United States Patent [19]

Genequand

[11] **3,842,267**

[45] **Oct. 15, 1974**

[54] **METHOD AND APPARATUS FOR MEASURING, BY IONIZATION, THE FLUX OF VAPOUR EMITTED DURING VACUUM VAPORIZATION**

[75] Inventor: **Pierre Genequand,** Geneva, Switzerland

[73] Assignee: **Batelle Development Corporation,** Columbus, Ohio

[22] Filed: **Feb. 7, 1973**

[21] Appl. No.: **330,537**

[30] **Foreign Application Priority Data**

Feb. 9, 1972 Switzerland........................ 1918/72

[52] **U.S. Cl.**.................. **250/291,** 250/282, 250/300

[51] **Int. Cl.**.. **H01j 39/34**

[58] **Field of Search**........... 250/296, 297, 291, 286, 250/273, 300, 425

[56] **References Cited**

UNITED STATES PATENTS

2,694,151	11/1954	Berry	250/286
2,958,774	11/1960	McNarry et al.	250/291
2,967,239	1/1961	Zemany	250/425
3,086,110	4/1963	Klopfer	250/291
3,247,373	4/1966	Herzog et al.	250/300

Primary Examiner—James W. Lawrence
Assistant Examiner—B. C. Anderson
Attorney, Agent, or Firm—Philip M. Dunson

[57] **ABSTRACT**

A method and apparatus for measuring, by ionization, the flux of vapour emitted by a substance subjected to vacuum vaporization, whereby a jet is produced within the vapour, and part of the particles contained in the jet are ionized. An essentially uniform magnetic field is produced in a volume crossed by the jet and is directed essentially perpendicularly to the jet, so that a section of the jet is permanently immersed in the magnetic field. The particles contained in a delimited volume situated within this section are ionized through being subjected to the action of at least one pulse of an ionizing radiation, so that the ionized particles constitute a package of ions describing, under the influence of the magnetic field, a circular trajectory. The amplitude of the variable component of the electric influence is measured which the package of ions exercises in the course of its revolutions along the circular trajectory on an electrode situated externally to the trajectory, the amplitude forming the measure of the flux.

13 Claims, 5 Drawing Figures

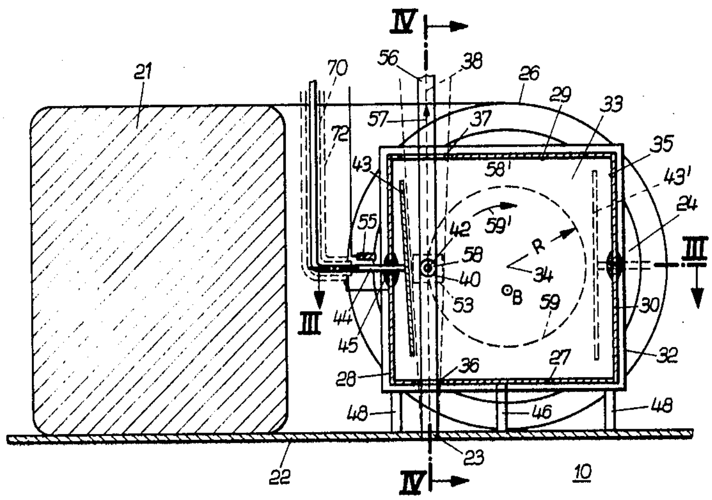
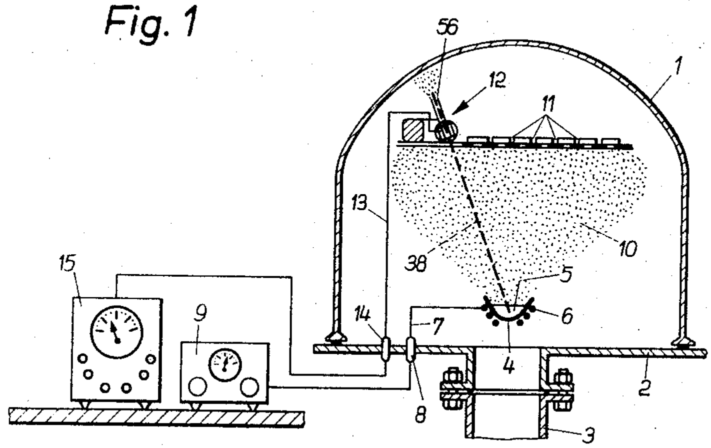


Fig. 1


56
12
11
1
13
10
38
5
15
9
14
7
6
4
2
8
3

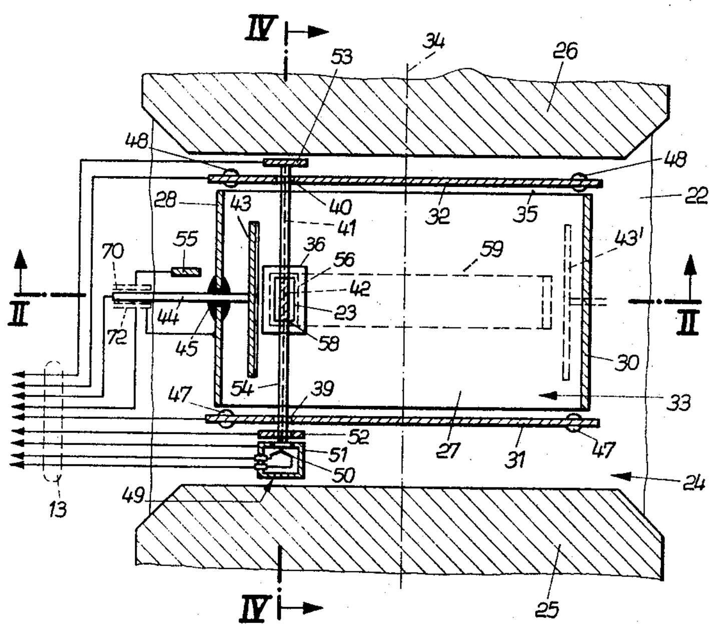
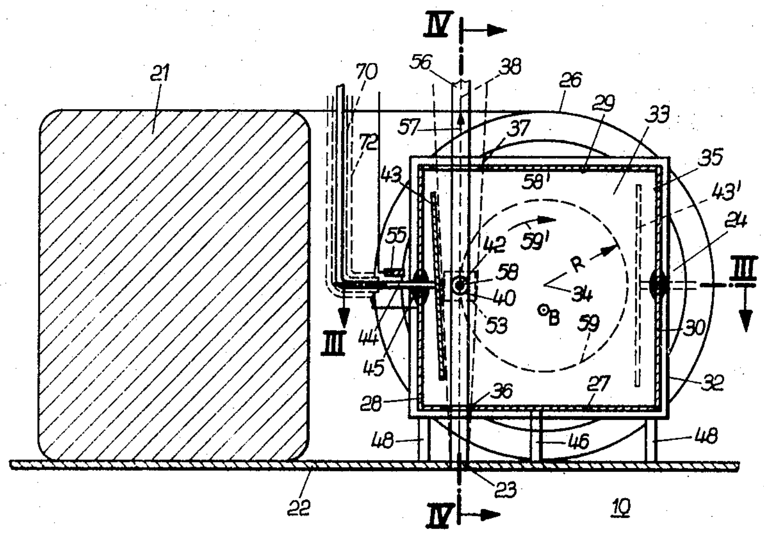

IV
34
26
53
48
48
28
43
40
41
32
35
22
70
55
36
56
42
23
59
43'
II
II
72
44
45
58
30
54
39
47
33
27
52
47
51
31
50
49
24
13
25
IV

Fig. 3

Fig. 2


IV
56
38
26
21
70
29
33
57
37
72
35
58'
43
43'
24
59'
55
42
R
58
III
40
34
B
53
59
30
III
44
45
36
27
32
28
48
46
48
23
22
10
IV

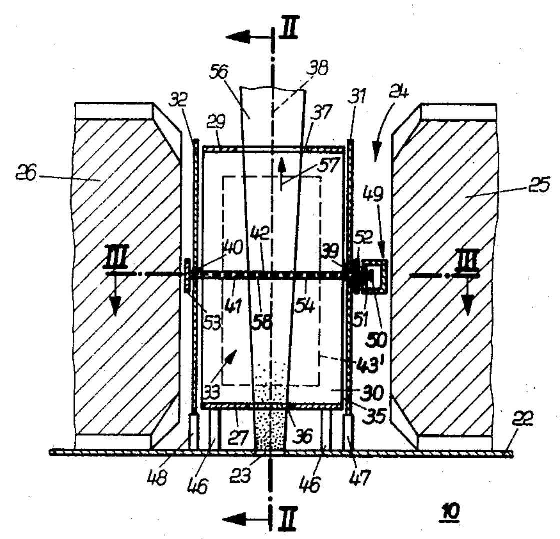

II
56
38
32
31
24
29
37
26
57
25
49
42
52
III
40
39
III
41
58
54
53
51
50
43'
33
30
35
27
36
22
48
46
23
46
47
II
10

Fig. 4

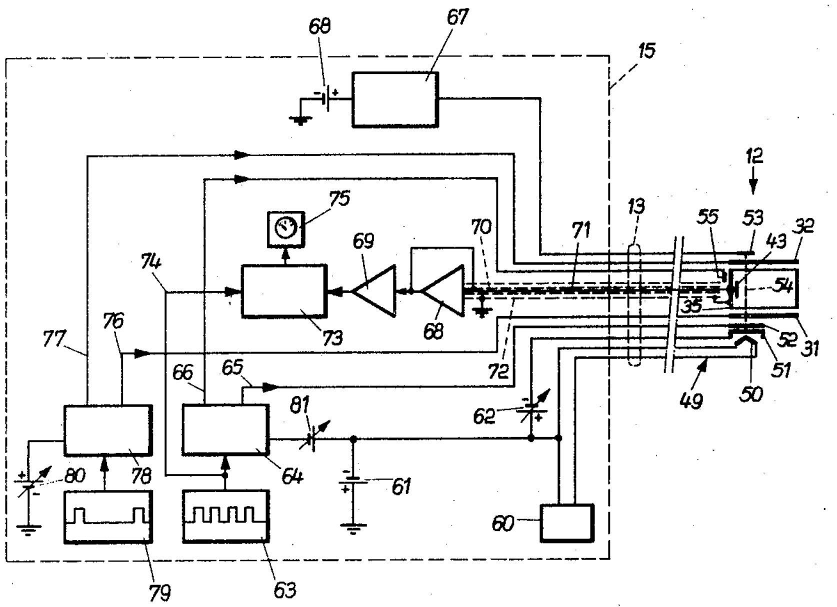

68
67
15
12
13
55
53
43
32
75
69
70
71
54
74
35
52
31
73
68
51
77
76
72
66
65
49
50
81
62
80
78
64
61
60
79
63

Fig. 5

METHOD AND APPARATUS FOR MEASURING, BY IONIZATION, THE FLUX OF VAPOUR EMITTED DURING VACUUM VAPORIZATION

BACKGROUND OF THE INVENTION

The present invention concerns a method for measuring, by ionization, the flux of vapour emitted by a substance subjected to vaporization in vacuum, whereby a jet is produced within the vapour and part of the particles contained in this jet are ionized.

It is common knowledge that vacuum vaporization consists in heating in an enclosure devoid of air (pressure below a limit of the order of 10^{-3} torr) a crucible containing a substance the temperature of which is increased to the point where it vaporizes, and to allow the vapour thus created to condense onto one or several substrates and to coat them with a film which is usually extremely fine (thickness between a few dozen Angstrom units and a few microns). The speed of condensation, therefore the speed with which the thickness of the deposited film increases, and the quality of this film depend on the speed of evaporation, consequently, on that of the vapour flow emitted by the substance contained in the crucible. Measuring this flux is, as one will appreciate, an important procedure, for knowledge of this flux permits control of the heating, most of time electric, of the crucible, in order to maintain the speed of deposit constant, or, conversely, to modify it at will. In view of the considerable extension assumed by these techniques, mainly in the fields of production of semiconductor integrated circuits, treatment of optical surfaces (anti-reflection treatment), production of interference light filters, etc., it is little wonder that many methods have been proposed to determine this flux. Among them, the only ones to be used in practice consist in measuring the ionic current initiated by this vapour when it is submitted to the action of a source of ionization. Usually, a slim jet is isolated within the vapour by means of one or several diaphragms, and submitted to the impact of ionizing rays, most of the time an electron beam projected in or through the jet. In this case indeed, the ionic current I^+ is proportionate to the electronic current I^- and to the number n of particles of vapour (molecules or atoms) contained in a unit volume (density of vapour), which in turn is equal to the ratio of the vapour flux ϕ per unit of surface (that is, the quantity to be measured) to the mean speed $\bar{v}$ of these particles within the jet. In other words, $\phi = k\ I^+ \bar{v}/I^-$, in which k designates a proportionality constant, which shows that, to the extent to which the mean speed $\bar{v}$ of the ions remains constant, the flux ϕ depends solely upon the ratio of the ionic currant I^+ to the electronic current I^-, which quantities are easily measured.

However, the condition $\bar{v} = Ct$ presupposes that the temperature of the vapour be kept unchanged, for the speed $\bar{v}$ is proportionate to the square root of the absolute temperature T. This condition, which affects the sensitivity of the measurement, that is, the relation which binds ϕ to I^+ for a given value of I^-, is not the only one which should be taken into account. It is also necessary to make sure that the electrodes which collect the currents I^+ and I^- remain absolutely clean so as to avoid their becoming soiled with dielectric layers (resulting, for instance, from pollution caused by vapours of oil from the pumps creating the vacuum in the closed space in which evaporation takes place) and thus turning into traps to which parasitic charges would adhere. This is especially important when the evaporated substance is a dielectric, as is the case in the anti-reflection treatment of optic parts or in certain stages of manufacture of integrated circuits. Finally, it is necessary to give the zone of ionization (the one in which the jet of vapour and the ionizing electronic beam meet) a shape that will ensure that the ionization efficiency will be as little as possible at the mercy of incidental fluctuations of the particles of vapour, that is, of variations in the position of the crucible with respect to the diaphragms delimitating the jet.

It is also necessary to eliminate the disturbing influence due to ions which are produced by collisions of the electrons of the electronic beam with the particles of the residual gas enclosed in the space; in effect, at a pressure of 10^{-3} torr the signal coming from the ions of residual gas is equal to the signal which would be produced by a flux of aluminum vapour giving a speed of deposit of 10 kA/s, which is far from being negligeable. This type of difficulty is eliminated in those procedures which make use of a sweeping electronic beam, that is, which alternately and repeatedly switches from a position from which it propagates outside the jet of vapour to a position from which it crosses the jet; the signal obtained in this case comprises a continuous component, due to the ions of the residual gas, and an alternating component due to the vapour flux to be measured, these components being easily separated electronically. A procedure of the sort is especially described in the Swiss Pat. No. 475,559. Resorting to a sweeping electronic beam and to a delimited jet of vapour has yet another advantage, in that the zone of interaction between this beam and this jet is well defined, this making it possible to keep under control the factor of sensitivity of the gauge which initiates the said procedure and, to a certain extent, to render it independent of the incidence of the vapour jet. In addition, this gauge does not contain the grating with which certain common types of ionization gauges of the triode type are provided. Therefore, it is not affected by those inconveniences resulting from the uncertain shape of the diffuse cloud which forms around this grating.

When the heating of the evaporating crucible is itself ensured by electronic bombardment, it is necessary to take additional precautions in order to eliminate perturbations arising from parasitic charges exterior to the gauge. Moreover, because of this very bombardment, the vapour is partly ionized, and a fairly important fraction of the bombarding electrons mixes with it; this fraction is constituted by those electrons which the vapour disperses in the whole of the enclosure, from the zone where it forms. Also, resorting to an electron gun of powder to heat the crucible causes considerable variations of the temperature of the vapour, which may fluctuate between 1,000°K and 10,000°K.

It is, of course, possible, in the known procedures, to prevent the diffused electrons coming from the electronic beam which serves to heat the crucible from reaching the electrodes of the gauge, and it is also possible to eliminate, by deflection, the ions formed by the heating beam; against this, however, it is almost impossible, in these procedures, to prevent or to compensate fluctuations of the temperature of the vapour.

Finally, since the vapour is complex, i.e., consisting of different constituents, the known procedures do not allow to isolate from the overall flux the flux of one of its constituents. They permit still less to carry out a "spectrum analysis" of the overall flux, i.e., to measure the partial flux of each of its constituents. Only the techniques of mass spectrography permit an analysis of the constituents. They are, however, not adaptable to the measurement of the vapour flux.

SUMMARY OF THE INVENTION

A primary object of the invention is to avoid these inconveniences. The process of the invention is characterized by the fact

that an essentially uniform magnetic field is produced in a volume crossed by the said jet and is directed essentially perpendicularly to the jet, so that a section of this jet is permanently immersed in the magnetic field;

that the particles contained in a delimited volume situated within this section are ionized through being submitted to the action of at least one pulse of an ionizing radiation so that these ionized particles constitute a package of ions describing, under the influence of this field, a circular trajectory;

and that the amplitude of the signal is measured which this package of ions generates in the course of its revolutions along this circular trajectory in an electrode situated externally to the trajectory, the amplitude forming the measure of the said flux.

With the process according to the invention the volume arranged in the air gap of the magnet by means of the ionisation of the vapor jet at least one package of ions, a so-called ion package, is formed. Due to the effect of the magnetic field, it describes a circular trajectory in the air gap in a plane which is essentially defined by the jet of the vapor particles and the direction perpendicular to the direction of the magnetic field. The electrical signal which can be measured, an alternative tension, for instance, and which is induced in the electrode by the rotating package of ions, is used to measure the vapor flux. Preferably, the ionization takes place periodically pulsating with the cyclotronic or rotation frequency of the ion package, whereby an amplification of the signal to be measured is accomplished. With a vapor flux which consists only of one type of particles, one obtains — as signal to be measured — an alternative tension with the cyclotronic frequency.

The present invention also has for an object to provide a gauge for carrying out this procedure. The gauge is characterized by the fact that it comprises:

a magnetic circuit provided with a gap in which prevails an essentially uniform magnetic field and placed in such a way that the jet traverses this gap by forming an essentially right angle with this field;

a source of ionizing radiation which emits this radiation in the form of a beam of which the axis intersects the axis of the jet and of which the intensity is modulated in at least one pulse, so that this source is capable of ionizing the particles of the jet which happen to be, for the duration of the pulse, in the volume defined by the intersection of the jet and the beam, which volume is situated in the magnetic field, and capable of transforming these particles into a package of ions which cyclically describe, under the influence of the magnetic field, a circular trajectory;

and at least a fixed electrode placed externally to this trajectory and externally to the jet, and by the fact that the said supply and measuring equipment comprises:

a detection circuit connected to this electrode and adjusted in such a way as to measure the amplitude of the periodic component of the electric charge which the package of ions induces upon this electrode in the course of its revolutions along this circular trajectory, the value of this amplitude constituting the measure of the said flux.

BRIEF DESCRIPTION OF THE DRAWING

The hereunder related description refers to an example of a gauge in conformity with the invention. The description is illustrated by the attached drawings in which:

FIG. **1** is an overall diagram showing the position of the gauge with respect to a system of vacuum evaporation.

FIG. **2** is a sectional view passing through the median plane (following line II—II of FIG. **4**) of a first part of the gauge pictured in FIG. **1**.

FIGS. **3** and **4** are partial sections, horizontal and transverse respectively, of this same first part, following lines III—III and IV—IV, respectively, of FIG. **2**.

FIG. **5** shows a block diagram of a second part of the gauge represented in FIG. **1**, as well as the connections of this second part with the first.

DESCRIPTION OF A PREFERRED EMBODIMENT

A typical gauge according to the present invention comprises a probe which is arranged in the vacuum space, and a supply and measuring system which is situated externally to the space, the connection between these two parts being provided by electric lines. This is what FIG. **1** shows. It gives the diagram of a vacuum space delimited by a bell jar **1** and a plate **2**, the latter being connected by a conduit **3** to a pumping set (not shown). The vacuum space encloses a crucible **4** containing a substance **5** to be evaporated, such as aluminum, for instance. The crucible **4** is brought up to a high temperature by means of a heating system constituted, for instance, by a spiral electric heater coil **6** which is connected by a line **7** which crosses the plate **2** through an insulator **8**, to a high-frequency generator **9** situated externally. Under these conditions, the substance **5** gives rise to a cloud of vapour **10** which tends to expand in the whole of the vacuum space and to condense on the cold parts, particularly on the objects **11** to be metallized, such as, for instance, plates which one wants to alluminumcoat. The gauge comprises a probe **12** situated in proximity to the objects **11** and connected, by a line **13** which crosses the plate **2** through an insulator **14**, to a supply and measuring system **15**. The gauge therefore consists of both the probe **12** and the equipment **15**.

The probe, which is pictured on a large scale in FIGS. **2** to **4**, comprises the following elements:

a magnet **21** lying flat on a base plate **22** that is pierced with an opening **23** situated at the level of the air gap **24** defined by the poles **25** and **26** of the magnet **21**, the base-plate **22** constituting a screen which intercepts the vapour **10** and lets part of it escape in the form of a jet **56**;

a set of metallic walls **27** to **32** which delimit within the air gap **24** a volume **33** electrically screened, that is, protected from the influence of electric charges outside the enclosure **27–32**, the volume **33** being centered with respect to the axis **34** of the poles **25, 26**. The walls **27** to **30** are mounted so as to form, between the four of them, a monolithic frame **35**, and the walls **31** and **32** are assembled so as to constitute two closures which shut off the volume **33** but are electrically independent one from the other and independent from the frame **35**. The walls **27** and **29** of the frame **35** are pierced with openings **36** and **37**, respectively, which are disposed in line with the opening **23** of the base plate **22**, the axis **38** of this alignment being shifted with respect to the center of the volume **33**, therefore with respect to the axis **34** of the poles, and passing through the center of the crucible **4** (see FIG. **1**). The walls **31** and **32** are pierced with holes **39** and **40**, respectively, which are aligned along a common axis **41** that is parallel to the axis **34** of the poles **25, 26** but shifted with respect to the latter in such a way as to intersect the axis **38** of the openings **23, 36,** and **37** at a point of intersection **42**. The frame **35** and the walls **31** and **32** are fixed to the base plate **22** by means of insulating feet **46** (for the frame **35**), **47** (for the wall **31**), and **48** (for the wall **32**);

a measuring electrode consisting of a plate **43** situated inside the volume **33** and borne by a conductor pin **44** traversing the wall **28** through an insulator **45** which provides the pin **44** with electric insulation from the wall **28**. Facing the pin **44** is an "equilibrium" electrode **55**;

an electron gun **49** comprising a cathode **50**, a Wehnelt electrode **51**, a modulation electrode **52**, all of which are placed to one side of and externally to the volume **33**, facing the opening **39** of the wall **31**, and a collecting electrode **53** situated on the other side of and externally to the volume **33**, facing the opening **40** of the wall **32**. The electron gun **49** thus is located in such a way as to emit, along the axis **41**, an electron beam **54** which goes right through the volume **33**, passing through the jet **56**.

Such are the main elements which make up the probe **12**. Those which are called upon to plan an electric role are connected with the measuring and supply equipment **15** by means of lines which have been grouped under the common designation of "the" line **13** of the probe **12** (see FIGS. **1** and **3**). The measuring and supply equipment **15**, of which a simplified diagram is given in FIG. **5**, comprises in the first place the circuits required to feed the electron gun **49**, i.e., a generator **60** to heat the cathode **50**, a continuous voltage source **61** which confers to the cathode **50** a negative voltage with respect to the ground, a continuous source **62** which fixes the potential of the Wehnelt electrode **51** with respect to the cathode **50**, and an oscillator **63** which controls the modulation electrode **52** by the intermediary of a symmetric circuit **64**, of which one of the outlets **65** is connected to the modulation electrode **52** and provides it with a sinusoidal voltage, and of which the other outlet **66** is connected to the equilibrium electrode **55** and provides it with a sinusoidal voltage which is symmetrical with the first. The reason for which the supply is ensured by two symmetrical voltages is disclosed further on. A continuous source **81** confers to the two electrodes **52** and **55** a negative voltage with respect to cathode **50**.

A circuit **67**, permitting the measuring of the current carried by the electron beam **54**, is connected to the collecting electrode **53**, and a source **68** brings to the collecting electrode **53** the positive voltage required to enable it to play its collecting role.

The measuring and supply equipment **15** also includes a set of two amplifiers **68, 69**, of which the first is a preamplifier **68** having a gain G = 1 and thus serving as an impedance transformer, whereas the second, which has a gain G greater than 1, ensures the required amplification of the signal picked up by the measuring electrode **43**. The output of the preamplifier **68** is connected to an inner shield **70** which encloses the wire **71** that makes the connection with the measuring electrode **43**, an outer shield **72** being adjusted externally to the whole equipment and communicating with the ground. The external shield **72** is connected to the frame **35** of the probe, so that this frame is also joined to the ground. The internal shield **70** is interrupted shortly before the wire **71** traverses frame **35**, and the external shield **72** is provided at this point with an opening enabling the equilibrium electrode **55** to exert an electrostatic influence on the wire **71**. Further on we shall see the reason for this arrangement, which, however, is not indispensable, but which improves the performances of the gauge. The output of the amplifier **69** is connected to a synchronous detector **73**, which also receives, through the intermediary of a line **74**, the signal generated by the oscillator **63**. The synchronous detector **73** is connected to an instrument **75** comprising an indicator or a recorder of any convenient type.

Finally, the walls **31** and **32** are each connected to one of the two outputs **76** and **77** of a symmetrizing circuit **78**, which is excited by a pulse generator **79** providing rectangular pulses at a frequency less than that of the sinusoidal signal provided by the generator **63**. A continuous voltage source **80** brings the two walls **31, 32** to a positive polarization voltage with respect to the ground.

The gauge so constituted works in the following manner. The opening **23** (FIGS. **2** and **4**) provided in the base plate **22** serves the function of a diaphragm and isolates within the cloud of vapour **10** a jet **56** in which the particles of vapour move in the direction of the arrow **57** (from bottom to top) and have a mean velocity $\bar{v}$ determined by the temperature of the cloud **10**. The electron beam **54**, of which the emission is modulated periodically to the frequency ω of oscillator **63**, meets the jet **56** and produces with each positive alternation of the modulation electrode **52** a package of positive ions **58**. Under the action of the uniform magnetic induction produced by the magnet **21** in its air gap **24**, consequently in the volume **33** delimited by the frame **35**, the package of ions **58** describes a circular trajectory **59**, as shown in FIG. **2** respecting the package of ions **58'** which moves in the direction of the arrow **59'**. The radius R of the circular trajectory **59** is dependant on the mass of ions (m), their speed ($\bar{v}$), their charge (q), and the magnetic induction (B) prevailing in the air gap, which dependance is in accordance with the known formula $R = m\,\bar{v}/qB$. With each revolution the package **58'** induces in the measuring electrode **43**, due to electrical influence, a charge of which the amplitude is, in its turn, proportional to the radius R, to the number of ions contained in the package, and to the number of revolutions performed in each unit of time. The number of ions contained in the package being proportional to the intensity I^- of the electronic current in the beam **54** and to the numerical density n of the particles (molecules, atoms) in the vapour over the window **23**, that is to say, to the quotient of the flux ϕ of this vapour by the speed $\bar{v}$ of the particles which make it up, it follows from this that the signal applied to the amplifier **68** has an amplitude equal to $S = K I^- \phi$, in which expression K is a constant that is independent of the speed $\bar{v}$. In other words, the signal S is directly proportional to the flux in the jet **56**, consequently to the quantity which one wishes to measure, and is independent of the average speed $\bar{v}$, consequently of the temperature of the vapour.

One sees that the signal S has its origin in the fact that the particles composing the jet **56** have a speed that is aimed in a well determined direction, in this case the direction **57**. The particles, which possess velocities distributed at random in all directions, as is the case for the molecules of the residual gas, produce individual signals which, statistically, have a null average. The result is that the gauge eliminates from the start any perturbation due to residual gas.

It is advisable to "recharge" the package of ions with each one of its revolutions. This result is obtained by giving the frequency of the oscillator **63** which modulates the electronic beam a value equal to the frequency of the revolutions. As this frequency equals $\omega = \bar{v}/R = qB/m$, it is necessary, in order to ensure this recharge, to adjust either the frequency ω of the oscillator **63**, or the magnetic induction B produced by the magnet **21**, to the ratio q/m appropriate to the nature of the evaporated substance.

It is not indispensable to use a synchronous detector **73** to detect the signal provided by the measuring electrode **43**, but it does offer the advantage of improving the signal to noise ratio and of easily eliminating parasitic signals which could be caused by charges that might be sporadically carried off by the jet of vapour. A similar filtering effect, though less efficient, could be obtained by effecting a selective amplification of the signal, through adjusting the amplifiers **68** and **69** to the frequency of the revolutions (cyclotron frequency) described by the package of ions **58**.

Owing to the fact that the package of ions **58**, which re-forms at each revolution, has a tendency to diffuse around the trajectory **59** and, as a result, to create a space charge which in its turn tends to perturb the movement of this package, it is advisable to empty periodically the volume **33** of all the ions it contains. This is the role which has been assigned to the walls **31** and **32**, between which the pulse generator **78** periodically establishes a "purging field." The frequency of the purging pulses is of the order of **50** to 100 times lower than the frequency of the "recharging" oscillator **63**; in other words, the volume **33** is purged of all its ions every 50 to 100 revolutions. This arrangement also renders it possible to impose to all the ions a well defined lifetime, less than the undetermined lifetime which they would have if one allowed solely the action of the perturbations; this is a particularity which is not devoid of importance, like recombination, diffusion, etc., for the lifetime of the ions determines the factor of sensitivity of the gauge.

Between the purges, the walls **31, 32,** are maintained at a positive potential, of the order of a fraction of a volt, which confines the package of ions **58** by preventing, thanks to the electric "basin" thus created, the ions from drifting either one way or the other in the direction of the axis **41** of the electron beam **54** and from colliding with the walls **31, 32.** As one sees, these walls **31, 32** act simultaneously for the ions as confining electrodes and as extracting electrodes.

The presence of the symmetrizing circuits **64** and **78** is explained by the fact that they eliminate any perturbation which might result from an electric influence exerted upon the measuring electrode by the voltages applied to the electrode of modulation **52** or the electrodes of extraction **31, 32.** In this way, the influence exerted upon the electrode **43** by the voltage applied by the output **65** of the symmetrizer **64** to the electrode **52** is compensated by the opposite influence exerted by the equilibrium electrode **55** to which the output **66** of this same symmetrizer **64** applies a polarity voltage opposed to the first. This is also the case with the two opposite voltages applied to the extraction electrodes **31** and **32,** of which the direct influences upon the measuring electrode **43** annul each other.

It should be noted that as soon as a package of ions forms within the jet **56,** this package places itself on a circular trajectory and moves cyclically along it until the package disappears, either through the destruction of the ions which constitute it (for instance, through recombination), or through diffusion of the package (for instance, under the influence of the forces of repulsion exerted among them by the ions constituting this package). Each of the revolutions performed by the package of ions causes a periodic variation of the influence which it exerts upon the measuring electrode **43,** so that the latter releases a signal of which the period is equal to the time-length of a revolution.

In principle, therefore, it would not be necessary to modulate the electronic beam at the rate of the revolutions. One could be content with suddenly ionizing a very short section of the vapour jet and with observing, with the help of a sensitive detector, the signals linked with the successive passages of the package of ions so formed, which signals would form a sequence of decreasing amplitude, and would have to be separated from the parasitic noise by means of a filter and/or by selective amplification of the frequency of the revolutions along the orbit **59.** This means that one could think of using an ionizing source other than the depicted electronic beam. It would be sufficient that the ionizing action of this source be released for a brief moment at intervals longer than the diffusion time of a package, or even larger than the lifetime of the ions, which intervals would succeed one another arbitrarily.

However, the use of an electronic beam as an ionizing source presents many advantages with regard to simplicity of use, so that this is the device which will mostly be reverted to, even if the beam, instead of being modulated in the periodic manner described in connection with FIG. **5,** is modulated in sporadic pulses as mentioned earlier.

We have seen that, for a given value of the magnetic induction B, the length of time needed to move along the orbit **59** depends on the ratio g/m of the ions. In other words, the frequency of the signal released by the probe is, for a given magnetic induction, specific to the evaporated substance. One can therefore identify the evaporated substance either by varying the frequency to which the system of amplification and detection is adjusted, whereby the magnetic induction is kept constant, or by varying the intensity of the magnetic induction, whereby the frequency of the amplification and detection system is kept fixed (one uses an electromagnet with variable exitation). Thus one obtains a "spectrum analysis," which gives the partial fluxes of the different constituents of a complex vapor containing several evaporated substances.

The cyclotronic frequency of an ionized particles is — with a constant magnetic field and according to the foregoing explanation — proportional to the elementary charges q on the particle and reciprocally proportional to the mass of the particle. Since the ionization of the particle in the vapor jet is mostly unifold, only, (one elementary charge is transferred per particle, only, multiple ionizations can be observed relatively seldom, only), with the frequency analysis according to the invention of the alternative tension signal induced in the electrode one can conclude directly to the mass of the particles included in the ionized vapor jet. Moreover — also in accordance with the foregoing explanation — the amplitude with the specific measuring frequency is proportional to the vapor flux. Therefore, with the frequency analysis and a determination of the amplitudes of the induced alternative tension signal one can measure directly the type (mass) and the contribution of particular components of the vapor jet to the vapor flux, if a vapor flux with more than one component is analysed.

It will be noted (FIG. 2) that the measuring electrode **43** slants with respect to the axis **38** of the jet of vapor. This is an advantageous disposition, though in no way compulsory, which makes it possible to bring the electrode **43** and the jet **56** closer to each other as much as possible, without risking that the electrode be touched by the jet even if the latter leans slightly to either side of the axis **38**, in particular on account of a slightly faulty centering of the crucible **4** (FIG. **1**) with respect to the opening **23** (FIG. **2**).

One can also use two fixed electrodes, namely the electrode **43** (which has already been mentioned) and an electrode **43'** (shown in FIGS. **2**, **3**, and **4** in dotted lines), whereby the two electrodes are essentially parallel to each other and disposed on both sides of the circular trajectory **59**. In this case the preamplifier **68** is of the differential type and has two inputs, one of which is connected to the electrode **43**, the other one to the electrode **43'**.

To diminish the space requirements of the apparatus, one can put the electron gun **49** into one of the poles **25**, **26** of the magnetic circuit **21** and put the collecting electrode **53** into the other pole. This arrangement does not affect in a considerable manner the uniformity of the field B in the volume **33**, where the ionized particles describe their circular movement.

To obtain a signal as clear as possible at the measuring electrode **43**, **43'**, it is advisable to adapt not only the frequency omega of the oscillator **63** to the cyclotronic frequency of the type of particles to be determined, but also to keep the duration of the ionizing pulse of the electron beam **54** relatively short with regard to the reciprocal cyclotronic frequency of the particles to be determined. With a multiple repetition of the ionizing pulses in the rhythm of the cyclotronic frequency of a vapor flux component the number of the ions included in the rotating package is increased, which leads to an increase of the contribution of this package to the signal, whereby the contribution of other vapor flux components to the signal with different cyclotronic frequencies is decreased since, due to the pulse sequence of the ionizing radiation being not synchronous to the cyclotronic frequencies of the other vapor flux components their ion packages are more or less uniformly distributed on their trajectories.

While the forms of the invention herein disclosed constitute presently preferred embodiments, many others are possible. It is not intended herein to mention all of the possible equivalent forms or ramifications of the invention. It is to be understood that the terms used herein are merely descriptive rather than limiting, and that various changes may be made without departing from the spirit or scope of the invention.

I claim:

1. A method for measuring the flux of vapour emitted by a substance subjected to vacuum vaporization, comprising the steps of

directing a portion of the vapour in the form of a jet through a selected region,

producing, in a volume crossed by the vapour jet, an essentially uniform magnetic field directed essentially perpendicularly to the vapour jet, so that a section of the vapour jet is permanently immersed in the magnetic field;

ionizing the particles contained in a delimited volume situated within this section by applying at least one pulse of electrons in a beam intersecting this volume, so that the ionized particles constitute a package of ions describing, under the influence of the magnetic field, a circular trajectory; and

measuring the amplitude of the induced signal which the package of ions generates in the course of its revolutions along the circular trajectory in an electrode situated externally adjacent to this trajectory, whereby this amplitude forms the measure of the flux of said vapour.

2. A method as in claim **1**, wherein the said amplitude is measured at the ionic cyclotron frequency corresponding to a selected type of molecular particle and to the intensity of said magnetic field, whereby the amplitude forms the measure of the flux of the particular component of the vapour that consists of molecular particles of the selected type.

3. A method as in claim **2**, wherein there is applied to the particles in the delimited volume a plurality of the electron pulses repeated at the said ionic cyclotron frequency.

4. A method as in claim **3**, wherein the intensity of the magnetic field is maintained substantially constant and the repetition frequency of the electron pulses is varied slowly over a selected range of frequencies to obtain an analysis of the evaporation rate of each said type of molecular particle in the vapour flux.

5. A method as in claim **3**, wherein the repetition frequency of the electron pulses is maintained substantially constant and the intensity of the magnetic field is varied slowly over a selected range of intensities to obtain an analysis of the evaporation rate of each said type of molecular particle in the vapour flux.

6. Apparatus for measuring the flux of vapour emitted by a substance subjected to vacuum vaporization, comprising a probe situated inside a vacuum chamber and provided with a screen having an opening, the screen being so located as to intercept the vapour and to let it escape through the opening in the form of a vapour jet, and

a supply and measuring equipment disposed externally to the vacuum chamber and connected to the probe by electric conductors, said probe comprising

a magnet provided with a gap in which prevails an essentially uniform magnetic field and so located that the vapour jet traverses the gap by forming an essentially right angle with the magnetic field;

an electron gun which emits an ionizing electron beam of which the axis intersects the axis of the vapour jet and of which the intensity is modulated in at least one pulse, so that the electron beam is capable of ionizing the particles of the vapour jet which happen to be, for the duration of the pulse, in the volume defined by the intersection of the vapour jet and the electron beam, which volume is situated in the magnetic field, and capable of transforming these particles into a package of ions which cyclically describe, under the influence of the magnetic field, a circular trajectory;

and a fixed electrode placed externally adjacent to the circular trajectory; and said supply and measuring equipment comprising

a detection circuit connected to the fixed electrode to measure the amplitude of the electric signal which the package of ions induces, by electric influence, upon the electrode in the course of its revolutions along the circular trajectory, the value of said amplitude constituting the measure of the flux.

7. Apparatus as in claim **6,** wherein the electron gun is positioned to direct the electron beam along an axis in a direction parallel to the magnetic field.

8. Apparatus as in claim **7,** wherein the electron gun is placed in one of the pole-pieces of the magnetic circuit, and the other pole-piece contains an electrode which collects the electrons that have traversed the vapor jet.

9. Apparatus as in claim **7,** wherein the electron gun comprises an electrode capable of modulating the intensity of the electron beam, the supply and measuring equipment comprises a pulse generator which is connected to the modulating electrode, and the detection circuit comprises a detector that is synchronized by the pulse generator.

10. Apparatus as in claim **6,** wherein a pair of confinement electrodes are disposed on opposite sides of the package of ions and substantially perpendicular to the magnetic field, and the supply and measuring equipment comprises a continuous voltage source connected to the electrodes to produce between them an electric field of confinement to maintain the circular trajectory of the package of ions in a plane substantially perpendicular to the direction of the magnetic field and approximately midway between the confinement electrodes.

11. Apparatus as in claim **10,** wherein the supply and measuring equipment comprises a pulse generator connected to the confinement electrodes to apply to them periodically symmetrical voltage pulses producing between the electrodes an electric field capable of eliminating any perturbation from the ions produced by the pulses of ionized radiation.

12. Apparatus as in claim **6,** wherein the fixed electrode comprises a plate essentially parallel to a plane defined by the axis of the vapour jet and the direction of the magnetic field, the plate having a position that is essentially symmetrical with respect to the volume of intersection of the vapour jet and the electron beam.

13. Apparatus as in claim **12,** wherein two fixed electrodes are arranged essentially parallel to each other on opposite sides of the circular trajectory, and the detection circuit comprises a differential detector to detect the difference between the electrical charges induced on the two electrodes by the package of ions.

* * * * *