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(54) Title: METHOD AND SYSTEM FOR GENERATING ELECTROMAGNETIC RADIATION

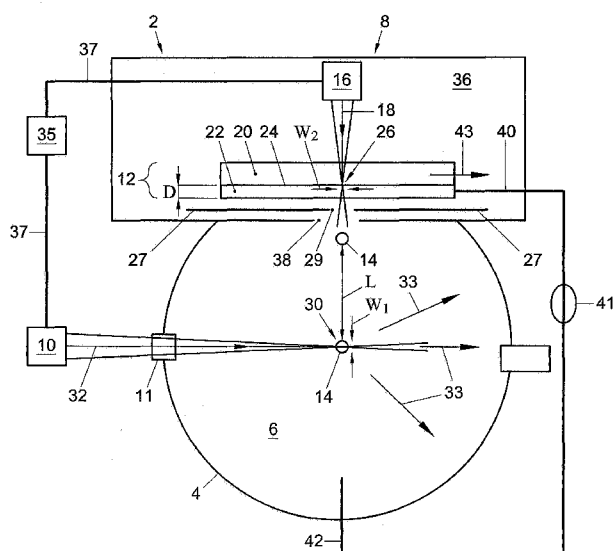


Fig. 1A

(57) Abstract: Method of generating electromagnetic radiation having a wavelength in the ultraviolet range, comprising: generating at least one liquid and/or solid particle that comprises an excitable material; moving the at least one particle in an irradiation region of a first radiation beam; and irradiating the at least one particle by means of the first radiation beam, for exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation. Generating the at least one particle comprises: providing a donor structure comprising at least a substrate and a donor layer, which donor layer comprises the excitable material; and irradiating the donor structure by means of a pulse of a second radiation beam causing release of a portion of the donor layer, said released portion forming the at least one particle.

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Title: Method and system for generating electromagnetic radiation

The invention relates to a method of generating electromagnetic radiation having a wavelength in the ultraviolet range and/or below the ultraviolet range, comprising the steps: - generating at least one liquid and/or solid particle that comprises an excitable material, e.g. a metal; - moving the at least one particle in an irradiation region of a first radiation beam; and - irradiating the at least one particle, when being present in the irradiation region of the first radiation beam, by means of the first radiation beam, for exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation. The invention further relates to a system for generating electromagnetic radiation having a wavelength in the ultraviolet range and/or below the ultraviolet range, the system comprising: - an enclosure enclosing a space to be evacuated; - a particle generator for generating at least one liquid and/or solid particle that comprises an excitable material, e.g. a metal, the particle generator further being arranged for moving the at least one particle in an irradiation region of a first radiation beam, said irradiation region being part of said enclosed space; and - a first radiation source, arranged for generating the first radiation beam, and further being arranged for, by irradiating the particle when being present in the irradiation region of the first radiation beam, exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation. The invention also relates to a lithographic system, i.e. a system arranged for carrying out lithography.

US patent 6,862,339 describes an example of the above-mentioned system for generating electromagnetic radiation. US 6,862,339 describes a pulsed laser-source that illuminates droplets that move through a vacuum. The laser beam pulses are arranged to excite a metal compound of the droplets when they pass through a focus region of the laser beam. As a result of such excitation, electromagnetic radiation is generated. Generated electromagnetic

radiation with a wavelength in the ultraviolet range may be collected using mirrors, and transmitted out of the system, for use in lithographic patterning.

US 6,862,339 relates to droplet generation by means of a droplet dispenser having a nozzle through which a fluid is dispensed, said fluid
5 forming the droplets. Such a nozzle may provide for a repeatable droplet generation process. However, such a nozzle is usually also susceptible for clogging. Clogging can occur for example as a result of contamination of a fluid that in use flows through the nozzle and from which the droplets are formed, or as a result of solidified parts of the fluid. Such solidification may result e.g.
10 from drying of the fluid near the nozzle, or from cooling, solidifying, and/or crystallisation of the fluid.

The possibility of clogging generally decreases a reliability of the droplet dispenser. Measures are possible to decrease a probability of clogging, e.g. using a nozzle having a relatively large inner diameter or using fluids
15 having a specific composition. However, such measures usually go at the expense of optimisation of the process of generating electromagnetic radiation. For example, a nozzle having a relatively large inner diameter may be limited in reliably producing droplets below a certain size. A requirement for a specific fluid may go at the expense of optimisation of the metal compound of the
20 droplet for generating the electromagnetic radiation.

Hence, there is a need for an improved method and system for generating electromagnetic radiation having a wavelength in the ultraviolet range and/or below the ultraviolet range.

According to an aspect of the invention, there is provided a method
25 of generating electromagnetic radiation having a wavelength in the ultraviolet range, in particular in the deep ultraviolet range and/or extreme ultraviolet range, and/or below the ultraviolet range, comprising the steps: - generating at least one liquid and/or solid particle, e.g. a droplet, that comprises an excitable material, e.g. a metal, such as tin and/or gadolinium, the at least one particle
30 optionally being substantially made of the excitable material; - moving, e.g.

accelerating, the at least one particle in an irradiation region of a first radiation beam, in particular of a pulse of a first radiation beam, the first radiation beam e.g. being a first laser beam, said irradiation region preferably being, at least partly, part of an evacuated space; and - irradiating the at least one particle, when being present in the irradiation region of the first radiation beam, by means of the first radiation beam, for exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation; wherein generating the at least one particle comprises the steps: - providing a donor structure comprising at least a substrate and a donor layer provided along a surface of the substrate, which donor layer comprises the excitable material; and - irradiating the donor structure by means of a pulse of a second radiation beam, e.g. a second laser beam, causing release, e.g. ejection, of a portion of the donor layer, at least part of said released portion forming the at least one particle. Thus, the at least one particle may be generated as a product of said released portion of the donor layer.

As, according to said aspect, the particle is generated by means of the second radiation beam, use of a nozzle for generating a droplet may be omitted. Thus, one or more problems related to use of the nozzle may be absent in the present method. Thus, advantageously, there may be provided, e.g., a combination of laser-induced generation of a particle followed by excitation of the particle by means of a laser.

The term 'release of a portion of the donor layer' may comprise release of the donor layer from the substrate or from another part of the donor structure. The term 'release of a portion of the donor layer' may comprise various ways of releasing. Preferably, said release of the portion of the donor layer comprises ejection of the portion of the donor layer in a direction away from the substrate surface. Optionally, release of the portion of the donor layer comprises ablation of a portion of the release layer that may be arranged in between the portion of the donor layer and the substrate. Preferably, the donor

structure and the second radiation beam are arranged for building a pressure acting on the portion of the donor layer for release of said portion of the donor layer. The invention may relate to other ways of release as well. As a result of said release, the at least one particle may have a release velocity, e.g. an
5 ejection velocity. Said ejection velocity may cause moving the at least one particle in the irradiation region of the first radiation beam.

The donor structure may be pre-processed to facilitate releasing portions thereof. For example, the portions of the donor layer to be released may be fully or partially isolated from the remainder of the donor layer by
10 grooves around the portions to be released. Said pre-processing may take place shortly before the portions are released, for example by a separate pre-processing tool in the system according to the invention. Preferably the donor structure is already pre-processed by a pre-processing tool separate from the system to minimize the risk of pollution of the system.

15 Heating the donor material may be considered as another way of pre-processing. Heating may take place contactless, e.g. by radiation with a further radiation source, or by contact with a heat source.

Preferably, steps, e.g. all steps, of said aspect of the invention are carried out repeatedly. Thus, a plurality of subsequent particles may be
20 generated by irradiating the donor structure by means of a plurality of pulses of the second radiation beam. Preferably, the method comprises realising relative motion between the donor layer and the second radiation beam at least in between subsequent pulses of the second radiation beam. As a result, subsequent pulses may irradiate subsequently different parts of the donor
25 layer. Optionally, realising the relative motion comprises rotating and/or translating the donor structure, and/or comprises translating and/or rotating the second laser beam, optionally while rotating and/or translating the donor structure. Preferably, a pulse frequency of the second radiation beam is in a range from 20 to 800 kiloHertz, e.g. in a range from 100 to 400 kiloHertz, in
30 particular in a range from 200-300 kiloHertz. Thus, particles may be generated

with a frequency in a range from 20 to 800 kiloHertz, e.g. in a range from 100-400 kiloHertz, in particular in a range from 200-300 kiloHertz. Preferably, a release velocity of the at least one particle is at least 50 meter per second, in particular at least 80 meter per second, typically approximately 100 meter per second. Said release velocity may be measured in the, in use, evacuated space, e.g. in the irradiation region of the first laser beam. The release velocity may, optionally, be at least 500 meter per second, in particular at least 800 meter per second, typically approximately 1000 meter per second. Such higher release velocities may be realized by providing the donor structure with an additional release layer between the substrate and the donor layer, as further specified below. Alternatively, or in addition higher release velocity may be realized by providing the higher energy pulses of the second radiation source. Combining said particle generation frequencies and velocities may be difficult to achieve by means of technologies that use a nozzle, e.g. ink jet technologies.

The relatively high release velocity may enable a relatively short dwelling time of a particle in the evacuated space. This may reduce shadowing of electromagnetic radiation caused by a particle that is not yet excited. Thus, a distance between subsequent particles generated by means of said subsequent pulses may be realised, which distance substantially reduces a shadow of the electromagnetic radiation caused by a particle that is not yet excited and that is subsequent to a particle that is being excited. Additionally, a relatively high release velocity may reduce, or substantially prevent, an influence of the excitation of one particle on another, subsequent, particle.

Optionally, the release velocity may be measured directly after release, e.g. within a distance of 50 micrometer from the donor structure.

In an embodiment, the irradiation region is part of the evacuated space and the donor layer is provided, at least partly, in the evacuated space. The at least one particle is preferably generated in the evacuated space. Optionally, the particle generator is, at least partly, positioned in the evacuated space. The method may, optionally, comprise transporting the donor

layer into and out of the evacuated space. Optionally, the evacuated space is provided in an enclosure that comprises a first slot and a second slot for respectively transporting the donor layer into and out of the evacuated space, and/or vice versa.

5 In an embodiment, the irradiation region is part of the evacuated space and the evacuated space is provided in an enclosure that comprises a pinhole. Preferably, the at least one particle is generated outside the evacuated space. Preferably, the method comprising transporting the at least one particle through the pinhole into the evacuated space. In an embodiment, the
10 transporter may be positioned out of the evacuated space. Furthermore, providing the donor layer at least partly in the evacuated space may be omitted. Hence, a relatively simple set-up may be used. However, in another embodiment, the transporter and/or the donor structure are provided, at least partly and optionally completely, inside the enclosure.

15 In an embodiment, moving the at least one particle towards the irradiation region comprises charging the particle. Preferably, said moving further comprises electrically, e.g. by using an electrostatic field, moving the electrically charged at least one particle in the irradiation region of the first radiation beam. By using electrical forces for moving the droplet, a variation in
20 position of subsequent particles may be reduced. Furthermore, a probability for generated particles to pass the irradiation region of the first radiation beam, may be increased. Electrically, and/or magnetically, moving the at least one particle may be used for adapting a movement direction of the at least one particle. Additionally, electrically, and/or magnetically, moving subsequent
25 charged particles may be used to increase the speed hence increasing the distance between the subsequent charged particles.

 According to a further aspect of the invention, there is provided a system for generating electromagnetic radiation having a wavelength in the ultraviolet range, in particular in the deep ultraviolet range and/or extreme
30 ultraviolet range, and/or below the ultraviolet range, the system comprising: -

an enclosure enclosing a space to be evacuated, said space optionally, in use, forming an evacuated space; - a particle generator for generating at least one liquid and/or solid particle, e.g. a droplet, that comprises an excitable material, such as tin and/or gadolinium, the at least one particle optionally being

5 substantially made of the excitable material, the particle generator further being arranged for moving, e.g. accelerating, the at least one particle in an irradiation region of a first radiation beam, in particular of a pulse of a first radiation beam, the first radiation beam e.g. being a first laser beam, said irradiation region being, at least partly, part of said enclosed space; and - a

10 first radiation source, e.g. a first laser source, arranged for generating the first radiation beam, and further being arranged for, by irradiating the particle when being present in the irradiation region of the first radiation beam, exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation; wherein the particle

15 generator comprises a second radiation source, e.g. a second laser source, arranged for generating a pulse of a second radiation beam, e.g. a second laser beam, and for irradiating, by means of the pulse of the second radiation beam, a donor structure comprising at least a substrate and a donor layer provided along a surface of the substrate, which donor layer comprises the excitable

20 material, said pulse, in use, causing release of a portion of the donor layer, at least part of said released portion forming the at least one particle. Although typically the first and the second radiation source are mutually different radiation sources, embodiments may be considered wherein a single radiation source functions as the first radiation source and as the second radiation

25 source.

The donor structure comprises at least the substrate and the donor layer provided along the surface of the substrate, which donor layer comprises the excitable material. Preferably, a variation of a thickness of portions of the donor layer before the release of those portions of the donor layer is at most

30 10%, more preferably at most 5%, in particular at most 2% or at most 1%.

Optionally, the donor structure is provided with a release layer that is arranged to interact with radiation of the second radiation beam, e.g. is arranged to be heated by the second radiation beam, said release layer being arranged in between the substrate and the donor layer. The release layer may
5 significantly increase an ejection velocity of the portion of the donor layer that is, in use, released by means of the pulse of the second laser beam.

Preferably, the second radiation source is arranged for generating a plurality of pulses of the second radiation beam. Preferably, the system comprises a transporter for realising relative motion between the donor layer
10 and the second radiation beam at least in between subsequent pulses of the second radiation beam. Preferably, the transporter is arranged for realising the relative motion by rotating and/or translating the donor structure, and/or by translating and/or rotating the second laser beam, preferably while rotating and/or translating the donor structure.

15 In an embodiment, the donor layer is provided, at least partly, in the space to be evacuated and/or, in use, in the evacuated space. Preferably, the second radiation beam is positioned for generating the at least one particle in the evacuated space. Optionally, the enclosure comprises a first slot and a second slot for respectively transporting the donor layer into and out of the
20 evacuated space, and/or vice versa.

In an embodiment, the enclosure comprises a pinhole. Preferably, the donor layer is provided, at least partly, outside the space to be evacuated and/or, in use, outside the evacuated space. Preferably, the second radiation beam is positioned for generating the at least one particle outside the
25 evacuated space. Preferably, the particle generator is arranged for transporting the at least one particle through the pinhole so that the at least one particle is moved into the evacuated space.

In an embodiment, the system is provided with a first electrode in electrical contact with the donor layer for charging the donor layer, thus
30 creating the at least one charged particle, and a second electrode that is

positioned for electrically moving the electrically charged at least one particle towards the irradiation region. According to another aspect of the invention, there is provided a lithographic system, e.g. a wafer stepper, including a system for generating electromagnetic radiation according to the invention, and/or for carrying out a method according to the invention, the lithographic system being arranged for carrying out a photolithographic process by means of the electromagnetic radiation. Thus, the electromagnetic radiation can be advantageously used. Said wafer stepper may optionally be a step-and-scan wafer stepper.

Further advantageous embodiments of the apparatus and method are described in the dependent claims.

The invention will now be described, in a non-limiting way, with reference to the accompanying drawings, in which:

Figure 1A shows a schematic cross-section of a system for generating electromagnetic radiation in a first embodiment according to the invention;

Figure 1B shows a donor structure of a system for generating electromagnetic radiation in a second embodiment according to the invention;

Figures 1C and 1D show an alternative donor structure,

Figure 2A shows a cross-section of a first embodiment of a transporter, and of a donor structure before release of a particle;

Figure 2B shows a cross-section of the first embodiment of the transporter, and of the donor structure after release of particles;

Figure 3A shows a cross-section of a second embodiment of a transporter;

Figure 3B shows a cross-section of a modified variation of the second embodiment of the transporter;

Figure 4A shows a perspective view of a donor structure 12, which can be used in a third embodiment of a transporter; and

Figure 4B shows, in cross section, a side view of the third embodiment of the transporter.

Figure 5A shows a perspective view of a donor structure 12, which can be used in a fourth embodiment of a transporter; and

5 Figure 5B shows, in cross section, a side view of the fourth embodiment of the transporter.

Unless stated otherwise, like reference numerals refer to like elements throughout the drawings.

10 Figure 1A shows a schematic cross-section of a system 2 for generating electromagnetic radiation in a first embodiment according to the invention. The system 2 comprises an enclosure 4 that encloses a space 6 to be evacuated. Hence in use the enclosure 4 encloses an evacuated space 6 (the evacuated space e.g. having a vacuum with a pressure smaller than
15 approximately 1 Torr, e.g. in a range from 0.01 millibar to 0.1 millibar). The system 2 further comprises a particle generator 8 for generating at least one particle 14 and a first radiation source, here a first laser source 10. By radiating the at least one particle 14 by means of a first laser beam 32, in use generated by the first laser source 10, an excitable, or, in other words,
20 energizable, material, comprised by the at least one particle 14 may be excited, or, in other words, energized. By means of such exciting, i.e. energizing, electromagnetic radiation may be generated, in a way known as such, having a wavelength in the ultraviolet range, in particular in the deep ultraviolet range, and/or below the ultraviolet range. Without wanting to be bound by any
25 theory, exciting the excitable material may comprise bringing the excitable material from a normal state to a state of higher energy. The excitable material may generate the electromagnetic radiation during fallback from an excited state to the normal state. The excitable material may be formed by a metal. Alternatively or additionally, the excitable material may be formed by
30 another material, e.g., possibly, a ceramic material. The enclosure 4 may be

provided with a transparent window 11 so that the first laser beam 32 can propagate into the evacuated space 6 inside the enclosure 4.

With a wavelength in the ultraviolet range is meant a wavelength smaller than 400 nanometer, and optionally larger than 5 nanometer. With a
5 wavelength in the deep ultraviolet range is meant a wavelength smaller than 300 nanometer, and optionally larger than 5 nanometer. Said deep ultraviolet range may comprise the extreme ultraviolet range, wherein a wavelength may be in a range from 5 nanometer to 121 nanometer. Said electromagnetic
10 radiation in the ultraviolet range, the deep ultraviolet range and the extreme ultraviolet range may comprise electromagnetic radiation having a wavelength of approximately 13.5 nanometer, e.g. between 12 and 15 nanometer, and/or of approximately 6.5 nanometer, e.g. between 5 and 8 nanometer. With a
wavelength below the ultraviolet range is meant e.g. a wavelength of at most 5 nanometer, and optionally larger than 1 nanometer. Thus, a wavelength of the
15 generated electromagnetic radiation may, at least partly, be in a range from 1 to 400 nanometer.

Optionally, the system 2 also comprises a donor structure 12. The donor structure 12 comprises a substrate 20 and a donor layer 22 provided along a surface 24 of the substrate 20. The donor layer 22 may be provided on
20 the substrate 20. Alternatively, a release layer (e.g. drawn in figure 1B with reference number 23) that is arranged to interact with radiation of a second radiation beam may be arranged in between the substrate 20 and the donor layer 22. Use of the release layer may be especially useful if absorbance of the
second laser beam 18 by the donor layer 22 is relatively poor. Thus, the energy
25 transfer to the particle is increased, hence the particle has a higher temperature and a higher speed.

The particle generator 8 may be arranged for generating at least one liquid and/or solid particle 14, preferably a plurality of the particles 14 that are preferably generated subsequently to each other. Thereto the particle
30 generator 8 may comprise a second radiation source for generating the second

radiation beam. Here, the second radiation source is formed by a second laser source 16. The second laser source 16 may be arranged for generating a second laser beam 18, being an example of the second radiation beam. In particular, the second laser source 16 may be arranged for generating a pulse of the
5 second laser beam 18. Hence, the second laser source 16 may be a pulsed laser source. The second laser source 16 may be arranged for irradiating, by means of the pulse of the second laser beam 18, the donor structure 12. Hence, the second laser source 16 and the donor structure 12 may be positioned so that, by means of the pulse of the second laser beam 18, the donor structure 12 is
10 irradiated. Said irradiating may cause release of a portion of the donor layer, said released portion forming the at least one particle.

Process parameters of the second laser beam 18 and the donor structure 12 suitable for generating the at least one particle 14 may be determined as follows. The metal comprised by the donor layer 22 may be
15 selected dependent on a desired wavelength or wavelength spectrum of the electromagnetic radiation to be generated. Subsequently, a wavelength or wavelength range of the second laser beam 18 is selected that is capable of interaction with the donor layer 22, e.g. by absorption in the metal of the donor layer 22. Alternatively, in case an additional release layer 23 is provided, a
20 wavelength or wavelength range of the second laser beam 18 is selected that is capable of interaction with the release layer. In that case the radiation of the second laser beam 18 may for example heat the release layer 23 by absorption therein, or by inducing a chemical reaction. In order to determine a suitable spectrum for the second laser beam a spectral transmission spectrum,
25 adsorption spectrum, or reflection spectrum of the donor layer 22 and the substrate 20, and possibly of the release layer 23, may previously have been determined. Based on such spectra, a wavelength of the second laser beam 18 may be selected such that it is absorbed by the donor layer and/or the release layer. Preferably, the wavelength of the second laser beam is not, or relatively
30 weakly, absorbed by the substrate 20. If such spectra are not determined or

not known, the wavelength may be chosen at approximately 350 nanometer and may later be varied if release of the portion of the donor layer cannot be achieved. Preferably, the substrate is chosen such that interaction with the substrate is substantially prevented at said wavelength of 350 nanometer. It
5 will be clear that alternatively another wavelength may be chosen.

Furthermore, a layer thickness of the donor layer is chosen, for example in a range between 0.05 and 1 micrometer. At very large donor thicknesses e.g. 5 micrometer, the release of the portion of the donor layer 22 may be difficult or unreliable. Without wanting to be bound by any theory, such may be caused by
10 a melting zone in the donor layer caused by the pulse of the second laser beam having not progressed through substantially the whole thickness of the donor layer at a moment on which the portion of the donor layer is to be released. An amount of ejected material from the donor layer 22 may be approximately proportional to the product of the thickness of the donor layer and an
15 irradiated area (said irradiated area may be approximately equal to a cross-section of the second laser beam along the donor layer 22). Accordingly, given a desired amount of material to be ejected a smaller thickness may be selected if a larger area is irradiated by the second radiation beam. If the thickness of the donor layer is substantially less than 0.05 micrometer, e.g. less than 0.01
20 micrometer, a relatively large lateral region (irradiation region) of the donor layer may have to be heated, to achieve desirable particle dimensions, e.g. in the range from a few micrometers to a few dozens of micrometers. This may necessitates relatively costly optics and/or laser equipment for obtaining a sufficient power density and homogeneity. Accordingly, a width W2 of the
25 irradiation region of the second laser beam 18 in or adjacent to the donor layer 22 is typically selected in a range of 10 to 100 micrometer. The selection of the width W2 depends further on a required size of the portion of the donor layer 22 to be released by the pulse of the second laser beam 18. A particular suitable range for W2 is between 50 and 90 micrometer. A duration of the
30 pulse (pulse length) of the second laser beam 18 is preferably chosen smaller

than 500 nanoseconds, optionally smaller than 1 nanosecond, e.g. smaller than 10 picoseconds. Without wanting to be bound by any theory, experiments appear to indicate that using a pulse duration that is significantly longer than 500 nanoseconds, e.g. larger than approximately 1 microsecond, may cause the generated heat to leak away without generating a small particle with sufficient release velocity. An intensity of the pulse of the second laser beam, or a laser fluence of the pulse of the second laser beam expressed in Joule per unit of area, may be arranged high enough for supplying a sufficient amount of energy for realising ejection or release of the portion of the donor layer. If an amount of energy comprised by the pulse is too low, e.g. the intensity or fluence of the pulse is too low, the portion of the donor layer may not be released or ejected. A relatively short duration of the pulse, e.g. a pulse with a duration smaller than 1 picoseconds it is not expected to lead to stable droplets. Such a laser source may be expensive. A required fluence of the pulse of the second radiation beam may be dependent on reflection of the pulse on an interface between the donor layer and the substrate. An optimal fluence of the second laser pulse may be determined experimentally for a specific donor layer 22 and donor structure 12. Dependent on the material selected for the donor layer 22, the fluence of the second laser beam 18 may be selected in the range from 10 to 1000 Joule per square centimeter. However, in case a release layer 23 is present, wherein a chemical reaction is induced by the second radiation beam, the fluence may even be lower than 10 J/cm². The second laser beam may be focussed in a focus region on or adjacent to the surface 24 of the substrate, in the release layer, and/or in donor layer. The second laser beam may e.g. be focussed in the donor layer adjacent to the surface 24 of the substrate.

Thus, more in general, an intensity or laser fluence of the pulse of the second radiation beam, a duration of the pulse of the second radiation beam, a wavelength of the second radiation beam, an irradiation region of the second radiation beam, e.g. a width W₂ of the irradiation region of the second

radiation beam in or adjacent to the donor layer and/or a position of a focus region of the second radiation beam, and/or a thickness D of the donor layer 22, may be arranged for causing release, e.g. ejection, of a portion of the donor layer 22.

5 As an example, the donor layer 22 may comprise copper as metal, e.g. the donor layer 22 may be made of copper. Furthermore, one or more of the following parameters may be used in said example. The donor layer thickness D may be in a range from 50 nanometer to 200 nanometer. The pulse length of the second laser beam 18 may be typically 6.7 picoseconds. A wavelength of the
10 second laser beam 18 may e.g. be 343 nanometer or 515 nanometer. A width, e.g. diameter, of the second laser beam 18 in or adjacent to the donor layer 22, e.g. in the focus region 26 of the second laser beam 18, may be in a range from 10 micrometer to 100 micrometer, typically 20 micrometer. A laser fluence of the second laser beam 18 may be in a range from 30 to 150 Joule per square
15 centimeter. By using parameters described above, or by using other parameters, the second laser source 16 may be arranged for generating the at least one liquid and/or solid particle 14, preferably a plurality of subsequent particles 14. Then, a diameter of the particles 14 may be in a range from 2 to 30 micrometer. Having a relatively small particle 14, e.g. having a diameter of
20 at most 20 micrometer or at most 10 micrometer, may enable evaporation of the particle 14 during excitation of the particle 14. Evaporated material of the particle may be removed relatively easily out of the evacuated space, e.g. by means of a vacuum pump for maintaining the vacuum in the evacuated space.

 As another example, the donor layer 22 may comprise tin as the
25 metal. The melting temperature of tin is lower than the melting temperature of copper. Without wanting to be bound by any theory, it can be expected that somewhat less energy may be required for releasing tin than for releasing copper. A donor layer 22 substantially made of tin may be required to be thicker than 200 nanometer, in order to achieve a predetermined amount of
30 electromagnetic radiation. With tin as the metal, the laser fluence level of the

second laser beam 18 may be in a range from 1 to 1000 Joule per square centimeter.

For other metals, e.g. in case the donor layer comprises gadolinium, process parameters may be arranged by using the guidelines mentioned
5 herein. If release or ejection is realised for a certain metal, e.g. copper, in particular adjustment of the wavelength and the fluence of the pulse may be required in case another metal is used.

Parameters of the second laser source 16 for releasing the portion of the donor layer 22, may be inferred from Laser-Induced Forward Transfer
10 techniques, examples of which are known as such to the skilled person (see e.g. David P. Banks, Christos Grivas, John D. Mills, Robert W. Eason, and Ioanna Zergioti, "Nanodroplets deposited in microarrays by femtosecond Ti-sapphire laser-induced forward transfer", Applied Physics Letters 89, 193107 (2006); and Aiko Narazaki, Tadatake Sato, Ryozi Kurosaki, Yshizo Kawaguchi, and
15 Hiroyuki Niino, "Nano- and microdot array formation by laser-induced dot transfer", Applied Surface Science 225 (2009), 9703-9706). It is further noted that Laser-Induced Forward Transfer technologies generally teach the skilled person away from the present invention, because these technologies are directed at transferring particles, instead of using these particles for
20 generating electromagnetic radiation.

Thus, more in general, the pulse of the second laser beam 18 may, in use, cause release of a portion of the donor layer 22, thus generating the at least one particle 14 as a product of said released portion of the donor layer 22. Said released portion forms the at least one particle 14. Said release may
25 comprise ejection of the particle 14. Without wanting to be bound by any theory, the pulse of the second laser beam 18 may cause reaction and/or evaporation of the donor layer 22 and/or the release layer in the irradiation region of the second laser beam 18. E.g., a plasma or vapour may be created in the donor layer adjacent to the substrate 20. Said plasma may propel the
30 portion of the donor layer out of the donor layer. Furthermore, the pulse may

cause melting of the donor layer 22 in the irradiation region. Thus, the particle 14 may be (at least partly) liquid. The release layer may be arranged for absorbing energy provided by the second laser beam 18. Thereto the release layer may comprise carbon, one or more metals, and/or triazene-polymers.

- 5 Preferably, a composition of the release layer is such that, after the release of the portion of the donor layer 22, a remainder of the release layer supporting said release of the portion of the donor layer 22, does not contaminate the support structure or another element of the system 2. In particular, the composition of the release layer is arranged for substantially preventing
- 10 movement of the remainder of the release layer in the irradiation region of the first laser beam. The reaction and/or evaporation of the donor layer 22 and/or the release layer may lead to an increase in pressure inside the donor layer 22 and/or in between the donor layer 22 and the substrate 20, e.g. inside the release layer. As a result of said pressure, the portion of the donor layer 22
- 15 may be ejected.

More in general, a method comprising generating the at least one particle, and a system arranged for generating the at least one particle, by means of the second radiation source, may be provided wherein the second radiation beam may travel through the substrate 20 before reaching the donor

20 layer 22 and/or the release layer 23. However, alternatively, the second radiation beam may first pass the donor layer. The at least one particle may be generated from an intact portion of the donor layer. With 'intact portion' is meant a portion of the donor layer that has yet been unused for generating a particle. A moment of generating the at least one particle may be controlled by

25 means of (the pulse of) the second radiation beam. A moment of exciting the excitable material comprised by the at least one particle may be controlled by means of (the pulse of) the first radiation beam. Said moments may be mutually synchronised, e.g. by means of a control unit. Furthermore, a position of generation, and/or a direction and magnitude of the release velocity

30 of the at least one particle may be controlled by means of (the pulse of) the

second radiation beam. Preferably, a thickness of yet unused portions of the donor layer, i.e. portions from which no particle has been generated yet, is uniform within 10%, 5%, 2%, or, most preferably, 1%. Hence, a well-controllable method and system may be provided being advantageous over
5 known methods respectively systems.

More in general, a pulse frequency of the second laser beam 18 may be in a range from 20, or 50 instead of 20, to 800 kiloHertz, e.g. in a range from 200-400 kiloHertz and/or or 100-300 kiloHertz. The present system may enable generation of particles 14 with a diameter smaller than 40 micrometer, or even
10 smaller than 20 micrometer. It is further noted that the particle 14 may e.g. be a droplet. Alternatively, the particle 14 may be solid. The particle 14 may also be partly solid and partly liquid. It is noted that a phase of at least a part of the particle 14 may change after generating the particle 14, e.g. may change from liquid to solid.

15 The first laser source 10 may be arranged for generating a first radiation beam, here a first laser beam 32. The particle generator 8 may further be arranged for moving the at least one particle 14, e.g. the plurality of subsequent particles 14, in an irradiation region, e.g. a focus region 30, of the first laser beam 32 generated by the first laser source 10. Such moving may be
20 realised at least by ejecting said released portion of the donor layer 22. Said focus region 30 may be part of the evacuated space 6 in the enclosure 4.

The donor layer 22 may comprises a metal or another excitable material, e.g. may be substantially made of the metal or the other excitable material. Hence, the particle 14 may comprises the metal, e.g. may be
25 substantially made of the metal. Optionally, said metal may in general be formed by an alloy and/or may be one of a plurality of metals. The alloy as well as other metals of the plurality of metals, may, in use, also be excited by the first laser beam. By selection of the alloy or the plurality of metals, a spectrum of the generated electromagnetic radiation may be adjusted. Said metal may
30 e.g. comprise tin, gadolinium, copper, and/or terbium. Such metals are

especially suitable for, when excited by the first laser source 10, generating electromagnetic radiation having a wavelength in the deep ultraviolet range-, and optionally in the extreme ultraviolet range.

The first laser source 10 may be arranged for, by irradiating the one
5 or more particles 14 when being present in the focus region 30 of the first laser beam 32, exciting the metal comprised by the one or more particles 14 and thereby generating the electromagnetic radiation. Said electromagnetic radiation is schematically indicated in figure 1A with reference number 33. More in general, a wavelength of the first radiation beam, a duration of a pulse
10 of the first radiation beam, a fluence or intensity of the first radiation beam, in particular of the pulse of the first radiation beam, and/or a width W1 of the irradiation region of the first radiation beam may be arranged for, by irradiating the one or more particle when being present in the irradiation region of the first radiation beam, exciting the metal comprised by the one or
15 more particle and thereby generating the electromagnetic radiation. Parameters of the first laser beam 32 for exciting the metal and thus generating the electromagnetic radiation with a wavelength in the deep ultraviolet range, are known as such to the skilled person. Also, properties of the vacuum in the evacuated space 6 for generating said electromagnetic
20 radiation. Such parameters and/or properties are e.g. described in US patent application publication 2005/0199829 and US patent 6,862,339 and references mentioned therein.

Thus, examples have been described wherein laser-induced generation (here by means of the second laser source) of a particle 14 is
25 followed by excitation of the particle by means of a laser, here the first laser source 10. Thus, droplet generation by means of forcing a fluid through a nozzle, e.g. a nozzle of an ink jet head, may be avoided. Hence, problems with clogging of the nozzle may be prevented. Furthermore, a freedom for choosing the metal, and a concentration of the metal in the particle, need not be
30 hampered by limitations to prevent said clogging. Thus, various metals may be

used. Thus, a desired wavelength of the electromagnetic radiation may be achieved. Especially, particles substantially made from gadolinium may be generated, in an embodiment of the present invention. Generating gadolinium droplet by means of a nozzle is difficult, due to the relatively high melting
5 temperature of gadolinium. However, also for particles made substantially of tin, advantageous embodiments may be provided. Additionally, in an embodiment, temperatures of the metal (or another excitable material) above a melting temperature may be limited to the portion of donor layer to be released. Thereto, optionally, a heat shield 27 may be generally provided in
10 between the donor layer and the first laser beam. The heat shield 27 may be provided with a heat shield aperture 29 through which the at least one particle 14 may pass. Examples of a composition of the heat shield are known as such. Thus, a probability of eroding the nozzle or other parts by means of high-temperature fluids, may be reduced.

15 In a variation of the first embodiment, the donor layer 22 is provided, at least partly, in the evacuated space 6. Then, the second radiation beam may be positioned for generating the at least one particle 14 in the evacuated space 6.

In a variation that is shown in figure 1A, the donor layer 22 is
20 provided, at least partly, outside the enclosure 4 and outside the evacuated space 6, e.g. in a generation space 36. The enclosure 4 may comprise an aperture, e.g. a pinhole 38. Said aperture may provide for a fluidum connection between the evacuated space 6 and the generation space 36. A size, e.g. a diameter, of the aperture may be in a range from 10 micrometer to 40
25 micrometer. With such a small aperture, the vacuum of the evacuated space 6 may still be maintained. In an embodiment, at least part of the donor layer 22 may be positioned substantially against, or in a vicinity of, a part of the enclosure 4 around the aperture, while preferably allowing for relative movement between the enclosure 4 and the donor layer 22. More in general, a
30 volume of the enclosure 4 and a size of the pinhole 38 may be arranged for

maintaining the vacuum in the enclosure 4. Further, the second radiation beam 18 may be positioned for generating the at least one particle 14 outside the evacuated space 6. Alternatively, in the generation space 36 a similar vacuum is applied as in the evacuated space 6 inside the enclosure 4.

5 Preferably, the particle generator 8 is arranged for transporting the at least one particle 14 through the pinhole 38 so that the at least one particle 14 is moved into the evacuated space 6. Thereto, in an embodiment, the system is optionally provided with a first electrode 40 that is positioned for charging the donor layer 20 and therewith also providing the at least one particle 14
10 with an electric charge, and a second electrode 42 that is positioned for electrically moving the electrically charged at least one particle 14 towards the irradiation region 30. At least part of the donor layer 22 may be regarded as the first electrode 40. In use, a voltage difference may be applied between the first electrode 40 and the second electrode 42. Thereto the system may be
15 provided with a voltage source 41. By means of the voltage source 41, the first electrode, and the second electrode, reliably directing the at least one particle 14 towards the irradiation region 30 may be enabled. The first and second electrode may be used for adapting a direction of movement of the at least one particle 14, so that the at least one particle 14 in use moves through the
20 irradiation region of the first laser beam. However, the voltage source 41, the first electrode 40, and the second electrode 42 are not necessary. Moving the at least one particle 14 in the evacuated space 6 may also be realised, or supported, by using suction of the vacuum of the evacuated space 6, optionally in combination with arranging the second laser beam 18 and the donor
25 structure 12 so that the at least one particle 14 is generated adjacent to the pinhole 38.

 It will be clear that, in the first embodiment, the second radiation source 16 may be arranged for generating a plurality of subsequent pulses of the second radiation beam 18. In the first embodiment or in another
30 embodiment, the system 2 may comprise a transporter for realising the

relative motion between the donor layer 22 and the second radiation beam 18 at least in between subsequent pulses of the second radiation beam. Then, the plurality of subsequent particles 14 may be generated. In figure 1A, such relative motion is schematically indicated by arrow 43. A velocity of relative motion, e.g. a velocity of the donor layer 22 relative to the second laser beam 18, may be approximately equal to a first product being equal to the product of a pulse frequency of the pulses of the second laser beam 18 and a diameter of the second laser beam 18 in or adjacent to the donor layer 22. The velocity may be in a range of 0.2 times said first product till 5 times said first product.

Alternatively, the velocity of relative motion may be approximately equal to a second product being equal to the product of a pulse frequency of the pulses of the second laser beam 18 and the square root of $(4 \cdot Z^3 / (6 \cdot D))$, wherein Z is a desired droplet diameter and D is the thickness of the donor layer 22. The velocity may be in a range of 0.2 times said second product till 5 times said second product. Various embodiments for the transporter are possible.

The system 2 may, more in general, be provided with a control unit 35. Said control unit may be electrically connected to the first laser source and the second laser source via electrical connections 37. The control unit 35 may be arranged for synchronising a moment at which the pulse of the first laser beam 32 is generated with a moment at which the pulse of the second laser beam 18 is generated. As a result, the first laser pulse may irradiate the particle 14 when the particle 14 is in the focus region 30 of the first laser beam 32. The control unit 35 may further be arranged for adjusting a position of the donor structure 12 in a direction transverse to the surface 24 of the substrate 20. The control unit 35 may further be arranged for controlling the transporter 44.

Figure 1B shows a donor structure 12 of a system 2 in a second embodiment according to the invention. In the second embodiment, the donor structure 12 may comprise a substrate 20 provided with a plurality of recesses 47 in the surface 24 of the substrate 20. By means of a recess 47, a pressure

generated by the pulse of the second radiation beam 18 may be focussed towards a centre of a portion 45 of the donor layer 22 released by said pulse. Hence, a number of the at least one particles 14 generated by a single pulse of the second laser beam 18 may be reduced. Thus, a larger fraction of the portion
5 of the donor layer 22 may reach the irradiated region 30 of the first radiation beam 32. The recesses 47 may be present in the surface 24 of the substrate 20 that faces the donor layer 22 and/or the release layer 23. The substrate provided with the recesses 47 may be applied generally. The substrate 20 provided with the recesses 47 may also be applied when the release layer 23 is
10 absent.

Figure 1C (in top-view) and Figure 1D (in cross-section according to D-D in Figure 1C) show a further embodiment, wherein the donor structure is pre-processed to facilitate releasing portions thereof. Therein the donor layer 22 comprises portions 22a of the donor layer to be released. The portions 22a to
15 be released are fully separated from the remainder of the donor layer 22 by grooves 22b that extend to the surface of the substrate 20. Alternatively, the portions to be released may be partially separated, e.g. by grooves 22c (FIG. 1C) that are interrupted or by grooves 22d (FIG. 1D) that do not extend over the full depth.

Figures 2A and 2B show a first embodiment of the transporter 44. In this embodiment, the transporter 44 may comprise a movable mirror 46. In particular, the mirror 46 may be cantable, or, in other words, rotatable, along at least one axis of rotation, but preferably along at least two axes of rotation that are mutually transverse or perpendicular. Such canting is indicated by
25 arrow 48. By canting the mirror 46, relative motion between the donor layer 22 and the second radiation beam 18 may be realised. As a result of canting, the second laser beam 18 may be rotated with respect to the donor layer 22. Additionally, the transporter may be arranged for translating the donor structure 12, e.g. during rotating the second laser beam 18. A direction of such
30 translation may be directed transverse to a plane of rotation of the second

laser beam 18. E.g., in the example of figure 2A, said translation may be in a direction out of the plane of the paper. Relative motion may thus be realised continuously, or at least in between subsequent pulses of the second radiation beam. In that way, illumination of another portion of the donor layer 22 than a portion that way previously released, may be enabled. Preferably, relative motion is achieved by translating and/or rotating the donor layer while holding the second laser beam 18 still at least in a plane transverse to the second laser beam 18. Figure 2A shows the donor structure 12 before release of a particle 14. Figure 2B shows the donor structure 12 after release of particles 14.

Former positions of removed portions of the donor layer are indicated by reference number 49. The transporter 44 in the first embodiment, in particular the cantable mirror 46, may be especially suitable to be provided inside the enclosure 4. Then, translating the donor layer 22 may be omitted or can take place at a lower speed. As in this embodiment the position where the particles are released is not fixed relative to the position of the focus region 30 of the first laser beam, however, additional facilities should be provided to guide the released particles towards the focus region 30. Such additional facilities may comprise for example a charging facility for charging the particles and an electrostatic lens for guiding the charged particles towards the focus region 30.

Figure 3A shows a second embodiment of the transporter 44. In this embodiment, the transporter may comprise a first roll 50A and a second roll 50B. The first roll 50A and the second roll 50B are arranged for rolling thereon the donor structure 12. Thus, the transporter 44 may be arranged for translating the substrate 20 relative to the second radiation beam 18. Said donor structure 12 may be flexible. The substrate 20 may, more in general, be made of glass. However, the substrate 20 may also be made of a flexible plastic and/or a flexible polymer. Providing a glass substrate 20 that is sufficiently thin (e.g. at most 50 or at most 100 micrometer) may provide for said flexibility. Furthermore, a glass substrate 20 has the advantage that it may be substantially free from interaction with the second laser beam 18. Hence, the

second laser beam 18 may pass substantially unaltered through the glass substrate 20, so that it may be fully employed for release of the portion of the donor layer 22. Preferably, a wavelength of the second laser beam 18 is chosen that combines a maximum absorption in the donor layer 22 and/or the release layer with a minimal absorption in the substrate 20.

The transporter may further comprise a guide 52, for guiding the donor structure 12 through the irradiation region of the second laser beam 18. The guide may comprise guiding rollers 52A, 52B. The guide may be mechanically connected to a body 54 of the transporter 44. Preferably, the guide is movably connected to the body 54. Such movement is indicated by arrows 56. The control unit 35 may further be arranged for controlling the guide 52, e.g. for controlling the rollers 52A, 52B and/or the movement of the guide 52 with respect to the body 54.

Figure 3B shows a modified variation of the second embodiment of the transporter 44. Instead of the roller 50A and 50 B for rolling thereon the donor structure 12, the transporter 44 may be provided with additional guide elements 52' and 52'' that enable rotating a donor structure 12 being formed as a loop closed in itself. The system 2 may be provided with a donor regeneration system 58. The regeneration system 58 may be arranged for removing a remainder of the donor layer 22, e.g. by stripping the remainder of the donor layer from the substrate 20, e.g. by means of a reverse plating step. The regeneration system 58 may further be arranged for applying a new donor layer 22, e.g. by means of a (plasma) vacuum deposition step and/or by means of a plating step. Using a donor structure 12 being closed in itself combines well with said regeneration system 58. However, the regeneration system 58 may optionally be used generally, e.g. in combination with other donor structures.

Optionally, the body 54 of the transporter is connected to the enclosure 4, as indicated in figure 3B. The particle generator 8 may be, at least partly, positioned in the evacuated space. The donor layer may be

provided, at least partly, within the enclosure 4 in the evacuated space 6.

Then, the plurality of subsequent particles 14 are preferably generated in the evacuated space 6. The system 2 for generating electromagnetic radiation may be arranged for transporting the donor layer 22 and the substrate 20 into and
5 out of the evacuated space, by means of the rollers 50A, 50B. Thereto the enclosure may comprise a first slot 53A and a second slot 53B for respectively transporting the donor layer into and out of the enclosure 4, and/or vice versa.

Figure 4A shows a perspective view of a donor structure 12, which can be used in a third embodiment of a transporter 44. Figure 4B shows a side
10 view of the third embodiment of the transporter 44. The transporter 44 in the third embodiment may be provided with a rotatable donor structure 12. Such rotation is indicated by arrow 60. The donor structure 12 may, at least partly, be shaped as disk 62. It is noted that, in other embodiments, the rotatable donor structure may be shaped as a cylinder. Thus, more in general, the donor
15 structure may, at least partly, be rotatable with respect to the second laser beam 18. It was found by the inventors that such a rotatable donor structure 12 may provide for a reliable and rapid movement of the donor layer 22 with respect to the second laser beam 18. The second radiation beam, here the second laser beam 18, may be movable with respect to the donor layer 22. Such
20 is indicated by arrow 64. Having a movable second laser beam 18 in combination with a rotatable donor structure 12 may enable relatively rapid, reliable, and/or substantially complete use of the donor layer 22. Thus, as illustrated in figure 4B, the transporter may be arranged for realising the relative motion by rotating the donor structure 12 with respect to the second
25 laser beam 18. The second laser beam 18 may be translated with respect to the donor structure 12 while rotating the donor structure 12. Alternatively, the rotatable donor structure 12 may in use be rotated and simultaneously be translated with respect to the second laser beam 18.

In case the rotatable donor structure is shaped as a disk, the donor
30 layer may, in variation, be provided as a spincoated liquid donor layer 22. In

other variations the donor layer 22 may be substantially solid. A donor regeneration system, for example as described with respect to figure 3B, may be provided in the variant of figure 4B as well.

Figure 4B further shows the body 54 of the transporter in the third embodiment, and the guide 52 of the donor structure 12. The guide 52 may be arranged for guiding the donor structure 12 through the irradiation region of the second laser beam 18. The guide may be mechanically connected to a body 54 of the transporter 44. Preferably, the guide is movably, e.g. rotatably, connected to the body 54. Such movement and rotation is indicated by arrows 66A and 66B, respectively. Thus, the transporter may be arranged for rotating the substrate 20 relative to the second radiation beam 18.

Figure 5A shows a perspective view of a donor structure 12, which can be used in a fourth embodiment of a transporter. Figure 5B shows, in cross section, a side view of the fourth embodiment of the transporter.

In this fourth embodiment, the donor structure 12 is shaped as a transparent drum which is transparent for the radiation of the second radiation source. The second radiation beam 18 axially enters the drum and is reflected in a radial direction by a mirror 28 towards the donor layer 22. The drum forming the donor structure 12 is rotated by drive rolls 57A, 57B. The drum, while rotating is displaced axially, so that the radiation beam 'scans' the surface of the drum and continuously irradiates a new part of

Alternatively, it would be possible to move the beam 18 itself, for example by displacing the mirror 28. In that case the position in space where the particles are released from the donor mater changes in time. To achieve that the particles arrive in the focus region 30 despite this varying release position, the direction of the particles may be controlled by an electric field provided they are charged at the time of release. It is however preferred that the second radiation beam hits the donor layer at a fixed position in space, so that direction control is not necessary.

A first embodiment of a method according to the invention (the first method) may be illustrated with reference to figures 1-5. Said generating electromagnetic radiation may have a wavelength in the deep ultraviolet range. Said first method may comprise the step of generating at least one
5 liquid and/or solid particle 14, e.g. at least one droplet 14, that comprises a metal, such as tin and/or gadolinium and/or copper. The first method may further comprise moving the at least one particle 14 in an irradiation region, e.g. focus region 30, of a first radiation beam, e.g. a first laser beam 32. Said irradiation region may, at least partly, be part of an evacuated space 6. Such
10 generating and moving may be carried out by means of the particle generator 8.

The first method may further comprise irradiating the at least one particle 14, when being present in the irradiation region of the first radiation beam, by means of the first radiation beam. In that way, the metal comprised
15 by the at least one particle 14 can be excited. Therewith the electromagnetic radiation can be generated. Parameters, e.g. a wavelength, frequency, and/or intensity (e.g. laser fluence) of the first radiation beam for realising said excitation are known as such to the skilled person.

In the first method, the generating of the at least one particle 14
20 may comprise the step of providing a donor structure 12 comprising at least a substrate 20 and a donor layer 22 provided along a surface 24 of the substrate 20. Said donor layer 22 may comprise the metal. The first method may further comprise the step of irradiating the donor structure 12 by means of a pulse of a second radiation beam, e.g. the second laser beam 18. Such may cause release
25 of a portion of the donor layer 22, thus generating the at least one particle 14 as a product of said released portion of the donor layer 22. Hence, said released portion forms the at least one particle.

In a variation, the first method comprises generating a plurality of subsequent particles 14 by irradiating the donor structure 12 by means of a
30 plurality of pulses of the second radiation beam. Then, the method also

comprising realising relative motion between the donor layer 22 and the second radiation beam, at least in between subsequent pulses of the second radiation beam. As a result, mutually subsequent pulses may irradiate mutually subsequent parts of the donor layer 22. Said variation of the first method may comprise realising the relative motion by rotating and/or translating the donor structure 12, e.g. with respect to the second laser beam 18, and/or by translating and/or rotating the second laser beam 18, e.g. with respect to the donor structure 12, preferably while rotating and/or translating the donor structure 12. Such realising of the relative motion may be generally applicable. Realising the relative motion may be performed by means of a transporter, e.g. the transporter 44 described with reference to figures 2A-4B.

A second embodiment of a method according to the invention (the second method) may comprise generating a plurality of subsequent particles 14 by irradiating the donor structure 12 by means of a plurality of pulses of the second radiation beam, here the second laser beam 18. A time interval between subsequent pulses of the second laser beam 18 may be arranged so that a distance L (figure 1A) between subsequent particles 14 generated by means of said subsequent pulses exceeds five times or ten times a diameter of the particles. Such a proportion between the distance L and the particle diameter may be difficult to achieve by using a nozzle at relatively high frequencies. E.g. in ink-jet systems such distance L usually is in a range of 2 to 4 times a droplet diameter. Thus, in the second method, a distance between subsequent particles may be arranged to reduce a shadow, of the electromagnetic radiation. Said shadow may be caused by particles subsequent to a particle generating the electromagnetic radiation. Electrically moving, e.g. accelerating, subsequent charged particles may be used for adapting, e.g. increasing, a distance between the subsequent charged particles. Thus, said shadow may also be reduced. A relatively high release velocity may also reduce the shadow, e.g. by means of increasing the distance L and/or by realising a relatively short dwelling time of a particle in the evacuated space.

In the first and/or second method, the donor layer 22 may be provided, at least partly, in the evacuated space 6. Then, the at least one particle 14 may be generated in the evacuated space 6. Alternatively, the evacuated space 6 may be provided in an enclosure 4 that comprises a pinhole 38. Then, the at least one particle 14 may be generated outside the evacuated space 6. The first and/or second method may comprise transporting the at least one particle 14 through the pinhole 38 into the evacuated space 6.

A third embodiment of a method according to the invention (the third method) may comprise moving the particle 14 towards the irradiation region by inducing an electric charge in the particles 14. The third embodiment may also comprise electrically moving the electrically charged droplet or subsequent electrically charged droplets in the irradiation region of the first radiation beam. Such is described with reference to the first electrode 40 and the second electrode 42, shown in figure 1A. Preferably, moving the particle towards the irradiation region of the first laser beam is caused substantially by the ejection of the portion of the donor layer by means of the second laser beam.

The invention also relates to a lithographic system, e.g. a wafer stepper. Said wafer stepper may comprise a system for generating electromagnetic radiation according to the first embodiment or a variation thereof. Thus, said wafer stepper may be arranged for carrying out the first, second and/or third method. The wafer stepper is arranged for carrying out a photolithographic process by means of the electromagnetic radiation. Examples of conventional lithographic systems are known as such to the skilled person so that a further description thereof is deemed superfluous.

Embodiments of the invention are not limited to the foregoing description and drawings. For example, an intensity of the second radiation beam near a circumference of the second radiation beam may exceed an intensity of the second radiation beam near a center of the second radiation beam. Thus, when measured in a cross-section of the second radiation beam

perpendicular to a propagation direction of the second radiation beam, the intensity of the second radiation beams may have a minimum in or near the center of the second radiation beam. For example, as illustrated in the figures, the second radiation beam, e.g. the second laser beam 18, may travel through
5 the substrate 20 before reaching the donor layer 22 and/or the release layer. The pulse of the second laser beam 18 may be a block pulse or may have another shape. E.g., the pulse of the second laser beam 18 may be formed from at least two pulses, e.g. block pulses, that have mutually different duration and fluence. As a further example, the invention may be applied for a donor
10 structure comprising a plurality of metals. Then, the at least one particle may comprise the plurality of metals. Thus, when herein the term 'metal' is used, it may, optionally, be replaced by the term 'metallic material', which may comprise a plurality of metals, a metallic compound, and/or an alloy. Alternatively the term 'metal' may be replaced by the term 'excitable material'
15 or 'energizable material'. In a yet further example, one or more other ways of moving the at least one particle in the irradiation region of the first laser beam are used, additionally or alternatively. Such ways may comprise electromagnetically moving, e.g. accelerating, the at least one particle. Equally all kinematic inversions are considered inherently disclosed and to be within
20 the scope of the present invention. The use of expressions like: "preferably", "in particular", "especially", "typically" etc. may relate to optional features. The term "comprising" does not exclude other elements or steps. The indefinite article "a" or "an" does not exclude a plurality. Features which are not specifically or explicitly described or claimed may be additionally comprised in
25 the structure according to the present invention without deviating from its scope.

Claims

1. Method of generating electromagnetic radiation having a wavelength in the ultraviolet range and/or below the ultraviolet range, comprising the steps:
- generating at least one liquid and/or solid particle that comprises an excitable material, e.g. a metal;
 - moving the at least one particle in an irradiation region of a first radiation beam; and
 - irradiating the at least one particle, when being present in the irradiation region of the first radiation beam, by means of the first radiation beam, for exciting the excitable material comprised by the at least one particle and thereby generating the electromagnetic radiation;
- wherein generating the at least one particle comprises the steps:
- providing a donor structure comprising at least a substrate and a donor layer provided along a surface of the substrate, which donor layer comprises the excitable material; and
 - irradiating the donor structure by means of a pulse of a second radiation beam causing release of a portion of the donor layer, said released portion forming the at least one particle.
2. Method according to claim 1, comprising carrying out the steps of claim 1 repeatedly, thus generating a plurality of subsequent particles by irradiating the donor structure by means of a plurality of pulses of the second radiation beam, the method comprising realising relative motion between the donor layer and the second radiation beam at least in between subsequent pulses of the second radiation beam, so that a later one of the subsequent pulses irradiates another part of the donor layer than a previous one of the subsequent pulses.

3. Method according to claim 2, wherein realising the relative motion comprises rotating and/or translating the donor structure, and/or comprises translating and/or rotating the second laser beam, preferably while rotating
5 and/or translating the donor structure.

4. Method according to one of claims 1-3, comprising carrying out the steps of claim 1 repeatedly, thus generating a plurality of particles by irradiating the donor structure by means of a plurality of pulses of the second
10 radiation beam, wherein a pulse frequency of the second radiation beam is in a range from 20 to 2000 kiloHertz and/or a release velocity of the at least one particle is at least 10 meter per second.

5. Method according to one of claims 1-4, comprising carrying out the steps of claim 1 repeatedly, thus generating a plurality of particles by irradiating the donor structure by means of a plurality of pulses of the second
15 radiation beam, wherein a pulse frequency of the second radiation beam is in a range from 20 to 800 kiloHertz and/or a release velocity of the at least one particle is at least 50 meter per second.

20

6. Method according to one of claims 1-5, wherein the irradiation region is part of an evacuated space and the donor layer is provided, at least partly, in the evacuated space, and wherein the at least one particle is generated in the evacuated space.

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7. Method according to one of claim 1-5, wherein the irradiation region is part of an evacuated space and the evacuated space is provided in an enclosure that comprises a pinhole, wherein the at least one particle is generated outside the evacuated space, the method comprising transporting
30 the at least one particle through the pinhole into the evacuated space.

8. Method according to one of claims 1-7, wherein moving the at least one particle towards the irradiation region comprises inducing an electric charge in the particle, and comprises electrically moving the electrically
5 charged droplet in the irradiation region of the first radiation beam.

9. System for generating electromagnetic radiation having a wavelength in the ultraviolet range and/or below the ultraviolet range, the system comprising:

10 - an enclosure enclosing a space to be evacuated;
- a particle generator for generating at least one liquid and/or solid particle that comprises an excitable material, e.g. a metal, the particle generator further being arranged for moving the at least one particle in an irradiation region of a first radiation beam, said irradiation region being part
15 of said enclosed space; and
- a first radiation source arranged for generating the first radiation beam, and further being arranged for, by irradiating the particle when being present in the irradiation region of the first radiation beam, exciting the excitable material comprised by the at least one particle and thereby
20 generating the electromagnetic radiation;
wherein the particle generator comprises a second radiation source arranged for generating a pulse of a second radiation beam and for irradiating, by means of the pulse of the second radiation beam, a donor structure comprising at least a substrate and a donor layer provided along a surface of the substrate, which
25 donor layer comprises the excitable material, said pulse, in use, causing release of a portion of the donor layer, said released portion forming the at least one particle.

10. System according to claim 9, further comprising the donor structure comprising at least the substrate and the donor layer provided along the surface of the substrate, which donor layer comprises the excitable material.
- 5 11. System according to claim 9 or 10, wherein the donor structure is provided with a release layer that is arranged to interact with radiation of the second radiation beam, said release layer being arranged in between the substrate and the donor layer.
- 10 12. System according to one of claims 9-11, wherein the second radiation source is arranged for generating a plurality of pulses of the second radiation beam, the system comprising a transporter for realising relative motion between the donor layer and the second radiation beam at least in between subsequent pulses of the second radiation beam, wherein the transporter is
15 arranged for realising the relative motion by rotating and/or translating the donor structure, and/or by translating and/or rotating the second laser beam, preferably while rotating and/or translating the donor structure.
13. System according to one of claims 9-12, wherein in use the donor
20 layer is provided, at least partly, in the evacuated space, and wherein the second radiation beam is positioned for generating the at least one particle in the evacuated space.
14. System according to one of claims 9-12, wherein the enclosure
25 comprises a pinhole, and wherein, in use, the donor layer is provided, at least partly, outside the evacuated space, and wherein the second radiation beam is positioned for generating the at least one particle outside the evacuated space, wherein the particle generator is arranged for transporting the at least one particle through the pinhole so that the at least one particle is moved in the
30 evacuated space.

15. System according to one of claims 9-14, provided with a first
electrode that is positioned for charging the donor layer, thus creating an at
least one charged particle, and a second electrode that is positioned for
5 electrically moving the electrically charged at least one particle towards the
irradiation region.

16. Lithographic system, including a system for generating
electromagnetic radiation according to one of claims 9-15, and/or being
10 arranged for carrying out a method according to one of claims 1-8, the
lithographic system being arranged for carrying out a photolithographic
process by means of the electromagnetic radiation.

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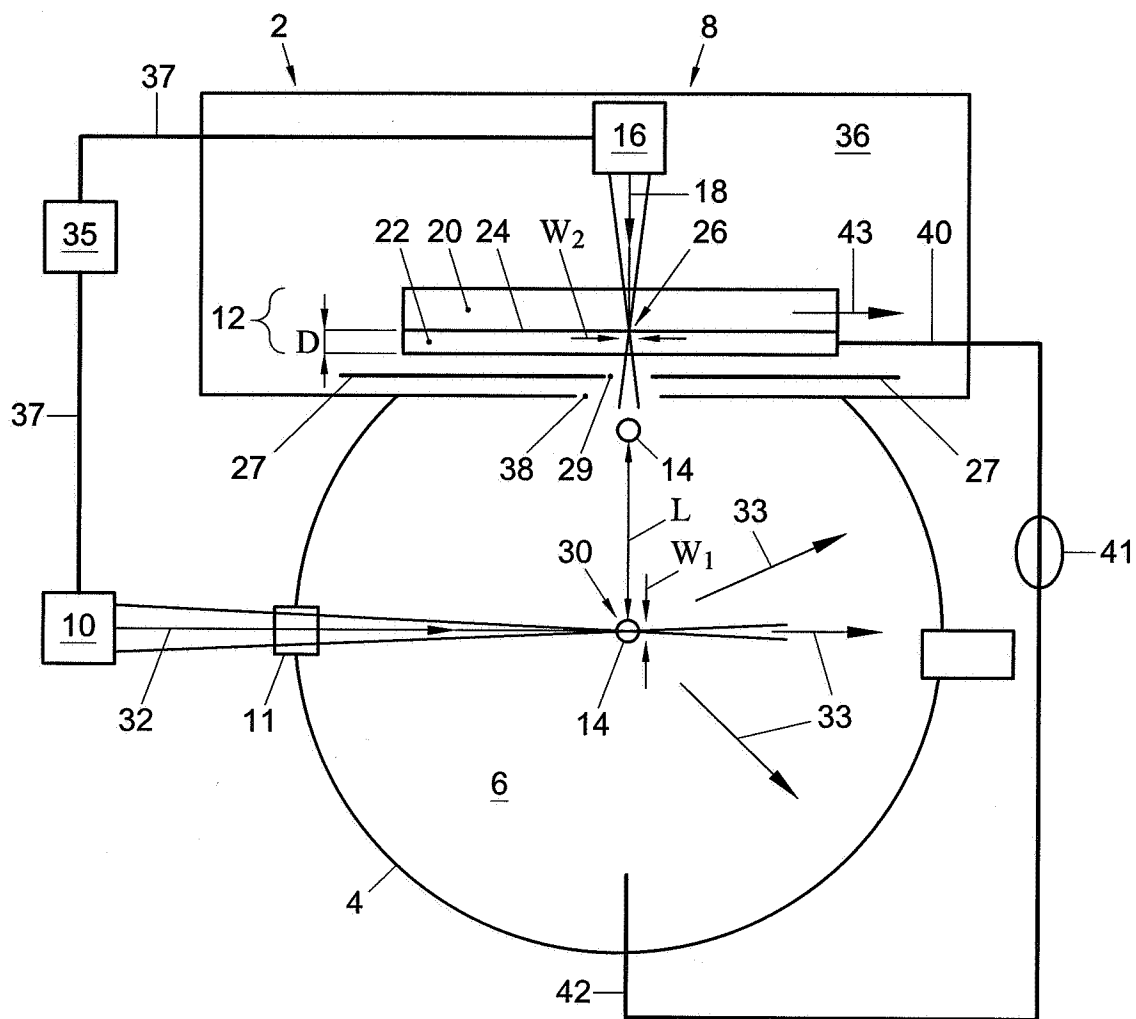


Fig. 1A

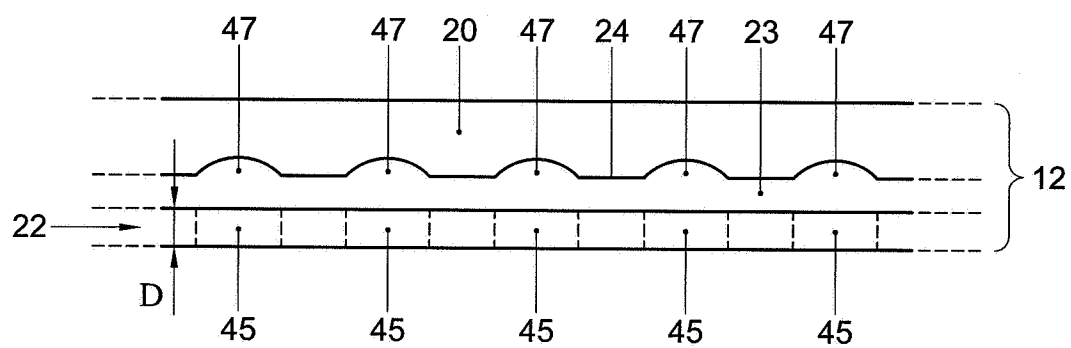


Fig. 1B

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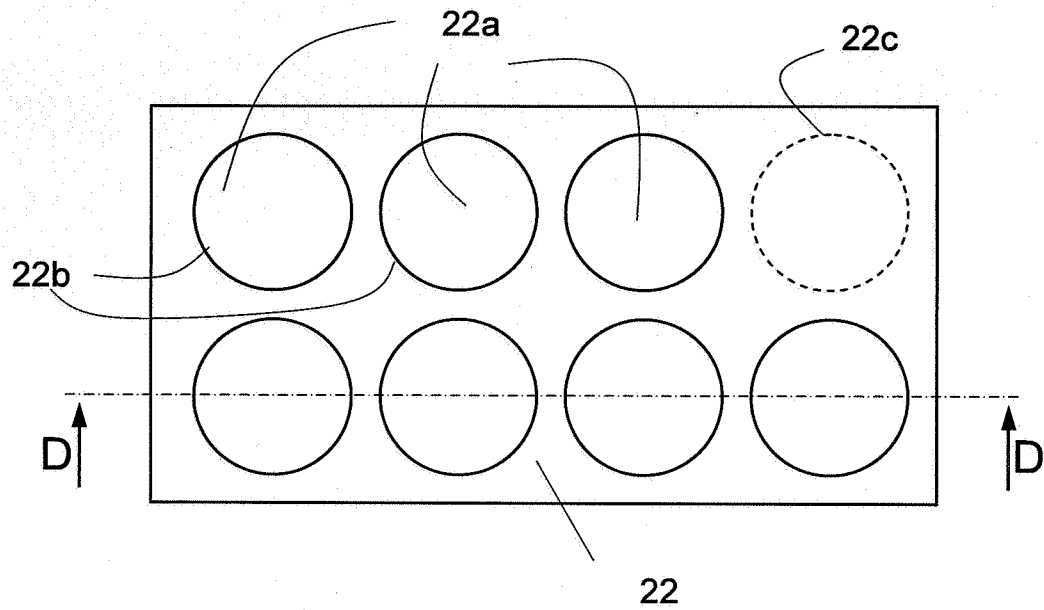


Fig. 1C

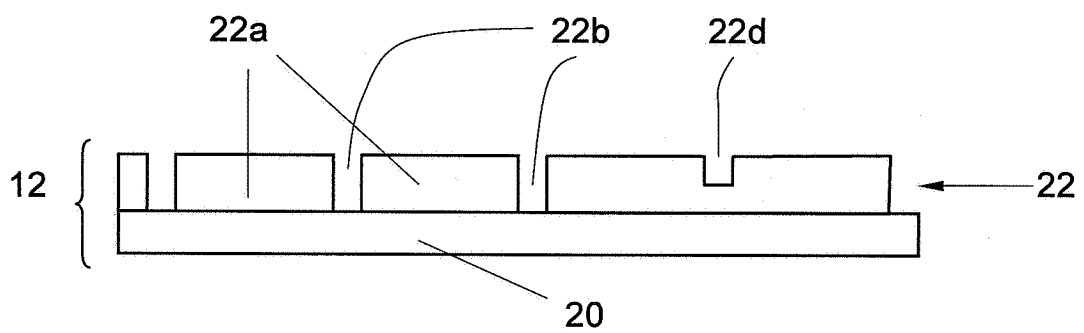


Fig. 1D

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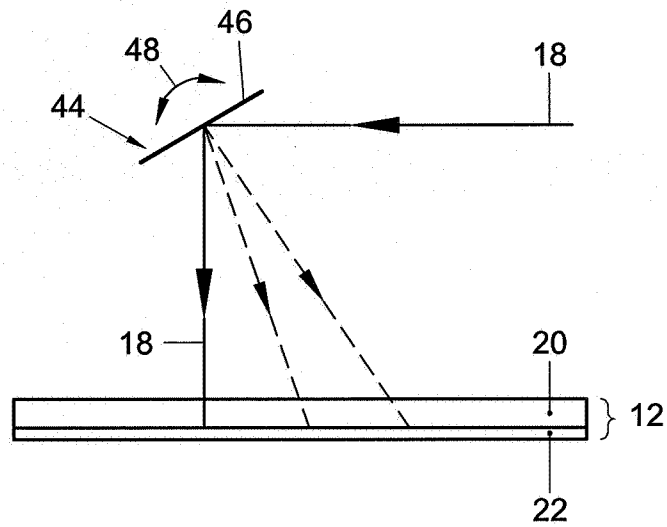


Fig. 2A

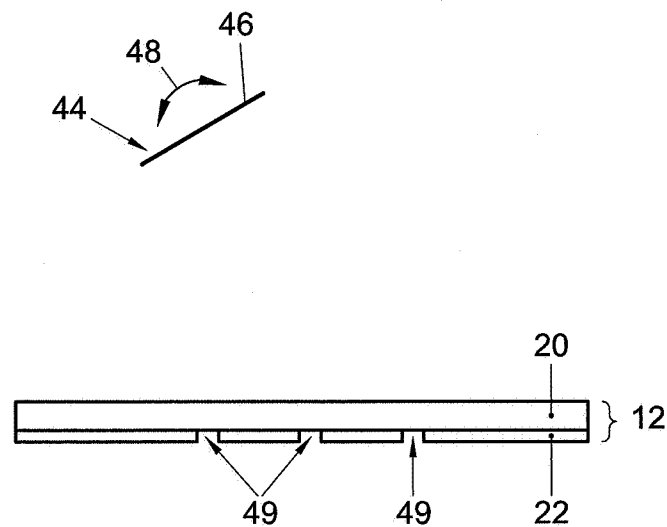


Fig. 2B

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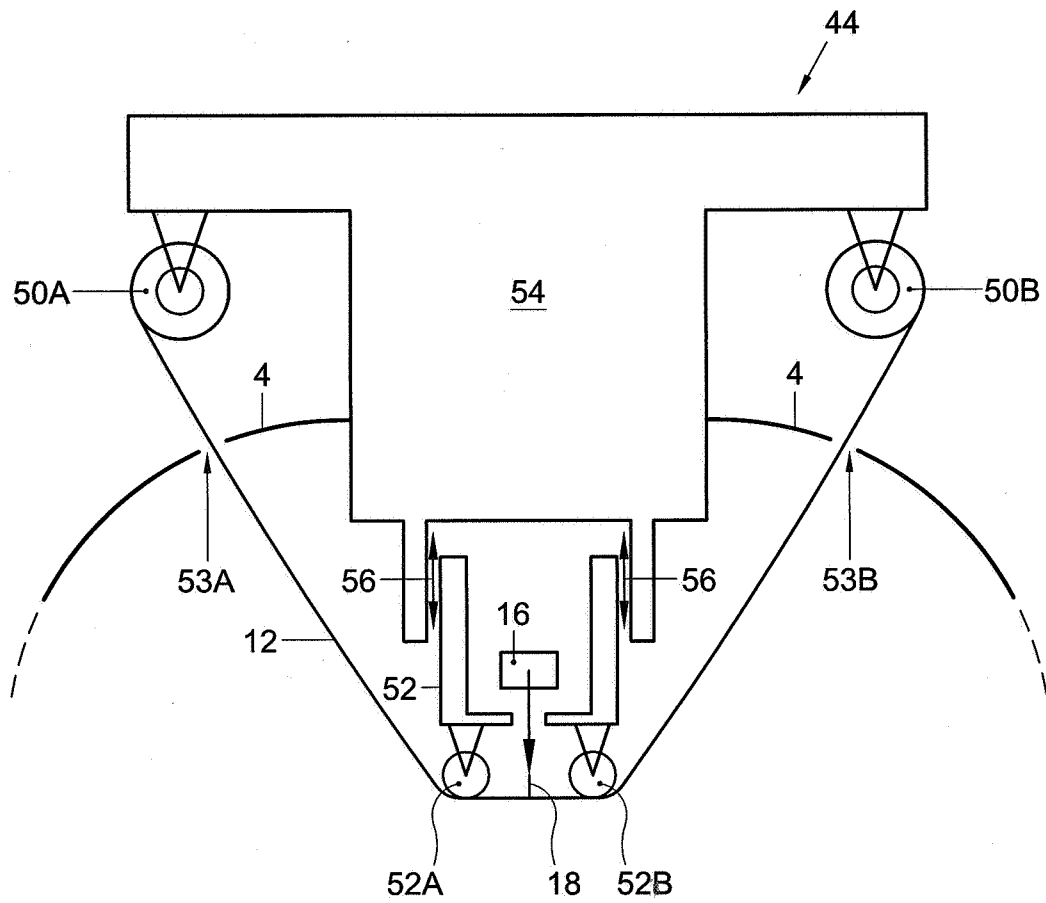


Fig. 3A

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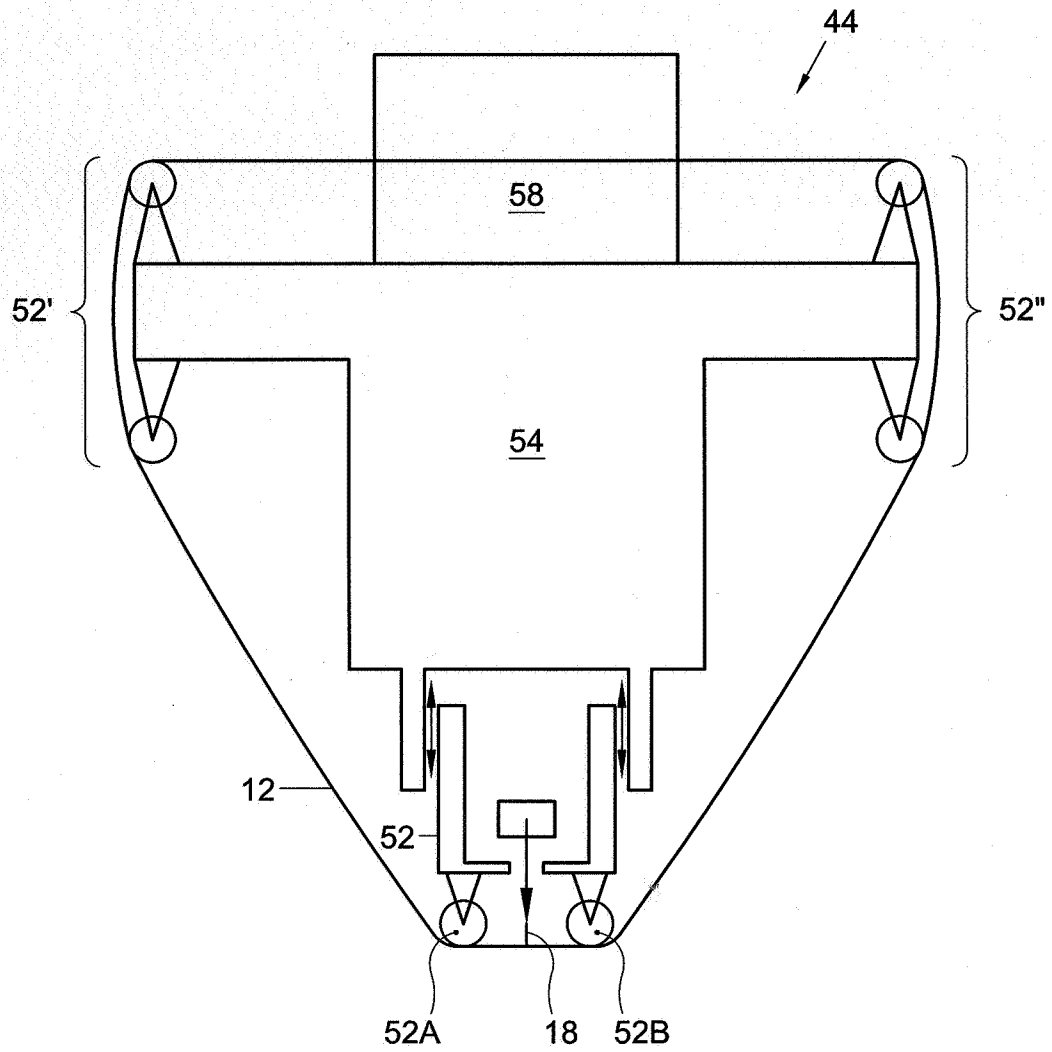


Fig. 3B

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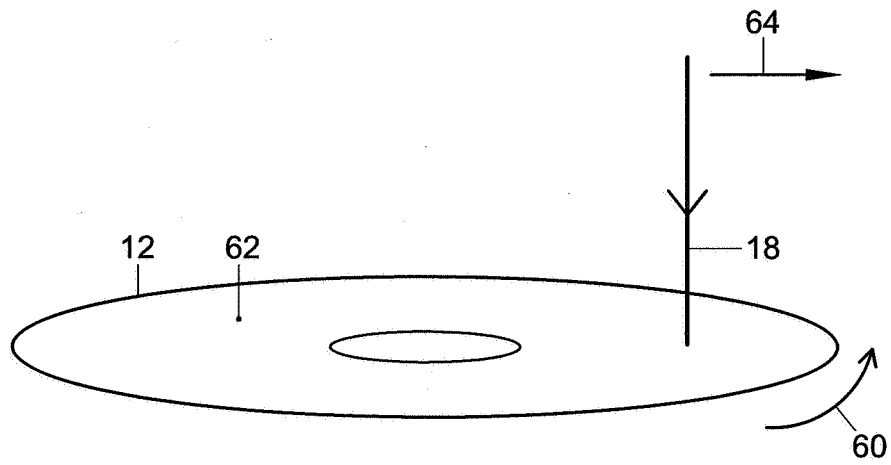


Fig. 4A

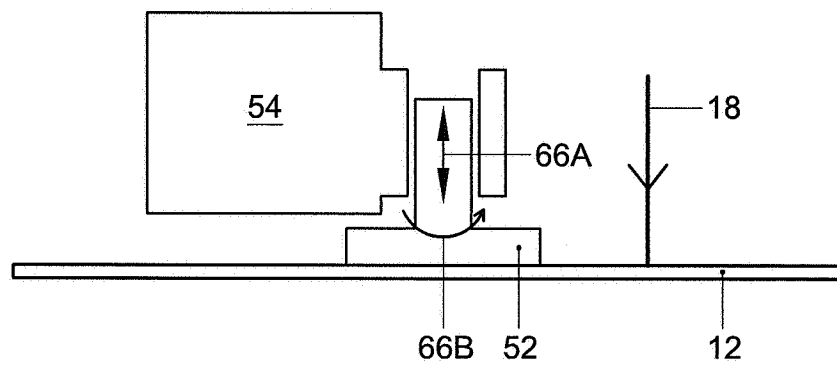


Fig. 4B

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Drum concept

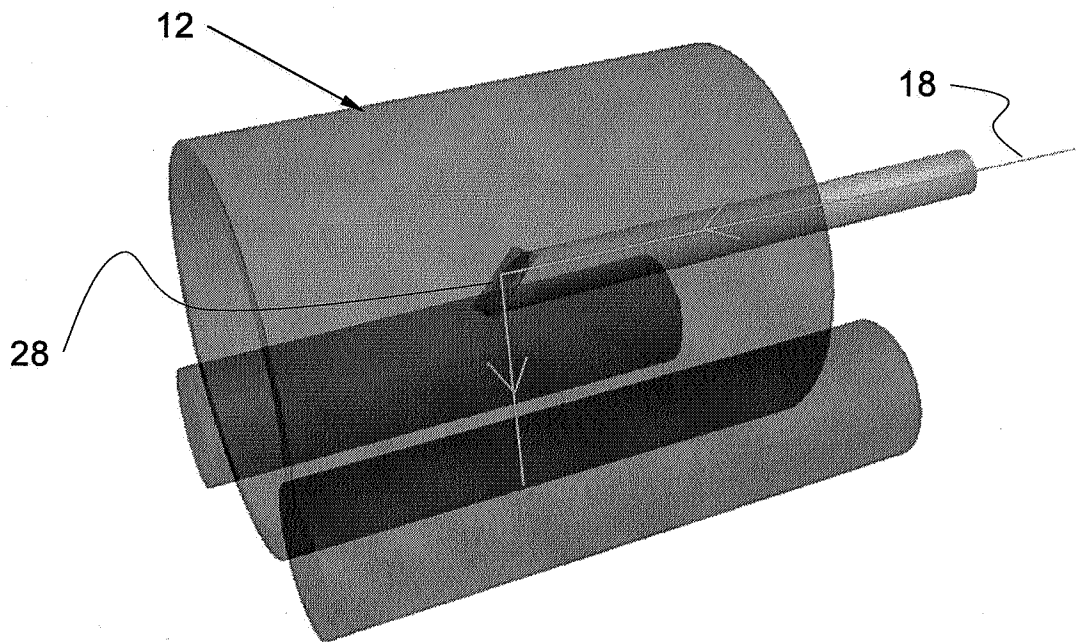


Fig. 5A

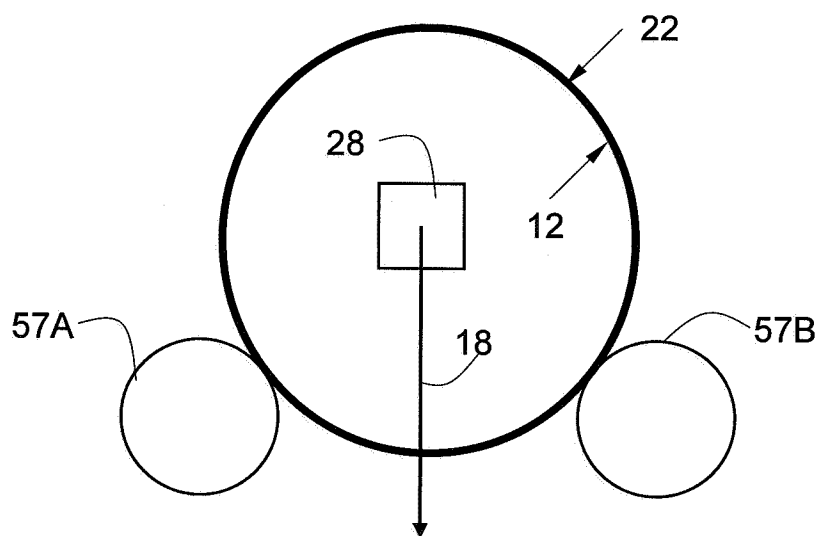


Fig. 5B

INTERNATIONAL SEARCH REPORT

International application No

PCT/NL2012/050287

A. CLASSIFICATION OF SUBJECT MATTER

INV. H05G2/00

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)

H05G

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NAKANO H ET AL: "EFFECTS OF AN ULTRASHORT PREPULSE ON SOFT X-RAY GENERATION FROM AN ALUMINIUM PLASMA PRODUCED BY FEMTOSECOND TI:SAPPHIRE LASER PULSES", APPLIED PHYSICS B: LASERS AND OPTICS, SPRINGER INTERNATIONAL, BERLIN, DE, vol. B63, no. 2, 1 August 1996 (1996-08-01), pages 107-111, XP000620066, ISSN: 0946-2171, DOI: 10.1007/BF01095257	1-5
A	section 1 Experimental setup -----	8
A	DE 199 83 270 B4 (AGENCY IND SCIENCE TECHN [JP]) 30 July 2009 (2009-07-30) paragraph [0018] ----- -/-	1,8



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

16 July 2012

Date of mailing of the international search report

24/07/2012

Name and mailing address of the ISA/

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Oestreich, Sebastian

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2012/050287

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HANEY S J ET AL: "PROTOTYPE HIGH-SPEED TAPE TARGET TRANSPORT FOR A LASER PLASMA SOFT-X-RAY PROJECTION LITHOGRAPHY SOURCE", APPLIED OPTICS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC; US, vol. 32, no. 34, 1 December 1993 (1993-12-01), pages 6934-6937, XP000414599, ISSN: 0003-6935, DOI: 10.1364/AO.32.006934 page 6934, column 2, line 16 -----	1,8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2012/050287

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			DE 19983270 T1	21-06-2001
			GB 2353929 A	07-03-2001
			US 6275565 B1	14-08-2001
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