potential is supplied from an R.F. oscillator 16 via coaxial line 17 to the top rectangular plate 18. The other terminal of the R.F. oscillator 16 is connected to the bottom plate 4 through ground. Thus, the R.F. electric field $E_{r.f.}$ is produced in the mass analyzer region of the ion beam with the R.F. field being mutually perpendicular to the beam axis (X axis) and the unidirectional magnetic field B. The +1 volt static potential on the side and top plates 5, 6 and 18, respectively, provides the small static electric field E in the analyzing region 3 and causes the ions to follow the beam path 15 with cycloidal trajectories.

When the R.F. electric field $E_{r.f.}$ is at the cyclotron resonance frequency ω_c the ions will absorb energy from the applied R.F. field $E_{r.f.}$ and the cycloidal orbits of the resonant ions will be increased causing them to collide with the surrounding rectangular plate structure and there to be neutralized and eliminated as ions. The R.F. energy absorbed from the R.F. electric field $E_{r.f.}$ is detected in the oscillator 16 and employed to produce a resonance spectrum, as more fully described below with regard to FIG. 4.

The cyclotron resonance frequency ω_c is defined as follows:

$$\omega_c = \frac{zeB}{m}$$

where z is the number of charges per ion, e is the electronic charge, B is the magnetic field strength, and m is the particle mass. Typically, the cyclotron resonance frequency for relatively low mass ions falls within the frequency range of 100 to 300 kHz. After the ions pass through the analyzing region 3, they pass into the ion collector region 2.

In the ion collector region 2, a four sided rectangular plate electrode structure 21 is positioned surrounding the beam path 15. The plate structure 21 is open on the ends and is grounded through the input impedance of an electrometer 22. In the collector structure 21, there are no electric fields and only the transverse magnetic field B. Under these conditions, the ions entering the collector region are free to move in a direction parallel to the direction of the magnetic field B and within a very short distance they are collected on the surrounding collector structure 21. The collected ion current is monitored by the electrometer.

The collector structure 21 is preferably elongated in the direction of the beam to prevent too great a discontinuity in the electric field of the analyzer region 3. Such a discontinuity might otherwise be produced by fringing field at the downstream end of the analyzer 3. The perturbations produced by the fringing electric fields are minimized by making the ion collecting electrode 21 of substantially the same transverse dimensions as the analyzer electrode structure 3 and by providing substantial length to the ion collector structure 21.

An optically transparent window 23 is sealed in a gas-tight manner into the wall of the vacuum envelope 10 in axial alignment with the beam path 15. The window 23 and the open ended ion collector structure 21 permit

an unobstructed light path along the beam path 15 between the window 23 and the analyzer region 3. This permits optical radiation emitted by the ions in the analyzer region to be monitored by an observer or by a light sensitive device such as a chromatometer or photocell. The optical emissions can be useful in interpreting reactions that are taking place in the analyzer region 3 in accordance with well-known techniques of emission spectroscopy. Alternatively, light may be passed through the window into the analyzer region to stimulate reactions, to produce ions, etc. The effect of the optical radiation may be monitored by observing its effect on the cyclotron resonance absorption signal.

An opaque tubular light shield 24 is disposed surrounding the light path between the window 23 and the ion collector 21 to prevent stray light from being seen by the observer. The filament 12 of the ion source 1 is incandescent and gives off light which is reflected from the side of the vacuum envelope. This light will be seen by the observer if the light shield 24 is not provided.

Referring now to FIGS. 2 and 2A, there is depicted the typical ion trajectories experienced under the conditions of cyclotron resonance. The ions pass out of the ion source 1 along the beam path 15 executing relatively tight cycloidal trajectories. In the analyzer region at resonance, the trajectories are expanded and the resonant ions are predominantly collected on the plates of the analyzer electrode structure.

Referring now to FIG. 3, there is shown the ion trajectories for non-resonant ions. The ions pass out of the ion source along the beam path 15 with small relatively tight cycloidal trajectories. In the analyzing region 3, the cycloidal orbits may expand and contact, especially if the applied R.F. electric field is near resonance of the ions. The ions pass through the analyzer into the collector region 2 where they are collected.

The ion current is monitored and at resonance there is a decrease in the collected ion current. The ion current, therefore, may be used to monitor resonance of the ions to obtain a mass spectrum, however, the absorption of R.F. from the oscillator 16 gives a more sensitive measurement. Also, the measured ion current is useful for adjusting the operating parameters of the spectrometer such as electron current in the ion source and for optimizing operating pressure in the spectrometer. In some cases, too many ions are being generated. In other cases, too few may be generated.

Referring now to FIG. 4, there is shown the mass spectrometer circuit. Briefly, the spectrometer includes a magnet 31 for producing a strong magnetic field B, as of 3000 gauss, in the gap thereof. The vacuum envelope 10, containing the electrode structure of FIG. 1, is immersed in the magnetic field B. Gas to be analyzed is leaked into the envelope 10 from a source, not shown, via inlet 32. The envelope 10 is continuously evacuated via a vacuum pump, not shown, via exhaust tubulation 33.

Radio frequency energy is supplied to the analyzer region 3 from an R.F. limited oscillator 16 operating at a certain fixed frequency. The magnetic field is scanned through cyclotron resonance, if any, of the ions under analysis by a scan generator 34 which feeds its scan signal to the magnet's power supply 35 which in turn scans the intensity of the magnetic field B.

An audio frequency field modulator 36 modulates the magnetic field B via current supplied to coil 37 to modulate the cyclotron resonance, if any, of ions under analysis. The audio modulation of the absorption of energy from the oscillator 16 is detected in the oscillator 16 and fed to an audio frequency amplifier 38 and thence to one input of a phase sensitive detector 39. A sample of the field modulation is fed to the other input of the phase sensitive detector 39. The output of the phase sensitive detector 39 is a D.C. cyclotron resonance signal which is fed to a recorder 41 to be recorded as a function of the field scan signal obtained from the scan generator 34.

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The recorder output is a mass spectrum of the sample under analysis.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention can be made without departing from the scope thereof it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In an ion cyclotron spectrometer apparatus, means for ionizing gas to be analyzed and for projecting the ions over a predetermined beam path, means at the terminal end of the beam path for collecting the ions, means forming an electrode structure disposed along the beam path intermediate said ionizing means and said ion collecting means to define a mass analyzing region of the beam path and for applying a radio frequency electric field to the beam to produce cyclotron resonance of the ions of the beam in such region for mass analysis of the ions, the improvement wherein, said ion collecting means is optically transparent taken in a direction coaxial with the ion beam path extending and through said ion collecting means and, whereby optical radiation may be passed along an optical path through said ion collecting means said mass analyzing region along said beam path.

2. The apparatus of claim 1 wherein said ion collecting means comprises a hollow four sided electrode structure which is open at opposite ends and coaxially disposed of the ion beam path with said four sides surrounding the longitudinal axis of the beam path.

3. The apparatus of claim 1 wherein said ion collecting means is apertured in axial alignment with a line-of-sight path coaxial with the beam path in said analyzer region of the beam and passing through said ion collecting means.

4. The apparatus of claim 1 including, means forming a vacuum envelope structure enclosing said gas ionizing means, said means for producing cyclotron resonance of the beam, and said ion collecting means, and means form-

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ing a gas tight optically transmissive window in said envelope, said window being in alignment with the ion beam path and an optical path through said ion collecting means.

5. The apparatus of claim 4 including, means forming an optically opaque light shield surrounding the light path from said window to said ion collecting means, whereby certain stray light generated outside of the beam path and within the spectrometer is not observed through said window.

6. The apparatus of claim 1 wherein said means for producing cyclotron resonance of the ions in the beam include, means for producing a unidirectional magnetic field, and means for producing an alternating electric field at the cyclotron resonance frequency, said fields being mutually orthogonal to each other and to the beam path in the analyzing region of the beam path.

7. The apparatus of claim 3 wherein said ion collecting means is elongated in the direction parallel to the longitudinal axis of the ion beam path in the mass analyzing region.

8. The apparatus of claim 7 wherein said ion collecting means has transverse dimensions substantially equal to the transverse dimensions of said mass analyzing electrode structure.

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