High Average Power Laser for EUV Lithography

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Abstract

We have demonstrated the operation of a high average power, all solid state laser and target system for EUV lithography. The laser operates at 1.06 µm with a pulse repetition rate of 200 Hz. Each pulse contains up to 400 mJ of energy and is less than 10 ns in duration. The EUV conversion efficiency measured with the laser is independent of the laser repetition rate. Operating at 200 Hz, the laser has been used for lithography using a 3 bounce Kohler illuminator.

Introduction

Commercialization of EUV lithography will require a high average power EUV source. Laser produced plasmas are the source of choice. Technical and cost of ownership analysis indicates that the laser source in this system must be capable of kilowatt average power, a pulse duration of approximately 10 ns. The preferred wavelength of operation is 1.06 µm. LLNL is developing diode pumped solid state lasers for this application. We have demonstrated initial operation of a 200 Hz, 400 mJ per pulse diode pumped solid state laser operating at 1.06 µm. This laser system is upgradable to the kilowatt average power level. This laser has been used to generate 13 nm radiation for lithography. In addition, no change of EUV radiation production efficiency was observed between single shot and operation at 200 Hz.
Laser system

The solid state diode pumped laser was designed and built at LLNL. The laser system employs a master oscillator with a 4 pass power amplifier and SBS (stimulated Brillouin scattering) phase conjugation (see figure 1).

![Diagram of laser system](image)

Figure 1: A schematic of the layout of the high average power laser.

![Photograph of laser system](image)

Figure 2: A photograph of laser system and associated laser optics and diagnostics.
The master oscillator is Q-switched and pumped by an array of solid state diode lasers. The oscillator rod is crystalline YAG. The amplifier is a YAG slab and is also diode pumped. The combination of crystalline laser medium and diode laser pumping yield a laser system capable of efficient high average and high peak power operation in a reliable all solid state design. The SBS phase conjugator is used to ensure a high quality output beam, near diffraction limited operation. A photograph of the laser system is shown in figure 2.

The laser is currently configured to operate at a repetition rate of 200 Hz with a pulse width of less than 10 ns with 400 mJ of energy per pulse for an average power of 80 W. The system has demonstrated stable operation with a rms power fluctuations less than 10% for many thousands of shots.

**EUV conversion efficiency**

Experiments were performed to determine the effect of repetition rate on EUV conversion efficiency. Figure 3 shows the conversion efficiency, Joules of radiation per electron volt of bandwidth per Joule of laser energy, as a function of laser intensity, for a series of single shot experiments from reference 3 and our data point for 200 Hz operation.

![Figure 3. EUV conversion efficiency as a function of laser intensity for single shot and 200 Hz laser repetition rate. The data was taken from a tungsten target with the laser operating at 1.06 μm.](image-url)
Although a new area of the target is exposed after each laser pulse, residual plasma and target ejecta could effect the conversion efficiency of subsequent pulses. The EUV radiation was measured with an solid state detector. The detector incorporated a multilayer EUV mirror and transmission filter to measure the emission near 13 nm from a solid tungsten target. First, we compared the x-ray conversion efficiency for single laser pulses selected with a Pockel cell from the high average power laser and compared the relative conversion efficiency to individual pulses from a 200 Hz pulse train. The measured conversion efficiency was identical for the two cases; the conversion efficiency is independent of the laser repetition rate at 200 Hz. We have taken this data and compared it to data from Spitzer using a single shot YAG laser under similar conditions. The data are in good agreement within the errors of the two experiments.

**Photoresist exposure**

The 200 Hz laser EUV source was used to illuminate the reticle plane of a multilayer coated 3 bounce Kohler condenser. As a demonstration of the utility of the laser source for lithography, a contact print of a zone plate mask was made with 13 nm radiation. The exposure of the 10 mm illuminated region took 5 s using SAL 605 resist.

This laser is capable of operating at 1.3 KHz with minor modifications. The target manipulator and data acquisition system are currently capable of operating at 1.3 KHz. When coupled with our 4 bounce imaging system, lithographic exposures will be made in a few seconds.

**Conclusions**

We have demonstrated the operation of a high average power, all solid state laser and target system for EUV lithography. The laser operates at 1.06 μm with a pulse repetition rate of 200 Hz. Each pulse contains up to 400 mJ of energy and is less than 10 ns in duration. The EUV conversion efficiency measured with the laser is independent of the laser repetition rate. Operating at 200 Hz, the laser has been used for lithography using a 3 bounce Kohler illuminator. The upgrade of the system to 1.3 KHz repetition rate will be used to perform lithographic exposures in a few seconds.

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