



(51) International Patent Classification:
H01J 35/10 (2006.01)

(21) International Application Number:
PCT/EP2012/059767

(22) International Filing Date:
24 May 2012 (24.05.2012)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US):
QUANTUM TECHNOLOGIE GMBH [DE/DE]; Pen-
tenriederstraße 39, 82152 Krailling (DE).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **CHAN, Ki** [CN/CN];
Suite 5408, 54/F, Central Plaza, 18 Harbour Road, Wan-
chai, Hong Kong (CN).

(74) Agent: **LOHR JÖSTINGMEIER & PARTNER;**
Junkersstraße 3, 82178 Puchheim (DE).

AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD,
SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

— with amended claims and statement (Art. 19(1))

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

(54) Title: COOLED ROTARY ANODE FOR AN X-RAY TUBE

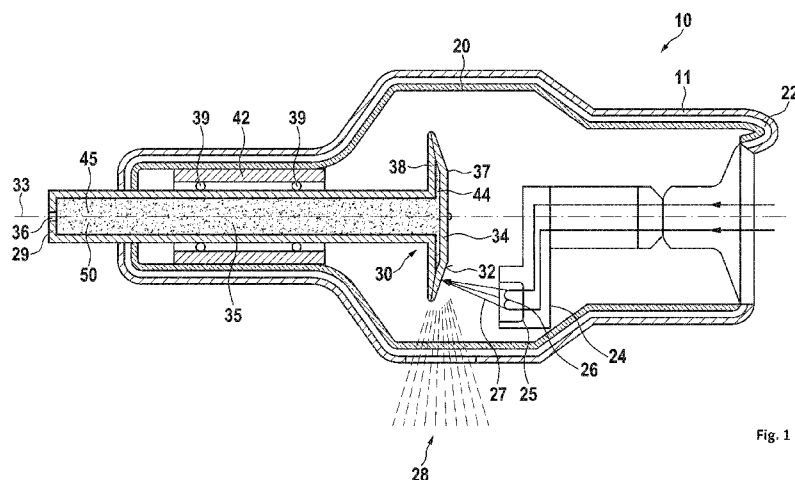


Fig. 1

(57) Abstract: An Anode (30) for an X-ray tube (10) comprising at least a stem (29) for rotary supporting the anode (30) and a disc (34), being coaxially attached to the stem (29) and having a peripheral target area (32) as target for an electron beam (27) on its frontal side, can be efficiently cooled if the the anode (30) has at least one cavity extending into the disc (34) and in particular, if the cavity has a coating (50) of at least one inorganic salt.

Cooled Rotary Anode for an X-ray Tube

Field of the invention

The invention relates to a cooled anode for an X-ray tube and to an X-ray tube.

Description of the related art

5 X-ray tubes are of significant importance in medical imaging, in particular as X-ray sources for CT-scanners. Of course X-ray tubes are as well important in other technological fields as there are for example the determination of crystal structures (see e.g. Ashcroft Mermin *Solid State Physics*, Saunders College Publishing, Chapt. 6) or the quick and reliable radiography which has become common use
10 by customs authorities, to name only a few. These applications require a high radiated power for obtaining detailed information about the objects being subjected to an X-ray based analysis.

Briefly speaking X-rays are produced by an abrupt slowing down of previously accelerated electrons. To this end an X-ray tube comprises a cathode, often in
15 form of a coiled filament. The filament is heated by a applying a current to the filament to induce thermal emission of the electrons. The electrons are drawn of by an anode. The voltage between the anode and the cathode is typically of the order of a several kV, e.g. 25 to 150kV. The electrons are thus accelerated towards the anode upto several keV, until they are slowed down by inelastic scattering with the anode's atoms. Due to energy conservation a part of the electrons' kinetic energy is emitted as phonons, i.e. X-rays, having a continuous energy spectrum. The emission of the x-rays is as well referred to as Bremsstrahlung. Often, peaks are observed in radiation spectra of x-ray tubes. These peaks are due to a recombination of excited electrons of the atoms. The high kinetic
20 energy of the electrons impinging the anode is unfortunately not only converted into short wavelength radiation but as well into heat. Only a few percent of the

electrical power provided to an X-ray tube is typically converted into X-rays, the remaining power is converted into heat. Efficient cooling of the X-ray tube, in particular of the anode is crucial for obtaining high X-ray intensities.

US 6,807,382 B2 discloses an X-ray tube. The X-ray tube has as usual an evacuated compartment. In the compartment are a cathode for thermal emission of electrodes and a tungsten alloy anode as target for the electrons. The anode is disc shaped and has a circular peripheral area onto which the electrons are focused. The disc is mounted on a rotor shaft of a motor, thus in operation the focal point of the electron beam forms a circular focal track on the peripheral area. Attached to the rear side of the anode disc is a graphite back plate as heat sink. Heat is transferred from the anode to its back plate by heat pipes. The heat pipes are briefly speaking evacuated cylindrical metal shells, being partially filled a working fluid like Sodium, Lithium, Zink or the like, i.e. fluids under operating conditions of the anode. In each metal shell is a capillary wick, being surrounded by a tube. The wick serves to transport the fluid to an evaporation end of the shell, which is in the proximity of the focal track. Thus, heat produced by the electrons impinging the focal track evaporates the liquid. The evaporated liquid (now in a gas state) condenses at the other end of the shell and thus transports heat from a region just behind the focal track towards the back plate.

20 **Summary of the invention**

The invention is based on the observation, that the heat transfer mechanism for cooling the anode is complicated and expensive.

The problem to be solved by the invention is to provide a simple and thus less expensive heat transfer mechanism for cooling the anode of an X-ray tube.

25 The problem is solved by an anode for an X-ray tube as defined by claim 1. The dependent claims relate to improvements of the invention.

The problem is solved by providing an anode for an X-ray tube. The anode may have a stem for rotary supporting the anode. A disc may be coaxially attached to the stem. The stem and the disc are preferably integrally formed. Preferably, the disc has a peripheral target area on its frontal side, for example an inlet made of tungsten. The anode has at least one cavity, extending from the stem into the disc. Accordingly the cavity may be formed by inner walls of the stem and/or the disc. At least part of the inner surface of the stem and/or the disc may be coated by at least one inorganic salt. Alternatively one may say that at least a part of the cavity is coated by at least one inorganic salt. More preferably the coating is a composition of inorganic salts as explained below in more detail. This inorganic salt or composition, respectively form a coating with an excellent thermal conductivity on the inner surfaces of the disc and the stem, respectively. This permits an efficient and simple heat transfer from the region of the target surface, to some cooling device.

Preferably, the cavity extends from the center of the disc at least to an area being opposite of the target area. The heat is produced in the material just behind the target area by electrons entering the solid and interacting with electrons of the solid's atoms. If the coated cavity extends to an area being opposite to the target area, the heat can be conducted from its place of origin to some cooling device, e.g. a heat sink.

The cavity may preferably be evacuated and may have an, e.g., coaxially aligned cylindrical through hole. This through hole permits to apply the coating by filling a solution of the inorganic salt(s) (or the composition) to the cavity and to subsequently remove the solvent to thereby apply the coating. This procedure may be repeated multiple times. The solvent may be water, which can easily be removed, e.g., by heating the anode and/or reduction of the pressure in the cavity.

After coating, the cavity may preferably be evacuated, e.g., via the through hole, which may closed afterwards, for example by a valve.

The disc may comprise at least a front half shell and a rear half shell. The two shells may be attached to each other thereby forming a recess in between of the shells. The recess may be a part of the cavity. This permits on the one hand to efficiently manufacture the disc with the cavity and at the same time to choose different materials for the front half shell and the rear half shell, to better adapt the two half shells to the operating conditions of the anode.

In a preferred embodiment, at least the rear half shell comprises a Molybdenum alloy body as this enhances heat dissipation and durability of the anode.

The coating may preferably comprise inorganic oxides. A solution for coating the cavity may comprise a composition of the following constituents:

sodium peroxide	2.705%
disodium oxide	2.505%
Silicon	1.6%
diboron trioxide	0.505%
Titanium	0.405%
copper oxide	0.405%
cobalt oxide	0.255%
beryllium oxide	0.255%
water, distilled, conductivity or of similar purity	89.256%
dirhodium trioxide	1.6%
trimanganese tetraoxide	0.255%
strontium carbonate	0.255%

Variations of the composition of about 10% are tolerable.

This composition is only one possible composition. Examples for further compositions are for example described in U.S. Patent Nos. 6132823, 6911231, 6916430, 6811720 and U.S. Publication No. 2005/0056807, which are incorporated by reference as if fully disclosed herein. The coating provided by applying
5 the such compositions to the cavity acts as a thermally conductive material to provide at least an almost perfect homogenous distribution of the heat produced by the impinging electrons. The cavity may as well be evacuated as suggested in the above references. The thermally conductive material is an inorganic material that is a combination of oxides and one or more pure elemental species, particularly
10 titanium and silicon.

The anode may of course be included in an evacuated compartment of an X-ray tube. Such X-ray tube may comprise at least a cathode for emitting electrons. The cathode may be for example some tungsten filament, being configured for applying an electrical current. Additionally the X-ray tube may comprise means
15 for focusing the electrons onto the target area of the anode and preferably means for rotary supporting the anode. At least the anode and the cathode are enclosed in the evacuated compartment. For example may the anode be rotary supported in the compartment. Alternatively, the compartment with the anode and the cathode may be rotated. The electron beam emitted by the cathode
20 should preferably be focused to some point on the target area. At least the anode should be rotated with respect to the electron beam, such that the focal point follows a "focal track" on the target area.

The compartment may be enclosed by a housing, forming a cooling space between the compartment and the housing. A coolant may be circulated in the
25 space. More preferably the coolant is circulated between a heat sink, or some other cooling device and the cooling space.

Description of Drawings

In the following the invention will be described by way of example, without limitation of the general inventive concept, on examples of embodiment with reference to the drawings.

5 Figure 1 shows a cross section of a simplified X-ray tube.

The X-ray tube 10 in Figure 1 has a compartment, being formed by compartment wall 20, e.g. of glass. The compartment 20 is enclosed in a housing 11, for example made of some metal. Between the compartment wall 20 and the housing 11 is a space 22, in which a coolant circulates. Preferably the coolant circulates between the space 22 and a heat exchanger (not shown).

The compartment 20 is evacuated and encloses a cathode assembly 24, having a filament cathode 26, being connected to a power supply. By applying electrical power to the cathode 26, the cathode 26 may be heated to obtain thermal emission of electrons.

15 The compartment 20 as well encloses part of an anode 30. The anode 30 has a T-shaped cross section. It comprises a stem 29 with a disc 34 attached to it. In the depicted example the stem 29 and the disc 34 are integrally formed, but may as well be separate parts. The disc 34 has a frontal side facing towards the cathode assembly 24. On the frontal facing side of the disc 34 is a peripheral target area 32 for electrons being emitted by the cathode 26 and subsequently accelerated by a voltage between cathode 26 and the anode 30.

The anode has a cavity 35 extending coaxially along axis 33. The cavity 35 includes a cylindrical hole 45 in stem 29, which extends into the disc 34. The stem has an opening 36 at its rear end.

25 The disc 34 has a front half shell and a rear half shell, forming a recess 44 in between. The recess is part of the cavity 34 and thus in fluid communication with

the cylindrical hole 45 of the stem 29. The term "fluid communication" is not to be understood such that a fluid is in the cavity, but only to explain that one could apply a continuous coating 50 to the cavity. In addition a coolant, e.g. a gas could be circulated in cavity, e.g. via the opening 36 in the rear side of the anode.

- 5 The anode 30 is rotary supported to rotate around axis 33 by bearing means. The bearing means are supported by the compartment wall 20 and comprise a bearing housing 42 with outer races for bearing balls 39. Inner races for bearing balls 39 are provided on the outer surface of the stem 29. The anode 30 may be rotationally driven by a motor with an electrical stator (not shown).
- 10 Focusing means 25 focus the electrons 27 on a spot on the target area 32. Thus an electron beam 27 is focused on the target area 32. In operation the focal point of the electron beam 27 forms a focal track on the rotating stem 29, in particular on the target area 32 of the stem 29

- At the inner surface of the anode 30 is a coating 50 comprising a composition of
- 15 inorganic salts and elements, e.g., those listed above in Table 1. Preferably the inner surface is fully coated. The coating 50 has an excellent thermal conductivity and provides for an excellent dissipation of heat away from the target area 32.

- In operation an electron beam 27 is emitted by the cathode 26 and focused on the target area 32. The anode 30 is rotated, thus the focused electron beam 27
- 20 impinges the anode 30 at a ring like focal track on the target area 32 as explained above. Part of the electrons are slowed down due to coulomb interaction with cores of atoms of the anode 30 and thus emits X-ray Bremsstrahlung. Most of the electrons however interact with electrons of the atoms and thus a large amount of their kinetic energy is converted into heat. This heat dissipates from
- 25 the target area towards the cavity wall, and is thus transferred to the coating 50. Coating 50 participates and thereby enhances conduction of the heat away from

the target area to the rear side of the anode, which is connected to some cooling device (not shown).

List of reference numerals

	10	X-ray tube
	11	housing
	20	compartment/ compartment wall
5	22	space, e.g. for coolant
	24	cathode assembly
	26	cathode
	27	electron beam
	28	X-rays
10	29	stem/shaft
	30	anode
	33	rotational axis of anode 30
	34	disc
	37	front half shell
15	38	rear half shell
	35	cavity
	36	opening of cavity
	39	bearing balls
	42	bearing housing
20	44	recess in disc (part of cavity 35)
	45	cylindrical hole in stem (part of cavity 35)
	50	coating

Claims

1. Anode (30) for an X-ray tube (10), the anode (30) comprising at least:
 - a stem (29) for rotary supporting the anode (30) and
 - a disc (34), being coaxially attached to the stem (29) and having a pe-
5 ripheral target area (32) as target for an electron beam (27) on its
frontal side,

characterized in that
the anode (30) has at least one cavity extending into the disc (34), the cavi-
ty having a coating (50) of at least one inorganic salt.
- 10 2. The anode (30) of claim 1
characterized in that
the cavity (35) extends from the center of the disc (34) at least to an area
being opposite of the target area (32).
- 15 3. The anode (30) of one at least one of the preceding claims
characterized in that
the cavity (35) includes a coaxially aligned cylindrical hole (45) of the
stem (29).
4. The anode (30) of one at least one of the preceding claims
characterized in that
20 the disc (34) comprises at least a front half shell (37) and a rear half
shell (38), being attached to each other thereby forming a recess (44),
wherein the recess is part of the cavity (34).

5. The anode (30) of claim 4,
characterized in that
the rear half shell (38) comprises an Molybdenum alloy body.
6. The anode (30) of one at least one of the preceding claims
5 characterized in that
the coating (50) comprise at least one the members of the group consisting
of Sodium Peroxide, Disodium Oxide, Silicon, Diboron Trioxide, Titanium,
Copper Oxide, Cobalt Oxide, Beryllium Oxide, Dirhodium Trioxide,
Trimanganese Tetraoxide and Strontium Carbonate.
- 10 7. X-ray tube (10), comprising at least a an evacuated compartment (20) en-
closing at least
– a cathode (26) for emitting electrons (27),
– an anode(30) with a target area (32) and
– means (25) for focusing the electrons (27) onto the target area (32)
- 15 characterized in that
the anode (30) is an anode of at least one of the preceding claims.
8. X-ray tube (10) of claim 7
characterized in that
the anode (30) is rotary supported in the compartment (20).
- 20 9. X-ray (10) tube of claim 7 or 8
characterized in that
the compartment (20) is enclosed by a housing (11), forming a space (22)
between the compartment and the housing, and in that the X-ray tube
comprises means for circulating a coolant in the space between the com-
25 partment (10) and the housing (11).

AMENDED CLAIMS
received by the International Bureau on 26 March 2013 (26.03.13)

1. Anode (30) for an X-ray tube (10), the anode (30) comprising at least:
 - a stem (29) for rotary supporting the anode (30) and
 - a disc (34), being coaxially attached to the stem (29) and having a pe-
5 ripheral target area (32) as target for an electron beam (27) on its
frontal side,
characterized in that
the anode (30) has at least one evacuated cavity extending into the
disc (34), the cavity having a coating (50) of at least one inorganic salt and
10 in that the coating (50) comprises at least one the members of the group
consisting of Sodium Peroxide, Disodium Oxide, Silicon, Diboron Trioxide,
Titanium, Copper Oxide, Cobalt Oxide, Beryllium Oxide, Dirhodium Triox-
ide, Trimanganese Tetraoxide and Strontium Carbonate.
2. The anode (30) of claim 1
15 characterized in that
the cavity (35) extends from the center of the disc (34) at least to an area
being opposite of the target area (32).
3. The anode (30) of one at least one of the preceding claims
characterized in that
20 the cavity (35) includes a coaxially aligned cylindrical hole (45) of the
stem (29).

4. The anode (30) of one at least one of the preceding claims
characterized in that
the disc (34) comprises at least a front half shell (37) and a rear half
shell (38), being attached to each other thereby forming a recess (44),
5 wherein the recess is part of the cavity (34).
5. The anode (30) of claim 4,
characterized in that
the rear half shell (38) comprises an Molybdenum alloy body.
6. X-ray tube (10), comprising at least a an evacuated compartment (20) en-
10 closing at least
- a cathode (26) for emitting electrons (27),
 - an anode(30) with a target area (32) and
 - means (25) for focusing the electrons (27) onto the target area (32)
- characterized in that
15 the anode (30) is an anode of at least one of the preceding claims.
7. X-ray tube (10) of claim 6
characterized in that
the anode (30) is rotary supported in the compartment (20).
8. X-ray (10) tube of claim 6 or 7
20 characterized in that
the compartment (20) is enclosed by a housing (11), forming a space (22)
between the compartment and the housing, and in that the X-ray tube
comprises means for circulating a coolant in the space between the com-
partment (10) and the housing (11).

STATEMENT UNDER ARTICLE 19 (1)

The amended claim 1 has the limitations of claims 1 and 6 as filed. Additionally it is specified that the cavity is evacuated as disclosed on page 5, lines 7 and 8 of the description as filed.

Claims 2 to 5 remained unchanged.

Claims 6 to 8 correspond to claims 7 to 9 as filed, respectively. The references have been adapted accordingly.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/059767

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01J35/10
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 10 2005 049270 A1 (SIEMENS AG [DE]) 19 April 2007 (2007-04-19) paragraphs [0028], [0029]; figure 3 -----	1-5,7-9
Y	EP 1 675 151 A1 (TOSHIBA KK [JP]; TOSHIBA ELECTRON TUBES & DEVIC [JP]) 28 June 2006 (2006-06-28) paragraphs [0020], [0024], [0031] -----	1-5,7-9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

16 January 2013

Date of mailing of the international search report

30/01/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Oestreich, Sebastian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/059767

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102005049270 A1	19-04-2007	CN 101030516 A	05-09-2007
		DE 102005049270 A1	19-04-2007
		JP 2007109659 A	26-04-2007
		US 2007086573 A1	19-04-2007

EP 1675151 A1	28-06-2006	CN 1868027 A	22-11-2006
		EP 1675151 A1	28-06-2006
		JP 4828942 B2	30-11-2011
		US 2006182222 A1	17-08-2006
		WO 2005038854 A1	28-04-2005
