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Efficient generation of extreme ultraviolet radiation from Sn plasma generated with CO_2 laser

CO2 レーザー駆動 Sn プラズマからの極端紫外光放射高効率化に関する研究

K.Yoshida1), H.Matsukuma1), T.Hosoda1), S.Fujioka1), H.Nishimura1), T.Somekawa2), and T.Yanagida3)

吉田健祐1), 松隈啓1), 細田達矢1), 藤岡慎介1), 余語覚文1), 西村博明1), 染川智弘2), 柳田達哉3)

1) Institute of Laser Engineering, Osaka University (2-6 Yamadaoka, Suita, Osaka 565-0871, Japan)
2) Institute for Laser Technology, Osaka University (2-6 Yamadaoka, Suita, Osaka 565-0871, Japan)
3) GIGAPHOTON INC. (3-25-1 Building T, Shinomiya, Hiratsuka-shi, Kanagawa 254-8555, Japan)

1) 大阪大学レーザーエネルギー学研究センター 〒565-0871 大阪府吹田市山田丘2-6
2) 公益財団法人レーザー技術総合研究所 〒565-0871 大阪府吹田市山田丘2-6
3) ギガフォトン株式会社 〒254-8555 神奈川県平塚市四之宮3-25-1 T棟

Extreme ultraviolet (EUV) light emission from laser produced Sn plasma was studied for use in mass-production of semiconductors. Absorption rate of laser energy by the plasma was measured to investigate correlation between the laser absorption and conversion efficiency (CE) defined as a fraction of laser energy converted to EUV light energy. We developed an integrating photo-sphere to measure both CO_2 laser light absorption and CE simultaneously. It is found that CE increases almost proportionally to the absorption rate when a preformed plasma is generated with a Nd:YAG laser pulse arriving prior to the main drive CO_2 laser.

1. Introduction

Photo-lithography is a key technology for volume manufacturing of high performance and compact semiconductor devices [1]. Smaller and more complex structures can be fabricated by using shorter wavelength light in the photo-lithography. Extreme ultraviolet (EUV) of 13.5 nm is a promising light source for the next generation photo-lithography [2,3].

One of the most critical issues in development of the next generation photo-lithography is to increase energy conversion efficiency (CE) from laser to the desired EUV light. High power radiation from laser-produced plasma (LPP) is the one of leading technologies for generation high-power EUV radiation at 13.5 nm. In LPP, target material is thermalized with a laser pulse, then absorbed energy is converted to EUV energy via several atomic processes. Now a day, CO_2 laser is widely used as a main driver for efficient EUV light emanation because CO_2 laser-produced Sn plasma is optically thin for EUV light at 13.5 nm so that self-absorption is smaller than those generated with shorter wavelength lasers [4].

Absorption rate of laser is considered to contribute greatly to the conversion efficiency. The absorption rate with using a single CO_2 laser pulse is estimated as 40-50% according to a radiation-hydrodynamic simulation [5]. The relatively low absorption is a crucial problem for efficient generation of EUV light. In order to solve this problem and to increase the energy absorption (then CE), a double pulse method has been proposed where plasma scale length is extended by pre-pulse irradiation [6]. In the present paper, we report the measurement for the laser absorption rate and comparison with CE obtained for the same plasma.

2. Measurement apparatus and its measurement method

For the double pulse method, we used a Nd: YAG laser (energy: 5 mJ, pulse width: 52 ps, intensity: 1×10^{12} W/cm^2) for pre-plasma formation and CO_2 laser (energy: 65 mJ, pulse width: 20 ns, intensity: 1×10^{10} W/cm^2) for the main drive, respectively. We designed an integrating photo-sphere for the measurement of absorption rate [7]. A picture of the integrating sphere which has open windows for laser inlet and detectors is illustrated in Fig.1. The integrating sphere collects the light scattered by target globally, and then we evaluate the absolute absorbed energy. Thermopile which has wavelength sensitivity of between 6 and 14 mm (SSC Co., MR1001) was used as a CO_2 laser light detector. The absolute EUV energy was

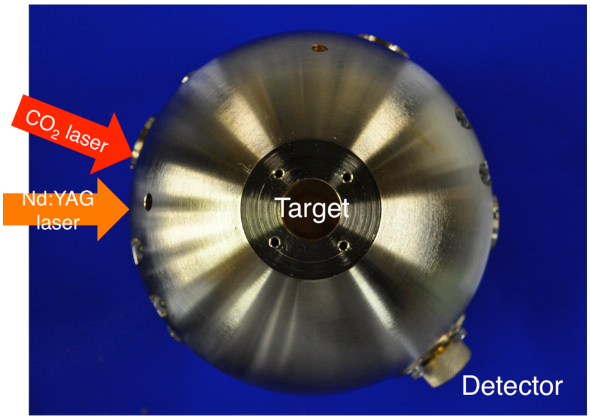

Fig.1. Scheme of the experiment with integrating sphere

measured with a calibrated EUV energy monitor (E-MON of Jenoptik [8]) installed at 37.5 degree with respect to the incident axis of the laser beam. The EUV energy monitor consists of an aperture, a pair of Mo/Si multilayer mirrors, a Zr filter, and an photodiode.

3. Experimental result

Figure 2 shows the dependence of CEs on interval of time between pre- and main-pulses. Figure 3 shows corresponding absorption rates. In Figs. 2 and 3, the case of single CO_2 pulse is also shown with dashed lines. CEs and absorption rates are slightly changed with time interval between the double pulses. On the other hand, drastic changing was observed between single and double pulses. CEs and absorption rates with double-pulse method are roughly 1.6 times larger than those with single pulse. This result suggests that the plasma scale length extension by pre-pulse laser plays a dominant role for boosting a CE.

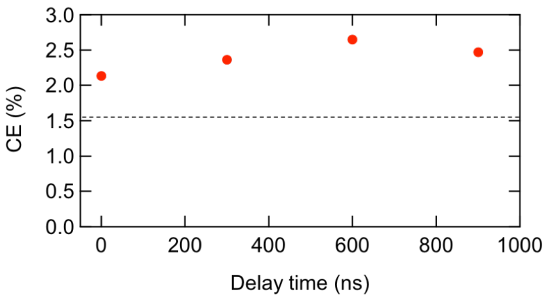

Fig.2. Comparison of Energy conversion efficiencies with single pulse (dotted black line) and double pulses (red dots)

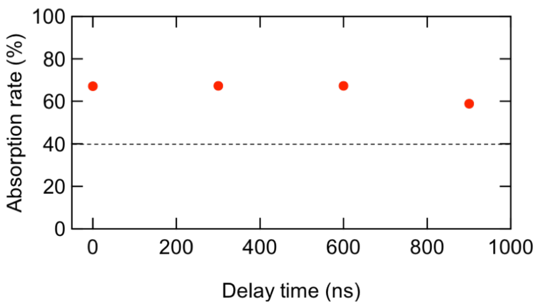

Fig.3. Comparison of absorption coefficients with single pulse (dotted black line) and double pulses (red dots)

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