LOW COST, HIGH AVERAGE POWER, HIGH BRIGHTNESS SOLID STATE LASER

The invention relates to laser systems and in particular to high power, high brightness solid state laser systems.

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 brightness laser pulses. Required brightness 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. To meet future commercial lithography needs, average laser power requirements are about 500 Watts for projection and 1000 Watts for proximity. 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. The first is the correction of aberrations due to thermal distortion and self focusing in the laser rod. This problem is currently being dealt with by utilizing a Stimulating Brillouin Scattering (SBS) cell to remove these aberrations. SBS cell materials perform efficiently for laser pulses of several nanoseconds or greater. 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 30 hertz. This high pulse energy design creates two additional problems. 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. The final problem is the cost of the X-ray lithography system. Flash lamp pumped lasers involve high maintenance costs. Maintenance costs can generally be reduced by pumping with diode lasers. Unfortunately, laser diodes required for the 10 joule per pulse 100 Hz lasers costs millions of dollars.

What is needed is a 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 a high average power, high brightness solid state laser system. A laser produces a first pulse laser beam with a high pulse frequency. A pulse spacing selector removes from the first pulse laser beam more than 80 percent of the pulses to produce a second pulse laser beam having a series of periodically spaced short pulses in excess of 1,000 pulses per second. A laser amplifier amplifies the second pulse train to produce an amplified pulse laser beam which is focused to produce pulses with brightness levels in excess of 10^{11} Watts/cm^2. A preferred embodiment produces an amplified pulse laser beam having an average power in the range of 1 KW, an average pulse frequency of 12,000 pulses per second with pulses having brightness levels in excess of 10^{14} Watts/cm^2 at a 20 μm diameter spot which is steered rapidly to simulate a larger spot size. These beams are useful in producing X-ray sources for lithography.

In a preferred embodiment, the laser is pumped by diode arrays operating at a relatively high duty factor in order to minimize the cost of the pump diodes.

As compared with prior art high brightness lasers, we have reduced the pulse duration by about 2 or 3 orders of magnitude, from a few ns to 100 ps or less. We achieve our very high brightness by focusing on a very small spot, but we are able to simulate a much larger spot by very rapidly steering our high average power beam over the area we need.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing showing the principal features of a preferred embodiment of the present invention for producing high brightness pulse laser beams useful for X-ray lithography.

FIGS. **1A**, **1B** and **1C** are qualitative representations of the pulse shape at various stages of the embodiment shown in FIG. **1**.

FIG. **2** is a drawing showing in greater detain a first portion of the embodiment of FIG. **1**.

FIG. **3** is a drawing showing in greater detail a second portion of the embodiment shown in FIG. **1**.

FIG. **4** is a drawing showing the amplifier pumping configuration using laser diodes for the embodiment shown in FIG. **1**.

FIG. **5** is a drawing showing a cluster of tightly focused spots.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the present invention can be described by reference to FIGS. **1**, **2** and **3**. As shown in FIG. **1**, this embodiment consists of a mode locked Nd:YAG laser oscillator **2**, a pulse spacing selector **20**, a beam expander **22**, a polarizing beam splitter **26**, a double pass amplifier section **24** and a beam steering PZT **48** on which the amplifier folding mirror **38** is mounted. The output of amplifier **24** is focused to a tiny spot on moving copper tape target **27**. FIG. **2** describes the seed laser laser section of the embodiment which is for producing very short duration pulses at a very high repetition rate and FIG. **3** describes the amplifying section for amplifying the pulses to produce a pulsed laser beam with an average power level of about 1 kW with pulses at brightness levels in the range of 10^{14} W/cm^2 on spot sizes of about 20 μm diameter. And finally, FIG. **5** shows the result of a beam steering mechanism to generate a cluster of few 20 μm spots **52** over a 500 μm diameter circular area on a metal target.

SEED LASER

FIG. **2** is a diagram of a Nd:YAG mode locked oscillator type laser device **2**. A Nd:YAG polished rod **4** (3 mm diameter and 2.5 cm long) is longitudinally pumped by a 5 bar impingement cooled laser diode array **6** (part number SDL3245-J5). The diode pump array is a quasi-CW at 20 percent duty factor (about 200 μs ON and 800 μs OFF) and 50 Watt average. The diode array wavelength is at 808 nm which corresponds to strong absorption in the Nd:YAG. The output of the pump diodes are collimated in the longitudinal axis by an array of cylindrical micro-lenses **8**. A fast focusing lens **10** concentrates the pump light at the back end of Nd:YAG crystal **4**. The back surface of Nd:YAG crystal **4** has 5 m