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(54) Title: A PHOTON DETECTOR WITH CONVERTER UNIT

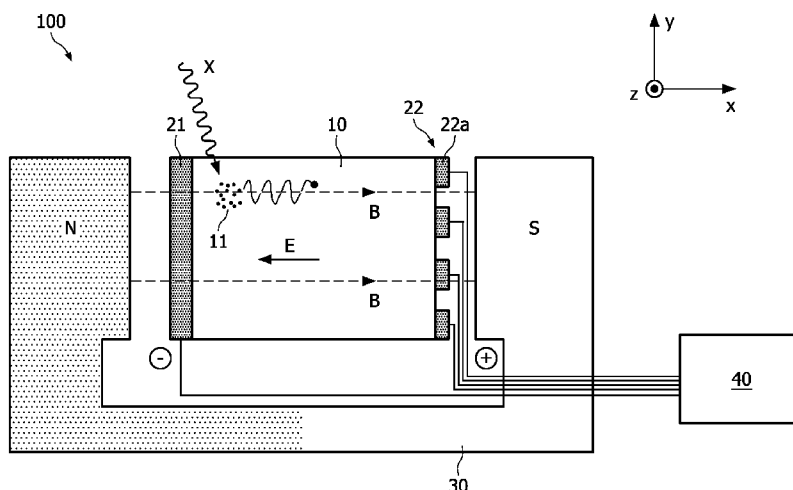


FIG. 2

(57) Abstract: The invention relates to a detector (100), particularly for X-ray photons, that comprises a converter unit (10) in which incident photons (X) are converted into electrical conduction charges (11) and electrodes (21, 22) that generate an electrical field and at which said charges (11) are collected. Furthermore, it comprises a magnetic field generator (30) for generating a magnetic field (B) inside the converter unit (10) that affects the movement of the electrical conduction charges (11), particularly by restricting possible drifts of the charges in directions perpendicular to the electrical field (E).

A photon detector with converter unit

## FIELD OF THE INVENTION

The invention relates to a photon detector comprising a converter unit for converting incident photons into electrical conduction charges. Moreover, it relates to a method for the detection of photons with such a converter unit and an imaging system  
5 comprising such a photon detector.

## BACKGROUND OF THE INVENTION

Photon detectors are for example required in X-ray devices like a CT (Computed Tomography) scanner for the detection of X-rays after their transmission through  
10 an object of interest. In solid-state detectors like the one that is known from the US 2006 0033029 A1, a converter unit consisting of a semiconductor material is used for converting incident photons into a cloud of electrical conduction charges, i.e. electrons and holes that are (temporarily and with certain restrictions) free to move in the semiconductor material. The charges can be detected by electrodes which generate an electrical field in the  
15 converter unit. Problems arise when the associated detection electronics has to deal with high photon fluxes as they are typical in for example CT applications. In this case it can be tried to make the pixel volumes associated to each electrode small in order to limit the counting rates said electrode has to deal with. The charges will however move in a more or less extended cloud through the converter unit and therefore give rise to signals in several neighboring small  
20 electrodes that may be misinterpreted as being generated by more than one photon.

## SUMMARY OF THE INVENTION

Based on this situation it was an object of the present invention to provide means that allow a reliable detection of photons, particularly at high fluxes.

25 This object is achieved by a photon detector according to claim 1, an X-ray detector according to claim 10, an imaging system according to claim 11, and a method according to claim 12. Preferred embodiments are disclosed in the dependent claims.

The photon detector according to the present invention serves for the detection of electromagnetic radiation, particularly of X-ray photons or  $\gamma$  photons. It comprises the following components:

- a) A converter unit for converting incident photons into electrical conduction charges. A photon that interacts with the material of the converter unit will typically generate, depending on its energy, not just one but a more or less extended cloud of electrical charges, i.e. electrons and holes that can "freely" move in the material (obeying possible restrictions imposed by the material, e.g. occupying only allowed conduction bands).
- b) An electrode arrangement for generating an electrical field in the converter unit when a voltage is applied to it. When for example a high potential is applied to a first electrode ("cathode") and a lower potential to a second electrode ("anode") of the arrangement, an electrical field will develop between the electrodes along which conduction electrons drift to the anode.
- c) A magnetic field generator for generating a magnetic field inside the converter unit that can affect the movement of the conduction charges in said converter unit. Typically, said magnetic field will be static with respect to the timescale on which a movement of electrical conduction charges generated by incident photons to an associated electrode takes place.

The described photon detector allows to take influence on the movement of electrical conduction charges inside the converter unit by the magnetic field that is generated with the magnetic field generator. Thus it is possible to control and limit or even eliminate an undesired spread of said charges, which would normally impair the spatial resolution of the device and/or which might lead to a misinterpretation of charges arriving at the "wrong" electrodes. The possibility to confine electrical charges to smaller movement corridors also allows the design of smaller pixels that can cope with higher photons fluxes.

The magnetic field generator can be built in many different ways, particularly as a permanent magnet and/or as an electromagnet. The use of an electromagnet has the advantage that the magnetic field can be switched on and off and/or be adjusted to a desired magnitude if necessary.

According to a preferred embodiment of the invention, the magnetic field generator is designed and disposed such that the magnetic field that is generated by it is directed along a desired movement path of the conduction charges in the converter unit. Due to the effect of the Lorentz force, moving charges will rotate around the field lines of the magnetic field in a distance that depends on their charge, mass, and velocity as well as on the

field magnitude. The movement of the particles will therefore be restricted to a cylinder around the magnetic field lines. In a semi-conductor the picture is more complex as the charges are not free. The band structure determines the allowed energy states and electron orbits (for conduction band electrons) in the presence of the magnetic field. Of importance is also the level of purity since the magnetic electron orbits will be followed only in between scattering events.

The magnetic field generator may further be designed and disposed such that the magnetic field that is generated by it inside the converter unit is substantially parallel to the electrical field that is generated by the electrode arrangement. This design is akin to the aforementioned one, as the direction of the electrical field will usually correspond to the desired movement paths of the conduction charges. It should be noted that the orientations of the parallel magnetic and the electrical fields may be identical or opposite, i.e. the associated field vectors may point into the same or into opposite directions.

By definition the magnetic field generator shall be designed such that it can generate a magnetic field which is strong enough to affect the movement of conduction charges in the converter unit. In this context it is preferred that the magnitude of the magnetic field will be larger than about 0.1 T (Tesla), preferably larger than about 1 T, depending on band-structure, impurity concentration, and electric field strength. With the above values, the movement of conduction charges can be restricted to reasonably small volumes.

In a preferred embodiment the electrode arrangement comprises a plurality of single electrodes, particularly a plurality of anodes. Each of these single electrodes is then associated to a corresponding pixel-volume of the converter unit which is defined by the condition that it comprises all electrical field lines that end at the considered single (pixel-)electrode. If electrical conduction charges in the pixel-volume would move without any disturbances purely under the influence of electrical forces, they would reach the associated pixel-electrode. Unavoidable drift effects, for example caused by collisions or thermal motion, will however make electrical conduction charges deviate from their ideal paths such that they will occasionally also reach neighboring electrodes of the associated pixel-electrode, an effect that is called "charge sharing". With the help of the magnetic field proposed by the present invention, the transverse movement of charges can be restricted, thus limiting the undesirable effects of spreading of the charge cloud. As a consequence, the size of the single electrodes – and thus of the associated pixel-volumes – can be made smaller.

According to a further development of the invention, the photon detector comprises a detection device to which the electrodes of the electrode arrangement are

connected, said detection device being adapted to detect free charges that have reached the electrodes. In this way it is possible to detect the conversion of a photon in the converter unit and to assign it to a particular (pixel-)electrode, i.e. to a position in the converter unit.

The aforementioned detection device is preferably further adapted to count  
5 and/or classify (with respect to their shape or magnitude) electrical pulses generated by electrical conduction charges that originate from the conversion of a photon. Thus it will be possible to count the rate of incoming photons. If the pulses are also classified with respect to their magnitude, which corresponds to the energy of the converted photons, it is additionally possible to provide spectrally resolved photon counts.

10 Suitable materials for the converter unit are any materials that provide the desired conversion of incident photons into electrical conduction charges. They comprise for example Si, Ge, GaAs, HgI, CZT and/or CdTe.

The invention further relates to an X-ray detector comprising a photon detector  
15 of the kind described above that is sensitive to X-rays. Moreover, it relates to an imaging system comprising a photon detector of the kind described above, wherein said imaging device may particularly be an X-ray, CT (Computed Tomography), PET (Positron Emission Tomography), SPECT (Single Photon Emission Computed Tomography) or nuclear imaging device.

The invention also relates to a method for the detection of photons,  
20 particularly of X-ray photons or  $\gamma$  photons, comprising the following steps:

a) Converting incident photons into electrical conduction charges in a converter unit.

b) Generating an electrical field in said converter unit.

c) Generating a magnetic field in said converter unit that affects the movement of

25 the conduction charges.

The method comprises in general form the steps that can be executed with a photon detector of the kind described above. Therefore, reference is made to the preceding description for more information on the details, advantages and improvements of that method.

## BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter. These embodiments will be described by way of example with the help of the accompanying drawings in which:

5 Fig. 1 illustrates an examination apparatus comprising a photon detector according to the present invention;

Fig. 2 schematically shows a section through a photon detector according to the present invention;

10 Fig. 3 illustrates the movement of a conduction electron in the converter unit of a photon detector according to the invention.

Like reference numbers in the Figures refer to identical or similar components.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

15 Fig. 1 shows schematically a side view of a Computed Tomography (CT) system 1 as one example of a device that requires the detection of photons. The CT system 1 comprises an X-ray source 2 and a corresponding photon detector 100 that are arranged opposite to each other on a rotatable ring. Between the X-ray source 2 and the detector 100, a patient 3 can be located on a table such that the detector 100 will sense the flux of X-ray photons X transmitted through the patient. During a common rotation of the X-ray source 2 and the detector 100, projection images of the patient 3 can be generated from different directions, from which an associated control and evaluation unit 4 (e.g. a workstation) can reconstruct three-dimensional slice images. The details of this technology are well known to a person skilled in the art.

25 Fig. 2 schematically sketches a section through the photon detector 100 or, more precisely, through one super-pixel of the detector as the detector will usually comprise a two-dimensional array of several thousands of such super-pixels. For simplicity the following discussion will however identify the photon detector and the (single) super-pixel.

The detector 100 comprises as a central component a converter unit 10 consisting of a material like CZT which can convert incident X-ray photons X (impinging from the space above the drawing plane, i.e. along the z-axis) into a cloud 11 of electrical conduction charges, i.e. electrons and holes. On opposite sides of the converter unit 10, electrode arrangements 21 and 22 are disposed, wherein each single electrode of these arrangements is individually connected to a detection device 40. In the shown example, the first electrode arrangement 21 is constituted by a large, single electrode that is operated as a

cathode, while the second electrode arrangement 22 is constituted by a plurality of single, isolated electrodes 22a that are operated as anodes. Due to the voltage applied between the electrode arrangements 21 and 22, an electrical field E is created inside the converter unit 10 which drives the conduction charges in x-direction towards the electrodes, for example the electrons to the single electrodes 22a that are operated as anodes. The area of the converter unit 10 is thus effectively divided into stripes or "pixel-areas" defined by the sub-volumes from which electrons are (ideally) collected at an associated single "pixel-electrode" 22a.

Semiconductor sensors with non-structured converter units like the one shown in Fig. 2 generically suffer from the effects of charge sharing in which the spread of the charge clouds generated by a single X-ray interaction inside the active volume of the semiconductor gives rise to signals in neighboring (pixel-)electrodes. At its origin lies the drift of the electrons and holes in the directions transverse to the applied electric field (y- and z-direction in Fig. 2). Therefore, the effect becomes more important for large sensor thickness and small pixel areas. In the case of photon-counting applications, pulse sharing can give rise to the erroneous registration of several low-energy counts triggered by a single high-energy X-ray photon.

At the advent of photon-counting X-ray CT, one main obstacle to be overcome is the count rate problem. X-ray tubes in commercial CT systems generate fluxes of about  $10^9$  photons  $\text{mm}^{-2} \text{s}^{-1}$  in a distance of about a meter from the anode. Available photon-counting semiconductor detectors can handle photon fluxes which are at least two orders of magnitude lower than the number quoted above. One approach to overcome this count rate limitation is to go to smaller pixel sizes at the cost of increasing pixel crosstalk and charge sharing.

One possible way to reduce charge sharing without simultaneously reducing the DQE of the detection system is to apply the electrical bias field in a direction perpendicular to the incoming photons (in Fig. 2 realized by an E-field in x-direction with the photons impinging from the z-direction). In this way, the drift length (i.e. the distance to the next electrode) can be reduced and with it the spread of the charge cloud during its collection at the electrodes.

Another way to reduce charge sharing that is proposed here is the use of a magnetic field in the direction of the charge carrier motion (i.e. usually the direction of the electric field). In a classical picture, such a magnetic field will force the electrons to move on spirals in addition to their movement towards the anodes. In this way any transverse motion can be suppressed at high enough field strengths and with it the transverse spread of the charge cloud upon arrival at the electrode.

In Fig. 2, the aforementioned magnetic field B is generated inside the converter unit 10 by a permanent magnet 30 the north pole of which is disposed next to the cathode 21 while its south pole is located next to the anode(s) 22a. Classically, electrons of a charge cloud 11 that is generated by an incident X-ray photon X will then make a spiraling movement around the magnetic field lines towards the associated anode. Quantum-mechanically, the band structure is modified by external magnetic field B resulting in a distortion of the allowed electric orbits in the conduction band. Many other geometrical configurations, as well as the use of electromagnets are possible. Also the directions of the E and B fields need not necessarily be perpendicular to the incoming photon flux.

In a simplified classical picture, the electrons are accelerated by the electric field E in the direction of the anodes 21a. In addition, the magnetic field B (parallel to the electric field) forces the charges to spiral around the direction of the fields on the surface of a cylinder (for homogenous fields). For free electrons, the relation between the Larmor radius r of the transverse motion is related to the mass m of the electron, its charge e, its velocity perpendicular to the B-field v, and the magnetic field B via the formula:

$$B = \frac{m v}{er} \quad (1)$$

For an electron with a kinetic energy of 5 eV, equation (1) predicts a magnetic field of B = 0.3 T for a Larmor radius of 25 μm. For electrons in a solid, the above picture is inadequate due to collisions and due to different effective masses of the electrons in a solid. As long as the charge collection time t<sub>C</sub> is not too large compared to the mean time interval between two collisions of the electrons, the effect of drift suppression is however noticeable. In particular for semiconductor materials with low impurity concentrations, the impurity scattering will be strongly reduced and the effect of the magnetic field on the particle orbits will be important.

Fig. 3 shows a possible electron orbit inside the active volume of a semiconductor crystal (converter unit).

In summary, the invention relates to a detector 100, particularly for X-ray photons, that comprises a converter unit 10 in which incident photons are converted into electrical conduction charges and electrodes on opposite sides of the converter unit that generate an electrical field and at which said charges are collected. Furthermore, it comprises a magnetic field generator for generating a magnetic field inside the converter unit that

affects the movement of the electrical conduction charges, particularly by restricting possible drifts of the charges in directions perpendicular to the electrical field. The invention can be used in any direct conversion X-ray detector system in which signals are generated through the collection of charges produced by the incoming X-rays. The only prerequisite is that providing the magnetic field is compatible with the performance of the detector from both a geometrical and operational point of view.

Finally it is pointed out that in the present application the term "comprising" does not exclude other elements or steps, that "a" or "an" does not exclude a plurality, and that a single processor or other unit may fulfill the functions of several means. The invention resides in each and every novel characteristic feature and each and every combination of characteristic features. Moreover, reference signs in the claims shall not be construed as limiting their scope.

## CLAIMS:

1. A photon detector (100), particularly for X-ray photons (X) or  $\gamma$  photons, comprising:
  - a) a converter unit (10) for converting incident photons into electrical conduction charges (11);
  - 5 b) an electrode arrangement (21, 22) for generating an electrical field (E) in the converter unit;
  - c) a magnetic field generator (30) for generating a magnetic field (B) in the converter unit that affects the movement of the conduction charges (11).
- 10 2. The photon detector (100) according to claim 1, characterized in that the magnetic field generator comprises a permanent magnet (30) or an electromagnet.
3. The photon detector (100) according to claim 1, characterized in that the magnetic field (B) generated by the magnetic field generator (30) is directed along a desired movement  
15 path of the conduction charges (11).
4. The photon detector (100) according to claim 1, characterized in that the magnetic field (B) generated by the magnetic field generator (30) is substantially parallel to the direction of the electrical field (E).  
20
5. The photon detector (100) according to claim 1, characterized in that the magnitude of the magnetic field (B) is larger than 0.1 T, preferably larger than 1.0 T.
6. The photon detector (100) according to claim 1, characterized in that the  
25 electrode arrangement (21, 22) comprises a plurality of single electrodes (22a).
7. The photon detector (100) according to claim 1, characterized in that the electrodes of the electrode arrangement (21, 22) are connected to a detection device (40) for detecting conduction charges (11) that have reached them.

8. The photon detector (100) according to claim 7, characterized in that the detection device (40) is adapted to count and/or classify electrical pulses generated by electrical conduction charges (11) originating from the conversion of a photon (X).

5

9. The photon detector (100) according to claim 1, characterized in that the converter unit (10) comprises a material selected from the group consisting of Si, Ge, GaAs, HgI, CdTe and CZT.

10 10. An X-ray detector comprising a photon detector (100) according to claim 1.

11. An imaging system, particularly an X-ray, CT, PET, SPECT or nuclear imaging device, comprising a photon detector (100) according to claim 1.

15 12. A method for the detection of photons, particularly X-ray photons (X) or  $\gamma$  photons, comprising:

a) converting incident photons into electrical conduction charges (11) by a converter unit (10);

b) generating an electrical field (E) in the converter unit (10);

20 c) generating a magnetic field (B) in the converter unit (10) that affects the movement of the conduction charges (11) therein.

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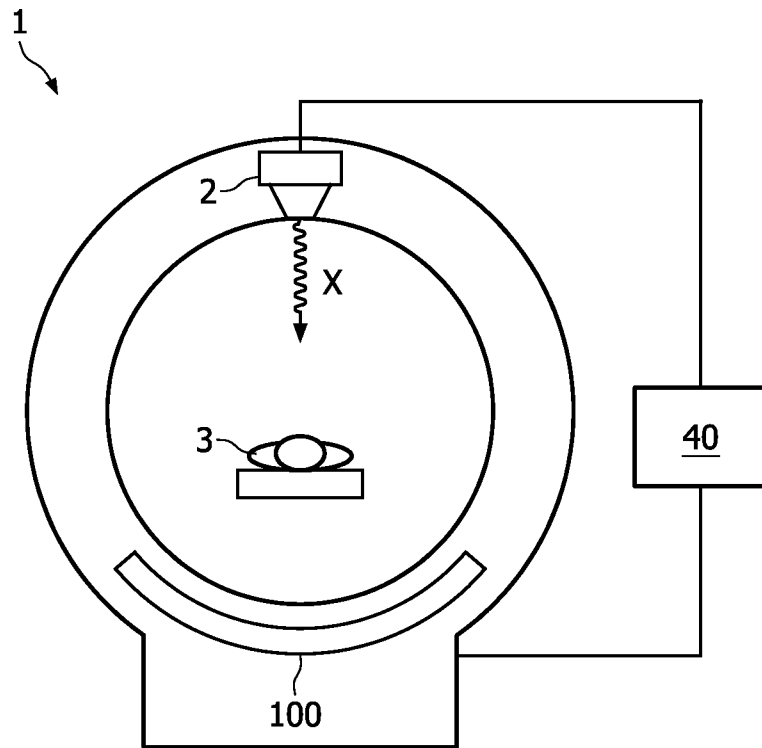


FIG. 1

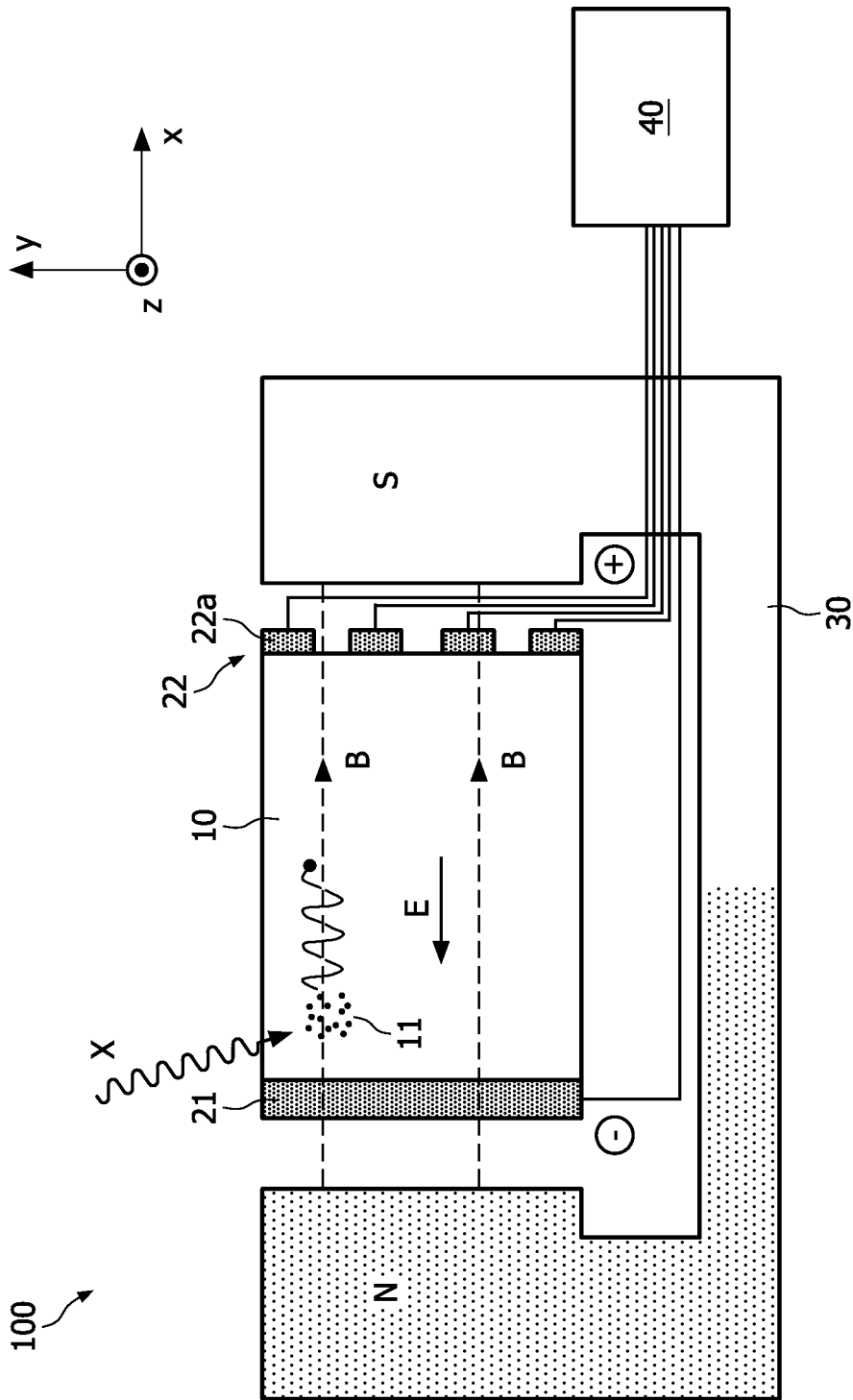


FIG. 2

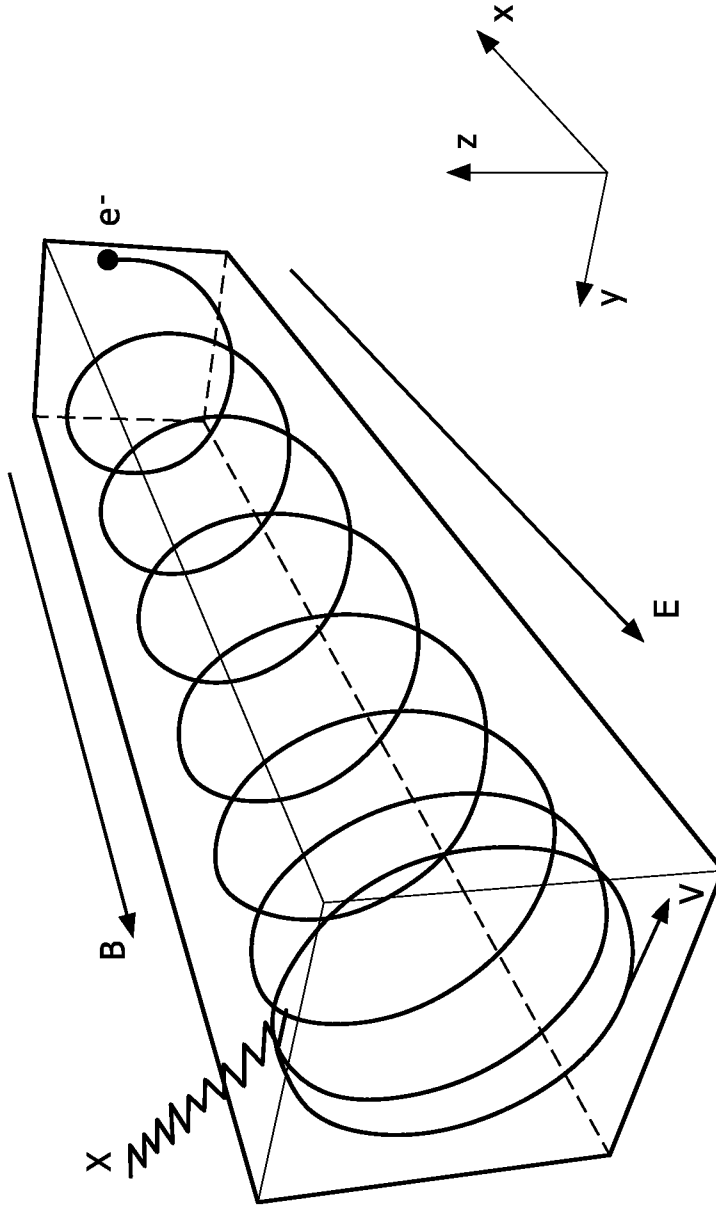


FIG. 3