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(54) **ELECTRON SENSOR FOR ELECTRON MICROSCOPY**

ELEKTRONENSENSOR FÜR DIE ELEKTRONENMIKROSKOPIE

CAPTEUR D'ÉLECTRONS POUR MICROSCOPIE ÉLECTRONIQUE

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Description

OBJECT OF THE INVENTION

[0001] The object of the present invention is an electron sensor for electron microscopy, and a system with a plurality of electron sensors for electron microscopy.

[0002] Therefore, the present invention can be framed in the field of sensors to detect electrons used in transmission electron microscopes (TEM), in scanning electron microscopes (SEM) or in scanning transmission electron microscopes (STEM).

BACKGROUND OF THE INVENTION

[0003] Currently, different applications in the field of electron microscopy detect and accumulate electrons to generate images, or energy spectrums. These images, or spectrums, are used in the study of materials in science and technology.

[0004] Specifically, these applications are based on the irradiation of a sample, with electrons accelerated at energies between 2 keV and 400 keV. Although less frequent, there are also TEM electron microscopes that operate with electrons accelerated at high energies of up to 1.2 MeV.

[0005] More specifically, in transmission electron microscopes (TEM), these accelerated electrons traverse the material that forms a sample, and by means of magnetic lenses, enlarged two-dimensional images are generated of the sample and diffraction patterns (two-dimensional images). Therefore, in TEM electron energy-loss spectroscopy applications (EELS or EFTEM), an energy filter is used that is manufactured with electromagnetic lenses, whereby an energy spectrum is obtained (one-dimensional image), or an energy-filtered image (two-dimensional image) with information about the chemical composition of the sample.

[0006] With the aim of obtaining the images, electron microscopes comprise electron sensors that are manufactured with "pixelated" semiconductors. In other words, semiconductors that on the surface where photons, or electrons, impact comprise a plurality of discrete electronic components. These discrete electronic components are organized by way of a one-dimensional or two-dimensional matrix, to detect the photons, or electrons, wherein each discrete electronic component is usually called "pixel". In this way, the "pixelated" semiconductors detect, by means of each "pixel", the position of impact of an electron, or a photon, in one or two spatial dimensions.

[0007] Specifically, the "pixelated" electron sensors used in TEM are manufactured with CCD, or CMOS-type technology. Particularly, CCD sensors include in each "pixel" a sensor part whereon the electrons impact and another electronic circuit part. Whilst, in the CMOS sensors, the electronics is distributed in each pixel, so that the electronics is irradiated by the electrons of the electron beam, making it susceptible to damage by irradiation. In both cases, these technologies are sensitive to damage by irradiation due to the high electron energies used in electron microscopes.

[0008] Another problem for these CMOS or CCD technologies is that the electrons are absorbed in different directions including the depth and width of the electron sensor. In this way, the effective resolution of the electron sensor is limited, i.e. the proximity wherein each "pixel" can be placed is delimited. This is due to the fact that if two adjacent "pixels" are too close to one another, when an electron impacts on a "pixel" it also generates a signal which can be appreciable in the adjacent "pixels". This effect is known as "charge sharing" or "cross-talk". In this way, in order for these "pixels" to be sufficiently separated and a good spatial resolution can be obtained in electron microscopes, the electron sensor has to be very big.

[0009] To avoid the first of these problems, i.e. the related to sensitivity to damage by irradiation, in TEM, indirect CMOS or CCD sensors are usually used. In these sensors, the electron does not directly impact on the semiconductor but on a scintillator, which is optically coupled to the sensor, and which, after the impact generates a cascade of photons, i.e. these electrons are converted into photons. These low-energy photons, within the visible spectrum, are those measured in the "pixelated" photon sensor. In contrast, this indirect detection of the electrons converted into photons does not solve the problem of "charge sharing" or "cross-talk" and degrades the sensor operation, affecting some of its technical characteristics such as detective quantum efficiency (DQE) and modulation transfer function (MTF). As a result of this, the quality of the images deteriorates, and it is necessary to increase the exposure time to form images with a suitable signal-noise ratio. This increase in exposure time is counter-productive for examining many types of sample, such as, for example, biological samples, which are highly susceptible to altering their atomic structure during the observation process in a TEM experiment.

[0010] Recently, with the aim of avoiding all these problems, CMOS sensors have been developed for their direct use, i.e. capable of measuring electrons without the need for photoconversion in transmission electron microscopes. These new CMOS sensors are based on a combination of known techniques such as: the use of submicrometric manufacturing techniques, "radhard layout" and backlighting to improve the resistance of the electronic circuit part in the pixels to damages by irradiation and to increase the "fill factor". As well as substrate thinning technologies of the electron sensor to improve the sensor's spatial resolution, by reducing the problem of "charge sharing".

[0011] It also uses "Silicon-on-Insulator" technology that allows greater substrate thinning with respect to conventional CMOS technology.

[0012] In any of these cases, the electron sensor thinning process is complex, and makes the CMOS or CCD sensors very fragile. This also reduces the "manufactur-

ing yield" and makes the process more expensive. Furthermore, despite the "radhard layout", these CMOS or CCD sensors are still susceptible to damage by irradiation when high-energy electron beams are used or with high current densities. Therefore, they are usually accompanied by additional protection systems in their application in TEM to control the irradiation dose.

[0013] More specifically, when CMOS or CCD sensors are used to capture images of diffraction patterns, which are usually formed by discrete points distributed in the image with a high electron current density, these sensors are even more susceptible of being damaged by irradiation.

[0014] Another type of direct sensors is of hybrid CMOS or CCD type, wherein to avoid damage by irradiation with electrons, they use a "pixelated" sensor which is separated from the electronic circuitry by means of the "bump-bonding" technique. In this case, the "fill factor", i.e. the ratio between the area with "pixels" of the sensor and its total area, is 100%. Furthermore, the electrons are completely absorbed in the electron sensor so that the electronic circuitry is not damaged by irradiation. Despite this, this hybrid technology is not a conventional technology, the number of pixels is limited due to its own manufacturing technology, and it has additionally "charge sharing" problems since the sensor cannot be thinned, which implies lower spatial resolution.

[0015] Finally, electron sensors made with SSD ("silicon strip detectors") technology have also been proposed, wherein the surface of the electron sensor, perpendicular to the beam of electrons which impacts it, contains a plurality of electrodes extended by way of parallel silicon bands and separated from one another forming one or two layers. In this type of electron sensors, the electrons may directly impact the sensor.

[0016] In contrast, this type of SSD sensor reduces the "fill factor" of the electron sensor and its substrate must be thinned below 50 μm to have a suitable spatial resolution for electron microscopes. Furthermore, they are not manufactured with conventional technologies. All of this entails an expensive and complex process, which makes the sensor very delicate as it can be broken easier, reducing the manufacturing yield.

[0017] A final problem relates to the dynamic range of "pixelated" electron sensors, i.e. the amplitude of the range of intensity values that can be measured in each pixel. In the sensors that receive the electrons directly, it is possible to obtain an infinite dynamic range, counting the number of electrons which impact on each "pixel" in a time interval. But this is not practical when the intensities in a "pixel" are very high since the electronics is not capable of processing the successive impacts with sufficient speed. In said situations, it is necessary to operate the detectors in integrator mode, i.e. it measures in each pixel the sum of the charge generated by a large number of impacts and not each individual impact. That value measured in integrator mode is an analog value that it is necessary to digitize, with a dynamic range determined by the number of bits of the analog-digital converter used. In current "pixelated" detectors, each pixel only has a digital-analog converter with a typical dynamic range of 12 bits. This range is insufficient in TEM when two-dimensional images of diffraction patterns are taken. As a result, the intensities go out of the dynamic range in some of the image's pixels and their real value is not captured.

DESCRIPTION OF THE INVENTION

[0018] The present invention discloses an electron sensor for electron microscopy using an electron microscope, wherein the electron sensor comprises a substrate, with a front plane and a rear plane parallel to one another, which is intended to absorb at least one electron of an electron beam, which traverses a sample and is generated by the electron microscope, and this electron is susceptible of generating an electric charge of free electron-hole (e-h) pairs in said substrate.

[0019] More specifically, the electron sensor according to the invention is defined in appended claim 1.

[0020] More specifically, the input unit comprises a series of input electrodes, or "pixels", separated from one another, and the lower plane of the guard unit comprises at least one guard electrode with a plurality of notches suitable for housing the upper plane of the series of input electrodes without directly contacting with them.

[0021] More specifically, the base unit is intended to reduce the "cross-talk" between adjacent input electrodes, and measure the energy of the electrons which impact on the substrate.

[0022] Additionally, the upper plane of the base unit comprises a base electrode with a plurality of notches suitable for housing the lower plane of the series of input electrodes without directly contacting with them.

[0023] Preferably, the joining area between the lower plane of the input unit and the upper plane of the base unit comprises an energy measurement unit to increase the precision of energy measurement of the electrons which traverse the input unit series.

[0024] Said energy measurement unit comprises a series of energy measurement electrodes.

[0025] Preferably, each energy measurement electrode comprises a superposition of measurement electrodes of appreciably oval configuration.

[0026] It should be highlighted that the input unit, the contact unit and the base unit are connected to an electronic circuit unit by means of tracks placed on the substrate of contacts with high electrical conductivity, e.g. gold or polysilicon.

[0027] Alternatively, the input unit, the contact unit, the energy measurement unit and the base unit are connected to an electronic circuit unit by means of tracks placed on the substrate of a contact with high electrical conductivity, e.g. aluminium, gold or polysilicon.

[0028] More specifically, the base electrode, each input electrode and each electrode of the superposition of energy measurement electrodes are connected, by

means of tracks placed on the substrate of a contact with high electrical conductivity, e.g. aluminium, gold or polysilicon.

[0029] Said electronic circuit unit is distanced from the base unit to avoid exposure to the radiation of the electrons and to the secondary radiation generated in the substrate.

[0030] Said electronic circuit unit allows measuring the impact position and the energy of the electrons in at least two different ways.

[0031] The circuit unit can measure in position count mode, where it counts how many electrons impact on each input electrode, in this way it is possible to know in what part of the lateral reception surface the electrons impact and the number of impacts. Additionally, the circuit unit can measure in position integrator mode, where it adds up the total charge released by the electrons which impact on each input electrode during a determined time and knowing on what part of the lateral reception surface they have impacted. In both cases, the electric charge generated in the sensor and which is not captured by the input electrode (point of impact of the electron) is captured by the energy measurement electrodes and/or by the base electrode. In this way, the "cross-talk" is reduced between the neighbouring input electrodes in the linear direction of the sensor.

[0032] Additionally, the circuit unit can measure in count and integrator mode, wherein it measures the number of electrons that impact on each input electrode knowing on what part of the lateral reception surface, whilst it integrates, i.e. adds up the total charge released by the electrons which impact on each energy measurement electrode during a determined time.

[0033] Alternatively, the circuit unit can measure in double integrator mode, wherein it adds up the total charge released by the electrons which impact on each input electrode and on each energy measurement electrode during a determined time, knowing on what part of the lateral reception surface the impact occurs.

[0034] Preferably, the electrodes of all the units of the front and rear planes of the substrate are made with doping materials diffused in the substrate. More specifically, the diffusions of p-type or n-type dopants of the rear and front faces of the substrate, respectively, and the doping of the substrate constitute an "array" of diodes with p-n bonds.

[0035] By this way, a polarization voltage is applied, by means of said circuit unit, between the electrodes of the rear and front faces of the substrate, so that the "diodes" are inverse polarized creating a depletion area in the substrate.

[0036] It should be highlighted that the electron sensor proposed is preferably a linear sensor, i.e. it is formed by a single line, or electrode vector, to measure a one-dimensional or two-dimensional image, and it allows measuring the energy of the electrons impacting each pixel of the image.

[0037] Preferably, this electron sensor can be manufactured with conventional lithographic techniques and the electronic circuitry by means of CMOS microelectronic technology. More specifically, it can be manufactured by means of standard CMOS technology, so that whilst in one area of the substrate the electronic circuit unit is manufactured, at the other end only the units that comprise the different electrodes are manufactured.

[0038] Additionally, this electron sensor allows its use as direct "pixelated" detector of the energy filters that are used in electron energy loss spectrometry applications (EELS or EFTEM). In the case of EELS, the sensor measures the one-dimensional energy spectrum dispersed by the energy filter. In the case of EFTEM, the sensor is used to form two-dimensional images in a specific energy range.

[0039] Additionally, by placing each sensor pixel of various electrodes at different depths (input electrode and energy measurement electrodes) to measure the charge generated by the impact of an electron, it is possible to measure the energy of the impacting electron without the need to use an energy filter.

[0040] In this way, an electron sensor is obtained that is resistant to damage by irradiation, which can directly measure the electrons which impact it with high spatial and energy resolution.

[0041] Likewise, by placing in each pixel not just one but several electrodes at different depths (input electrode and energy measurement electrodes), it is possible to measure the charge generated by the impact of the electrons in a determined time (integrator mode) using more than one electrode in each and, thus, obtaining a greater dynamic range of the sensor compared with the existing pixelated sensors.

[0042] Another advantage of this electron sensor is that it allows forming said two-dimensional images in a TEM microscope, scanning the electron beam by electromagnetic means and capturing the image line by line. This is a difference with respect to the sensor technologies used in image formation applications with optical photons, or X-rays, which are particles without electric charge and, therefore, they cannot be scanned by scanning the beam by electromagnetic means.

[0043] Additionally, as said electron sensor is formed by a single line of input electrodes, the problem of "charge sharing" is eliminated in the transversal direction of the sensor.

[0044] Furthermore, due to the fact that the lateral reception surface does not contain electrodes, the "fill factor" of the electron sensor design proposed here is 100%. This enables detecting impacts of electrons between two input electrodes, using for this averaged signal techniques between adjacent input electrodes, known as subpixel techniques, and, in this way, increase the effective resolution of the sensor.

[0045] By way of summary, this electron sensor is easy to manufacture and allows generating one-dimensional or two-dimensional images with greater image range, as well as, measuring the electron energy with electrodes

at different depths of the substrate, without the electronics for control and processing of the sensor signals being exposed to the irradiation of the electron beam.

DESCRIPTION OF THE DRAWINGS

[0046] To complement the description being made and in order to aid towards a better understanding of the characteristics of the invention, in accordance with a preferred example of practical embodiment thereof, a set of drawings is attached as an integral part of said description wherein, with illustrative and non-limiting character, the following has been represented:

Figure 1.- Shows a perspective view of a preferred embodiment of the electron sensor.

Figure 2.- Shows a side schematic view of the preferred embodiment of the electron sensor.

Figure 3a.- Shows a detailed schematic view of the position of the electrodes.

Figure 3b.- Shows a detailed schematic view of the position of the electrodes wherein an electron beam impacts on the lateral reception surface.

Figure 4.- Shows a detailed schematic view of the connections of the electrodes.

Figure 5a.- Shows a schematic view of a first configuration of several electron sensors placed in parallel.

Figure 5b.- Shows a schematic view of a second configuration of several electron sensors placed in parallel.

Figure 5c.- Shows a schematic view of a third configuration of several electron sensors placed in parallel.

Figure 5d.- Shows a schematic view of a fourth configuration of several electron sensors placed in parallel.

Figure 5e.- Shows a schematic view of a fifth configuration of several electron sensors placed in parallel.

PREFERRED EMBODIMENT OF THE INVENTION

[0047] In a preferred embodiment of the invention, as shown in figures 1 and 2, the electron sensor (1), for TEM electron microscopy, comprises a silicon substrate (2) that perpendicularly receives, by means of a lateral reception surface (3), an electron beam (10) that has come from traversing a sample, not represented, to investigate. Wherein said electron beam (10) is produced by the TEM microscope, and comprises at least one electron with an electric charge and an energy. To form an image (11), the impact position and/or energy of a large number of electrons of the electron beam (10) are measured.

[0048] The substrate (2) comprises a rear plane (2p) and a front plane (2a) parallel to one another, and perpendicular to the lateral reception surface (3). A contact unit (14) is placed on said rear plane (2p), and on its front plane (2a) the following are placed on, by order of shortest to longest distance to the lateral reception surface (3): a guard unit (15), an input unit (16), an energy measurement unit, a base unit (18) and an electronic circuit unit (12).

[0049] Preferably, the substrate (2) has a thickness between 300 and 600 μm, and is made of slightly doped p-type silicon with resistivity between 2 and 10 KΩ.

[0050] When this electron beam (10) impacts on the lateral reception surface (3), the electrons of the electron beam (10) are losing energy by means of the generation of a free charge of electron-hole (e-h) pairs in the silicon of the substrate (2). The generation of an electron-hole pair in silicon requires 3.6 eV so that a single electron of 100 keV that impacts on the lateral reception surface (3) generates approximately 27,777 e-h pairs.

[0051] It should be highlighted that when the electron impacts on the lateral reception surface (3), it describes a random trajectory and loses energy as it generates a free charge of e-h pairs. This electron is finally totally absorbed by the substrate (2) at a distance, which may be hundreds of micrometres, from the lateral reception surface (3) i.e. from the point of impact. Therefore, each electron that impacts is absorbed at some point of an area typically called interaction volume. This interaction volume usually has the form of a pear, as is schematically shown in figure 2 and in figure 3b, and its size depends on the initial energy of the electron.

[0052] More specifically, before impacting on the lateral reception surface (3) said electron beam (10) traverses a mask (9) opaque to the electrons, preferably manufactured in platinum, with a notch which extends throughout the width of the electron sensor (**1**). More specifically this notch has a width equal to the pitch between "pixels" of the input unit (16), and preferably it is close to the lateral reception surface (3). In this way, the mask (9) defines the effective width of the "pixel" in the direction of the thickness of the substrate (2).

[0053] Preferably, as shown in figures 1, 2 and 3a, the contact unit (14) which comprises a contact electrode (4) substantially occupies the entire width of the rear plane (2p) and has a maximum height of 400 μm. Said contact electrode (4) is a deposition of doped p+-type silicon intended to capture the free holes generated in the substrate (2) by the impact of said electron of the electron beam (10) and which are pulled by an electric polarization field towards the rear plane (2p).

[0054] Preferably, the guard unit (15) comprises a guard electrode (5). The guard electrode (5) is placed so

that it extends along the width and length of the substrate (2), bordering the entire front plane (2a). Its geometry is substantially an array of strips as four strips that form a frame, wherein the side closest to the lateral reception surface (3) has a plurality of notches. Said guard electrode (5) is a deposition of doped n-type silicon with a height of 2 μm intended to capture the free electrons generated in the substrate (2) by the impact of said electron of the electron beam (10) and which are pulled by the electric polarization field towards the front plane (2a).

[0055] The input unit (16) comprises a series of input electrodes (6) preferably of rectangular configuration and separated from one another, to capture the specific point of impact of the electrons of the electron beam (10) on the lateral reception surface (3). Said input electrodes (6) are depositions of doped n-type silicon intended to capture the free electrons generated in the substrate (2) by the impact of said electron of the electron beam (10) and which are pulled by the electric polarization field towards the front plane (2a).

[0056] Specifically, the input electrodes (6) have an appreciably rectangular configuration with a height of 10 to 70 μm and a width of 4 to 20 μm. More specifically, their upper plane is housed in said plurality of notches of the guard electrode (5). Each one of these input electrodes (6) are separated from the adjacent one by a distance of 10 to 50 μm. It should be highlighted that each notch of the guard electrode (5) has a height of at least 1 μm and a width of at least 6 μm, wherein said width is always at least 1 μm greater than the width of the input electrode (6) that it houses, so that they are never in direct contact, as can be seen in figure 3a.

[0057] Furthermore, the number of input electrodes (6) determines the spatial resolution of the electron sensor (1). In this way, in this preferred embodiment, the number of input electrodes (6) or "pixels" is equal to 2048, the width of each input electrode (6) is 10 μm and the height is 50 μm, and the separation between each central vertical axis of each input electrode (6) is 25 μm. Therefore, the width of the electron sensor (1) is at least 51,200 μm. It should be highlighted that these 2048 input electrodes (6) have not been totally represented in figures to facilitate their understanding.

[0058] Preferably, the lower plane of each one of the input electrodes (6) are housed in a plurality of receptacles of the base unit (18). In other words, the base unit (18) comprises a base electrode (8) with said plurality of receptacles that partially cover each one of the input electrodes (6).

[0059] More specifically, this base electrode (8) extends along the width of the front plane (2a) and has a height between 100 and 400 μm. It should be highlighted that the size of these receptacles is variable, but they preferably have an appreciably oval configuration with a height between 10 and 150 μm, and a width between 10 and 35 μm. Preferably, the base electrode (8) comprises a height of 200 μm, and each receptacle has a height of 50 μm and a width of 20 μm. Said base electrode (8) is a deposition of doped n-type silicon intended to capture the free electrons generated in the substrate (2) by the impact of said electron of the electron beam (10) and which are pulled by the electric polarization field towards the front plane (2a).

[0060] It should be highlighted that for each input electrode (6) the guard electrode (5) has a notch, and the base electrode (8) has a receptacle.

[0061] In this preferred embodiment, as is shown in greater detail in figure 3a, in the joining area between each input electrode (6) and the base electrode (8), i.e. the area between the lower plane of the input electrodes (6) and the upper plane of the base electrode (8), the electron sensor (1) comprises the energy measurement unit. This energy measurement unit, in turn, comprises an energy measurement electrode (7) for each input electrode (6). These energy measurement electrodes (7) increase the precision of the energy measurement of the electrons which traverse the series of input electrodes (6). Specifically, these energy measurement electrodes (7) are surrounded by the base electrode (8) and have appreciably oval shape with a height between 10 and 20 μm, and a width between 20 and 30 μm. Preferably, each energy measurement electrode (7) comprises a height of 20 μm and a width of 20 μm. Said energy measurement electrodes (7) are depositions of doped n-type silicon intended to capture the free electrons generated in the substrate (2) by the impact of said electron of the electron beam (10) and which are pulled by the electric polarization field towards the front plane (2a). In this way, as is shown in figure 3b, it increases the precision of the electron sensor to measure the charge (and therefore the energy) generated in the substrate by the impacting electrons (1).

[0062] More specifically, figure 3b shows the probability that the electrons of the electron beam (10) are absorbed at different depths in the substrate (2). Additionally, this figure 3b shows by which electrode or electrodes (6, 7, 8) the charge generated by the electron throughout its trajectory through the substrate (2) shall be detected. In this way, it can be verified how the electron sensor (1) detects with great precision where the electrons impact by means of the input electrode (6). Additionally, this electron sensor (1) enables measuring the energy of the electron of the electron beam (10) detecting the free charge of e-h pairs generated at different depths, by means of the electrodes (6, 8), (7, 8) or (6,7,8). These electrodes (6, 7, 8) detect the depth and lateral distribution at which the electrons are absorbed in the substrate (2), with both the depth and lateral distribution proportional to the initial energy of the electrons.

[0063] It should be highlighted that the distance between each electrode (5, 6, 7, 8) of the front plane (2a) is between 1 and 2 μm. More specifically, these separation areas are found in the following electrodes (5, 6, 7, 8):

- between each notch of the guard electrode (5) and each input electrode (6),

- between each guard electrode (5) and the base electrode (8),
- between each input electrode (6) and each receptacle of the base electrode (8),
- between each input electrode (6) and each energy measurement electrode (7),
- between each energy measurement electrode (7) and each receptacle of the base electrode (8).

[0064] Additionally, the base electrode (8), each input electrode (6) and each energy measurement electrode (7) are connected, by means of metal tracks (13, 13', 13") generally of aluminium placed on the substrate (2), to an electronic circuit unit (12) inserted in the front plane (2a) of the substrate (2) after the base electrode (8), as is schematically shown in figure 4. Additionally, contact electrode (4) is also connected to the electronic circuit unit (12) by means of a metal track, not represented.

[0065] Said electronic circuit unit (12) comprises an electric generator to generate a polarization voltage between the electrodes (5, 6, 7, 8) of the front plane (2a) and the contact electrode (4) of the rear plane (2p). Specifically, the electrodes (5, 6, 7, 8) are at a negative polarization potential with respect to the contact electrode (4). In this way, the polarization voltage generates an electric field which serves to pull the holes or the free electrons of the e-h pairs generated in the substrate (2) towards the rear plane (2p) or towards the front plane (2a).

[0066] More specifically, the free electrons of the e-h pairs generated by the impact of an electron are pulled towards the electrodes (5,6, 7, 8) of the front plane (2a) and the holes are pulled towards the only contact electrode (4) of the rear plane (2p) of the electron sensor (1). This movement of charges induces an electric current in the electrodes (4, 5, 6, 7, 8) which, through metal tracks (13, 13', 13") placed on the substrate (2), is measured in the electronic circuit unit (12).

[0067] More specifically, the electronic circuit unit (12) comprises at least one electronic circuit to condition and process the information captured by the electrodes (5, 6, 7, 8) by the impact of at least one electron of the electron beam (10) received on the lateral reception surface (3).

[0068] Preferably, several electron sensors (1) are placed in parallel with different configurations to obtain different advantages, and to generate two-dimensional images formed by the successive addition of one-dimensional lines measured by each one of the electron sensors (1).

[0069] The first configuration of several electron sensors (1) in parallel, is shown in figure 5a, wherein three electron sensors (1) are linked, distanced from one another. Each one of these electron sensors (1) has dimensions of the electrodes (4, 5, 6, 7, 8) optimized to detect a range of initial energies of the electrons of the electron beam (10). In this case, preferably for TEM microscopes, each one of the electron sensors (1) is configured to detect, respectively, the following electron energy ranges: 60-120 keV, 120-200 keV and 200-300 kV. In this way, depending on the energy used in a specific application, it is possible to select the use of a single electron sensor (1) to form the image (11).

[0070] The second configuration of several electron sensors (1) in parallel, is shown in figure 5b, wherein two electron sensors (1) are positioned, displaced from one another at a distance of half a pixel to duplicate the spatial resolution. In this case, both electron sensors (1) are used at the same time.

[0071] The third configuration of several electron sensors (1) in parallel, is shown in figure 5c, wherein at least two electron sensors (1), although preferably three, are placed in parallel. In this way, it is possible to acquire images at a greater speed, i.e. more frames per second, without reducing the exposure time by means of the "Time-Delay-Integration" technique which is applied with linear sensors in optical applications. This configuration is especially useful in applications which require the capture of series of two-dimensional images at high speed such as, for example, in dynamic applications with TEM microscopes (in-situ TEM).

[0072] The fourth configuration of several electron sensors (1) in parallel, is shown in figure 5d, wherein at least two electron sensors (1) are placed in parallel and each one of them comprises input electrodes (6) and/or energy measurement electrodes (7) with different sizes. This configuration allows forming the image (11) with different resolutions.

[0073] The fifth configuration of several electron sensors (1) in parallel, is shown in figure 5e, wherein they are connected to a plurality of electron sensors (1) to form a two-dimensional image (11) scanning the electron beam (10) successively in discrete steps and capturing a line of pixels in each position with each electron sensor (1). In other words, to form a two-dimensional image (11) of 2048 x 2048 pixels and if the electron sensor (1) comprises a line of 2048 input electrodes (6), it would have to measure 2048 lines in 2048 discrete positions. The process is more efficient, placing preferably 3 electron sensors (1) with a separation of 512 pixels. In this way, the electron beam (10) would be scanned at an equivalent distance of 512 pixels instead of 2048 pixels, and the capture of the two-dimensional image (11) would be performed in a quarter of the time.

[0074] It should be highlighted that the present electron sensor (1) is susceptible of measuring a one-dimensional or two-dimensional image.

[0075] Preferably, to measure one-dimensional images, typically when it is used in combination with an energy filter, both the electron sensor (1) and the electron beam (10), which is projected from the electron microscope, are maintained in the same horizontal position.

[0076] Whilst at least four methods are used to measure two-dimensional images. In any of these methods, the two-dimensional image (11) is formed by means of the capture of multiple projection lines of the electron

beam (10) with the electron sensor (1).

[0077] Preferably, in the first method, the electron sensor (1) is fixed in a position in the projection plane of the electron beam (10), and the representation projected by the TEM is scanned by means of electromagnetic systems (e.g. coils of the projection lens included in any TEM), which is displaced in a direction perpendicular to the linear direction of the sensor.

[0078] Preferably, in the second method, the projection of the electron beam (10) is in a fixed position, and the electron sensor (1) is displaced by mechanical means such as the use of an electric motor with a mechanical system that transforms the rotation of the motor in linear displacement. The advantage of this method is that it is not necessary to control the TEM's electromagnetic systems for the beam scanning.

[0079] Preferably, in the third method, the projection of the electron beam (10) and the electron sensor (1) is in a fixed position, and the sample is displaced by mechanical means such as the use of an electric motor with a mechanical system that transforms the rotation of the motor in linear displacement. The advantage of this method is that it is not necessary to control the TEM's electromagnetic systems for the beam scanning.

[0080] Preferably, in the fourth method, when the sensor is used as sensor in EFTEM applications, the projection of the electron beam (10) filtered by an energy filter, the electron sensor (1) and the sample, are in a fixed position, and the energy-filtered electron beam is scanned in the perpendicular direction of the electron sensor (1) using the electromagnetic systems present in the energy filters that are commonly used in TEM for spectrometry applications.

[0081] In another preferred embodiment, not represented, the electron sensor (1) is also applicable for measuring the energy of transmitted and secondary electrons in scanning electron microscopes in transmission mode, called STEM and SEM, by means of the scaling of the size of the electron sensor (1) and the number and the geometry of the pixels or electrodes (4, 5, 6, 7 8), to adapt it to these applications and the particular energy ranges of the application.

[0082] More specifically, in SEM and STEM applications, the images of the electron sensor (1) that we propose would be fixed in one position of the microscope, since the images and spectrums in these applications are formed by scanning a beam from point to point.

Claims

1. Electron sensor (1) for electron microscopy using an electron microscope, wherein the electron sensor (1) comprises a substrate (2), with a front plane (2a) and a rear plane (2p) parallel to one another, the substrate (2) being adapted to absorb at least one electron of an electron beam (10) after traversing a sample and being generated by the electron microscope, wherein the electron is susceptible of generating an electric charge of free electron-hole (e-h) pairs in the substrate (2), **characterized in that** the electron sensor (1) further comprises:

   - a lateral reception surface (3), placed on one of the sides of the substrate (2) to perpendicularly receive the electron beam (10),
   - a contact unit (14), placed on the rear plane (2p), and

   the following units placed on the front plane (2a) by order of shortest to longest distance to the lateral reception surface (3):

   - a guard unit (15), bordering in parallel at least the lateral reception surface (3) receiving the electron beam (10), and adapted to avoid leakage currents in the edge of the substrate (2),
   - an input unit (16), adapted to detect the input point of the electrons of the electron beam (10), a base unit (18), adapted to measure the energy of the electrons of the electron beam (10) which impact on the lateral reception surface (3),
   - an electronic circuit unit (12), linked to at least the base unit (18), the contact unit (14) and the input unit (16), which comprises an electric generator and electric circuit,

   wherein said electric generator is adapted to generate an electric polarization current, between the front plane (2a) and the rear plane (2p), adapted to pull the free electrons generated in the substrate (2) towards the base unit (18) and/or the input unit (16), adapted to pull the free holes towards the contact unit (14); and to allow the electrons and the holes to be captured by their respective units, and wherein the electric circuit is adapted to condition and process the free electrons to form a one-dimensional or two-dimensional image (11) with greater dynamic range.

2. Electron sensor (1) according to claim 1, **characterized in that** the input unit (16) comprises a series of input electrodes (6).

3. Electron sensor (1) according to claim 2, **characterized in that** the input electrodes (6) comprise a height between 10 and 70 μm, a width between 4 and 20 μm, and wherein said input electrodes (6) are separated from one another at a distance between their vertical axes between 10 and 50 μm.

4. Electron sensor (1) according to claim 3, **characterized in that** the input electrodes (6) comprise a height of 50 μm, a width of 10 μm, and are separated from one another at a distance between their vertical axes of 25 μm.

5. Electron sensor (1) according to any of claims 2 to 4, **characterized in that** the guard unit (15) comprises at least one guard electrode (5) close to the lateral reception surface (3), and on the lower plane of the guard unit (15) there is a plurality of notches to house the upper plane of the input electrodes (6) without directly contacting.

6. Electron sensor (1) according to claim 5, **characterized in that** the guard electrode (5) is placed as four strips that form a frame, two of them along the width and two along the length of the substrate (2) wherein the strip of the guard electrode (5) closest to the lateral reception surface (3) has a plurality of notches to house the upper plane of the input electrodes (6) without directly contacting.

7. Electron sensor (1) according to any of claims 5 to 6, **characterized in that** the guard electrode (5) comprises a height of 2 µm, and each notch has a height of at least 1 µm and a width at least 1 µm greater than that of the width of the input electrode (6).

8. Electron sensor (1) according to any of claims 2 to 7, **characterized in that** the base unit (18) comprises a base electrode (8) with a plurality of receptacles in its upper plane to house the lower plane of the input electrodes (6) without directly contacting.

9. Electron sensor (1) according to claim 8, **characterized in that** the base electrode (8) extends along the width of the substrate (2) and has a height between 100 and 400 µm.

10. Electron sensor (1) according to claim 9, **characterized in that** the base electrode (8) comprises a height of 200 µm.

11. Electron sensor (1) according to claim 8, **characterized in that** each receptacle of the base electrode (8) has an appreciably oval configuration with a height between 10 and 150 µm, and a width between 10 and 35 µm.

12. Electron sensor (1) according to claim 8, **characterized in that** each receptacle of the base electrode (8) comprises a height of 50 µm and a width of 20 µm.

13. Electron sensor (1) according to any of claims 8 to 12, **characterized in that** the joining area between the lower plane of the input electrodes (6) and the upper plane of the base electrode (8) comprises a series of energy measurement electrodes (7) to measure the energy of the electrons which, on impacting on the lateral reception surface (3), traverse the input electrodes (6).

14. Electron sensor (1) according to claim 13, **characterized in that** the energy measurement electrodes (7) have an appreciably oval shape with a height between 10 and 20 µm, and a width between 20 and 30 µm.

15. Electron sensor (1) according to claim 14, **characterized in that** the energy measurement electrodes (7) comprise a height of 20 µm and a width of 20 µm.

16. Electron sensor (1) according to claim 15, **characterized in that** each energy measurement electrode (7) comprises a superposition of measurement electrodes of appreciably oval configuration.

17. Electron sensor (1) according to claim 1, **characterized in that** the contact unit (14) comprises a contact electrode (4) which substantially occupies the entire width of the rear plane (2p) and has a maximum height of 400 µm.

18. Electron sensor (1) according to claim 13, **characterized in that** the contact electrode (4), base electrode (8), each input electrode (6) and each energy measurement electrode (7) are connected, by means of metal tracks (13, 13', 13") placed on the substrate (2), to the electronic circuit unit (12), which is inserted in the front plane (2a) of the substrate (2) after the base electrode (8),

19. Electron sensor (1) according to claim 16, **characterized in that** the contact electrode (4), the base electrode (8), each input electrode (6) and each electrode of the superposition of energy measurement electrodes are connected, by means of metal tracks (13, 13', 13") placed on the substrate (2), to the electronic circuit unit (12), which is inserted in the front plane (2a) of the substrate (2) after the base electrode (8).

20. System for electron microscopy using an electron microscope, **characterized in that** it comprises at least two electron sensors (1) according to any of claims 1 to 17, placed in parallel to generate two-dimensional images formed by the successive addition of one-dimensional lines measured by each one of the electron sensors (1).

Patentansprüche

1. Elektronensensor (1) für die Elektronenmikroskopie unter Verwendung eines Elektronenmikroskops, wobei der Elektronensensor (1) ein Substrat (2) mit einer vorderen Ebene (2a) und einer hinteren Ebene (2p), die parallel zueinander sind, umfasst, wobei das Substrat (2) ausgelegt ist, um mindestens ein Elektron eines Elektronenstrahls (10) nach Durch-

laufen einer Probe zu absorbieren, und von dem Elektronenmikroskop erzeugt wird, wobei das Elektron fähig ist, eine elektrische Ladung von freien Elektron-Loch-(e-h)-Paaren im Substrat (2) zu erzeugen, **dadurch gekennzeichnet, dass** der Elektronensensor (1) ferner umfasst:

- eine seitliche Empfangsfläche (3), die auf einer der Seiten des Substrats (2) angeordnet ist, um den Elektronenstrahl (10) senkrecht zu aufzunehmen,
- eine Kontakteinheit (14), die auf der hinteren Ebene (2p) angeordnet ist, wobei die folgenden Einheiten auf der vorderen Ebene (2a) in der Reihenfolge des kürzesten zum längsten Abstand zur seitlichen Aufnahmefläche (3) angeordnet ist:
- eine Schutzeinheit (15), die parallel mindestens die seitliche Empfangsfläche (3) begrenzt, die den Elektronenstrahl (10) aufnimmt, und ausgelegt ist, um Leckströme am Rand des Substrats (2) zu vermeiden,
- eine Eingabeeinheit (16), die ausgelegt ist, um den Eingangspunkt der Elektronen des Elektronenstrahls (10) zu erkennen, eine Basiseinheit (18), die ausgelegt ist, um die Energie der Elektronen des Elektronenstrahls (10) zu messen, die auf die seitliche Aufnahmefläche (3) einwirken,
- eine elektronische Schaltungseinheit (12), die mindestens mit der Basiseinheit (18), der Kontakteinheit (14) und der Eingabeeinheit (16) verbunden ist und einen elektrischen Generator und eine elektrische Schaltung umfasst, wobei der elektrische Generator ausgelegt ist, einen elektrischen Polarisationsstrom zwischen der vorderen Ebene (2a) und der hinteren Ebene (2p) zu erzeugen, der ausgelegt ist, die im Substrat (2) erzeugten freien Elektronen zur Basiseinheit (18) und/oder zur Eingabeeinheit (16) zu ziehen, der ausgelegt ist, die freien Löcher in Richtung der Kontakteinheit (14) zu ziehen;

und um zu ermöglichen, dass die Elektronen und die Löcher von ihren jeweiligen Einheiten erfasst werden, und wobei die elektrische Schaltung ausgelegt ist, die freien Elektronen zu konditionieren und zu verarbeiten, um ein eindimensionales oder zweidimensionales Bild (11) mit größerem Dynamikbereich zu erzeugen.

2. Elektronensensor (1) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Eingabeeinheit (16) eine Reihe von Eingangselektroden (6) umfasst.

3. Elektronensensor (1) nach Anspruch 2, **dadurch gekennzeichnet, dass** die Eingangselektroden (6) eine Höhe zwischen 10 und 70 μm, eine Breite zwischen 4 und 20 μm umfassen und wobei die Eingangselektroden (6) in einem Abstand zwischen ihren vertikalen Achsen zwischen 10 und 50 μm voneinander getrennt sind.

4. Elektronensensor (1) nach Anspruch 3, **dadurch gekennzeichnet, dass** die Eingangselektroden (6) eine Höhe von 50 μm, eine Breite von 10 μm umfassen und in einem Abstand zwischen ihren vertikalen Achsen von 25 μm voneinander getrennt sind.

5. Elektronensensor (1) nach einem der Ansprüche 2 bis 4, **dadurch gekennzeichnet, dass** die Schutzeinheit (15) mindestens eine Schutzelektrode (5) nahe der seitlichen Aufnahmefläche (3) umfasst und auf der unteren Ebene der Schutzeinheit (15) eine Vielzahl von Kerben vorhanden ist, um die obere Ebene der Eingangselektroden (6) ohne direktes Kontaktieren aufzunehmen.

6. Elektronensensor (1) nach Anspruch 5, **dadurch gekennzeichnet, dass** die Schutzelektrode (5) als vier Streifen angeordnet ist, die einen Rahmen bilden, zwei davon entlang der Breite und zwei entlang der Länge des Substrats (2), wobei der Streifen der Schutzelektrode (5), welcher der seitlichen Aufnahmefläche (3) am nächsten liegt, eine Vielzahl von Kerben aufweist, um die obere Ebene der Eingangselektroden (6) ohne direktes Kontaktieren unterzubringen.

7. Elektronensensor (1) nach einem der Ansprüche 5 bis 6, **dadurch gekennzeichnet, dass** die Schutzelektrode (5) eine Höhe von 2 μm umfasst und jede Kerbe eine Höhe von mindestens 1 μm und eine Breite von mindestens 1 μm aufweist, die größer als die Breite der Eingangselektrode (6) ist.

8. Elektronensensor (1) nach einem der Ansprüche 2 bis 7, **dadurch gekennzeichnet, dass** die Basiseinheit (18) eine Basiselektrode (8) mit einer Vielzahl von Behältern in ihrer oberen Ebene umfasst, um die untere Ebene der Eingangselektroden (6) ohne direktes Kontaktieren unterzubringen.

9. Elektronensensor (1) nach Anspruch 8, **dadurch gekennzeichnet, dass** sich die Basiselektrode (8) entlang der Breite des Substrats (2) erstreckt und eine Höhe zwischen 100 und 400 μm aufweist.

10. Elektronensensor (1) nach Anspruch 9, **dadurch gekennzeichnet, dass** die Basiselektrode (8) eine Höhe von 200 μm umfasst.

11. Elektronensensor (1) nach Anspruch 8, **dadurch gekennzeichnet, dass** jeder Behälter der Basiselektrode (8) eine merklich ovale Konfiguration mit einer Höhe zwischen 10 und 150 μm und einer Breite zwi-

schen 10 und 35 μm aufweist.

12. Elektronensensor (1) nach Anspruch 8, **dadurch gekennzeichnet, dass** jeder Behälter der Basiselektrode (8) eine Höhe von 50 μm und eine Breite von 20 μm umfasst.

13. Elektronensensor (1) nach einem der Ansprüche 8 bis 12, **dadurch gekennzeichnet, dass** der Verbindungsbereich zwischen der unteren Ebene der Eingangselektroden (6) und der oberen Ebene der Basiselektrode (8) eine Reihe von Energiemesselektroden (7) umfasst, um die Energie der Elektronen zu messen, die beim Aufprall auf die seitliche Aufnahmefläche (3) die Eingangselektroden (6) durchqueren.

14. Elektronensensor (1) nach Anspruch 13, **dadurch gekennzeichnet, dass** die Energiemesselektroden (7) eine merklich ovale Form mit einer Höhe zwischen 10 und 20 μm und einer Breite zwischen 20 und 30 μm aufweisen.

15. Elektronensensor (1) nach Anspruch 14, **dadurch gekennzeichnet, dass** die Energiemesselektroden (7) eine Höhe von 20 μm und eine Breite von 20 μm umfassen.

16. Elektronensensor (1) nach Anspruch 15, **dadurch gekennzeichnet, dass** jede Energiemesselektrode (7) eine Überlagerung von Messelektroden mit merklich ovaler Konfiguration umfasst.

17. Elektronensensor (1) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Kontakteinheit (14) eine Kontaktelektrode (4) umfasst, die im Wesentlichen die gesamte Breite der hinteren Ebene (2p) einnimmt und eine maximale Höhe von 400 μm aufweist.

18. Elektronensensor (1) nach Anspruch 13, **dadurch gekennzeichnet, dass** die Kontaktelektrode (4), die Basiselektrode (8), jede Eingangselektrode (6) und jede Energiemesselektrode (7) mittels Metallschienen (13, 13', 13"), die auf dem Substrat (2) angeordnet sind, mit der elektronischen Schaltungseinheit (12) verbunden sind, die in die vordere Ebene (2a) des Substrats (2) nach der Basiselektrode (8) eingefügt ist.

19. Elektronensensor (1) nach Anspruch 16, **dadurch gekennzeichnet, dass** die Kontaktelektrode (4), die Basiselektrode (8), jede Eingangselektrode (6) und jede Elektrode der Überlagerung von Energiemesselektroden mittels Metallschienen (13, 13', 13"), die auf dem Substrat (2) angeordnet sind, mit der elektronischen Schaltungseinheit (12) verbunden sind, die in die vordere Ebene (2a) des Substrats (2) nach der Basiselektrode (8) eingefügt ist.

20. System für die Elektronenmikroskopie unter Verwendung eines Elektronenmikroskops, **dadurch gekennzeichnet, dass** es mindestens zwei Elektronensensoren (1) nach einem der Ansprüche 1 bis 17 umfasst, die parallel angeordnet sind, um zweidimensionale Bilder zu erzeugen, die durch sukzessives Hinzufügen eindimensionaler Linien erzeugt werden, die von jedem der Elektronensensoren (1) gemessen werden.

Revendications

1. Capteur d'électrons (1) pour microscopie électronique utilisant un microscope électronique, dans lequel le capteur d'électrons (1) comprend un substrat (2), avec un plan avant (2a) et un plan arrière (2p) parallèles l'un à l'autre, le substrat (2) étant adapté pour absorber au moins un électron d'un faisceau d'électrons (10) après avoir traversé un échantillon et étant généré par le microscope électronique, dans lequel l'électron est susceptible de générer une charge électrique de paires électron-trou (e-h) libres dans le substrat (2), **caractérisé en ce que** le capteur d'électrons (1) comprend en outre :

- une surface latérale de réception (3), placée sur l'un des côtés du substrat (2) pour recevoir perpendiculairement le faisceau d'électrons (10),
- une unité de contact (14), placée sur le plan arrière (2p), et

les unités suivantes placées sur le plan avant (2a) par ordre de la distance la plus courte à la plus longue par rapport à la surface latérale de réception (3) :

- une unité de garde (15), bordant en parallèle au moins la surface latérale de réception (3) recevant le faisceau d'électrons (10), et adaptée pour éviter les courants de fuite dans le bord du substrat (2),
- une unité d'entrée (16), adaptée pour détecter le point d'entrée des électrons du faisceau d'électrons (10), une unité de base (18), adaptée pour mesurer l'énergie des électrons du faisceau d'électrons (10) qui impactent la surface latérale de réception (3),
- une unité de circuit électronique (12), liée à au moins l'unité de base (18), l'unité de contact (14) et l'unité d'entrée (16), qui comprend un générateur électrique et un circuit électrique,

dans lequel ledit générateur électrique est adapté pour générer un courant de polarisation électrique, entre le plan avant (2a) et le plan arrière (2p), adapté pour tirer les électrons libres générés dans le substrat (2) vers l'unité de base (18) et/ou l'unité d'entrée

(16), adapté pour tirer les trous libres vers l'unité de contact (14) ; et pour permettre aux électrons et aux trous d'être capturés par leurs unités respectives, et dans lequel le circuit électrique est adapté pour conditionner et traiter les électrons libres pour former une image unidimensionnelle ou bidimensionnelle (11) avec une plus grande plage dynamique.

2. Capteur d'électrons (1) selon la revendication 1, **caractérisé en ce que** l'unité d'entrée (16) comprend une série d'électrodes d'entrée (6).

3. Capteur d'électrons (1) selon la revendication 2, **caractérisé en ce que** les électrodes d'entrée (6) comprennent une hauteur entre 10 et 70 μm, une largeur comprise entre 4 et 20 μm, et dans lequel lesdites électrodes d'entrée (6) sont séparées les unes des autres à une distance entre leurs axes verticaux entre 10 et 50 μm.

4. Capteur d'électrons (1) selon la revendication 3, **caractérisé en ce que** les électrodes d'entrée (6) comprennent une hauteur de 50 μm, une largeur de 10 μm, et sont séparées les unes des autres à une distance entre leurs axes verticaux de 25 μm.

5. Capteur d'électrons (1) selon l'une quelconque des revendications 2 à 4, **caractérisé en ce que** l'unité de garde (15) comprend au moins une électrode de garde (5) à proximité de la surface latérale de réception (3), et sur le plan inférieur de l'unité de garde (15) il y a une pluralité d'encoches pour loger le plan supérieur des électrodes d'entrée (6) sans contact direct.

6. Capteur d'électrons (1) selon la revendication 5, **caractérisé en ce que** l'électrode de garde (5) est placée sous la forme de quatre bandes formant un cadre, deux d'entre elles le long de la largeur et deux le long de la longueur du substrat (2) dans lequel la bande de l'électrode de garde (5) la plus proche de la surface latérale de réception (3) a une pluralité d'encoches pour loger le plan supérieur des électrodes d'entrée (6) sans contact direct.

7. Capteur d'électrons (1) selon l'une des revendications 5 à 6, **caractérisé en ce que** l'électrode de garde (5) comprend une hauteur de 2 μm, et chaque encoche a une hauteur d'au moins 1 μm et une largeur d'au moins 1 μm supérieure à celle de la largeur de l'électrode d'entrée (6).

8. Capteur d'électrons (1) selon l'une des revendications 2 à 7, **caractérisé en ce que** l'unité de base (18) comprend une électrode de base (8) avec une pluralité de réceptacles dans son plan supérieur pour loger le plan inférieur des électrodes d'entrée (6) sans contact direct.

9. Capteur d'électrons (1) selon la revendication 8, **caractérisé en ce que** l'électrode de base (8) s'étend le long de la largeur du substrat (2) et a une hauteur entre 100 et 400 μm.

10. Capteur d'électrons (1) selon la revendication 9, **caractérisé en ce que** l'électrode de base (8) comprend une hauteur de 200 μm.

11. Capteur d'électrons (1) selon la revendication 8, **caractérisé en ce que** chaque réceptacle de l'électrode de base (8) a une configuration sensiblement ovale avec une hauteur entre 10 et 150 μm, et une largeur entre 10 et 35 μm.

12. Capteur d'électrons (1) selon la revendication 8, **caractérisé en ce que** chaque réceptacle de l'électrode de base (8) comprend une hauteur de 50 μm et une largeur de 20 μm.

13. Capteur d'électrons (1) selon l'une des revendications 8 à 12, **caractérisé en ce que** la zone de jonction entre le plan inférieur des électrodes d'entrée (6) et le plan supérieur de l'électrode de base (8) comprend une série d'électrodes de mesure d'énergie (7) pour mesurer l'énergie des électrons qui, lors de l'impact sur la surface latérale de réception (3), traversent les électrodes d'entrée (6).

14. Capteur d'électrons (1) selon la revendication 13, **caractérisé en ce que** les électrodes de mesure d'énergie (7) ont une forme sensiblement ovale avec une hauteur comprise entre 10 et 20 μm, et une largeur entre 20 et 30 μm.

15. Capteur d'électrons (1) selon la revendication 14, **caractérisé en ce que** les électrodes de mesure d'énergie (7) comprennent une hauteur de 20 μm et une largeur de 20 μm.

16. Capteur d'électrons (1) selon la revendication 15, **caractérisé en ce que** chaque électrode de mesure d'énergie (7) comprend une superposition d'électrodes de mesure de configuration sensiblement ovale.

17. Capteur d'électrons (1) selon la revendication 1, **caractérisé en ce que** l'unité de contact (14) comprend une électrode de contact (4) qui occupe sensiblement toute la largeur du plan arrière (2p) et a une hauteur maximale de 400 μm.

18. Capteur d'électrons (1) selon la revendication 13, **caractérisé en ce que** l'électrode de contact (4), l'électrode de base (8), chaque électrode d'entrée (6) et chaque électrode de mesure d'énergie (7) sont connectées, au moyen de pistes métalliques (13, 13', 13") placées sur le substrat (2), à l'unité de circuit électronique (12), qui est insérée dans le plan avant

(2a) du substrat (2) après l'électrode de base (8).

19. Capteur d'électrons (1) selon la revendication 16, **caractérisé en ce que** l'électrode de contact (4), l'électrode de base (8), chaque électrode d'entrée (6) et chaque électrode de la superposition d'électrodes de mesure d'énergie sont connectées, au moyen de pistes métalliques (13, 13', 13") placées sur le substrat (2), à l'unité de circuit électronique (12), qui est insérée dans le plan avant (2a) du substrat (2) après l'électrode de base (8).

20. Système de microscopie électronique utilisant un microscope électronique, **caractérisé en ce qu'**il comprend au moins deux capteurs d'électrons (1) selon l'une quelconque des revendications 1 à 17, placés en parallèle pour générer des images bidimensionnelles formées par l'ajout successif de lignes unidimensionnelles mesurées par chacun des capteurs d'électrons (1).

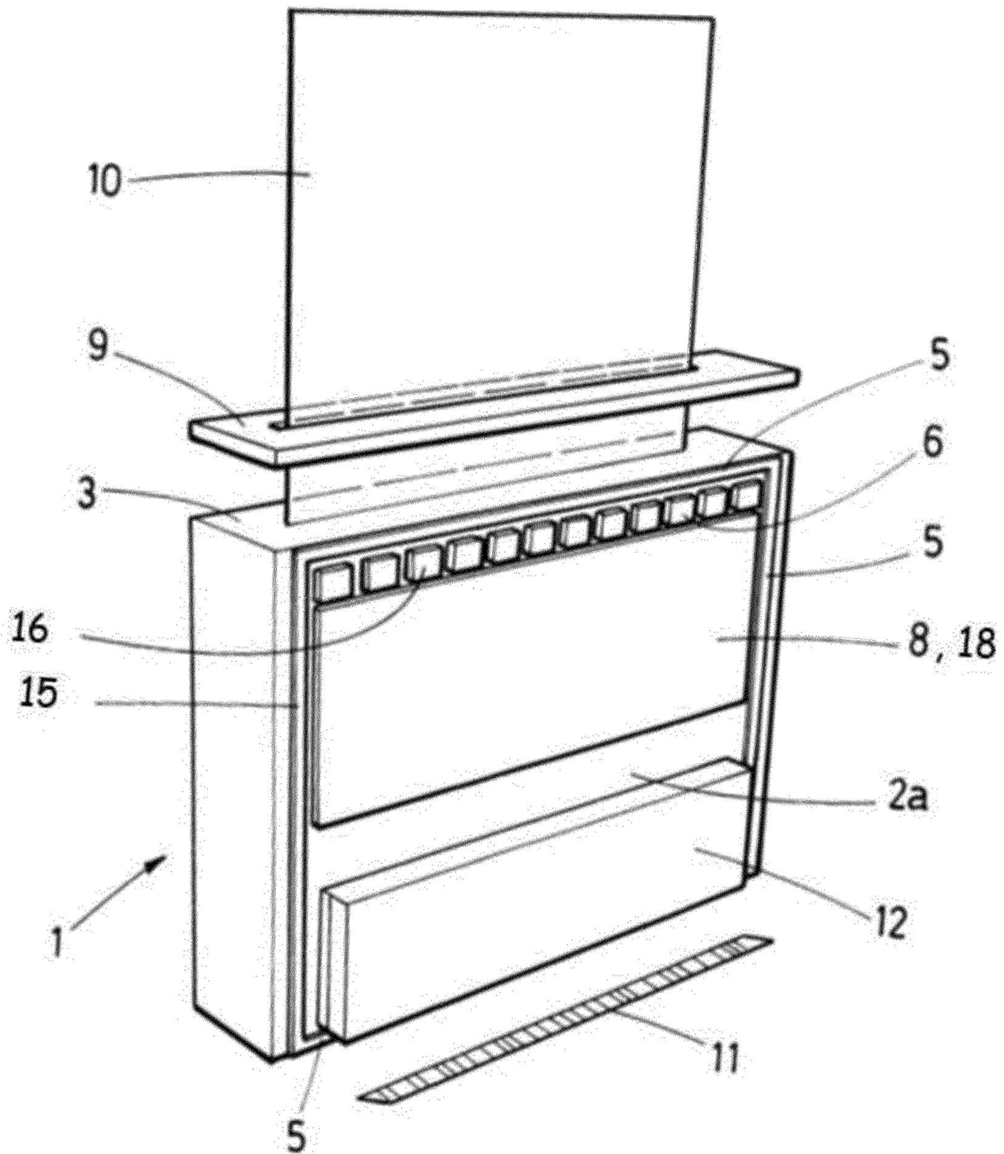


FIG.1

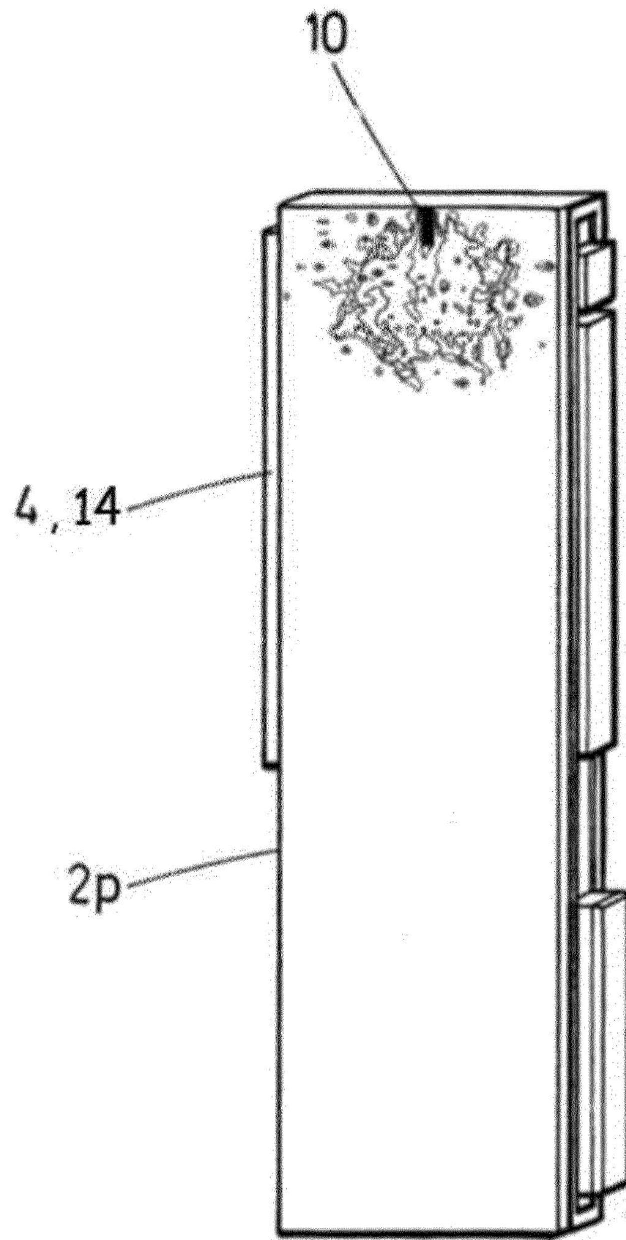


FIG.2

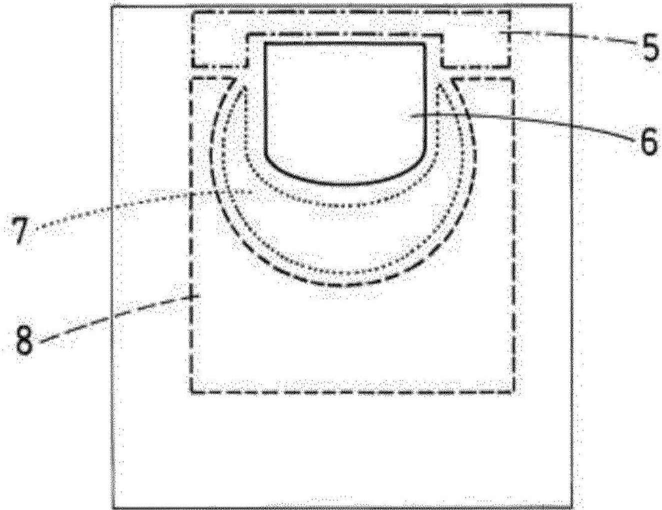
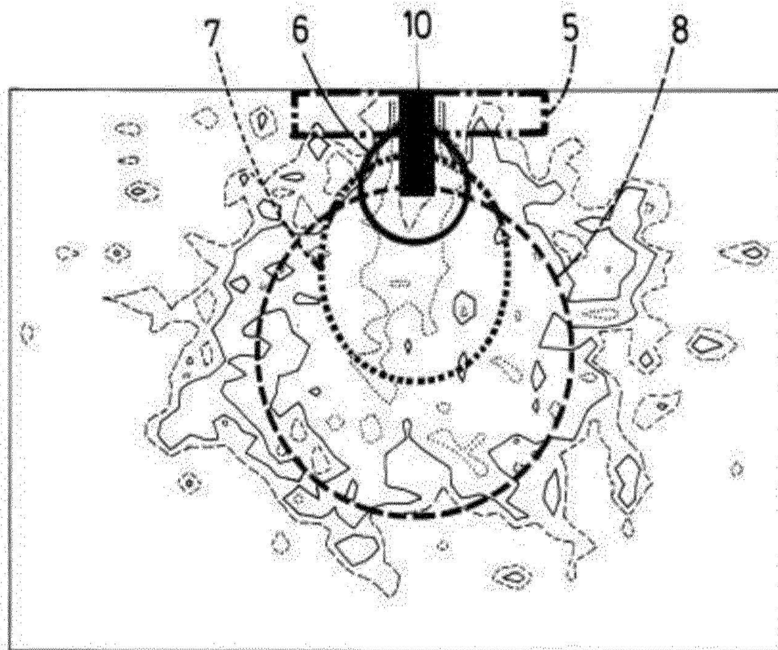


FIG.3A



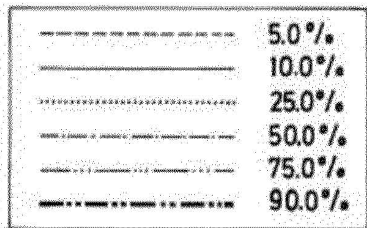


FIG.3B

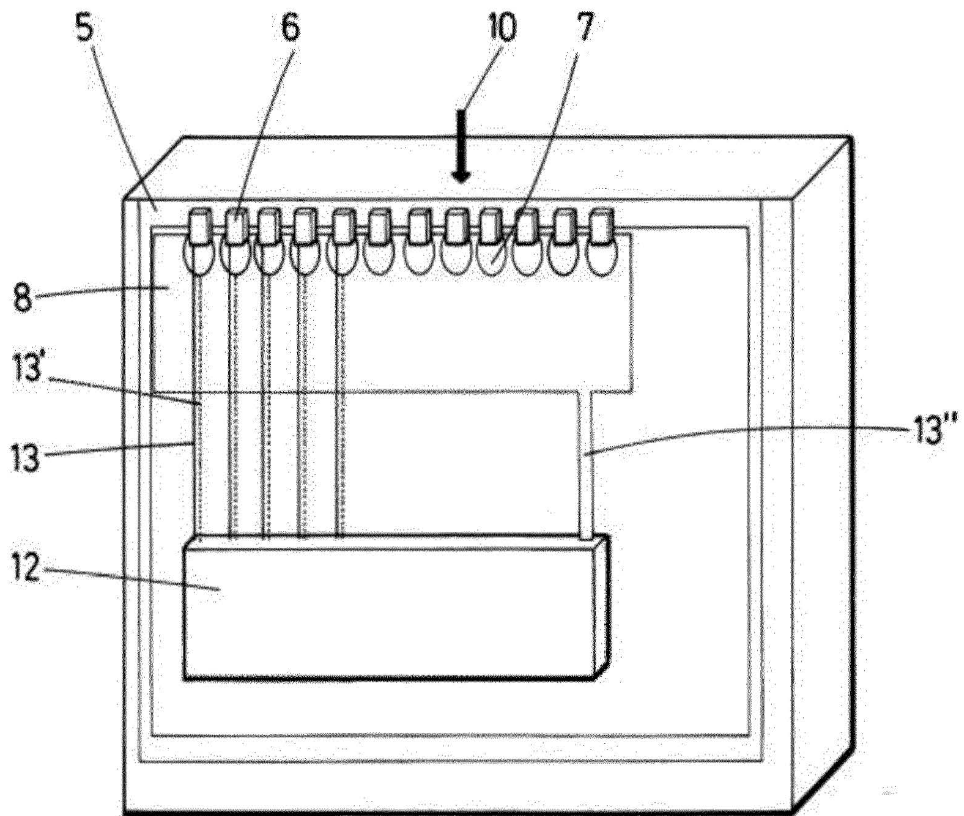


FIG.4

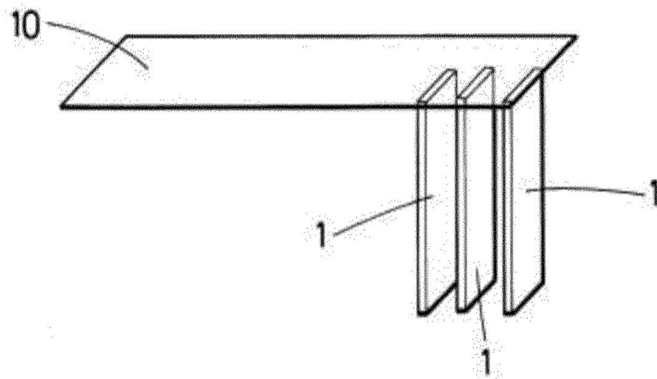


FIG.5a

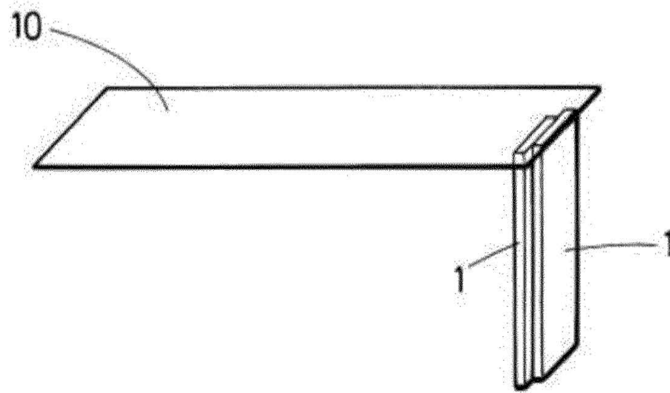


FIG.5b

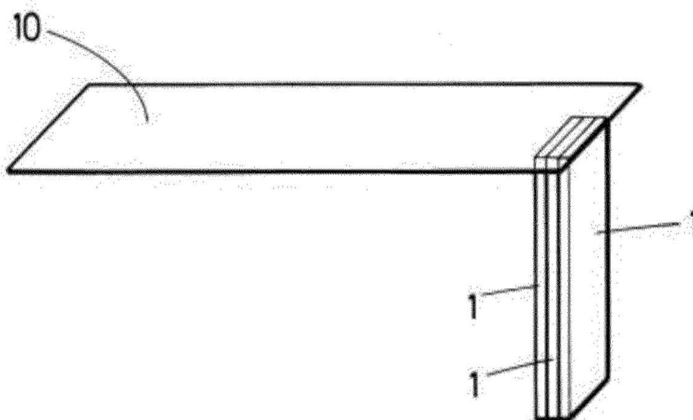


FIG.5c

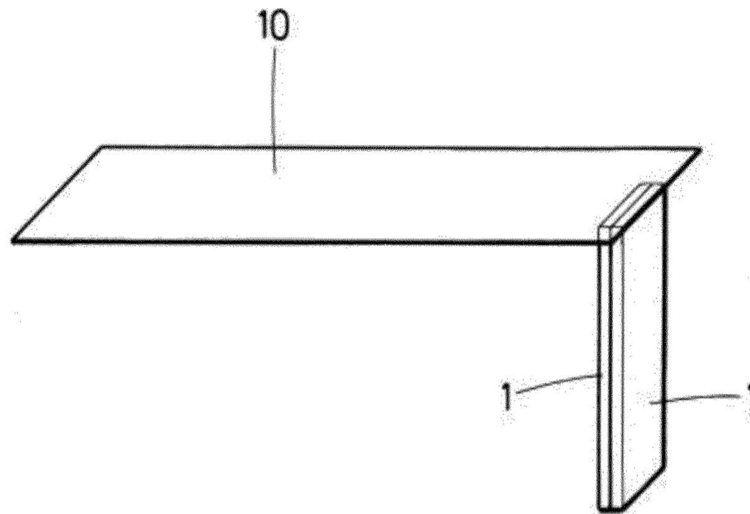


FIG.5d

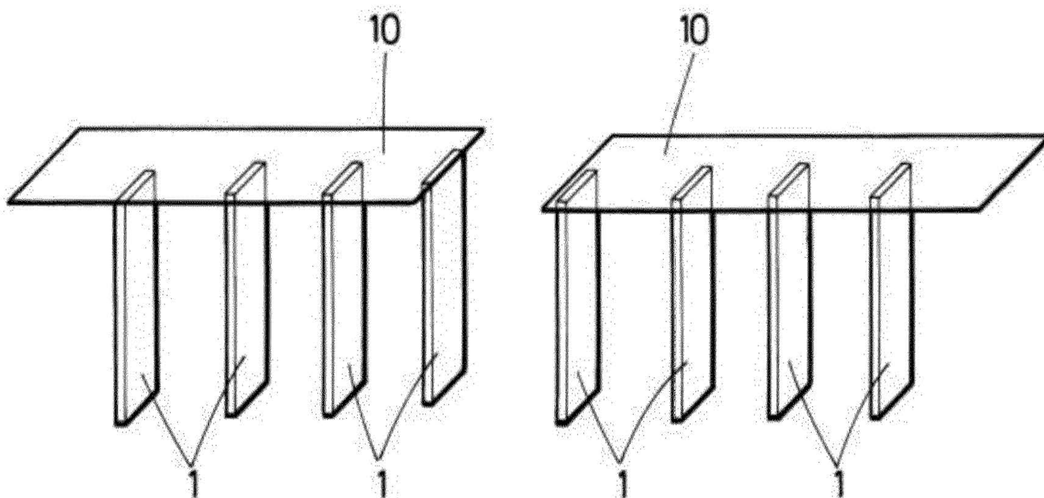


FIG.5e