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[54] **DEVICE FOR DIRECT MEASUREMENT OF THE CURVE OF CONCENTRATION OF AN ELEMENT IN A MATERIAL**

[75] Inventors: **Bruno Blanchard; Noel Hilleret; Joel Monnier,** all of Grenoble; **Jean-Baptiste Quoirin,** Saint-Martin **D'Heres, all of France**

[73] Assignees: **Commissariat A L'Energie Atomique,** Paris, France; **Commissariat A L'Energie Atomique,** Paris, France

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[30] **Foreign Application Priority Data**

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

[58] **Field of Search**................. 250/49.5 P, 49.5 PE, 250/49.5 T, 41.9 D, 41.9 DS; 73/23.1

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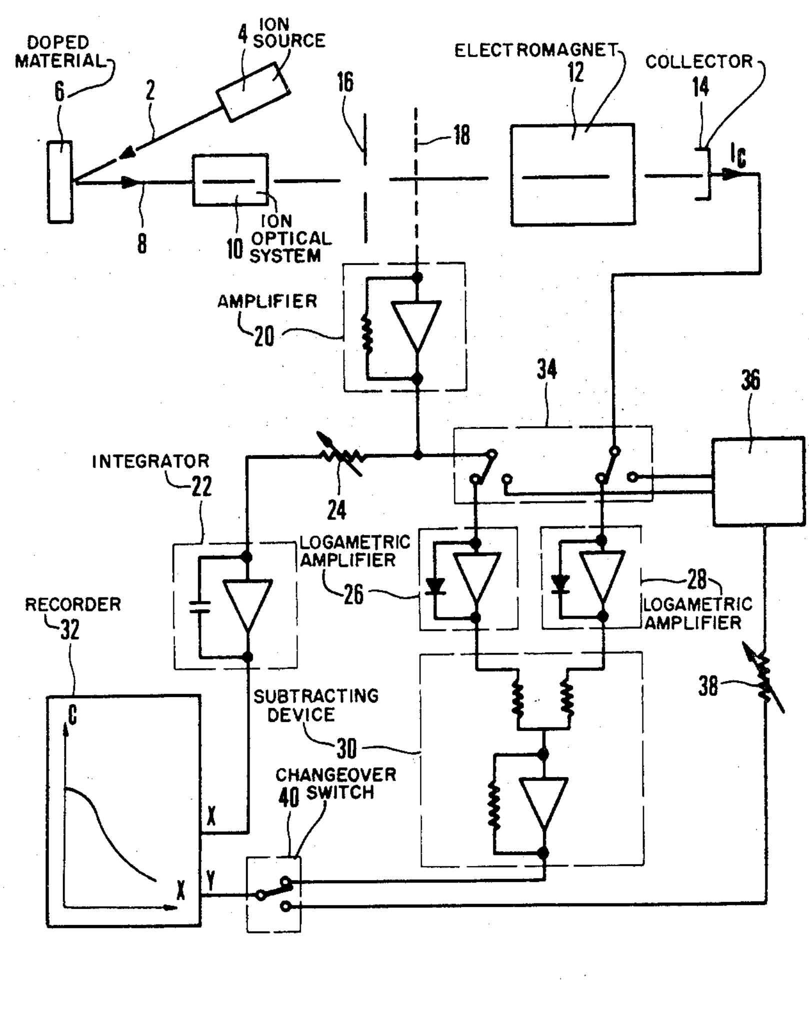
Primary Examiner—James W. Lawrence
Assistant Examiner—B. C. Anderson
Attorney—Cameron, Kerkam & Sutton

[57] **ABSTRACT**

A method for direct measurement of the curve of concentration of an element in a material, wherein said material is subjected to bombardment by a beam of primary ions and said material in turn emits a beam of secondary ions, wherein said method consists in recording simultaneously the total current corresponding to all the ions contained in said secondary beam and the ratio of the current which corresponds solely to the ions of said element contained in said beam, to said total current.

5 Claims, 2 Drawing Figures



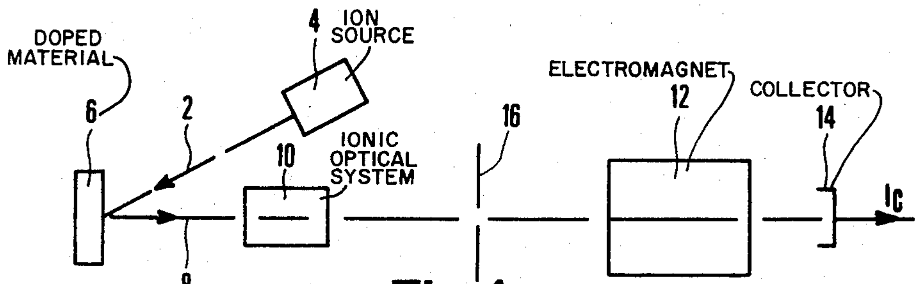


Fig : 1 PRIOR ART

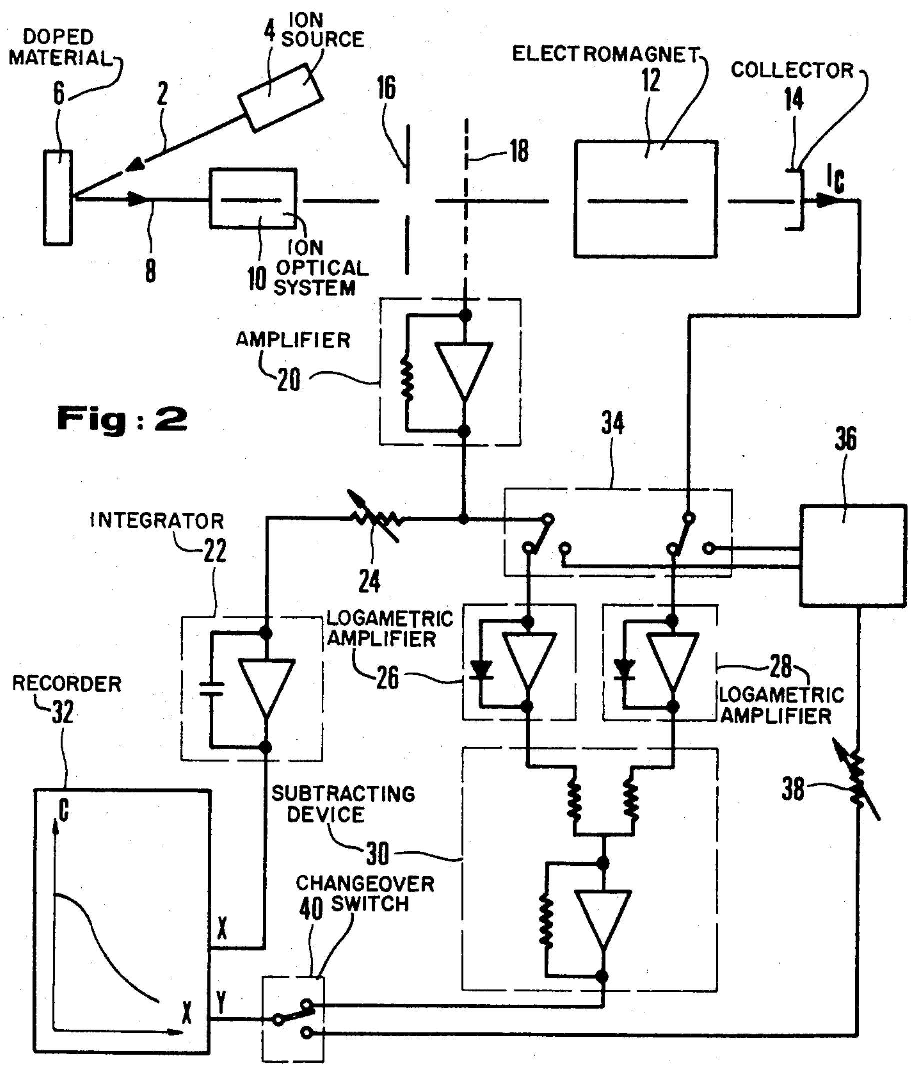


Fig : 2

DEVICE FOR DIRECT MEASUREMENT OF THE CURVE OF CONCENTRATION OF AN ELEMENT IN A MATERIAL

The invention is directed to a method for plotting the curve of concentration of an element in a material and also to an apparatus which carries out said method and is primarily applicable to the curve obtained by diffusion or implantation of an impurity in a semiconductor (doping of Si or Ce).

It is known that interesting analytical information can be obtained in regard to the chemical or isotopic surface composition of any given material by subjecting the surface of this latter to bombardment by an ion beam. This beam of primary ions progressively pulverizes the material at a predetermined rate known as the rate of attack or alternatively as the rate of pulverization. The ions derived from this pulverization are representative of the composition of the material and the detection of the ions accordingly permits a stratigraphic study of said material.

There already exist ionic probes which carry out the above method and a very diagrammatic illustration of which is given in FIG. 1. Under the effect of the primary ion bombardment 2 derived from the source 4 contained in the probe, the material 6, which is doped with impurities and the concentration curve of which is to be determined, becomes progressively hollowed and the atoms constituting the surface are ejected in a beam having a main direction 8. The secondary ions of this beam which are representative of the image of the material are accelerated and focused by an ionic optical system 10. They are then separated according to their mass by means of an electromagnet 12 which is interposed on the path. Finally, the ions corresponding to the impurities with which the material is doped are collected on a collector 14 and this latter delivers a current which is proportional to the quantity of ions detected.

The disadvantage of probes of this type lies in the fact that the rate of pulverization or of attack as hereinabove defined is liable to vary (for example in dependence on the primary ion current). In consequence, correct calibration of the apparatus both in depth of pulverization and in concentration of impurities cannot be obtained since these parameters depend on said rate.

The aim of this invention is to provide a method and a device for measuring the curve of impurities by means of the probes described above, thereby complying with practical requirements more effectively than comparable methods and devices of the prior art, particularly by making it possible to eliminate variations in the rate of attack.

A further aim of the invention is to obtain a record of the curve of impurities directly by electronic means in a single measurement, thus dispensing with the need for tedious analysis which is necessary in devices of the prior art in order to find the concentration curve as a function of the depth.

To this end, the invention proposes a method for direct measurement of the curve of concentration of an element in a material, wherein said material is subjected to bombardment by a beam of primary ions and said material in turn emits a beam of secondary ions, wherein said method consists in recording simultaneously the total current corresponding to all the ions contained in said secondary beam and the ratio of the current which corresponds solely to the ions of said element contained in said beam, to said total current.

The invention also proposes a device which serves to carry out said method and comprises a source of primary ions, an ionic optical system for accelerating and focusing, an electromagnet which separates the secondary ions ejected from said material according to their mass and retains only the ions of said element, an ion collector for delivering a current Ic which is proportional to the quantity of ions received, said device being essentially characterized in that it comprises :

A metallic grid interposed between said optical system and said electromagnet and followed by an amplifier for delivering a current I_T which is proportional to the total quantity of secondary ions.

A ratio circuit which makes it possible to obtain the quantity Ic/I_T and receives at both inputs respectively said current Ic which is derived from the ion collector and a fraction of said current I_T.

A recorder XY which receives at the input X the remaining fraction of the current I_T by means of an integrating circuit and receives at the input Y the current delivered from said ratio circuit, the curve of impurities of said material being thus directly displayed by said recorder.

In an advantageous mode of application of the invention, the ratio circuit comprises two logarithmic amplifiers, the outputs of which are connected to a subtracting device, which makes it possible to provide a wider range of recording.

Further properties and advantages of this invention will become apparent from the following description in which one embodiment of the apparatus according to the invention is given by way of example and not in any sense by way of limitation, reference being made to the accompanying drawings, in which :

FIG. 1 shows very diagrammatically a device of the prior art ;

FIG. 2 shows the device according to the invention associated with the device of the prior art.

The elements of FIG. 1 have already been described in the foregoing. However, it is necessary to add the diaphragm 16 which is placed after the optical system 10. This diaphragm allows only the central portion of the secondary-ion beam to pass through the electromagnet 12 in order to increase the resolution of the measurement.

The probe of FIG. 1 gives the current Ic corresponding to the ionic abundance of the doping element in the secondary beam as a function of time.

Postulating that the rate of attack is constant :

$$x = k_1 \cdot t \quad (1)$$

$$C = k_2 \cdot [Ic\,(t)/I_T\,(t)] \quad (2)$$

wherein :

x = depth of pulverization of the material

t = time

C = concentration of impurities

k_1 and k_2 are constants of proportionality

I_T is the total current produced by the secondary beam, as obtained in this case by means of a different adjustment of the field of the electromagnet which accordingly selects only the ions relating to the pure material. This assumes that the ions corresponding to the doping are negligible.

One may extract from these relations the curve of impurities, that is to say $C(x)$ as a function of x.

In actual fact, the variations in the rate of attack come into consideration and these expressions are written as follows :

$$X = k'_x \int_0^t v(t)\, dt \quad (3)$$

$$C = k'_c \cdot [Ic\,(t)/v\,(t)] \quad (4)$$

wherein $v(t)$ = rate of attack as a function of time k'_z and k'_c are constants of proportionality.

In FIG. 2, the elements which are common to FIG. 1 are designated by the same reference numerals. It is noted that provision is made on the path of the secondary beam for a metallic grid 18 which is placed between the diaphragm 16 and the electromagnet 12. This grid is made up of copper wires having a thickness of 25 μ and spaced at intervals of 100 μ. This grid collects a small fraction (namely a maximum of one-quarter) of the ions contained in the secondary beam. Said grid is followed by an amplifier 20 for delivering a current I_T which is proportional to the total quantity of secondary ions.

The incorporation of said grid 18 results from the following observations made by the inventors :

a. Under certain experimental conditions, mainly when the density of primary ions in respect of a given material is not too high, the current I_T is proportional to the rate of pulverization.

b. The ratio of the current Ic, relative to the ions of impurities, to said current I_T as measured before the electromagnet, is proportional to the concentration of impurities.

This latter observation holds true only in respect of a low concentration of impurities (lower than 10^{-2}).

Expressions (3) and (4) accordingly become :

$$x = k''_z \int_0^t I_T(t)\, dt. \quad (5)$$

$$C = k''_c\,[Ic\,(t)/I_T\,(t)] \quad (6)$$

wherein $k''x$ and $k''c$ are constants.

It is therefore readily apparent that the method according to the invention makes it possible to eliminate variations in the rate of attack.

A further advantage of the invention appears from a study of relations (5) and (6), namely the possiblity of obtaining directly by means of an analog circuit the concentration curve of impurities, that is to say C as a function of x. Inasmuch as the concentrations are expressed to the power of 10, it is usually more convenient to calculate log.C. The result thereby achieved as shown in FIG. 2 is that the current I_T at the output of the amplifier 20 drives on the one hand an integrator 22 preceded by a potentiometer 24 and, on the other hand, in the case of the figure shown, a first logarithmic amplifier 26. The current Ic delivered by the ion collector 14 drives a second logarithmic amplifier 28. The currents log I_T and log Ic thus obtained at each output respectively pass into a variable-gain subtracting device 30 which delivers the quantity log Ic/I_T.

A recorder X–Y designated by the reference 32 and advantageously consisting in this case of a plotting table receives at its input X the current which is delivered by the integrator 22 and is representative of the depth x of pulverization of the material and, at its input Y, the quantity log Ic/I_T which is delivered by the subtraction device 30 is representative of the concentration C of impurities in said material.

FIG. 2 also shows another mode of operation by means of a changeover switch 34. A fraction of the current I_T at the output of the amplifier 20 as well as the current Ic delivered by the ion collector 14 drive directly a quotientmeter 36 which restores the ratio Ic/I_T. This quotientmeter is connected at the output to a variable potentiometer 38 which transmits said ratio of the currents Ic and I_T to the channel Y of the recorder 32 by means of a changeover switch 40 whilst the channel X continues to receive the current delivered by the integrator 22. It is readily apparent that the switches 34 and 40 are actuated simultaneously according to the type of recording which is chosen, a broad dynamic range being made possible in the case of logarithmic recording.

Initial adjustment of the device can be carried out from material having a known impurity curve. The potentiometer 24 serves to calibrate the quantity as abscissae, namely in this case the depth of pulverization. Similary, the variable gain of the subtracting device 30 or the potentiometer 38 makes it possible to calibrate the quantity as ordinates, namely in this case the concentration expressed respectively by log Ic/I_T and Ic/I_T.

It is clearly demonstrated by the foregoing that the device as described has numerous advantages over existing devices and among these can be mentioned the following :

independence of the parameters C and x with respect to variations in the rate of pulverization,

direct obtainment of the record of C as a function of x,

direct and simultaneous obtainment of Ic and I_T and not by means of two successive adjustments.

It is self-evident that the invention is not limited to the mode of execution which has been described by way of example and that the scope of this patent extends to alternative forms of either all or part of the arrangements described which remain within the definition of equivalent means.

What we claim is:

1. A device for direct measurement of the curve of concentration of an element in a material including a source of primary ions, an ionic optical system for accelerating and focusing the ejected secondary ions, an electromagnet which separates the secondary ions ejected from said material according to their mass and which retains only the ions of said element, an ion collector for delivering a current Ic which is proportional to the quantity of ions received comprising

a metallic grid interposed between said optical system and said electromagnet and followed by an amplifier for delivering a current I_T which is proportional to the total quantity of secondary ions,

a ratio circuit to obtain the quantity Ic/I_T and receives at its two inputs respectively said current Ic which is derived from the ion collector and a fraction of said current I_T,

a recorder XY which receives at the input X the remaining fraction of the current I_T by an integrating circuit and, of the input Y, the current derived from said ratio circuit, the curve of impurities of said material being thus displayed directly by said recorder.

2. A device according to claim 1, wherein said ratio circuit comprises a first logarithmic amplifier which receives said fraction of the current I_T at its input, a second logarithmic amplifier which receives said current Ic at its input, a variable-gain subtraction device whose inputs are connected respectively to the output of said logarithmic amplifiers so that the quantity log Ic/I_T is obtained.

3. A device according to claim 1, wherein said ratio

circuit is a quotientmeter for delivering directly the quantity Ic/I_T.

4. A device according to claim 1, wherein said metallic grid is made up of copper wires 25 μ in diameter and spaced at intervals of 100 μ.

5. A device according to claim 2 including a switching system to transmit to the channel Y of the recorder the quantity log Ic/I_T or Ic/I_T depending on the desired mode of operation, while the channel X of said recorder continues to receive a quantity corresponding to said current I_T.

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