LASER PLASMA X-RAY SOURCE

This application is a continuation of application Ser. No. 467,779, filed Nov. 19, 1990, now U.S. Pat. No. 5,003,543.

FIELD OF THE INVENTION

The present invention generally relates to systems which produce X-rays from plasmas and, in particular, to those systems which generate a hot plasma by focussing an intense, short-duration light pulse from a laser onto a target. In this type of X-ray source, the concentrated energy contained in the focussed laser beam effectively vaporizes the target material, raising it to such extreme temperatures that the vapor atoms are multiply ionized and X-rays are emitted when free electrons in the plasma recombine with the ions in the plasma. One application for plasma generated X-rays is in the field of lithography.

BACKGROUND OF THE INVENTION

In photolithography processes, light is passed through a mask having a desired pattern onto a light-sensitive substrate. Diffraction effects can degrade the replication when the mask includes fine-scale features comparable to the wavelength of light, typically on the order of one fourth (¼) to one half (½) micrometer. Recently, much attention has been focused on the use of X-rays for lithography applications since X-rays have much shorter wavelengths. Thus, X-ray lithography is one of the leading techniques being considered for producing the next generation of micro-electronic components.

Several sources for the production of X-rays for use in lithography have been developed. Electron-impact X-ray sources generally produce high-energy X-rays which are not stopped in the resist layer and can continue on to damage the substrate material. Synchrotron sources emit softer X-rays but are limited by high cost and large physical dimensions. Laser produced X-rays have been tested but have thus far yielded poor performance and efficiency.

It is generally known that X-rays having high light-to-X-ray conversion efficiencies can be produced if four criteria are satisfied: (1) the laser pulse intensity is greater than approximately 6 TW/sq cm. at the focussed spot on the target; (2) the focal spot is not so small that the expansion of the plasma causes rapid cooling; (3) the wavelength of the laser radiation is short enough to optimize the coupling between the laser pulse and the plasma target; and (4) an approximate target material is chosen.

The criteria outlined above may be met by more than one type of laser, including solid state and discharge-pump rare-gas-halide lasers. Discharge-pumped rare-gas-halide lasers, more commonly referred to as excimer lasers, produce pulses of shorter wavelength than solid-state lasers and allow more efficient coupling to the plasma target. Unfortunately, the pulses produced are generally too low in energy and too long in duration to give the instantaneous peak power required to produce a sufficiently high plasma temperature. As a result of low peak power, prior systems which generate X-rays using discharge-pumped lasers have yielded poor conversion efficiency. A laser of this type would require compression of the output pulse by an order of magnitude to produce the instantaneous intensity required for adequate light-to-X-ray conversion efficiency.

Presently, excimer lasers having pulse widths in the nanosecond range are available. However, the power output of these short pulse lasers is too low for generation of a plasma which will emit X-rays useful in lithography applications. On the other hand, the high power lasers produce pulses which are too long in duration to be useful in X-ray generation. It is generally believed that nanosecond length pulses are required for generation of X-rays from a plasma to allow the laser power to be put in the plasma before the plasma expands excessively.

SUMMARY OF THE INVENTION

The pulse compression technique of the present invention uses an electro-optical shutter which trims the output pulse provided by a master oscillator to a desired duration. The pulse is then split into several pieces which are sequentially passed through a laser power amplifier. After amplification, the pieces are reassembled into a single short pulse which is focussed at a predetermined focal spot on a laser-plasma target.

In order to introduce and then remove the necessary delays between the laser pulse pieces before and after propagation through the amplifier, separate paths, distinguishable by angle, are constructed for each pulse piece. The physical limitations of these systems, in particular, the required magnitudes of the angles in the optical delay paths, have heretofore either limited the realizable pulse compression ratios to small values or resulted in large, awkward, and complicated configurations. A poor degree of overlap between the angled beams from the master oscillator and the gain region of the amplifier can result in serious losses of laser energy. Since the gain medium of an excimer laser is known to be unable to store energy for more than a few nanoseconds, some of the available energy in the gain medium is wasted if the beams fail to fill the gain region for an appreciable fraction of the duration of the discharge. Furthermore, for beams with paths angled with respect to the electrode surfaces, additional energy is lost when the edges of the beams strike the laser amplifier electrodes.

The present invention provides a solution which shortens the output pulse of a high power excimer laser to a value which will produce the required intensity at the focal spot of the plasma target. The invention advantageously achieves this reduction in pulse duration without the substantial loss in output energy often associated with prior pulse compression techniques.

More specifically, in one embodiment, the system uses polarization to distinguish and separate pulses during the introduction and removal of the delays, thus reducing the number of angled paths required for a given compression ratio. In addition, the system advantageously utilizes an optical beam expander/reducer assembly to reduce the angular difference between the beams as they travel through the laser gain region and thus to allow more beams to pass through the amplifier without problems resulting from poor overlap with the gain region.

In an alternate embodiment, instead of separating the multiple pulses into two groups distinguishable by polarization, the pulses travel in two distinguishable planes. The number of mirrors required can be reduced by half since the pulses can travel along substantially similar paths in each plane. The expander/reducer lens