(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 751 593 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
16.12.2020 Bulletin 2020/51

(51) Int Cl.:
H01J 35/06 (2006.01) ***H01J 35/18*** (2006.01)

(21) Application number: **19179329.8**

(22) Date of filing: **11.06.2019**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Siemens Healthcare GmbH**
91052 Erlangen (DE)

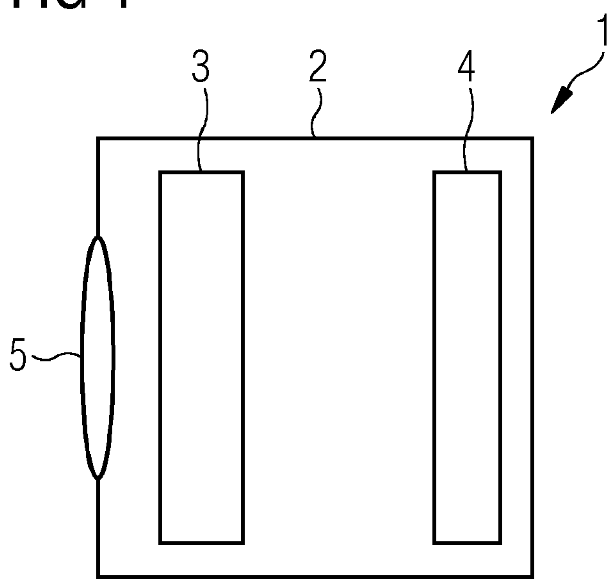
(72) Inventors:
- **Freudenberger, Jörg**
  90562 Kalchreuth (DE)
- **Fritzler, Anja**
  91052 Erlangen (DE)
- **Geithner, Peter**
  91058 Erlangen (DE)

(54) X-RAY DEVICE AND METHOD OF APPLYING X-RAY RADIATION

(57) The present invention provides an X-ray device (1) comprising a housing (2) configured to provide a vacuum therein; a cathode (3) arranged inside the housing (2) and configured to emit electrons; an anode (4) arranged inside the housing (2) and configured to produce x-ray radiation when impacted by electrons emitted by the cathode (3); and an application device (5) configured to apply the x-ray radiation produced by the anode (4); wherein the cathode (3) comprises a material transparent to x-ray radiation and is arranged such that x-ray radiation produced by the anode (4) passes through the cathode (3).

The present invention can be used in medicinal imaging, therapy, spectroscopy, and the like. Geometries and configurations can be improved compared to previously known x-ray devices when it comes to requirements for space, materials used, complexity of electrical wiring, distance between cathode and anode, and providing supplementary functions.

FIG 1



Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present application is directed to an x-ray device and a method of applying x-ray radiation.

State of the Art

[0002] X-ray radiation is being used in a multitude of applications, ranging from medicinal imaging or therapy, security checks at airports, to crystallography. The most common devices for generating x-ray radiation are x-ray tubes, which are vacuum tubes in which electrons are emitted by a cathode and accelerated towards an anode, where the electrons produce x-ray radiations through bremsstrahlung or other physical processes. X-ray tubes are generally simpler in construction and use than other ways of producing x-ray radiation like for example synchrotron radiation generated in particle accelerators.

[0003] US 2018/0333591 A1 describes such an x-ray device, which further comprises a converter to transform polychromatic x-ray radiation produced by bremsstrahlung into characteristic monochromatic radiation. Said x-ray device and other similar x-ray devices, as described for example in DE 19 639 241 C2, have complex beamlines for both the electrons traveling from the cathode to the anode and for the x-ray radiation traveling from the anode to the point of application.

[0004] This leads to generally small angles of incidence of the x-ray radiation and accompanying lowered intensity of radiation as well as heating of other components of the x-ray device by x-ray photons which are not directed towards the point of application.

Summary of the invention

[0005] Against this background, an objective of the present invention is to provide means to simplify the beamlines of electrons and x-ray radiation in an x-ray device.

[0006] According to the present invention, this task is solved by an x-ray device with the characteristics of the patent claim 1, and by a method of applying x-ray radiation with the features of the patent claim 14.

[0007] Consequently, an x-ray device is provided, which comprises a housing configured to provide a vacuum therein, a cathode configured to emit electrons, an anode configured to produce x-ray radiation when impacted by electrons emitted by the cathode, and an application device configured to apply the x-ray radiation produced by the anode. The cathode comprises a material transparent to x-ray radiation and is arranged such that x-ray radiation produced by the anode passes through the cathode.

[0008] Furthermore, a method of applying x-ray radiation is provided. In this method electrons are emitted from a cathode. X-ray radiation is produced with an anode being impacted by the electrons emitted from the cathode, and the x-ray radiation produced by the anode is applied. The cathode comprises a material transparent to x-ray radiation and is arranged such that x-ray radiation produced by the anode passes through the cathode before being applied.

[0009] It is an idea of the present invention to combine a pathway for the produced x-ray radiation with the cathode, which constitutes an essential part of the x-ray production. This opens up a multitude of geometries for constructing an x-ray device and arranging its constituent components. These geometries and configurations can be improved compared to previously known x-ray devices when it comes to requirements for space, materials used, complexity of electrical wiring, distance between cathode and anode, and providing supplementary functions.

[0010] Advantageous configurations and further embodiments can be derived from the dependent claims as well as from the description with reference to the figures.

[0011] According to a further embodiment, the cathode forms part of the housing. This configuration allows exterior access to the cathode which can advantageously simplify design, construction, and maintenance of the x-ray device.

[0012] According to a further embodiment, the anode forms part of the housing. This configuration allows exterior access to the anode which can advantageously simplify design, construction, and maintenance of the x-ray device.

[0013] According to a further embodiment, the cathode is arranged between the anode and the application device. This arrangement allows an advantageously easy guidance of the electrons from the cathode to the anode and subsequently of the produced x-ray radiation from the anode to the converter.

[0014] According to a further embodiment, the cathode is arranged in a cylindrical shape and the anode is arranged in a cylindrical shape surrounding the cathode. This arrangement provides an advantageously simple guiding of the electrons from the cathode to the anode. Furthermore, the anode can be realized in a large size, which advantageously improves the heat capacity and heat dissipation through a large exterior surface.

[0015] According to a further embodiment, the application device is arranged outside the housing. This configuration allows exterior access to the application device which can advantageously simplify design, construction, and maintenance of the x-ray device

[0016] According to a further embodiment, the application device is configured to be exchangeable. This allows advantageously quick and easy refurbishing of the x-ray device to be customized for different parameters of use.

[0017] According to a further embodiment, the application device comprises a converter, configured to convert incident x-ray radiation into monochromatic x-ray radiation. Monochromatic x-ray radiation is very desirable in many applications, in particular in medical diagnosis, where the radiation dosage can be significantly reduced by employing monochromatic x-ray radiation.

[0018] According to a further embodiment, the application device comprises a collimator configured to narrow the x-ray radiation. In this configuration, non-desirable exposure of surroundings to x-ray radiation can advantageously be minimized.

[0019] According to a further embodiment, the x-ray device comprises a cooling device configured to cool the anode. Actively cooling the anode which gets heated by the impacting electrons from the cathode advantageously prolongs the expected life span of the x-ray device and increases its safety.

[0020] According to a further embodiment, the cathode is provided with high negative voltage and the anode is grounded. In case that no voltage is applied to the anode, design, construction, and maintenance of the anode part of the x-ray device is advantageously simplified.

[0021] According to a further embodiment, the cathode is grounded and the anode is provided with high positive voltage. In case that no voltage is applied to the cathode, design, construction, and maintenance of the cathode part of the x-ray device is advantageously simplified.

[0022] According to a further embodiment, a surface of the anode facing the cathode comprises a dome shape. In this configuration, the surface of the cathode which is impacted by electrons from the cathode is increased, which advantageously improves the production of x-ray radiation by the anode.

[0023] According to a further embodiment of the method, the x-ray radiation produced by the anode is converted into monochromatic x-ray radiation, which is then subsequently applied. Monochromatic x-ray radiation is very desirable in many applications, in particular in medical diagnosis, where the radiation dosage can be significantly reduced by employing monochromatic x-ray radiation.

[0024] The above-mentioned configurations and further embodiments can be combined with each other, if it is reasonable. Further possible configurations, further embodiments and implementations of the invention also include combinations of features of the invention described before or in the following with regard to the examples of implementation not explicitly mentioned. In particular, the skilled person will also add individual aspects as improvements or additions to the respective fundamental form of the present invention.

Brief description of the drawings

[0025] This invention is explained in more detail below using the examples given in the schematic illustrations. They show in

Fig. 1 a schematic representation of an embodiment of an x-ray device;

Fig. 2 a schematic cross-section of an embodiment of an x-ray device;

Fig. 3 a schematic cross-section of a further embodiment of an x-ray device;

Fig. 4 a schematic cross-section of a further embodiment of an x-ray device;

Fig. 5 a schematic flow chart of an embodiment of a method of applying x-ray radiation; and

Fig. 6 a schematic flow chart of a further embodiment of a method of applying x-ray radiation.

[0026] The following figures are intended to convey a further understanding of the forms in which the invention is carried out. They illustrate embodiments and serve in connection with the description to explain principles and concepts of the invention. Other embodiments and many of the above-mentioned advantages can be derived from the drawings. The elements of the drawings are not necessarily shown to scale.

[0027] In the figures of the drawings, identical elements, characteristics and components with the same function and effect are provided with the same reference signs, unless otherwise specified.

Detailed description of embodiments

[0028] Figure 1 shows a schematic representation of an embodiment of an x-ray device 1. The x-ray device comprises a housing 2, a cathode 3, an anode 4, and an application device 5. The housing 2 is airtight and configured to provide a vacuum therein. The cathode 3 and the anode 4 are arranged inside the housing 2. The application device 5 is arranged to form part of the housing 2. The cathode 3 comprises a material transparent to x-ray radiation and is arranged between the anode 4 and the application device 5.

[0029] In use, the cathode 3 emits electrons into the vacuum inside the housing 2, for example through the field emission effect, thermionic emission, or other well-known physical processes. Under effect of the electrical field between the cathode 3 and the anode 4, the electrons are accelerated towards the anode 4. Upon impacting on the anode 4, the electrons interact with the anode 4 and thereby produce x-ray radiation through bremsstrahlung, characteristic x-ray emission, or the like. This x-ray radiation radiates outwards from the anode 4 back in the direction of the cathode 3. Since the cathode 3 comprises a material transparent to x-ray radiation, the x-ray radiation passes through the cathode 3 towards the application device 5, from where it can be applied for any conceivable beneficial effect. In the x-ray device 1 shown in Figure 1, the application device 5 comprises an aperture through which x-ray radiation can be directed towards a target, for example to use for medical imaging, or for sterilization of materials.

[0030] The cathode 3 may for example comprise carbon nanotube emitters arranged on a ceramic substrate, for example Aluminum-Nitride or Silicone-Carbide. In that case, the cathode may further comprise control electrodes made from Beryllium, Aluminum or other conductive materials comprising elements with low atomic number, preferably with an atomic number of less than 20. The cathode 3 can however also comprise other materials transparent to x-ray radiation. The cathode 3 can for example comprise a Silicone based Field emission emitter.

[0031] Figure 2 shows a schematic cross-section through a part of a further embodiment of an x-ray device 1. In the embodiment shown in Figure 2, the application device 5 comprises a converter 6, comprising a truncated pyramid shape, and a collimator 7. The components of the x-ray device 1 are configured and arranged rotationally symmetrical around an axis of symmetry X passing through the center of the converter 6. Both the cathode 3 and the anode 4 of the embodiment shown in Figure 2 comprise a cylindrical shape, wherein the cathode 3 is arranged surrounding the converter 6 and the anode 4 is arranged surrounding the cathode 3. The converter 6 and the collimator 7 are arranged outside of the housing 2 and the cathode 3 is configured to form part of the housing 2.

[0032] The x-ray device 1 functions essentially the same as the x-ray device 1 described in conjunction with Figure 1. The arrangement of the cathode 3 and the anode 4 greatly increases the impact surface of the anode 4, resulting in a high intensity of the produced x-ray radiation. The x-ray radiation produced by the anode 4 passes through the cathode 3 and impacts the converter 6, which converts the x-ray radiation produced by the anode 4, e.g. through bremsstrahlung, into monochromatic x-ray radiation. Through the shape of the converter 6, most of the converted monochromatic x-ray radiation radiates in the direction of the axis of symmetry X. The collimator 7 is arranged in such a way as to narrow the converted monochromatic x-ray radiation even further.

[0033] As the application device 5 and its components, converter 6 and collimator 7, are arranged outside the housing 2. It is easily possible to configure the application device 5 to be exchangeable. In that way, for example different converters 6 can be provided in accordance to the specific desired application of the x-ray device 1.

[0034] Figure 3 shows a schematic cross-section through a part of a further embodiment of an x-ray device 1. The x-ray device 1 comprises essentially the same features as the x-ray device 1 shown in Figure 2. In the embodiment shown in Figure 3, the cathode 3 is connected to the other parts of the housing 2 by a first isolator 8, which comprises for example Aluminum Oxide. The housing 2 is further surrounded by a second isolator 9, which can for example comprise Polyether ether ketone, which is transparent to x-ray radiation. On top of the second isolator 9, the x-ray device comprises a secondary collimator 10.

[0035] In the embodiment shown in Figure 3, the cathode is supplied with a high voltage, for example upwards of 100kV, the exact circuitry used not being shown for clarity of the drawing. Doing so requires providing first isolator 8 and second isolator 9, but is beneficial for the anode 4, which is not supplied with any voltage. For example, as the anode 4 is not supplied with any voltage, a cooling device, which is not shown, can be provided to utilize water cooling for the anode 4 in a simple and safe manner. Other forms of cooling, like air cooling or utilizing any other cooling medium, can also be provided.

[0036] Alternatively, the anode 4 can be supplied with a high voltage and the cathode 3 can be grounded. In that case, a simpler arrangement of the cathode 3, similar to the one shown in Figure 2, may suffice.

[0037] Figure 4 shows a schematic cross-section through a part of a further embodiment of an x-ray device 1. The embodiment shown in Figure 4 comprises essentially all features of the x-ray device shown in Figure 3. In addition, a surface of the anode 4 facing the cathode 3 comprises a dome like shape. This further increases the surface area of the anode 4 impacted by the electrons emitted by the cathode 3. Furthermore, the intensity of x-ray radiation impacting on the converter 6 is increased, as the converter 6 is situated in the focal point of the anode 4.

[0038] Figure 5 shows a schematic flow chart of a method 100 of applying x-ray radiation. In a first method step 101, electrons are emitted by a cathode. The electrons are accelerated away from the electron and impact on an anode, thereby producing x-ray radiation in a further method step 102. The x-ray radiation produced in method step 102 is then applied in a further method step 103. Before being applied in method step 103, the x-ray radiation produced in method step 102 passes through the cathode, which comprises a material transparent to x-ray radiation.

[0039] Figure 6 shows a schematic flow chart of a further method 100 of applying x-ray radiation. The method 100 shown in Figure 6 differs from the method 100 shown in Figure 5 in that it comprises a further method step 104. In the further method step 104, the x-ray radiation produced in method step 102 is converted into monochromatic x-ray radiation, which is then subsequently applied in method step 103.

Claims

1. X-ray device (1) comprising:

a housing (2) configured to provide a vacuum therein;
a cathode (3) arranged inside the housing (2) and configured to emit electrons;
an anode (4) arranged inside the housing (2) and configured to produce x-ray radiation when impacted by electrons emitted by the cathode (3); and
an application device (5) configured to apply the

x-ray radiation produced by the anode (4); wherein the cathode (3) comprises a material transparent to x-ray radiation and is arranged such that x-ray radiation produced by the anode (4) passes through the cathode (3).

2. X-ray device (1) according to claim 1, wherein the cathode (3) forms part of the housing (2).

3. X-ray device (1) according to claim 1 or claim 2, wherein the anode (4) forms part of the housing.

4. X-ray device (1) according to any of the preceding claims, wherein the cathode (3) is arranged between the anode (4) and the application device (5).

5. X-ray device (1) according to any of the preceding claims, wherein the cathode (3) is arranged in a cylindrical shape and wherein the anode (4) is arranged in a cylindrical shape surrounding the cathode (3).

6. X-ray device (1) according to any of the preceding claims, wherein the application device (5) is arranged outside the housing (2).

7. X-ray device (1) according to any of the preceding claims, wherein the application device (5) is configured to be exchangeable.

8. X-ray device (1) according to any of the preceding claims, wherein the application device (5) comprises a converter (6), configured to convert incident x-ray radiation into monochromatic x-ray radiation.

9. X-ray device (1) according to any of the previous claims, wherein the application device (5) comprises a collimator (7) configured to narrow the x-ray radiation.

10. X-ray device (1) according to any of the previous claims, further comprising a cooling device configured to cool the anode (4).

11. X-ray device (1) according to any of the previous claims, wherein the cathode (3) is provided with high negative voltage and the anode (4) is grounded.

12. X-ray device (1) according to any of claims 1 to 10, wherein the cathode (3) is grounded and the anode (4) is provided with high positive voltage.

13. X-ray device (1) according to any of the previous claims, wherein a surface of the anode (4) facing the cathode (3) comprises a dome shape.

14. Method (100) of applying x-ray radiation, comprising:

emitting (101) electrons from a cathode;
producing (102) x-ray radiation with an anode being impacted by the electrons emitted from the cathode; and
applying (103) x-ray radiation produced by the anode;
wherein the cathode comprises a material transparent to x-ray radiation and is arranged such that x-ray radiation produced by the anode passes through the cathode before being applied.

15. Method (100) according to claim 14, further comprising a step of converting (104) x-ray radiation produced by the anode into monochromatic x-ray radiation, wherein the monochromatic x-ray radiation is subsequently applied.

FIG 1

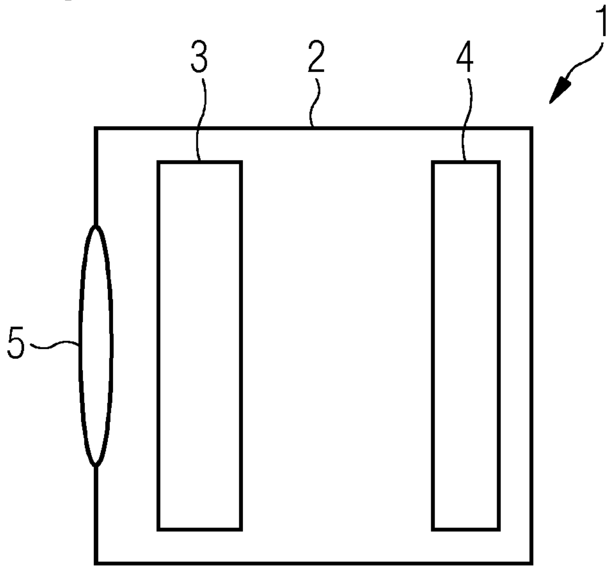


FIG 2

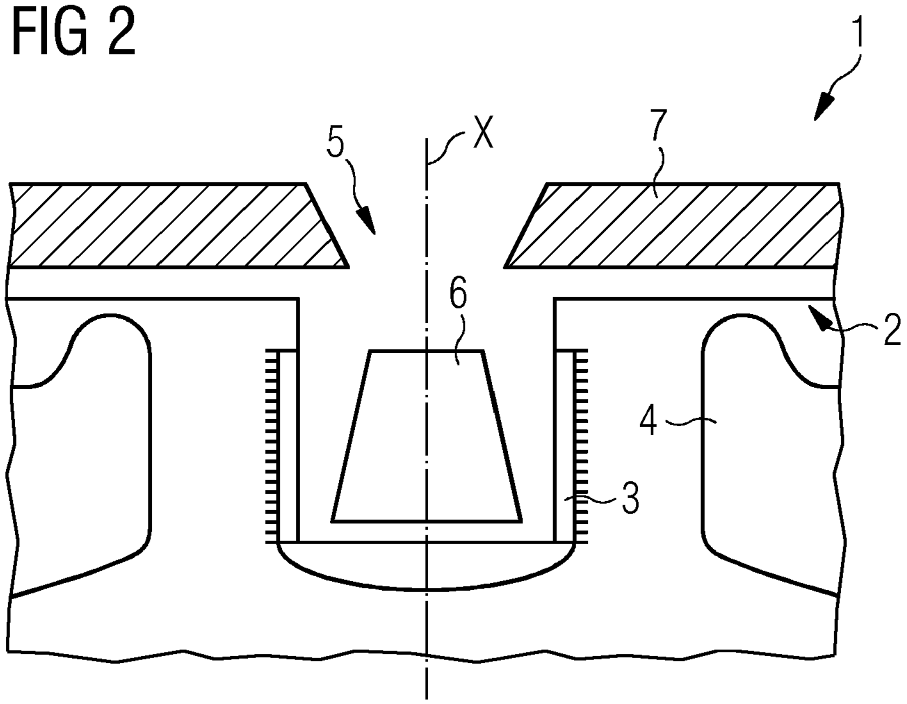


FIG 3

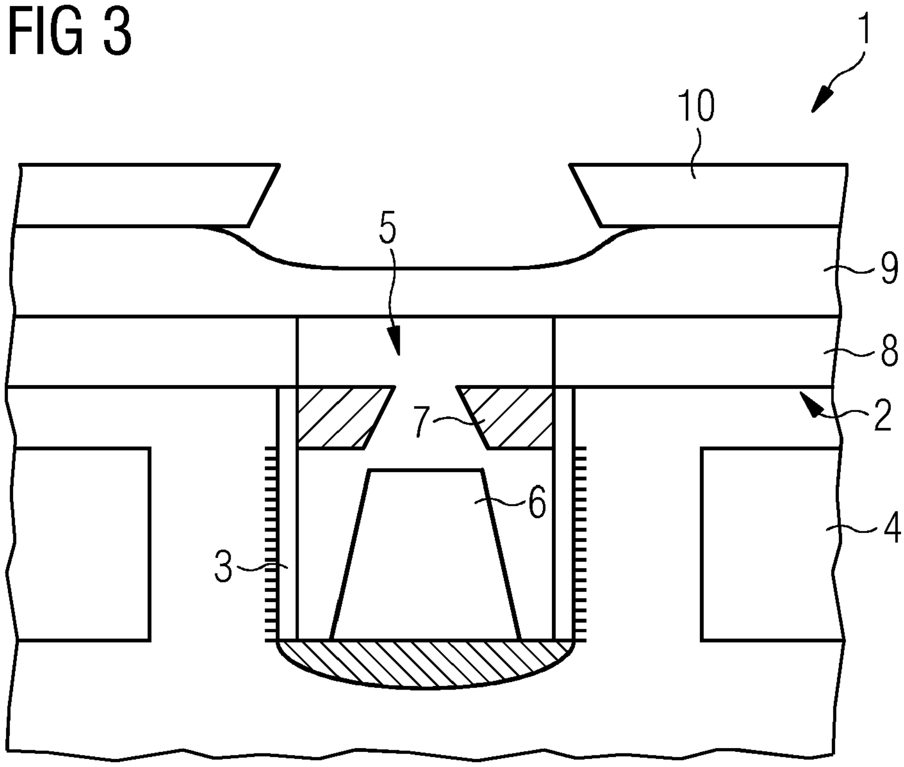


FIG 4

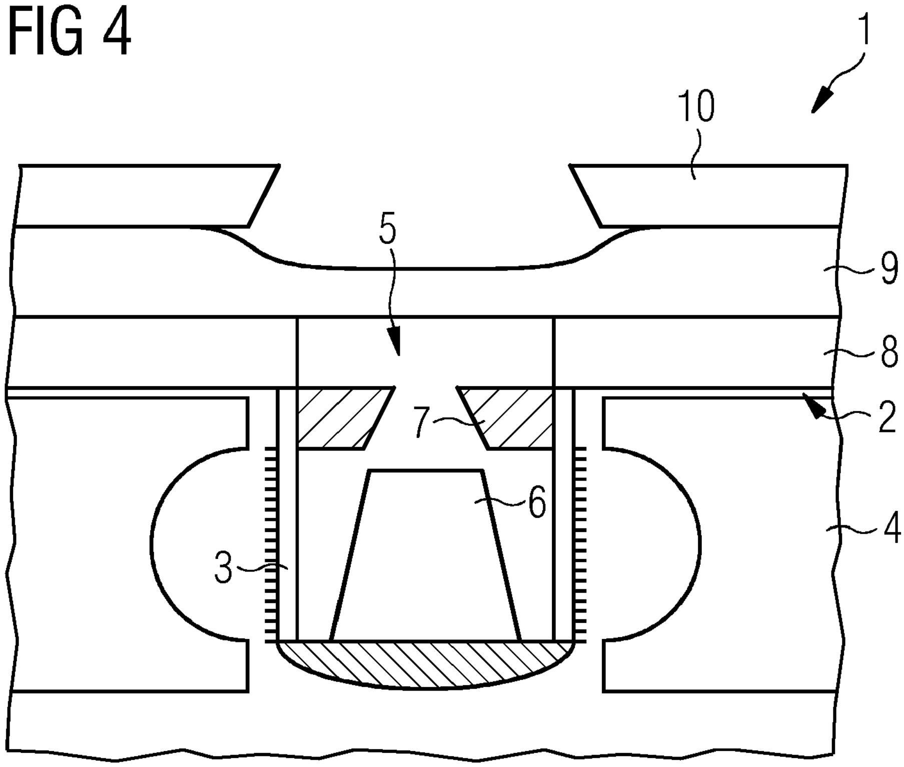


FIG 5

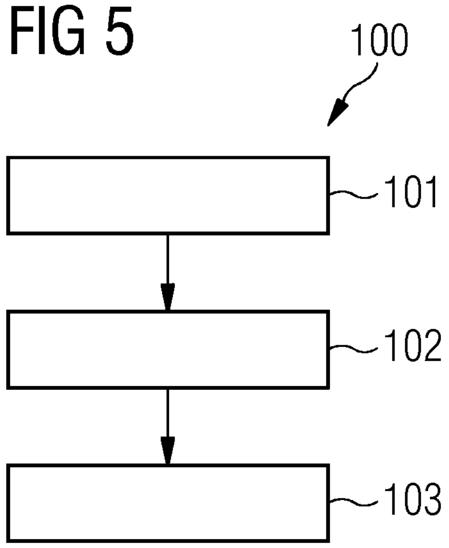
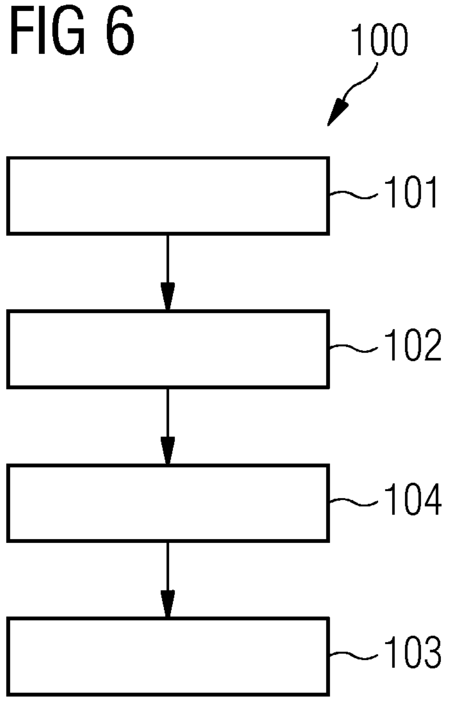


FIG 6



Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 19 17 9329

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 6 333 968 B1 (WHITLOCK ROBERT R [US] ET AL) 25 December 2001 (2001-12-25) * the whole document * -----	1-4,6-9, 11,12, 14,15	INV. H01J35/06 H01J35/18
X	US 6 477 233 B1 (RIBBING CAROLINA [SE] ET AL) 5 November 2002 (2002-11-05) * figure 9 * * column 3, lines 66,67 * * column 5, lines 58-61 * -----	1,2,4,6, 8,14,15	
X	US 2008/267354 A1 (HOLM KURT [CH] ET AL) 30 October 2008 (2008-10-30) * figure 6a * * paragraphs [0031], [0053], [0062] * -----	1-6,10, 13,14	

TECHNICAL FIELDS SEARCHED (IPC)
H01J

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	12 December 2019	Giovanardi, Chiara

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 19 17 9329

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

12-12-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6333968 B1	25-12-2001	AU 6124301 A	12-11-2001
		US 6333968 B1	25-12-2001
		WO 0184585 A1	08-11-2001
US 6477233 B1	05-11-2002	EP 1058286 A1	06-12-2000
		JP 2001035427 A	09-02-2001
		US 6477233 B1	05-11-2002
US 2008267354 A1	30-10-2008	EP 1747570 A1	31-01-2007
		JP 2007538359 A	27-12-2007
		US 2008267354 A1	30-10-2008
		WO 2005117058 A1	08-12-2005

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 20180333591 A1 **[0003]**
- DE 19639241 C2 **[0003]**