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(54) **METHOD AND APPARATUS FOR GENERATING X-RAY RADIATION**

VERFAHREN UND VORRICHTUNG ZUR ERZEUGUNG VON RÖNTGENSTRAHLUNG

PROCEDE ET APPAREIL PERMETTANT DE GENERER DES RAYONS X

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- **PATENT ABSTRACTS OF JAPAN & JP 05 258 692 A (NIKON CORP) 08 October 1993**
- **HEMBERG O; HANSSON B A M; HERTZ H M: "Target analysis of laser-plasma droplet-target system" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, vol. 4144, 1 January 2000 (2000-01-01), pages 38-42, XP002962594 VA ISSN: 0277-786X**

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Description

Technical Field

[0001] The present invention generally relates to a method and an apparatus for generating X-ray radiation, especially with high brilliance. The generated radiation can for example be used in medical diagnosis, non-destructive testing, lithography, microscopy, materials science, or in some other X-ray application.

Background Art

[0002] X-ray sources of high power and brilliance are applied in many fields, for instance medical diagnosis, non-destructive testing, crystal structural analysis, surface physics, lithography, X-ray fluorescence, and microscopy.

[0003] In some applications, X-rays are used for imaging the interior of objects that are opaque to visible light, for example in medical diagnostics and material inspection, where 10-1000 keV X-ray radiation is utilized, i.e. hard X-ray radiation. Conventional hard X-ray sources, in which an electron beam is accelerated towards a solid anode, generate X-ray radiation of relatively low brilliance. In hard X-ray imaging, the resolution of the obtained image basically depends on the distance to the X-ray source and the size of the source. The exposure time depends on the distance to the source and the power of the source. In practice, this makes X-ray imaging a trade-off between resolution and exposure time. The challenge has always been to extract as much X-ray power as possible from as small a source as possible, i.e. to achieve high brilliance. In conventional solid-target sources, X-rays are emitted both as continuous Bremsstrahlung and characteristic line emission, wherein the specific emission characteristics depend on the target material used. The energy that is not converted into X-ray radiation is primarily deposited as heat in the solid target. The primary factor limiting the power, and the brilliance, of the X-ray radiation emitted from a conventional X-ray tube is the heating of the anode. More specifically, the electron-beam power must be limited to the extent that the anode material does not melt. Several different schemes have been introduced to increase the power limit. One such scheme includes cooling and rotating the anode, see for example Chapters 3 and 7 in "Imaging Systems for Medical Diagnostics", E. Krestel, Siemens Aktiengesellschaft, Berlin and Munich, 1990. Although the cooled rotating anode can sustain a higher electron-beam power, its brilliance is still limited by the localized heating of the electron-beam focal spot. Also the average power load is limited since the same target material is used on every revolution. Typically, very high intensity sources for medical diagnosis operate at 100 kW/mm², and state of the art low-power micro-focus devices operate at 150 kW/mm².

[0004] Applications in the soft X-ray and EUV wave-

length region (a few tens of eV to a few keV) include, e.g., next generation lithography and X-ray microscopy systems. Ever since the 1960s, the size of the structures that constitute the basis of integrated electronic circuits has decreased continuously. The advantage thereof is faster and more complex circuits requiring less power. At present, photolithography is used to industrially produce such circuits having a line width of about 0.13 μm. This technique can be expected to be applicable down to about 0.1-0.07 μm. In order to further reduce the line width, other methods will probably be necessary, of which EUV projection lithography is a strong candidate, see for example "International Technology Roadmap for Semiconductors", International SEMATECH, Austin TX, 1999. In EUV projection lithography use is made of a reducing EUV objective system in the wavelength range around 10-20 nm.

[0005] In the soft X-ray and EUV region, compared to the conventional generation of hard X-ray radiation as discussed above, a different scheme for generation of radiation is normally used since the conversion efficiency from electron-beam energy into soft X-ray radiation, in solid targets, generally is too low to be useful. A common technique for generation of soft X-ray and EUV radiation is instead based on heating of the target material for production of a hot, dense plasma using intense (around 10¹⁰-10¹³ W/cm²) laser radiation, such as disclosed in Chapter 6 in "Soft X-rays and Extreme Ultraviolet Radiation: principles and application", D.T. Attwood, Cambridge University Press, 1999. These so-called laser produced plasmas (LPP) emit both continuous radiation and characteristic line emission, wherein the specific emission characteristics depend on target material and plasma temperature. Traditional LPP X-ray sources, using a solid target material, are hampered by unwanted emission of debris as well as limitations on repetition rate and uninterrupted usage, since the delivery of target material becomes a limiting factor. This has led to the development of regenerative, low debris targets including gas jets (see for example US-A-5 577 092, and the article "Debris-free EUVL sources based on gas jets" by Kubiak et al, published in OSA Trends in Optics and Photonics, No. 4, p. 66, 1996), and liquid jets (see for example US-A-6 002 744, and the article "Liquid-jet target for laser-plasma soft x-ray generation" by Malmqvist et al, published in Review of Scientific Instruments, No. 67, p. 4150, 1996). These targets have been extensively used in LPP soft X-ray and EUV sources. However, the applicability of LPP sources is limited by the relatively low conversion efficiency of electrical energy into laser light and then of laser light into X-ray radiation, necessitating the use of expensive high-power lasers.

[0006] Quite recently, electron-beam excitation of a gas-jet target has been tested for direct, non-thermal generation of soft X-ray radiation, albeit with relatively low power and brilliance of the resulting radiation, see Ter-Avetisyan et al, Proceedings of the SPIE, No. 4060, pp 204-208, 2000.

[0007] There are also large facilities such as synchrotron light sources, which produce X-ray radiation with high average power and brilliance. However, there are many applications that require compact, small-scale systems that produce X-ray radiation with a relatively high average power and brilliance. Compact and more inexpensive systems yield better accessibility to the applied user and thus are of potentially greater value to science and society.

[0008] WO 97/40650 discloses a method for generating X- or EUV-radiation via laser plasma emission, in which at least one target is generated in a chamber, and at least one pulsed laser beam is focused on the target in the chamber.

[0009] US 4,953,191 discloses an apparatus for the generation of high intensity X-rays, comprising means for providing a smooth, non fluctuating flow of liquid metal over a surface, and means for directing an electron beam to impinge on said liquid metal as it flows over said surface to generate high intensity X-rays.

[0010] US 6,069,937 discloses an illumination apparatus for illuminating an object with X-rays.

[0011] EP 957 506 discloses an X-ray source which includes an electron source and a target which emits X-rays in response to the incidence of the electrons. The target consists of a liquid metal which circulates during operation of the X-ray source. A window which can be traversed by electrons is arranged between the electron source and the target, and the window is cooled by the liquid metal.

[0012] US 5,052,034 discloses an X-ray generator that has an anode formed by an electrically conductive liquid having low vapor pressure, in which X-rays are tapped at an angle close to the critical angle of total reflection in order to provide a flat beam tap. A Faraday pump is provided for circulating the anode fluid guided in an insulating member. An electrical current flowing between electrodes perpendicularly relative to the magnetic field direction and flow direction provides the Lorentz force that accelerates the anode fluid. A nozzle (a Laval nozzle) is provided in the channel of the anode fluid and serves the purpose of matching the magnetic circulating pressure to the gas pressure $p < 10^{-9}$ bar present in the housing to guarantee a smooth boundary surface of the exposed portion of the anode fluid flowing from the nozzle to the point of incidence of the electron beam, which is an indispensable prerequisite for the applicability of the beam tap at the critical angle of the total reflection.

[0013] US 5,763,930 discloses a high energy photon source, including a pulse power source that provides electrical pulses for creating a high temperature, high density plasma that pinches a working gas to provide radiation at the spectral line of the gas.

[0014] Hemberg et al. "Target analysis of laser-plasma droplet-target system" (Proceedings of the SPIE, Bellingham, Vol. 4144, 1 Jan 2000, pp. 38-42 - XP002962594) investigates the speed of microscopic droplets used for laser-plasma soft X-ray generation un-

der various conditions.

[0015] WO 99/51355 discloses a diffuser system and energy emission system for photolithography.

5 Summary of the Invention

[0016] It is an object of the present invention to solve or alleviate the problems described above. More specifically, the invention aims at providing a method and an apparatus for generation of X-ray radiation with very high brilliance in combination with relatively high average power.

[0017] It is also an object of the invention to provide a compact and relatively inexpensive apparatus for generation of X-ray radiation.

[0018] The inventive technique should also provide for stable and uncomplicated generation of X-ray radiation, with minimum production of debris.

[0019] A further objective is to provide a method and an apparatus generating radiation suitable for medical diagnosis and material inspection.

[0020] Still another object of the invention is to provide a method and an apparatus suitable for use in lithography, non-destructive testing, microscopy, crystal analysis, surface physics, materials science, X-ray photo spectroscopy (XPS), X-ray fluorescence, protein structure determination by X-ray diffraction, and other X-ray applications.

[0021] These and other objectives, which will be apparent from the following description, are wholly or partially achieved by the method and the apparatus according to the appended independent claims. The dependent claims define preferred embodiments.

[0022] Accordingly, the invention provides a method for generating X-ray radiation, according to claim 1.

[0023] Hard X-ray radiation is generated by direct conversion of the electron-beam energy to Bremsstrahlung and characteristic line emission, essentially without heating the jet to a plasma-forming temperature.

[0024] The jet target provides several advantages over the solid anode conventionally used in generation of hard X-ray radiation. More specifically, the liquid jet has a density high enough to allow for high brilliance and power of the generated radiation. Further, the jet is regenerative to its nature so there is no need to cool the target material. In fact, the target material can be destroyed, i.e. heated to a temperature above its melting temperature, due to the regenerative nature of the jet target. Thus, the electron-beam power density at the target may be increased significantly compared to non-regenerative targets. In addition, the jet can be given a very high propagation speed through the area of interaction. Compared to conventional stationary or rotating anodes, more energy can be deposited in such a fast propagating jet due to the correspondingly high rate of material transport into the area of interaction. The combination of these features allows for a significant increase in brilliance of the generated hard X-ray radiation. Thus, the use of a small,

high-density, regenerative, high-speed target in the form of a jet, formed by urging a liquid substance under pressure through an outlet opening, should typically allow for a 100-fold increase in brilliance of the generated hard X-ray radiation compared to conventional techniques.

[0025] In order to achieve the power density allowed for by this novel, regenerative target, the electron beam should preferably be properly focused thereon. Typically, the acceleration voltage used for generating the electron beam will be in the order of 5-500 kV, but might be higher. The beam current will typically be in the order of 10-1000 mA, but might be higher.

[0026] It should be noted that the electron beam can be pulsed or continuous.

[0027] For optimum utilization of the accessible electron beam power, the beam is preferably focused on the jet to essentially match the size of the beam to the size of the jet. In this context it is possible to use a line focus instead of a point focus, the transverse dimensions of the line focus being essentially matched to the transverse dimensions of the jet. The jet is preferably generated with a diameter of about 1-100 μm but may be as large as millimeters. Thereby, the radiation will be emitted with high brilliance from a small area of interaction. To better utilize the generated radiation, the inventive apparatus and method may naturally be used in conjunction with X-ray optics, such as polycapillary lenses, compound refractive lenses or X-ray mirrors.

[0028] The target jet is generated by urging a liquid substance through an outlet opening, such as a nozzle or an orifice, typically by means of a pump and/or a pressurized reservoir yielding a pressure typically in the range of 0.5-500 MPa to bring about a jet propagation speed of about 10-1000 m/s from the outlet opening. The substance is not limited to materials normally in a liquid state, but may also include a solid, for example a metal, heated to a liquid state before being urged through the outlet opening, or a gas, for example a noble gas, cooled to a liquid state before being urged through the outlet opening. Alternatively, the substance can comprise materials dissolved in a carrier liquid. After its formation, the jet may attain different hydrodynamic states. Slow jets are normally laminar and break up into droplets under the influence of surface tension while fast jets are more or less turbulent and are spatially continuous in a transitional region before they turn into a spray. Any type of hydrodynamic state of the jet may be employed with the inventive technique. In another conceivable embodiment, the jet is allowed to freeze to a solid state before interacting with the electron beam.

[0029] Further, depending on the type of substance, the jet may be electrically conductive or not. This has implications on the transport of charge deposited in the jet at the area of interaction. If the jet is electrically conductive, the charge can be removed through the jet itself such that the jet will remain at essentially ground potential. On the other hand, if the jet is nonconductive, the deposited charge can be removed from the area of inter-

action by the motion of the jet itself. Any build-up of charge at the area of interaction might influence the electron-beam focusing. With a nonconductive jet, a high jet propagation speed could be favorable to minimize the build-up of charge.

[0030] The gas atmosphere may vary within the inventive apparatus. The necessary layout of the gas atmosphere in the apparatus depends on both the desired wavelength of the generated radiation and the type of electron source. Typically, the need for a vacuum environment is higher at the electron source than at the area of interaction. It is possible to use localized gas pressures and differential pumping schemes to maintain different pressures in different parts of the apparatus.

Brief Description of the Drawing

[0031] The invention will now be described for the purpose of exemplification with reference to the accompanying drawing, which illustrates a currently preferred embodiment and is a schematic view of an inventive apparatus for generating X-ray radiation by interaction of an electron beam and a liquid jet.

Description of Preferred Embodiments

[0032] The apparatus shown in the drawing includes a chamber 1, an electron source 2, and a target generator 3. The electron source 2 is arranged to emit a pulsed or continuous electron beam 4 into the chamber 1 and focus the beam 4 on a target 5, which is generated by the target generator 3. Although not shown in the drawing, more than one electron beam 4 may be generated, the beams 4 being focused from one or more directions on the target 5. The electron source 2, which incorporates acceleration and focusing elements (not shown), can be of conventional construction and is powered by a voltage power supply 6. Depending on the desired characteristics of the electron beam 4, the electron source 2 might be anything from a simple cathode source to a complex high-energy source such as a racetrack.

[0033] As will be further described below, X-ray radiation (indicated by arrows in the drawing) is generated by the beam 4 interacting with the target 5 inside the chamber 1. Normally, a vacuum environment is provided in the chamber 1, due to requirements of the electron source 2.

[0034] For the formation of a microscopic and spatially stable target 5 in a vacuum environment, the target generator 3 is arranged to generate a spatially continuous jet 5 from a substance in a liquid state. The target generator 3 shown in the drawing includes a reservoir 7 and a jet-forming outlet opening 8, typically a nozzle opening, which is connected to a liquid outlet of the reservoir 7 and opens in the chamber 1. The reservoir 7 holds the substance from which the jet 5 is to be formed. Depending on the type of substance, the reservoir 7 can be provided with cooling or heating elements (not shown) to maintain

the substance in a liquid state while it is being urged through the outlet opening 8 at high pressure, normally 0.5-500 MPa, typically by feeding high-pressure gas to a gas inlet 7' of the reservoir 7. The diameter of the outlet opening 8 is typically smaller than about 100 μm . The resulting jet 5, which is stable and microscopic and has essentially the same diameter as the outlet opening 8, propagates at a speed of about 10-1000 m/s in the chamber 1. Although not shown in the drawing, the jet 5 could propagate to a break-up point where it spontaneously breaks up into droplets or a spray, depending on the operating parameters of the target generator 3. The distance to the break-up point is essentially determined by the hydrodynamic properties of the liquid substance, the dimensions of the outlet 8 and the speed of the liquid substance.

[0035] When the liquid substance leaves the outlet opening 8, it is cooled by evaporation. It is therefore conceivable that the jet 5 may freeze, such that no droplets or sprays are formed.

[0036] As shown in the drawing, the electron beam 4 impinges on the jet 5 before the jet 5 spontaneously, or by stimulation, breaks up into droplets, i.e. while it is still a small collimated jet. Thus, the area of interaction 9 between the beam 4 and the jet 5 is located on a spatially continuous portion of the jet 5, i.e. a portion having a length that significantly exceeds the diameter. Thereby, the apparatus can be continuously or semi-continuously operated to generate X-ray radiation, as will be described below. Further, this approach results in sufficient spatial stability of the jet 5 to permit the focal spot of the electron beam 4 on the jet 5 to be of approximately the same size as the diameter of the jet 5. In the case of a pulsed electron beam 4, this approach also alleviates the need for any temporal synchronization of the electron source 2 with the target generator 3. In some cases, similar advantages can be obtained with jets consisting of separate, spatially continuous portions. It should be emphasized, however, that any formation of condensed matter emanating from a liquid jet can be used as target for the electron-beam within the scope of the invention, be it liquid or solid, spatially continuous, droplets, or a spray of droplets or clusters.

[0037] By properly adapting the characteristics of the electron beam 4 in relation to the characteristics of the target 5, the interaction of the beam 4 with the jet 5 results, in that radiation is emitted from the area of interaction 9 by direct conversion, essentially without heating the jet 5 to a plasma-forming temperature.

[0038] A plasma-based operation is most effective for generating soft X-ray and EUV radiation, i.e. in the range from a few tens of eV to a few keV, whereas as an essentially non-plasma, direct conversion operation is more efficient for generation of harder X-rays, typically in the range from about 10 keV to about 1000 keV.

[0039] In the following, the operation of the apparatus will be discussed in general terms. Examples of conceivable realizations are also given, without limiting the dis-

closure to these examples.

[0040] During operation, for generation of hard X-ray radiation to be used in, inter alia, medical diagnosis, the electron source 2 is controlled in such a manner, in relation to the characteristics of the target 5, that essentially no plasma is formed at the area of interaction 9. Thereby, hard X-ray radiation is obtained via Bremsstrahlung and characteristic line emission. It is preferred that the distance from the outlet opening 8 to the area of interaction 9 is sufficiently long, typically 0.5-10 mm, so that the beam-jet-interaction does not damage the outlet. In one conceivable realization, use is made of a jet 5 of liquid metal having a diameter of about 30 μm and a propagation speed of about 600 m/s, the jet 5 being irradiated about 10 mm away from the outlet opening 8 by means of an electron beam 4 of about 100 mA and 100 keV, the beam 4 being focused on the jet 5 to obtain a power density of about 10 MW/mm² in the area of interaction 9. This power density is roughly a factor of 100 better than in conventional solid-target systems, as discussed by way of introduction. By means of the invention, a high-resolution image can be obtained with a low exposure time. The jet 5 is preferably formed from metals heated to a liquid state. In this context, tin (Sn) should be easy to use, although other metals or alloys may be used for generation of radiation in a desired wavelength range. Further, it is also conceivable to use completely different substances for generating the jet 5, such as gases cooled to a liquid state or material dissolved in a carrier liquid.

[0041] The apparatus can include a window (not shown) transparent to X-rays for extracting the generated radiation from the chamber 1 to the exterior where patients, or other objects, can be imaged. By using a microscopic liquid jet 5 as a target, the size of the X-ray radiation is generated from a very small area of interaction 9, resulting in a high brilliance.

[0042] It should also be noted that, when the electron source 2 is operated for X-ray generation and/or emits pulsed electron radiation, a large portion of the liquid substance may remain unaffected by the electron beam 4 and propagate unhindered through the chamber 1. This would result in an increase of pressure in the vacuum chamber 1 owing to evaporation. This problem can be solved, for instance, by using a differential pumping scheme, indicated in the drawing, where the jet 5 is collected at a small aperture 10 and then recycled to the reservoir 7 by means of a pump 11 that compresses the collected substance and feeds it back to the reservoir 7. It should be realized that the inventive method and apparatus can be used to provide radiation for medical diagnosis, non-destructive testing, lithography, crystal analysis, microscopy, materials science, microscopy-surface physics, protein structure determination by X-ray diffraction, X-ray photo spectroscopy (XPS), X-ray fluorescence, or in some other X-ray application.

Claims

1. A method for generating X-ray radiation, comprising the steps of forming a target jet (5) propagating through an area of interaction (9), directing at least one electron beam (4) onto the jet (5) in the area of interaction (9), and controlling the electron beam (4) to interact with the jet (5) at an intensity such that Bremsstrahlung and characteristic line emission is generated in the hard X-ray region essentially without heating the jet (5) to a plasma-forming temperature, wherein the target jet is formed by urging a liquid substance under pressure through an outlet opening such that the target jet propagates through the area of interaction (9) at a propagation speed in the range 10-1000 m/s. 5
2. A method according to claim 1, wherein the liquid substance is obtained by heating a solid material, preferably a metal, to a liquid state. 10
3. A method according to claim 1, wherein the liquid substance is obtained by cooling a gas, preferably a noble gas, to a liquid state. 15
4. A method according to any one of claims 1-3, wherein the jet (5) is in a solid state in the area of interaction (9). 20
5. A method according to any one of claims 1-3, wherein the jet (5) is in a liquid state in the area of interaction (9). 25
6. A method according to any one of the preceding claims, wherein the beam (4) interacts with a spatially continuous portion of the jet (5) in the area of interaction (9). 30
7. A method according to claim 5, wherein the beam (4) interacts with at least one droplet in the area of interaction (9). 35
8. A method according to claim 5 or 7, wherein the beam (4) interacts with a spray of droplets or clusters in the area of interaction (9). 40
9. A method according to any one of the preceding claims, wherein electron beam (4) interacts with the jet (5) at a distance of 0.5-10 mm from the outlet opening (8). 45
10. A method according to any one of the preceding claims, wherein the electron beam (4) is focused on the jet (5) to essentially match a transverse dimension of the electron beam (4) to a transverse dimension of the jet (5). 50
11. A method according to any one of the preceding claims, wherein the jet (5) is generated with a diameter of 1-10000 μm . 55
12. A method according to any one of the preceding claims, wherein the electron beam (4) is generated by means of an acceleration voltage of 5-500 kV with a beam current of 10-1000 mA.
13. A method according to any one of the preceding claims, wherein said at least one electron beam is a pulsed electron beam directed onto the jet (5).
14. A method according to any one of the preceding claims, wherein said at least one electron beam is a continuous electron beam directed onto the jet (5).
15. A method according to any one of claims 1-14, further comprising using the generated radiation for medical diagnosis.
16. A method according to any one of claims 1-14, further comprising using the generated radiation for non-destructive testing.
17. A method according to any one of claims 1-14, further comprising using the generated radiation for crystal analysis.
18. A method according to any one of claims 1-14, further comprising using the generated radiation for microscopy.
19. A method according to any one of claims 1-14, further comprising using the generated radiation for protein structure determination by X-ray diffraction.
20. An apparatus for generating X-ray radiation, comprising a target generator (3) arranged to form a target jet for propagation through an area of interaction (9), and an electron source (2) for providing at least one electron beam (4) and directing the at least one electron beam (4) onto the jet (5) in the area of interaction (9) and for controlling the electron beam (4) to interact with the jet (5) at an intensity at which Bremsstrahlung and characteristic line emission is generated in the hard X-ray region essentially without heating the jet (5) to a plasma-forming temperature, wherein the target generator (3) is arranged to form the target jet by urging a liquid substance under pressure through an outlet opening to give the target jet a propagation speed in the range 10-1000 m/s through the area of interaction (9).
21. An apparatus according to claim 20, wherein the target generator (3) is controllable to provide condensed matter in the area of interaction (9).
22. An apparatus according to claim 20 or 21, wherein

the target generator (3) is controllable to provide a spatially continuous portion of the jet (5), at least one droplet, or a spray of droplets or clusters in the area of interaction (9).

23. An apparatus according to any one of claims 20-22 wherein the electron source (2) is controllable to direct the electron beam (4) onto the jet (5) at a distance in of 0.5-10 mm from the outlet opening (8).
24. An apparatus according to any one of claims 20-23, wherein the electron source (2) is controllable to essentially match a transverse dimension of the electron beam (4) to a transverse dimension of the jet (5) by focusing the electron beam (4) on the jet (5).
25. An apparatus according to any one of claims 20-24, wherein the target generator (3) is adapted to generate the jet (5) with a diameter of 1-10000 μm .
26. An apparatus according to any one of claims 20-25, wherein the electron source (2) is controllable to generate the electron beam (4) by means of an acceleration voltage of 5-500 kV, the electron beam (4) having an average beam current of 10-1000 mA.
27. An apparatus according to any one of claims 20-26, wherein the electron source (2) is controllable for generation of at least one pulsed electron beam (4).
28. An apparatus according to any one of claims 20-27, wherein the electron source (2) is controllable for generation of at least one continuous electron beam (4).

Patentansprüche

1. Verfahren zur Erzeugung von Röntgenstrahlung, umfassend die folgenden Schritte: Bilden eines Targetstrahls (5), der sich durch einen Wechselwirkungsbereich (9) ausbreitet, Richten mindestens eines Elektronenstrahls (4) auf den Strahl (5) im Wechselwirkungsbereich (9), und Steuern des Elektronenstrahls (4) derart, dass er mit dem Strahl (5) bei einer Intensität derart wechselwirkt, dass Bremsstrahlung und eine charakteristische Linienemission im harten Röntgenbereich erzeugt werden im Wesentlichen ohne Erhitzen des Strahls (5) auf eine Plasma bildende Temperatur, wobei der Targetstrahl durch Drücken einer flüssigen Substanz unter Druck durch eine Auslassöffnung derart gebildet wird, dass der Targetstrahl sich durch den Wechselwirkungsbereich (9) mit einer Ausbreitungsgeschwindigkeit im Bereich von 10-1.000 m/s ausbreitet.
2. Verfahren nach Anspruch 1, wobei die flüssige Sub-

stanz durch Erhitzen eines festen Materials, vorzugsweise eines Metalls, bis zu einem flüssigen Zustand erhalten wird.

3. Verfahren nach Anspruch 1, wobei die flüssige Substanz durch Kühlen eines Gases, vorzugsweise eines Edelgases, bis zu einem flüssigen Zustand erhalten wird.
4. Verfahren nach irgendeinem der Ansprüche 1-3, wobei der Strahl (5) im Wechselwirkungsbereich (9) in einem festen Zustand ist.
5. Verfahren nach irgendeinem der Ansprüche 1-3, wobei der Strahl (5) im Wechselwirkungsbereich (9) in einem flüssigen Zustand ist.
6. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der Strahl (4) mit einem räumlich kontinuierlichen Abschnitt des Strahls (5) im Wechselwirkungsbereich (9) wechselwirkt.
7. Verfahren nach Anspruch 5, wobei der Strahl (4) mit mindestens einem Tropfen im Wechselwirkungsbereich (9) wechselwirkt.
8. Verfahren nach Anspruch 5 oder 7, wobei der Strahl (4) mit einem Sprühstrahl von Tropfen oder Clustern im Wechselwirkungsbereich (9) wechselwirkt.
9. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der Elektronenstrahl (4) mit dem Strahl (5) in einer Entfernung von 0,5-10 mm zur Auslassöffnung (8) wechselwirkt.
10. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der Elektronenstrahl (4) auf den Strahl (5) fokussiert wird, um im Wesentlichen eine Querdimension des Elektronenstrahls (4) an eine Querdimension des Strahls (5) anzupassen.
11. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der Strahl (5) mit einem Durchmesser von 1-10.000 μm erzeugt wird.
12. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der Elektronenstrahl (4) mittels einer Beschleunigungsspannung von 5-500 kV mit einem Strahlstrom von 10-1.000 mA erzeugt wird.
13. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der mindestens eine Elektronenstrahl ein gepulster Elektronenstrahl ist, der auf den Strahl (5) gerichtet wird.
14. Verfahren nach irgendeinem der vorangehenden Ansprüche, wobei der mindestens eine Elektronenstrahl ein kontinuierlicher Elektronenstrahl ist, der

auf den Strahl (5) gerichtet wird.

15. Verfahren nach irgendeinem der Ansprüche 1-14, ferner umfassend die Verwendung der erzeugten Strahlung für eine medizinische Diagnose.
16. Verfahren nach irgendeinem der Ansprüche 1-14, ferner umfassend die Verwendung der erzeugten Strahlung für eine zerstörungsfreie Prüfung.
17. Verfahren nach irgendeinem der Ansprüche 1-14, ferner umfassend die Verwendung der erzeugten Strahlung für eine Kristallstrukturanalyse.
18. Verfahren nach irgendeinem der Ansprüche 1-14, ferner umfassend die Verwendung der erzeugten Strahlung für die Mikroskopie.
19. Verfahren nach irgendeinem der Ansprüche 1-14, ferner umfassend die Verwendung der erzeugten Strahlung für eine Proteinstrukturbestimmung durch Röntgenbeugung.
20. Vorrichtung zur Erzeugung von Röntgenstrahlung, umfassend einen Targetgenerator (3), der derart angeordnet ist, dass er einen Targetstrahl für die Ausbreitung durch einen Wechselwirkungsbereich (9) bildet, und eine Elektronenquelle (2) zum Bereitstellen mindestens eines Elektronenstrahls (4) und Richten des mindestens einen Elektronenstrahls (4) auf den Strahl (5) im Wechselwirkungsbereich (9) und zum Steuern des Elektronenstrahls (4) derart, dass er mit dem Strahl (5) bei einer Intensität wechselwirkt, bei welcher Bremsstrahlung und eine charakteristische Linienemission im harten Röntgenbereich erzeugt werden im Wesentlichen ohne Erhitzen des Strahls (5) auf eine Plasma bildende Temperatur, wobei der Targetgenerator (3) derart angeordnet ist, dass er den Targetstrahl durch Drücken einer flüssigen Substanz unter Druck durch eine Auslassöffnung bildet, um dem Targetstrahl eine Ausbreitungsgeschwindigkeit im Bereich von 10-1.000 m/s durch den Wechselwirkungsbereich (9) zu geben.
21. Vorrichtung nach Anspruch 20, wobei der Targetgenerator (3) derart steuerbar ist, dass er kondensierte Materie im Wechselwirkungsbereich (9) bereitstellt.
22. Vorrichtung nach Anspruch 20 oder 21, wobei der Targetgenerator (3) derart steuerbar ist, dass er einen räumlich kontinuierlichen Abschnitt des Strahls (5), zumindest einen Tropfen oder einen Sprühstrahl von Tropfen oder Clustern, im Wechselwirkungsbereich (9) bereitstellt.
23. Vorrichtung nach irgendeinem der Ansprüche 20-22, wobei die Elektronenquelle (2) für das Richten des

Elektronenstrahls (4) auf den Strahl (5) in einer Entfernung von 0,5-10 mm zur Auslassöffnung (8) steuerbar ist.

24. Vorrichtung nach irgendeinem der Ansprüche 20-23, wobei die Elektronenquelle (2) derart steuerbar ist, dass sie im Wesentlichen eine Querdimension des Elektronenstrahls (4) an eine Querdimension des Strahls (5) durch Fokussieren des Elektronenstrahls (4) auf den Strahl (5) anpasst.
25. Vorrichtung nach irgendeinem der Ansprüche 20-24, wobei der Targetgenerator (3) an die Erzeugung des Strahls (5) mit einem Durchmesser von 1-10.000 μm angepasst ist.
26. Vorrichtung nach irgendeinem der Ansprüche 20-25, wobei die Elektronenquelle (2) für die Erzeugung des Elektronenstrahls (4) mittels einer Beschleunigungsspannung von 5-500 kV steuerbar ist, wobei der Elektronenstrahl (4) einen durchschnittlichen Strahlstrom von 10-1.000 mA aufweist.
27. Vorrichtung nach irgendeinem der Ansprüche 20-26, wobei die Elektronenquelle (2) für die Erzeugung mindestens eines gepulsten Elektronenstrahls (4) steuerbar ist.
28. Vorrichtung nach irgendeinem der Ansprüche 20-27, wobei die Elektronenquelle (2) für die Erzeugung mindestens eines kontinuierlichen Elektronenstrahls (4) steuerbar ist.

Revendications

1. Procédé de génération d'un rayonnement de rayons X, comprenant les étapes de formation d'un jet cible (5) se propageant à travers une zone d'interaction (9), d'orientation d'au moins un faisceau d'électrons (4) sur le jet (5) dans la zone d'interaction (9), et de commande du faisceau d'électrons (4) de façon à ce qu'il interagisse avec le jet (5) à une intensité telle qu'un rayonnement de freinage et une émission de raies caractéristiques soient générés dans la région de rayons X durs essentiellement sans chauffage du jet (5) jusqu'à une température de formation de plasma, dans lequel le jet cible est formé en forçant une substance liquide sous pression à travers une ouverture de sortie de façon à ce que le jet cible se propage à travers la zone d'interaction (9) à une vitesse de propagation dans la plage de 10 à 1 000 m/s.
2. Procédé selon la revendication 1, dans lequel la substance liquide est obtenue par chauffage d'un matériau solide, préférentiellement un métal, jusqu'à un état liquide.

3. Procédé selon la revendication 1, dans lequel la substance liquide est obtenue par refroidissement d'un gaz, préférablement un gaz noble, jusqu'à un état liquide.
4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel le jet (5) est dans un état solide dans la zone d'interaction (9).
5. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel le jet (5) est dans un état liquide dans la zone d'interaction (9).
6. Procédé selon l'une quelconque des revendications précédentes, dans lequel le faisceau (4) interagit avec une partie spatialement continue du jet (5) dans la zone d'interaction (9).
7. Procédé selon la revendication 5, dans lequel le faisceau (4) interagit avec au moins une gouttelette dans la zone d'interaction (9).
8. Procédé selon la revendication 5 ou 7, dans lequel le faisceau (4) interagit avec une pulvérisation de gouttelettes ou des agrégats dans la zone d'interaction (9).
9. Procédé selon l'une quelconque des revendications précédentes, dans lequel le faisceau d'électrons (4) interagit avec le jet (5) à une distance de 0,5 à 10 mm de l'ouverture de sortie (8).
10. Procédé selon l'une quelconque des revendications précédentes, dans lequel le faisceau d'électrons (4) est focalisé sur le jet (5) pour faire essentiellement correspondre une dimension transversale du faisceau d'électrons (4) à une dimension transversale du jet (5).
11. Procédé selon l'une quelconque des revendications précédentes, dans lequel le jet (5) est généré avec un diamètre de 1 à 10 000 μm .
12. Procédé selon l'une quelconque des revendications précédentes, dans lequel le faisceau d'électrons (4) est généré au moyen d'une tension d'accélération de 5 à 500 kV avec une intensité de faisceau de 10 à 1 000 mA.
13. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit au moins un faisceau d'électrons est un faisceau d'électrons pulsés dirigé sur le jet (5).
14. Procédé selon l'une quelconque des revendications précédentes, dans lequel ledit au moins un faisceau d'électrons est un faisceau d'électrons continu dirigé sur le jet (5).
15. Procédé selon l'une quelconque des revendications 1 à 14, comprenant en outre l'utilisation du rayonnement généré pour un diagnostic médical.
16. Procédé selon l'une quelconque des revendications 1 à 14, comprenant en outre l'utilisation du rayonnement généré pour un test non destructeur.
17. Procédé selon l'une quelconque des revendications 1 à 14, comprenant en outre l'utilisation du rayonnement généré pour une analyse de cristaux.
18. Procédé selon l'une quelconque des revendications 1 à 14, comprenant en outre l'utilisation du rayonnement généré pour une microscopie.
19. Procédé selon l'une quelconque des revendications 1 à 14, comprenant en outre l'utilisation du rayonnement généré pour une détermination de structure de protéine par diffraction des rayons X.
20. Appareil de génération d'un rayonnement de rayons X, comprenant un générateur de cible (3) agencé de façon à former un jet cible pour une propagation à travers une zone d'interaction (9), et une source d'électrons (2) pour délivrer au moins un faisceau d'électrons (4) et diriger l'au moins un faisceau d'électrons (4) sur le jet (5) dans la zone d'interaction (9) et pour commander le faisceau d'électrons (4) de façon à ce qu'il interagisse avec le jet (5) à une intensité à laquelle un rayonnement de freinage et une émission de raies caractéristiques sont générés dans la région de rayons X durs essentiellement sans chauffage du jet (5) jusqu'à une température de formation de plasma, dans lequel le générateur de cible (3) est agencé de façon à former le jet cible en forçant une substance liquide sous pression à travers une ouverture de sortie pour donner au jet cible une vitesse de propagation dans la plage de 10 à 1 000 m/s à travers la zone d'interaction (9).
21. Appareil selon la revendication 20, dans lequel le générateur de cible (3) peut être commandé de façon à délivrer une matière condensée dans la zone d'interaction (9).
22. Appareil selon la revendication 20 ou 21, dans lequel le générateur de cible (3) peut être commandé de façon à délivrer une partie spatialement continue du jet (5), au moins une gouttelette, ou une pulvérisation de gouttelettes ou des agrégats dans la zone d'interaction (9).
23. Appareil selon l'une quelconque des revendications 20 à 22, dans lequel la source d'électrons (2) peut être commandée de façon à diriger le faisceau d'électrons (4) sur le jet (5) à une distance de 0,5 à 10 mm de l'ouverture de sortie (8).

24. Appareil selon l'une quelconque des revendications 20 à 23, dans lequel la source d'électrons (2) peut être commandée de façon à faire essentiellement correspondre une dimension transversale du faisceau d'électrons (4) à une dimension transversale du jet (5) en focalisant le faisceau d'électrons (4) sur le jet (5). 5
25. Appareil selon l'une quelconque des revendications 20 à 24, dans lequel le générateur de cible (3) est adapté à générer le jet (5) avec un diamètre de 1 à 10 000 μm . 10
26. Appareil selon l'une quelconque des revendications 20 à 25, dans lequel la source d'électrons (2) peut être commandée de façon à générer le faisceau d'électrons (4) au moyen d'une tension d'accélération de 5 à 500 kV, le faisceau d'électrons (4) ayant une intensité moyenne de faisceau de 10 à 1 000 mA. 15 20
27. Appareil selon l'une quelconque des revendications 20 à 26, dans lequel la source d'électrons (2) peut être commandée pour une génération d'au moins un faisceau d'électrons pulsés (4). 25
28. Appareil selon l'une quelconque des revendications 20 à 27, dans lequel la source d'électrons (2) peut être commandée pour une génération d'au moins un faisceau d'électrons continu (4). 30

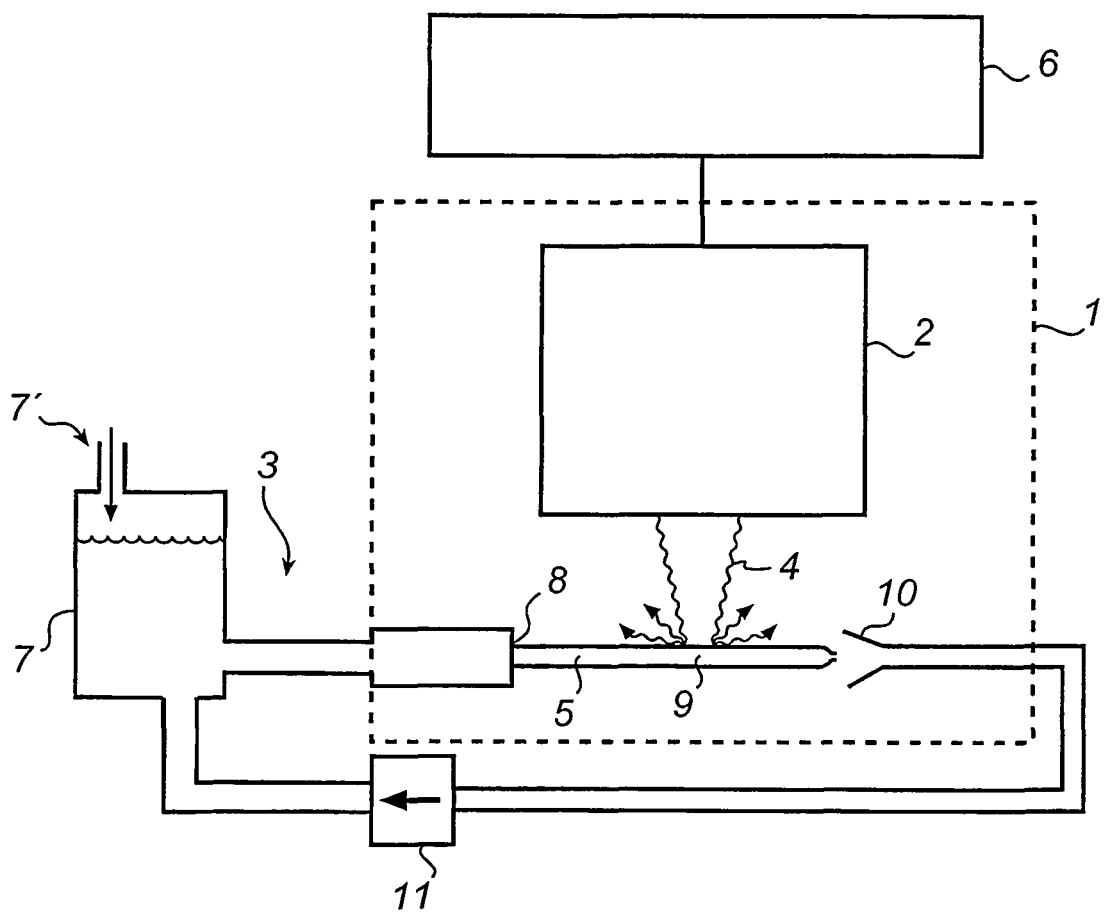
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