ELSEVIER
ADVANCED
TECHNOLOGY

0030-3992(95)00043-7

Optics & Laser Technology, Vol. 27, No. 6, pp. 375–378, 1995

0030-3992/95 $10.00 + 0.00

Investigation of contact lithography in the 5–20 nm region with a laser plasma source

Y. GUO

In this paper, we present experiments of extreme ultraviolet (EUV) contact lithography based on a compact laser-produced plasma (LPP) and investigated the radiation of the plasma from Cu, Fe, W targets. We measured the depth of development of a polychlorinated methylstyrene (PCMS) resist exposed through a 100 l mm^{-1} Cu net for times ranging from 10 to 40 minutes using different targets.

KEYWORDS: contact lithography, laser plasma

Introduction

At present, extreme ultraviolet (EUV) lithography (5–20 nm region) is widely used in various practical applications, such as the production of VLSI microelectronic circuits on Si wafers with submicrometre features[1], the three-dimensional microelement etching LIGA technique[2], and so on. Various types of EUV source are considered for lithography, for example electron impacts, laser-produced plasma (LPP) or *Z*-pinchlike plasma source. Among these sources, the repetitive LPP source is particularly well suited to the needs of non-synchrotron based EUV lithography, because the source is small, stable and its emission curve has a peak in the EUV region with very low levels of hard X-rays.

Most work on developing LPP sources has been carried out using high power pulsed lasers, and some of these sources have seen successfully used in areas of lithography[3–6]. However, there is much to be done to improve LPP sources for lithography using a low energy commercially available repetitive laser. These sources have some potentially attractive features, such as low capital outlay, small size, etc. Although the average power of the LPP sources is small, these sources can be conveniently used as useful EUV sources by means of source optimization.

A high energy pulsed laser focused onto a solid target produces a dense, high temperature plasma. This plasma can emit both spectral lines and strong continuum radiation in the EUV spectral region. The continuum radiation may originate from a combination of bremsstrahlung, recombination radiation, and blended spectral lines in the case of targets having complex ionic configurations. It is well known from laser–plasma interaction physics[1] that EUV emissions can be generated five times more efficiently from plasma produced by a laser at 1. 06 μm wavelength.

Our experimental work is aimed at the development of lithographic conditions and procedures. The purpose of the work described in this paper is to demonstrate this improved performance and to expose EUV resists using a compact LPP source. The exposure results are also presented.

Experimental conditions and procedures

The experimental set-up of EUV contact lithography consists of a LPP source driven by a pulsed laser and exposure chamber. The laser used in this work is a Q-switched Nd : YAG laser, which produces 8 ns FWHM pulses of 1.06 μm radiation with energies up to 800 mJ and repetition rates up to 10 Hz. Its beam divergence is 0.58 mrad measured by a long focal length lens. These pulses are focused by an aspherical fused silica lens of short focal length (f = 100 mm) through a Pyrex window onto cylindrical targets. To prevent damaging the optics and to reduce reflection losses, the surfaces of the lens and the vacuum window are coated with antireflecting multilayers for the wavelength 1.06 μm.

As shown in Fig. 1, the target cylinders (19 mm in diameter and 25 mm long) are attached to a stepping-motor driven screw, and the target drive is usually set so

The authors are in the State Key Laboratory of Applied Optics, Changchun Institute of Optics and Fine Mechanics, Academia Sinica, PO Box 1024 Changchun 130022, People's Republic of China. Received 19 October 1994. Revised 6 December 1994. Accepted 9 January 1995.

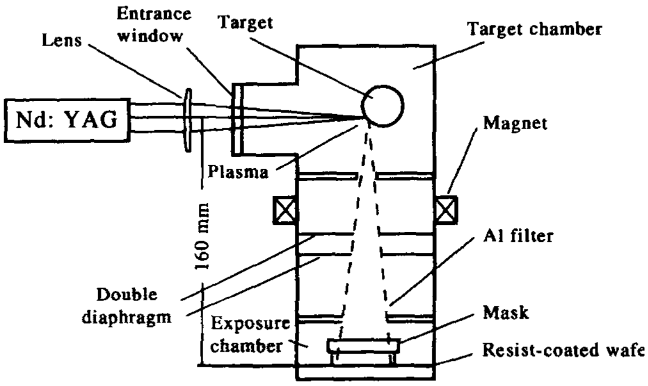

Fig. 1 The experimental set-up

that a fresh area of target material is advanced to the laser's focal position before each laser pulse, when the target is rotated on a helical drive.

The irradiance onto the laser target is mainly characterized by the resultant average power density obtained at the laser focus. The laser produces single-mode pulses that can be well focused. Usually, the damage craters are used as indicators of both proper laser operation and attainment of best focus. The crater diameters are about 140 μm for lower power shots on refractory targets, which is an upper bound on the minimum focal spot diameter. Thus, the lower bound on the averaged irradiance is about 5.6×10^{11} W cm^{-2}. This is sufficient to create a broadband emitting plasma.

The laser beam with an incidence angle of 27° to the target surface's normal is chosen as a compromise between a reduced EUV throughput to the wafer surface and an intolerable level of target debris in the exposure chamber containing the wafer. A negative resist, PCMS (polychlorinated methylstyrene)[7], which generally has a higher sensitivity to the 5–20 nm region, is spun to a thickness of 1.0 μm on the surface of 30 mm diameter silicon wafers. The resist is then prebaked for 30 min at 80°–90°C in a nitrogen atmosphere. The mask is placed in contact with the resist-coated wafer in a kinematic mount designed to allow precise alignment of both the mask and the wafer when clamped together. The assembly mounted mask/wafer will be inserted in the exposure chamber.

The aluminium filter[8] is placed in front of the resist and mask to avoid the effect of the visible light and UV part of the plasma radiation. The filter is composed of a $(CH_2)_n$ film with a thickness of 1.0 μm and an Al thin film with a thickness of 0.14 μm.

Unfortunately, the laser plasma produces a lot of particles. This is a serious problem in lithographic experiments and so a method has been proposed to eliminate the target's debris and material evaporation ejected from the plasma, in which a strengthened magnetic field isolation is induced between the target and the Al filter, and double diaphragms are inserted between the target chamber and the exposure chamber. We adjusted the distance from the source to the mask/wafer assembly to be 160 mm, and increased the repetition rates of the laser to 10 Hz, because a reduction of the EUV energy density per pulse, for example by increasing the distance, and an enhancement of the

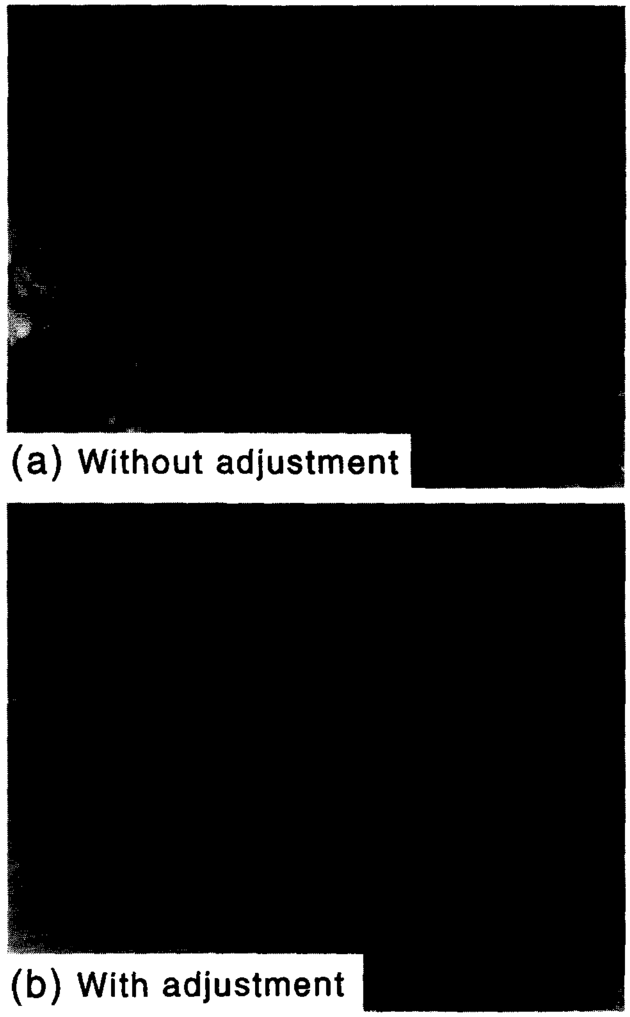

Fig. 2 Comparison photomicrographs of the Al filter surface obtained at the same exposure times using a Cu target. (a) Without adjustment; (b) with adjustment

repetition rates will yield the same average EUV power density. Figure 2 shows photomicrographs of an Al filter surface obtained at the same exposure times using a Cu target. The laser target chamber and the exposure chamber are evacuated to about 1.33×10^{-3} Pa by a diffusion pump.

After exposure, the mask and wafer are separated. The resist exposed is usually developed in a (*n*–amyl acetate):(iso-propyl alcohol AR) (3 : 1) mixture solution for 30–45 s, and post-baked for 30 min at 120°C.

Results and discussion

As shown in Fig. 3, the relative spectral characteristics in the 8–20 nm region from the Cu, Fe (steel), W target materials are measured using the constant-deviation type grazing incidence monochromator with an electron multiplier (EMT) having a CsI-coated CuBeO photocathode. The emissions from the Cu and Fe targets are predominantly dense line spectra overlaying weaker continua while the emissions from the W target are almost exclusively continuous with very few discrete spectral lines observable.

In the contact exposure method, three free-standing Cu nets (10 l mm^{-1} circular net, 20 l mm^{-1} circular net, and 100 l mm^{-1}–square net) are used respectively to simulate

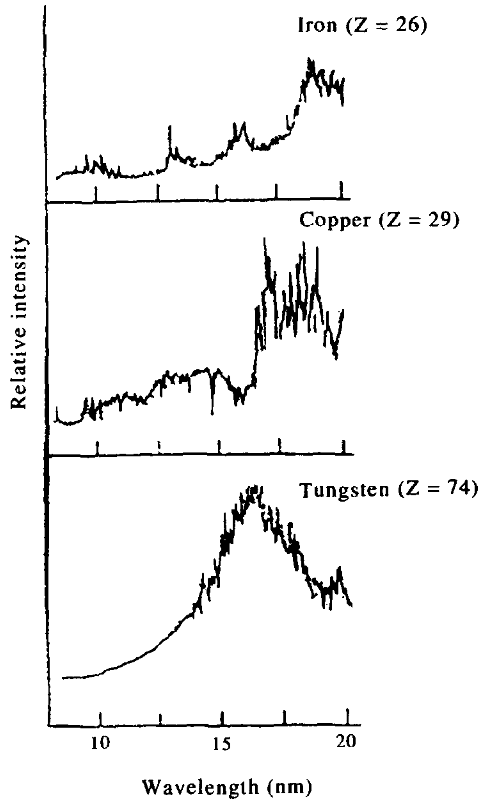

Fig. 3 The spectra from various target materials. The intensity scales are the same for all spectra

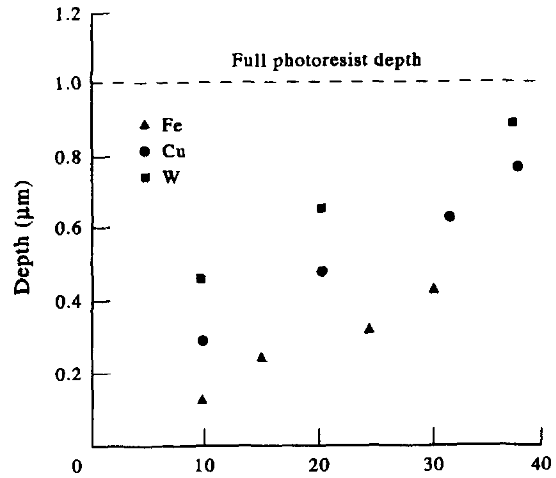

Fig. 4 The depth of the photosensitized (etched) resist as a function of exposure time to pulsed laser plasma radiation produced at a repetition rate of 10 Hz

the mask structure. After exposure to EUV radiation, the depth of the resist removed on development corresponds to the depth photosensitized and, therefore, to the amount of radiation received by the resist that is effective in bond formation. The depths of the development of the photoresists, exposed for times ranging from 10 to 40 min using Cu, Fe(steel) or W targets, are measured with a Talystep (made by Rank Taylor Hobson, Leicester), and the results are summarized in Fig. 4. It appears that radiation from W and Cu targets is at least twice as effective in exposing masked PCMS lithographs as the continuous emission from Fe, with W being slightly superior to Cu. The relative ordering of W > Cu > Fe for exposure efficiency may have a slightly greater spread than implied by Fig. 4, since the quantities of ablation products produced by

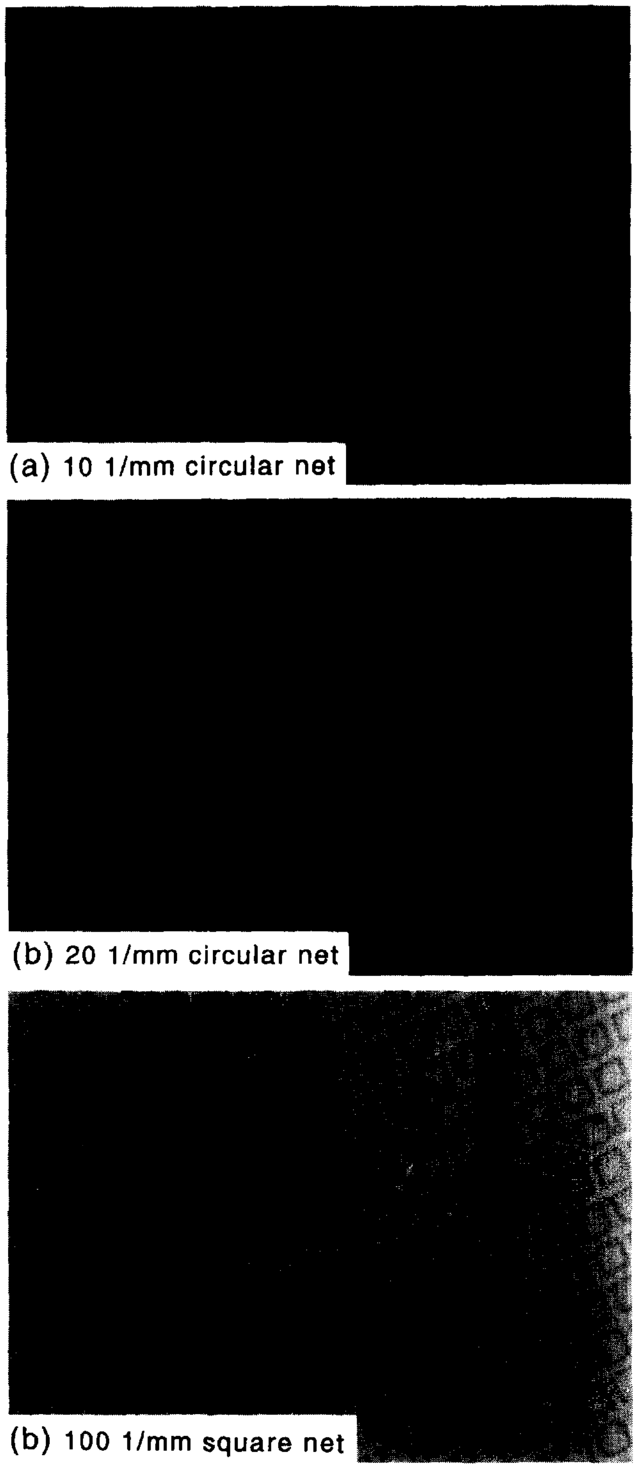

Fig. 5 Photomicrographs of developed PCMS resist exposed through Cu nets (magnification ~ ×770). (a) 10 l mm^{-1} circular net; (b) 20 l mm^{-1} circular net; (c) 100 l mm^{-1} square net

these targets fall in the order W > Fe > Cu. Finally, the Cu target is chosen as a best compromise target material. The photomicrographs of the developed patterns of PCMS resist are shown in Fig. 5, respectively (magnification ~770). The edge quality of the picture demonstrates some advantages of EUV lithography, including that the best pattern of about 0.75 μm depth can be provided in 40 min.

Conclusions

We have constructed a compact LPP source that has served as a laboratory replacement for synchrotron radiation sources in the EUV region. We have performed experimental work on LPP-based lithography and investigated the relative spectral characteristics of these plasma emissions from Cu, Fe, W targets and developed optimal exposure conditions and procedures. The exposures are made in a 1.0 μm thick layer of negative resist PCMS. We used a 100 1 mm^{-1} free-standing Cu net to simulate mask structure and have measured the depth of development of resists exposed for times ranging from 10 to 40 min using different targets. The results are summarized.

We believe that the results presented here represent a major advance of LPP for EUV lithography applications, and we suggest that an exposure device based on commercially available repetitive Nd: YAG laser technology can surpass electron impact sources in terms of brightness and wafer throughput and will be considerably cheaper and more compact than synchrotron systems.

References

1 **Chaker, M., Pepin, H., Bareau, V., Boily, S., Lafontaine, B., Fabbro, R., Toubhans, I., Faral, B., Currie, J.F., Nagel, D., Peckerar, M.** Laser created X-ray sources for microlithography, *SPIE Proc,* **733** (1986) 58–64

2 **Yangchao, T., Shaojun, F., Yilin, H., Ya, K., Shaoming, T.** Primary study of Deep-Etch synchrotron radiation lithography, *Acta Optica Sinica,* **14** (1994) 447–448

3 **Hoffman A.L., Albrecht, G.F., Crawford, E.A., Rose, P.H.** High brightness laser/plasma source for high throughput sub-micron X-ray lithography, *SPIE Proc,* **537** (1987) 198–205

4 **Crawford, E.A., Hoffman, A.L., Albrecht G.F., Sogard, M.R.,** Properties of a laser-plasma X-ray source for X-ray lithography, *J Vac Sci Technol,* **5** (1987) 1575–1587

5 **Kuhne, M., Petzold, H.C.** Soft X-ray radiation from laser-produced plasmas characterization of radiation emission and its use in X-ray lithography, *Appl Opt,* **27** (1988) 3926–3932

6 **Davis, G.M., Gower, M.C., O'Neill, F., Turcu, I.C.E.** Plasma X-ray source for lithography generation by a ≈30 J, 30 ns KrF laser, *Appl Phys Lett,* **53** (1988) 1583–1585

7 **Zewen, L., Yangchao, T., Yiguan, H., Ya, K.** Primary experimental results of synchrotron radiation X-ray lithography, *Chinese Sci Bull,* **39** (1994) 572–573

8 **Maolian, L., Mingyang, S., Guiying, S., Baojin, G.** Development of soft X-ray filter, *Acta Optica Sinica,* **6** (1986) 493–499