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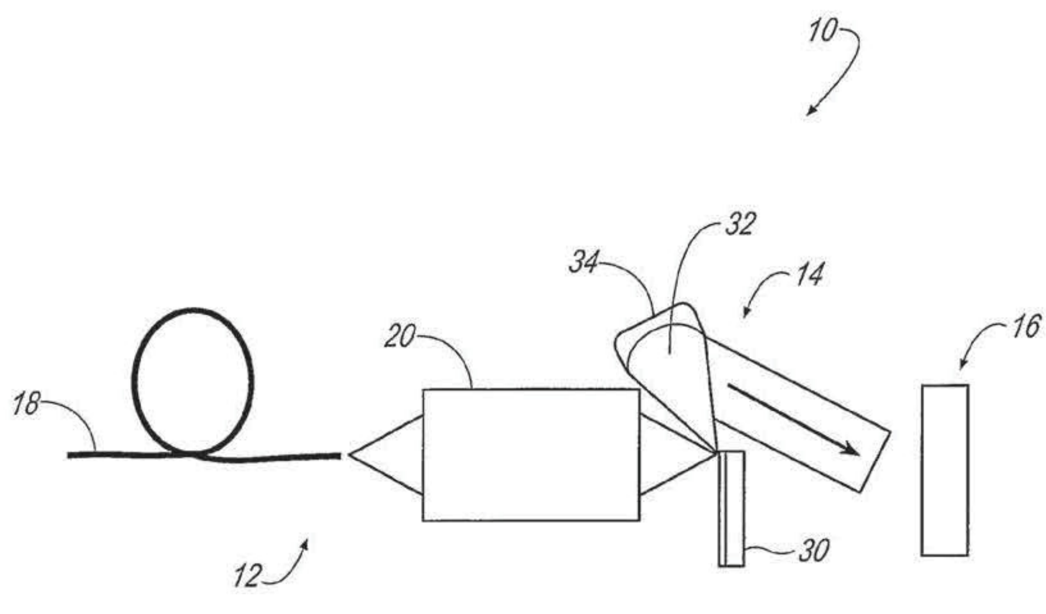
(54) Title: FIBER LASER-BASED EUV-LITHOGRAPHY



(57) Abstract: A method and apparatus is disclosed for performing lithography operation. A fiber laser (18) is provided that generates laser light that is used by adaptive optics (20) to focus the laser light onto a plasma target (30) to generate plasma as a source of EUV radiation.

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FIBER LASER - BASED EUV-LITHOGRAPHY

BACKGROUND

[0001] Lithography is a process used in semiconductor fabrication. In order to continue semiconductor integrated circuit speed increase at the rate predicted by the Moore's Law, which states that the circuit density of microchips doubles every 18 months, the limits of optical lithography must be expanded. To meet this prediction, the manufacturing of next generation electronic devices will demand lithography light sources having wavelengths with high power and high-frequency, otherwise known as EUV (extreme ultraviolet). However, producing radiation at such high power and frequencies is technologically very difficult and, although some sources of EUV radiation do exist, none of these systems are currently adequate for practical use in industrial EUV lithography.

[0002] One way to produce EUV radiation having such desired characteristics is by generating laser-produced plasma and then using the radiation from the plasma to perform the lithography process. In such a method, a pulsed laser beam is focused on a plasma target having the requisite material for producing plasma. The laser-matter interaction, resulting from the targeted laser pulse on the material, leads to the formation of hot plasma. The formation of such hot plasma serves as a source of EUV radiation for the lithography process.

[0003] Typically, such EUV generation requires very high laser light peak intensities on the target, thus necessitating the use of large and complex laser systems capable of producing high energy pulses at high average power. This also presents a further problem that it is essential that laser sources are sufficiently compact, robust and affordable for productive industrial use. The present invention was developed in light of these and other drawbacks.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 is a schematic view of a lithography device according to an embodiment of the invention;

[0005] Figure 2 is a schematic view of a lithography device according to an embodiment; and

[0006] Figure 3 is a schematic view of a lithography device according to an embodiment.

DETAILED DESCRIPTION OF AN EMBODIMENT

[0007] A method and apparatus for EUV lithography provides a high EUV radiation source having a lower power consumption by the laser and a reduced amount of debris generated by the plasma target. As a result, this radiation source does not require a large complex laser or a high-energy supply to the laser. The method and apparatus includes an improved laser source that uses fiber lasers in combination with adaptive optics. In addition, the method and apparatus allows for minimal debris generation as the overall power and target size is reduced from that of the conventional art.

[0008] Further, the present invention uses a pulsed high-power fiber laser configuration which uses optimum-duration pulses to further enhance the generation of EUV radiation. Additionally, to utilize the enhanced wave front characteristics of laser light from the fiber laser configuration to achieve the desired spot size on the plasma target, the present invention includes adaptive optics which enable the laser light to be focused into a small diffraction-limited spot on the plasma target with an improved energy concentration, thus reducing energy requirements by the laser, minimizing the needed volume of the plasma target and substantially reducing the amount of laser-produced debris.

[0009] Referring now to Figure 1, an embodiment of the present invention is shown and described. In Figure 1, an optical lithography system 10 is shown including optics 12, plasma portion 14, and lithography target 16. The optics 12 generally includes a fiber laser 18 and adaptive optics 20. As will be readily understood by one skilled in the art, fiber lasers, such as fiber laser 18, use optical fiber to culminate laser light to its diffraction limit while maintaining wave front control. As will be readily understood by one skilled in the art, fiber lasers use optical fiber to produce high quality optical beam (diffraction limited beam) which can be focused into a diffraction limited spot of minimum size, compared to the optical wavelength, by using wave front control. Wave front control ensures that all the beam distortions acquired during beam generation and transmission to the target are compensated for. More specifically, the fiber laser 18, as opposed to conventional solid state laser configurations, maximizes the organization of light at a given energy level to allow it to be focused on a relatively small area. Preferably, fiber laser 18 includes a high gain fiber amplifier, which allows for the production of laser pulses with pulse durations in the 1-ps to 1-ns duration range for reasons that will be described in greater detail. Also preferably, fiber laser 18 uses a diode-laser source, which enables enhanced control over the temporal profile of the laser pulse as will also be described in greater detail.

[00010] The adaptive optics 20, as will be readily understood by one skilled in the art, is a series of optical components including lenses mirrors and other known optical devices that adapt or change to achieve the desired image sharpness or image size. The adaptive optics includes deformable mirrors and high NA (numerical aperture) optics that allows enhanced control over the focusing of laser light generated by fiber laser 18. The adaptive optics will be described in greater detail below.

[00011] The plasma portion 14 generally includes a plasma target 30, plasma 32 and focusing element 34. The plasma target 30 is constructed of a material that generates plasma 32 upon sufficient laser energy being transmitted to the plasma target 30 by optics 12. The plasma 32 emits EUV radiation that is used for conducting lithography operations on lithography target 16. The focusing element 34 focuses the resulting EUV radiation on the lithography target 16.

[00012] The adaptive optics 20 serves to reduce the focused spot size on the plasma target 30 relative to that achievable with standard optics. Reduction of the focused spot size on the plasma target 30 reduces the amount of energy needed to be supplied to the fiber laser 18 to generate the desired plasma with the desired EUV radiation. Specifically, the pulse energy E_{pulse} provided by the laser and the fluence F, or flux of photons, of a beam are related through the beam cross-section area A. Specifically, $E_{\text{pulse}} = AF$. A is the cross-sectional area of a beam at any point and F is the fluence at that same point along the beam. Therefore:

$$A_L F_L \cong A_T F_T$$

[00013] Where $A_L F_L$ is the cross-sectional area of the laser beam at the laser multiplied by the fluence F_L of the laser light at the laser and $A_T F_T$ is the area of the laser beam at the plasma target 30 times the fluence F_T at the plasma target 30. The energy fluence on a plasma target 30 needed for generating plasma 32 with the desired EUV output is approximately $F_T \approx 1$ kJ/cm2. Therefore, the required fluence at the laser is determined by the ratio between the areas of the focused spot on the plasma target and the beam in the fiber of the fiber laser 18: $F_L \cong (A_T / A_L) F_T$. For light at ~1-$\mu$m wavelengths,

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