Introduction

Interaction of high-intensity radiation with molecules clusters bound by Van Der Waals force has recently shown a great interest, thanks to the intense radiation flux achievable in the EUV (Extreme Ultra-Violet) region. This range of rays is useful in so many different applications as like lithography, spectroscopy and microlithography[1,2]. In order to produce radiation with wavelengths in the scale of nm, an effective way already tested is to use laser induced plasma radiation available by focusing high-energy-density beams on molecules/atoms clusters with densities close to the solid ones. Thus, each cluster can contain several hundred millions of atoms within volumes of about 10 nm of section. The most utilized gases for different applications in literature are Xe[3-6,21,22,27], Ar[7-12], Kr[13,14], SF6[15,16] and mixes of Ar and Kr[17] or CO2 and Ar[18,19]. It's good to notice that a great number of above mentioned experiments have been done by means of solid-state lasers, as femtosecond Ti-Za[4,5,8-12,14,18,20,22] and Neodymium[3,7,13,15-17,21,27]. It is of great interest the way to produce plasma radiation through a TEA CO_2[12] laser source where the gas jet is initialized by a pre-pulse emitted by a low-power Nd:YAG laser source. Main authors show experimental results reporting a very high intensity of 0.6%, though they use quite a low fluence of about 10^{10} W/cm^2 compared with other works (usually 10^{12} W/cm^2).

This study mainly points to the experimental apparatus setup and analysis. In particular, laser interaction is got with Xenon gas that, under a proper laser pulse excitation, produces, besides a continuous light spectrum, a discrete line spectrum: one of which is really useful for lithographic applications, i.e. near 13.4 nm[20-22].

The interest on gaseous targets in EUV production for lithographic applications lies above all in the fact that during such interaction, unlike solid targets, this gases don't produce debris which could potentially pollute microchip wafer under construction. At this aim in this paper we describe improve of new EUV plasma laser source based on Xenon gas jet on our setup. The preliminary results will be shown.

Installation of the supersonic gas jet system inside the interaction chamber.

A pulsed valve is needed to inject a high-density flux inside the vacuum chamber, so as to produce a plume characterized by a large number of clusters.

In this experiment we set a pulsed valve electronically guided by a 12V-voltage signal able to close a high-pressure gas channel and, in the same time, suitable for maintaining low downstream pressure. Laser source automation has been possible through a train of TTL pulses, which set the timing of both laser system and pulsed valve, synchronizing laser event to the gas jet into vacuum chamber. Initially, the gas efflux has been studied by means of a microphone as regards temporal profile, obtaining a voltage signal proportional to valve aperture. An aperture time length of about 15ms was so measured.

Characterization of the laser induced plasma radiation in the EUV spectrum

First measurements of EUV emission of our source has been done focusing laser pulse emitted from two amplifiers that given in output only 800 mJ. Spot dimension 100 µm, with a fluence of $2.16 \cdot 10^{11}$ W/cm^2. Gas stream was expanded at 300 K and with a backing pressure of 1.4 bar. The dynamic value of chamber pressure reached $7.8 \cdot 10^{-2}$ mbar. In such condition the Hagena scale parameter was estimated to be $\Gamma > 2 \cdot 10^3$[23,24,25,26]. Cluster beam has been injected inside the interaction chamber through the pulsed valve at a frequency rate of 0.2 Hz. In order to maximize the IR/EUV conversion efficiency, laser beam would be focused on the gas plume within a distance range of 0.50±0.25 mm from the relief. This result has been achieved by analyzing the EUV emission signal versus the spot axial position. Moreover, EUV signal intensity could be improved by varying the shot delay respect to the valve electric pulse: an optimum delay of about 2 ms was found, minimizing the residue energy.

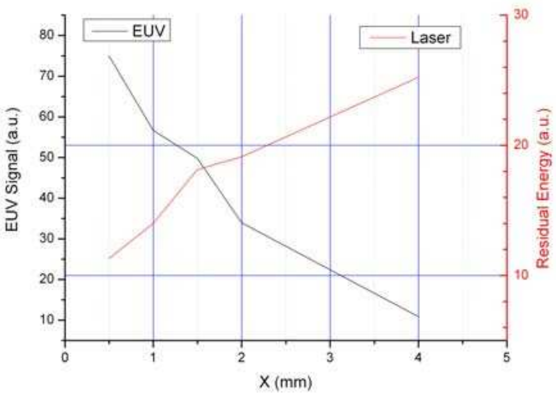

Figure 1

Conclusions

EUV emission energy of described radiation source is fitted vs. incident energy in Figure 2. Clearly, plasma energy is proportional to the incident energy signal. For this reason, IR/X-EUV conversion efficiency has been calculated for only two values of plasma energy, always imposing the maximum gain condition. Results are shown in Table 1.

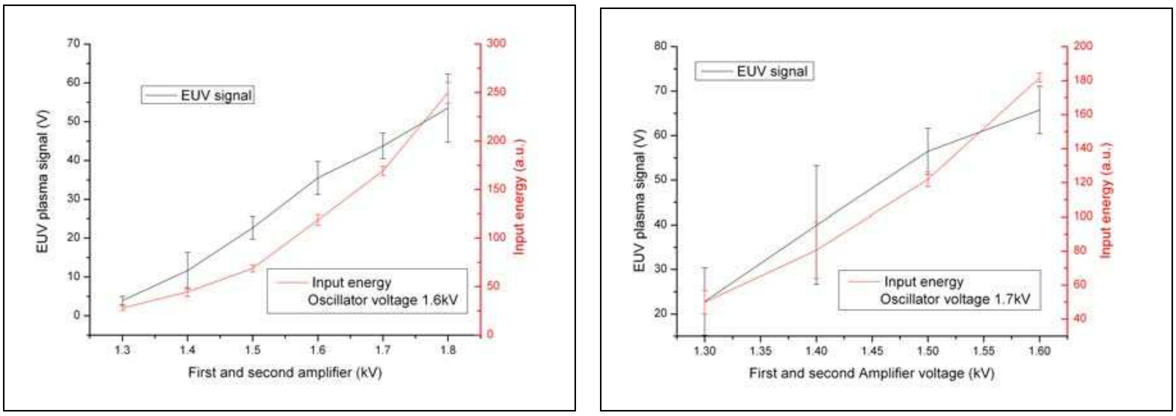

Figure 2 - EUV emission energy vs. incident energy

V_x (V)	Q_x (J)	J/cm^2	IR energy (J)	Laser fluence (J/cm^2)	Ex/EIR efficiency(%)
20	1.69E-07	1.05E-04	0.78	1.66E+11	0.38
80	6.76E-07	4.19E-04	3.94	8.39E+11	0.30

Table 1 – IR/EUV conversion efficiency

The two efficiencies are quite comparable and this agrees with EUV energy profile vs. incident radiation energy, shown in Figure 2.

Note that conversion efficiency tends to reduce with incident energy growing. It is probably due to the low pressure condition which cannot eventually guarantee the production of enough high-density clusters to absorb laser radiation for higher fluence values.

A remarkable aspect lays on the fact that such conversion efficiencies resulted in this work are larger if compared with other authors' ones, but almost similar to values obtained using CO_2 laser source[6], showing a radiation conversion near 0.6%. In conclusion we have shown the first result obtained in a our EUV plasma laser source setup and the first measurement showed a good conversion efficiency result compared with other authors'.

The efficiency of EUV radiation produced has been measured by means of a Pin Diode properly shielded with a 1μm-thick Zr-sheet, characterized by a high spectral transmission near 13 nm, and this proved the effectiveness of our radiation source to emit in the EUV range (13.4 nm) suitable for lithography.

References

1 H. Kondo, T Tomie, and H. Shimizu, *Applied Physics Letters*, 72, 2668, 1998.

2 S. Ter-Avetisyan, M. Schnürer, H. Stiel, U. Vogt, W. Radloff, W. Karpov, W. Sandner, and P.V. Nickles, *Physical Review E*, 64, 036404-1, 2001.

3 I. Yu Skobelev, et al., *Journal of Physics B*, 32, 113, 1999.

4 S. Ter-Avetisyan, *Phisical Review E*, 64, 036404, 2001.

5 M. Schnürer, et al. *The European Physical Journal D*, 14, 331, 2001.

6 H. Komori, et al. *Applied Physic B*, 83, 213, 2006.

7 I. Yu. Skobelev, et al., *Physical Review E*, 55, 3773, 1997.

8 G.C. Junkel-Vives, et al, *Journal of Quantitative Spectroscopy & Radiative Transfer*, 71, 417, 2001.

9 I. Yu. Skobelev, et. al., *Journal of Experiment and Theoretical Physics*, 94, 73, 2002.

10 G. C. Junkel-Vives, et al., *Physical Review A*, 64, 021201-1, 2001.

11 G. C. Junkel-Vives, et al. *Physical Review E*, 65, 036410, 2002.

12 J. Abdallah, at al., *Physical Review A*, 68, 063201, 2003.

13 S. Ya. Khakhalin, et al., *Journal of Optical Society of America B*, 12, 1203, 1995.

14 S. B. Hansen, et al., Physical review E, 71, 016408, 2005.

15 A. Bartnik, et al., *Quantum Electronics*, 27, 334, 1997.

16 A. Bartinik, et al., *Quantum Electronics*, 27, 68, 1997.

17 V. M. Dyakin, et al., *Quantum Electronics*, 27, 691, 1997.

18 C. Stenz, et al., *Quantum Electronics*, 30, 721, 2000.

19 I. Yu. Skobelev, et al. *Journal of Experimental and Theoretical Physics,* 94, 966, 2002.

20 P.V. Nickles, M. Schnürer, H. Stiel, U. Vogt, S. Ter-Avetisyan, I. Will, *Procceding of SPIE*, 4781, 2002.

21 S. Ter-Avetisyan, U. Vogh, H. Stiel, M. Schnürer, I. Will, P. V. Nickless, *Journal of Applied Physics*, 94, 5489, 2003.

22 P.V. Nickles, M. Schnürer, H. Stiel, U. Vogt, S. Ter-Avetisyan, and W. Sandner, *Procceding of SPIE*, 4504, 106, 2001.

23 O. Hagena, *Review of Scientific Instrument*, 63, 2374, 1992.

24 O. F. Hagena, *Physics of Fluids*, 17, 894, (1974).

25 J. Wörmer, V. Guzielski, J. Stapelfeldt, T. Möller, *Chemical Physics. Letters*., 159, 321, 1989.

26 J. W. G. Tisch, T. Ditmire, D. J. Fraser, N. Hay, M. B. Mason, E. Springate, J. P. Marangos, M.H.R. Hutchinson, *Journal Physics B*, 30, L709, 1997.

27 H. Stiel, et al., *Proceedings of SPIE*, 4781,2002.