Water Laser Plasma X-Ray Point Source and Apparatus

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A high repetition-rate laser plasma target source system and lithography system is disclosed. The target source system comprises a preferred embodiment a liquid tank source and freezer which freezes microscopic particles into crystal shapes which are projected by a nozzle jet from a high repetition rate liquid-droplet injector into the path of a flashing laser beam, which results in producing soft x-rays of approximately 13 nm. Uncollected and unshot target crystals are collected and reliquified by a heater source in order to be recycled back to the liquid tank source. Optionally an auxiliary source and detector system can be used to allow for instantaneous triggering of the laser beam. The target source system can be incorporated into well known EUV lithography systems for the production of wafer chips.


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ABSTRACT
Fig. 1

100

640

M₄

M₃

M₂

M₁

630

600

610

P₂

Reflection
Mask
500

Laser Source
101

Optical Laser Beam
102

450

Target
320

400

200

300

P₁

P₃

P₄

700

Wafer
Fig. 3
Fig. 4
Fig. 5

Compact High Repetition Rate Laser 802

Collector Mirror Housing 810

Pumping System 815

Target System 820

Small Laser-Plasma Vessel (~25 cms) 817

EUV Exposure Chamber 840
WATER LASER PLASMA X-RAY POINT SOURCE AND APPARATUS

This invention relates to lasers, and in particular to an ice water target source for laser plasma soft-x-ray or EUV projection lithography.

BACKGROUND AND PRIOR ART

For soft x-ray or EUV projection lithography there is a need for a high repetition-rate laser plasma source that can radiate at a specific wavelength of approximately 13 nm in the EUV part of the spectrum and capable of operating at approximately 1200 Hz. This type of source should comprise a compact high repetition-rate laser and a renewable target system capable of operating for prolonged periods of time. For a production line facility, there would need to be uninterrupted system operation for periods of approximately 3 months. That is, uninterrupted operation for some 10^9 shots. To make the irradiation system cost effective, current system cost scenarios indicate the unit shot material cost must be in the vicinity of $10^{-6} per shot. Target sources for laser plasma soft-x-ray projection lithography have encompassed several systems such as tape driven targets and solid targets and frozen gases which all have inherent problems.

U.S. Pat. No. 5,151,928 to Hirose discloses a system which uses film type tapes as a target source. However, tape driven targets are limited mass targets that are difficult to construct, prone to breakage and produce low velocity debris that can damage the other components such as the mirrors in the laser output system. Furthermore, using and replacing the tapes is generally cumbersome and costly.

Solid targets also have many problems. Known solid target sources include rotating solid wheels of Sn or tin, or copper or gold. These sources inherently can produce various ballistic particles types that can emanate from the plasma in various directions. When using tin as the target, the interaction of the laser light with the plasma, causes highly stripped, energetic ions to be formed by collision ionization. These ions can stream ballistically from the plasma region with velocities of between 10^6 and 10^7 centimeters per second. Furthermore, after the interaction of the plasma and the tin target, hot clumps or clusters of target material are boiled off of the target. This material has been determined to be another form of debris particles that can have velocities in the range of 200 to 2500 centimeters per second. The sizes of these particles range from less than 1 to greater than 200 micrometers. These larger particles can cause cold particle cratering on many of the components used to construct visible and x-ray optical components such as the mirrors and are capable of puncturing thin-film x-ray filters. All of these debris size particles can degrade the surface quality or the operating performance by overcoating the optical elements in the laser output system. Likewise, other solid targets besides tin can produce similar debris type particles.

Frozen gasses such as Krypton, Xenon, and Argon have also been tried as laser source targets, and also have problems. Besides the exorbitant cost required for containment costs, these gasses are also quite expensive and would be difficult to have a continuous high repetition rate that would cost significantly greater than $10^{-6}. Moreover, all previous embodiments of frozen gas targets have envisaged massive (continuous) large-mass pellets targets which produce particular debris.

SUMMARY OF THE INVENTION

The first objective of the present invention is to provide an inexpensive, continuously sequencing target system as a laser plasma x-ray source.

The second object of this invention is to provide a target system that produces non-damaging debris for a laser plasma x-ray source.

The third object of this invention is to provide a laser plasma target source capable of producing x-rays in the region of 13 nm within a narrow bandwidth.

The fourth object of this invention is to provide a laser plasma target source that can operate at a frequency of approximately 1000 Hz to 100 kHz.

The fifth object of this invention is to provide a laser plasma target source that can operate continuously.

The sixth object of this invention is to generate a narrow band EUV radiation source.

In a preferred embodiment, the target source system comprises a liquid tank source and freezer means which freezes microscopic particles into crystal shaped droplets which are projected by a nozzle jet on a high repetition rate liquid-droplet injector into the path of a flashing laser beam, which results in producing soft x-rays of approximately 13 nm. Uncollected and unshot target crystals are collected and reliquified by a heater source in order to be recycled back to the liquid tank source. Optionally an auxiliary source and detector system can be used to allow for instantaneous triggering of the laser beam.

Further objects and advantages of this invention will be apparent from the following detailed description of a presently preferred embodiment which is illustrated schematically in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 illustrates an overview of an EUV Lithography system that uses the water laser x-ray plasma source.

FIG. 2 shows a preferred embodiment of the apparatus used as the laser target source in FIG. 1.

FIG. 3 shows comparative x-ray spectroscopic data from laser plasma targets.

FIG. 4 illustrates a modification for the embodiment of FIG. 2.

FIG. 5 shows exterior containers used for housing the components of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Before explaining the disclosed embodiment of the present invention in detail it is to be understood that the invention is not limited in its application to the details of the particular arrangement shown since the invention is capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

FIG. 1 illustrates an overview of an EUV Lithography system 300 that uses the water laser x-ray plasma source 300 which will be discussed later in reference to FIG. 2. The components of the EUV Lithography system 100 will now be discussed. The laser beam source 101 used to irradiate the EUV target can be a high repetition rate Nd:Yag or KrF excimer laser. 200 indicates the vacuum enclosure for the laser plasma target. Element 300 refers to the apparatus that continuously creates replenishable target material 230 for each laser shot, such as ice droplets. Element 420 is a first
EUV collector mirror which can be spherical in overall shape or have a spherical surface. The surface of this mirror can be coated with special multilayer structures to provide high reflectivity at near-normal incidence at selected EUV wavelengths such as 7 nm, 13 nm, and so on. Element 450 is a second multilayered coated EUV collector mirror. Although not shown, alternatively a third or more multilayered coated EUV collector mirrors can be incorporated in the FIG. 1 system. 500 refers to a specially fabricated mask structure having reflecting surfaces comprising a structure pattern to be imaged onto the wafer 700. Elements 610, 620, 630 and 640 refer to various other spherical reflective components well known to be used in an optical system of high precision that are capable of imaging reflection mask 500 to wafer 700. Elements 610, 620, 630 and 640 can further be coated with multilayer EUV normal incidence coatings for preselected wavelengths to be used in the system. Enclosure 600 denotes a separate vacuum enclosure for housing components 610, 620, 630 and 640 of the imaging system. Alternatively, enclosure 600 can contain a low background gas such as He. Finally element 700 is a lithographic wafer comprising an EUV sensitive resist on a semiconductor substrate.

In operation an optical laser beam 102 is emitted from source 101 striking target 320. Radiation 400 in the form of x-rays from the laser plasma source generated from target 300 are collected at mirror 420 and subsequently focussed via mirrors 450 onto mask 500 which subsequently reflects a preselected pattern via mirrors 610 to 640 to wafer 700.

FIG. 2 shows a preferred embodiment of the apparatus 300 used to create the continuously replenishable target material used as the laser target 320 in FIG. 1. A source supply of basic laser target material such as a pressurized water tank 304 can supply water to injector 310 either as a continuous stream of water under pressure, or as a vapor or steam that is subsequently frozen by freezer means 308. The components of apparatus 300 can be housed in a vacuum enclosure 302. Means 306 freezes the steam from tube 305 into frozen pellets 320 of ice crystals or snow. These frozen pellets of ice can be formed by passing the droplets through a single metallic tube 307 that has been thermo-electrically cooled or chilled by liquid Nitrogen having an approximate temperature of minus 77 degrees Centigrade. Alternatively, element 307 can comprise concentric metallic tubes where the area between the inner and outer tubes includes cold liquid helium of approximately minus 260 degrees Centigrade. An additional freezing technique can be accomplished by the inherent freezing that can take place within the vacuum chamber 302. In the latter technique small droplets of water injected into a vacuum will freeze due to rapid evaporation from the surface of the droplet. Under this technique approximately 10% of the mass of a 100 ng water droplet will be lost to evaporation before the droplet freezes.

Element 310 of FIG. 2 represents a nozzle jet device for projecting crystals into the path of laser beam 102. High repetition rate liquid-droplet injectors with nozzle jets such as those described in U.S. Pat. Nos. 5,126,755 and 5,142,297 which are incorporated by reference can be utilized to project the frozen water droplets 320. Although these patents describe specific embodiments of ink jet systems, the laser plasma target system disclosed in this application can utilize any type of ink jet type droplet injectors, so long as the droplet size can be made to approximate 100 ngm in mass. Element 330 signifies a vacuum collector system for absorbing unused or unshot targets. An optional heater system 340 can reliquify unused or unshot targets that can be recycled through collector tube 350. Unused targets will liquify on contact with the collector 330. Enhanced liquification can be introduced by heating the collector with an optional heating coil element 340. A pump within line 350 will suck the unused liquid to reservoir tank 304 or alternatively to a waste site.

The operation of apparatus 300 will now be discussed in reference to FIG. 2. Source tank 304 creates steam that feeds through line 305 and becomes frozen by freezer means 308. Alternatively, the vacuum space within chamber 302 can inherently cause the steam to freeze into crystal forms such as those having a snow flake shape. Nozzle jet 310 projects microparticle ice crystals 320 at a rate of up to 1012 Hz to 100,000 Hz. Collector system 330 which is in the path of crystals 320 collects the unused and unshot target crystals. Heater 340 reliquifies the crystals in order that the crystals can be recycled and pumped through line 350 back to tank source 304.

FIG. 3 shows comparative x-ray spectroscopic data from laser plasma targets. Two spectra are shown. One is of the typical radiance of an ice target laser plasma compared to the emission of conventional target plasma. Superimposed on the spectra of the conventional target(from a Sn target) is an example of the reflectivity of typical EUV mirrors as a function of EUV radiation wavelength. Line “a” shows a typical radiation pattern along 0 to 13.4 nm that comes from materials such as Sn, An, Cu, W, Xe, or Kr as laser target sources. Line “b” shows the narrow line emission emanating at a wavelength of 13 nm from using an ice target such as the crystal particle droplets 320 shown in FIG. 2. Line c shows the typical reflectivity function of a Mo/Si multilayer EUV mirror operating at 13 nm. As mentioned in the background section, for soft x-ray or EUV project electrotagraphy there is a need for a high repetition-rate laser plasma source that can radiate at a specific wavelength of approximately 13 nm in the EUV part of the spectrum and capable of operating at approximately 1200 Hz. Thus, using ice crystals as a target source fulfills these needs.

FIG. 4 illustrates an auxiliary laser beam particle detection system 510, 515, 515, 516, 520, 521 for use with the embodiment 300 of FIG. 2. Element 102 refers to flashing focussed laser beam. The beam 102 is focussed to intensities on the ice target of 1014 to 1022 w/cm2,sufficient to create a plasma having a temperature high enough to ensure the copious production of Li-like oxygen ions. Elements 321 through 324 constitute the path of ice crystal droplets emanating from nozzle jet 310. Elements 515 and 516 refers to an electrostatic guidance system which causes the ice crystals to have an electrostatic charge. These electrostatic guidance system functions. The first function is an electrostatic charging by a device generating an charge or by a device that generates an miniature electron beam that causes the droplet 322 to be charged. The second function of the system 515, 516 is as an array of charged electrodes which provide a variable electric field that can be manipulated to guide the trajectory of the charged droplets 322 to pass...
The invention can be used as an x-ray source for x-ray lithography, the invention is not limited to this use. While the invention has been described as an x-ray source for x-ray lithography, the invention is not intended to be, nor should it be considered as suggesting the teachings herein.

1. A method of producing x-rays from a target source comprising the steps of: continuously feeding frozen water into a target source; irradiating the target source with a laser; and producing x-rays therefrom.

2. The method of producing x-rays of claim 1, further comprising the step of: removing residual water particles after the step of irradiating.

3. The method of producing x-rays of claim 2, wherein the step of removing further includes: vaporizing the residual water particles.

4. The method of producing x-rays of claim 2, wherein the step of removing further includes: heating the residual water particles.

5. The method of producing x-rays of claim 2, wherein the step of removing further includes: collecting the residual water particles with a vacuum.

6. The method of producing x-rays of claim 1, wherein the step of feeding further includes: freezing the water particles into ice crystals.

7. The method of producing x-rays of claim 6, wherein the step of feeding further includes: projecting the frozen particles through a high repetition rate liquid-droplet injector. The remaining components work in the same manner and operation as FIG. 2.

While the invention has been described as an x-ray source for x-ray lithography, the invention is not limited to this use. The invention can be used as an x-ray source for x-ray microscopy, x-ray imaging systems, x-ray spectroscopy, x-ray fluorescence absorption spectroscopy, x-ray diffraction, x-ray protein diffraction studies, and x-ray interferometry.

While the preferred embodiment refers to collecting unshot and unused crystal targets for recycling, optionally the unused droplet targets can be vaporized additionally by laser beams, microwaves or infrared radiation. Alternatively, the unshot droplets can be captured and vaporized by a heated surface.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.

We claim:

A method of producing x-rays from a target source comprising the steps of:

1. continuously feeding frozen water into a target source;
2. irradiating the target source with a laser;
3. producing x-rays therefrom.

The method of producing x-rays of claim 1, further comprising the step of: removing residual water particles after the step of irradiating.

The method of producing x-rays of claim 2, wherein the step of removing further includes: vaporizing the residual water particles.

The method of producing x-rays of claim 2, wherein the step of removing further includes: heating the residual water particles.

The method of producing x-rays of claim 2, wherein the step of removing further includes: collecting the residual water particles with a vacuum.

The method of producing x-rays of claim 1, wherein the step of feeding further includes: freezing the water particles into ice crystals.

The method of producing x-rays of claim 6, wherein the step of feeding further includes: projecting the frozen particles through a high repetition rate liquid-droplet injector.

The method of producing x-rays of claim 6, wherein the step of producing further includes: producing x-rays of approximately 13 nm.

The method of producing x-rays of claim 6, wherein the step of feeding the target source further includes: continuously feeding the target source at a frequency of approximately 1000 Hz.

The method of producing x-rays of claim 6, wherein the step of feeding the target source further includes: continuously feeding the target source in a noninterfering shot sequence approaching 2 X 10^7 targets.

The method of producing x-rays of claim 6, wherein the step of feeding the target source further includes: continuously feeding the target source in a noninterfering shot sequence exceeding 2 X 10^7 targets.

A method of producing 13 nm x-rays comprising the steps of:

1. forming ice crystals; and
2. irradiating the frozen ice crystals with a light source.

The method of producing 13 nm x-rays of claim 12, wherein the light source is: a laser.

An apparatus for producing x-rays comprising:

A supply of water;
means for freezing the water into crystals;
means for feeding the crystals into a target path;
means for irradiating a laser beam into the target path creating x-rays; and
means for collecting residual crystals.

The apparatus for producing x-rays of claim 14, wherein the means for feeding the crystals further includes: a high repetition rate liquid-droplet injector.

The apparatus for producing x-rays of claim 14, wherein the x-rays have an approximate wavelength of 13 nm.