LASER GENERATED X-RAY SOURCE

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This invention is a Continuation-in-Part Application of Ser. No.: 08/295,283, filed Aug. 24, 1994 pending and Ser. No.: 08/339,755 filed Nov. 15, 1994 now U.S. Pat. No. 5,491,707. This invention relates to laser systems and in particular to high power, high intensity laser systems for generating X-rays.

BACKGROUND OF THE INVENTION

There is a growing need for reliable, economical X-ray sources for X-ray lithography. It is known that X-ray sources can be produced by illuminating certain metals with very high intensity laser pulses. Required intensity levels are in the range of 10^{11} to 10^{13} W/cm^2 for projection lithography and 10^{13} to 10^{15} W/cm^2 for proximity lithography. Average, power levels of about 3.5 Watts are needed for a production rate of about 10 wafers per hour. To meet future needs for high production rate lithography, average laser power levels up to about 500 Watts for projection and 1000 Watts for proximity are needed. In addition, the lithography process needs call for an X-ray spot diameter of about a few 100 μm. Designing a laser to meet these requirements involves solving several current problems. For nanosecond laser pulses, the energy needed to achieve the required brightness is 10 to 30 Joules per pulse and the repetition rate needed to achieve the required power is 100 to 300 Hertz. This high pulse energy design creates a serious problem. The amount of debris produced by nanosecond pulsed lasers focused on solid targets, when operated at the required brightness and power levels, is unacceptable. (Studies done by Rutherford and CREOL indicate that the debris level from metal targets is related to the pulse duration. The shorter the pulse duration the lower the debris level.) There is a research program underway to reduce debris by using solid xenon as an X-ray target, but it is at a very early stage and costs are uncertain.

Excimer lasers are well known. The construction and operation of these lasers are described in detail in Excimer Lasers, edited by C. K. Rhodes, Springer, 1984.

Workers at the Rutherford Appleton Laboratory have proposed (App. Phys. Lett. 55 (25), December 1989 and 71 (1), January 1992) an excimer laser system delivering a series of 10 to 15 pulses each pulse having a duration of 100 to 150 picoseconds with the pulse train duration of about 20 to 30 nanoseconds. The beam is incident on a moving metal film to produce X-rays. They have also proposed systems described in International Patent Application PCT/GB94/00928, International Publication Number WO 94/26080, published 10 Nov. 1994. These systems utilize a series of about 4 to 16 bunched pulses, each pulse having a duration of about 1 to 10 picoseconds and spaced apart by about 2 nanoseconds to produce pulse trains with durations in the range of about 20 to 30 nanoseconds. This prior art system is represented generally in FIG. **1**. A laser pulse generator **25** (comprised of a titanium sapphire oscillator pumped with an argon ion laser) generates a continuous train of pulses of visible or infrared light with a pulse duration of 1–10 picoseconds (ps) and a pulse repetition frequency of 80 MHz. The pulses from the pulse generator **25** are counted by a divider **24** which applies trigger pulses **13** at intervals of 1 ms, i.e. as a train of pulses with a repetition rate of 1 kHz.

This pulse train, or selected pulses from it, is applied to a synchronization and control unit **12**. In response to each trigger pulse **13**, the control unit **12** opens an optical gate **26** to apply one pulse from the pulse generator **25** to a laser preamplifier **27** which is also triggered with appropriate synchronization by the control unit **12** and which is capable of a repetition rate equal to that of the pulse train applied to it and boosts the energy of each pulse so applied. The output pulses of visible or infrared light from the preamplifier **27** are applied to a frequency converter unit **28** which in turn generates corresponding pulses of uv light (of which the frequency is, for example, two or three times that of the visible or infrared light). These uv pulses are passed through an optical multiplexer **29** which converts each seed pulse into a train of pulses such as sixteen pulses. These trains of pulses are are applied as seed pulses to an excimer amplifier **30** (also triggered with appropriate synchronization, by control unit **12**). The output pulses from the excimer amplifier are focused on target tape **16** by lens **19** of target chamber **15**.

The Rutherford approach does not use the excimer lasers efficiently as preamplifier and amplifier. In order to efficiently extract energy from an excimer laser amplifier, the energy fluence of the input pulse should be greater than 1 micro Joule per square centimeter and preferably as high as 1 milli Joule per square centimeter. As compared to the present invention, the Rutherford system has four important deficiencies: (1) it uses an argon-ion pump laser which is known to be extremely inefficient; (2) the output of titanium-sapphire seed laser requires third harmonic generation which also adds to the inefficiency of the system; (3) the KrF excimer does not have the power capability of XeCI excimer lasers; and (4) the Rutherford device does not utilize certain known energy enhancement technologies.

Laser pulse enhancement techniques such as q-switching and cavity dumping are well known.

What is needed is an efficient laser system that meets the needs of X-ray lithography to provide 1) high average power and high brightness, 2) low debris levels and 3) low capital and maintenance cost.

SUMMARY OF THE INVENTION

The present invention provides an improved high average power, high brightness laser system. The laser system comprises an XeCI excimer amplifier, an XeCI excimer preamplifier, a means for generating a picosecond seed pulse tailored for the XeCI preamplifier and the XeCI amplifier and a means for focusing the output pulse laser beam onto a spot smaller in area than 100×10^{-6} cm^2.

We first produce a seed laser beam consisting of a series of bunches of short duration pulses with a bunch frequency in excess of 100 pulses per second. These seed laser pulses are produced by a Nd:YAG pumped dye laser oscillator with a cavity dumper. The pulses in the beam are preamplified in a multipass preamplifier and the pulses are then multiplexed in a pulse train generator into a larger number of lower power pulses. A multi-pass laser amplifier then amplifies each pulse in the bunched pulse laser beam to produce an amplified pulse laser beam which is then tightly focused to so that the individual pulses are at brightness levels in excess of 10^{11} Watts/cm^2.

A prototype device built and tested by Applicants and their fellow workers has produced a pulsed laser beam with 50 ps, 30×10^{-3} Joule pulses at 1,120 pulses per second to provide a beam with average power of 34 Watts. Focusing