J. Phys. IV France **11** (2001)

Development of a X-UV Michelson interferometer for probing laser produced plasmas with a X-ray laser

S. Hubert[1,2], Ph. Zeitoun[1], E. Béchir[2], L. Vanbostal[1], A. Carillon[1], F. Delmotte[3], P. Fourcade[1], M. Idir[1], S. Le Pape[1], M.F. Ravet[3], D. Ros[1] and G. Jamelot[1]

[1] *LSAI, Université Paris-Sud, bâtiment 350, 91405 Orsay cedex, France*
[2] *CEA/DAM, Centre de Bruyères-le Chatel, 91680 Bruyères-le-Chatel, France*
[3] *IOTA, Université Paris-Sud, bâtiment 503, 91403 Orsay cedex, France*

Abstract : We have developed and used a soft x-ray Michelson interferometer to probe large laser-produced plasmas. The aim investigated is to obtain electron density profiles and thus important informations on the plasma dynamic. This paper describes our design and presents some preliminary results using a nickel-like x-ray laser operating at 13.9 nm. Wewill present numericals results which show the interest of using x-ray laser to probe laser-produced plasma by interferometry.

1. INTRODUCTION

One of the major goal of the ICF programs consists in achieving 2D maps of the electron density in a region close to the critical density. Optical probing of the plasma, through interferometry, is a powerful and very sensitive diagnostic tool that can be used to study and characterize (in two-dimensions) this region of great interest. The electron density, N_e, in a plasma is related to refraction index, n, by $n = \sqrt{1 - N_e / N_c}$ where N_c is the critical electron density given by $N_{c[\mathrm{cm}^{-3}]} = 1.1.10^{21} \times \lambda^{-2}_{[\mu\mathrm{m}]}$ and λ the interaction laser wavelength. After propagating through the plasma, the probe beam undergoes a phase shift which can be measured by interferometry. Indeed the number of fringe shifts N_f (with negligible refraction effects) is directly proportionnal to electron density according to :

$$N_f \approx \frac{L}{2\lambda} \cdot \frac{N_e}{N_c} ,$$

where L is the plasma length.

However two major constraints limit the accessible electron density : refraction and absorption. The former places limits on the density gradients magnitude that can be tolerated and the latter on the maximum plasma density that can be measured. The deflexion angle θ of the probe beam induced by refraction effects scales as $\theta \propto \lambda^2 N_e$ and the absorption coefficient (inverse bremsstrahlung) κ_{ib} scales as $\kappa_{ib} \propto \lambda^2 N_e$. These strong scalings of both effects make advantageous to use short wavelength probe. For these reasons we chose to use a x-ray laser for probing plasma owing to their high brightness, their short wavelengh and short pulses duration. The Ni-like silver x-ray laser of the LSAI at Palaiseau [1] is thus well suited for this kind of studies by virtue of its properties. Its short wavelength (13.9 nm, J = 0-1) enables to minimize both refraction and absorption effects and futhermore it corresponds with the reflectivity peak of Mo/Si multilayer optics. Its short pulse duration (~ 40 ps) would minimize the fringe spatial blurring owing to the plasma motion.

2. THE X-UV MICHELSON INTERFEROMETER

Choosing an interferometer in the x-uv range for probing plasmas is governed mainly by technological considerations and plasma size. For plasmas relevant to ICF programs, they are generally of few millimeters size. For this reason we have chosen a Michelson interferometer which aperture is only limited by the one of the beamsplitter. Recent progress in multilayer technology enable the fabrication of x-uv beamsplitters like it has been demonstrated by L. B. Da Silva and *al.* [2]. We utilized beamsplitters fabricated in collaboration between the LSAI, the CEA and the IOTA in France. They have been optimized to work with an incidence angle of 45°. The beamsplitters have a $5 \times 5\,\mathrm{mm}^2$ active window and consist of 890 nm of silicon nitride membrane with 5.5 layer pairs of Mo/Si on each side. The original point in their fabrication consists in the Mo/Si coating on both sides of the membrane. The reason is related to the Michelson nature which needs to have the same optical path on each arm. To achieve this point in the x-uv range we chose to coat an other multilayer structure on the rear side acting as a compensating plate. Measured beamsplitter reflectivity is 23 ± 2 % and the transmission is 15 ± 2 % at 13.9 nm. Figure 1 shows both reflectivity and transmission versus photon energy measured at the LURE synchrotron with an incidence angle of 45°.

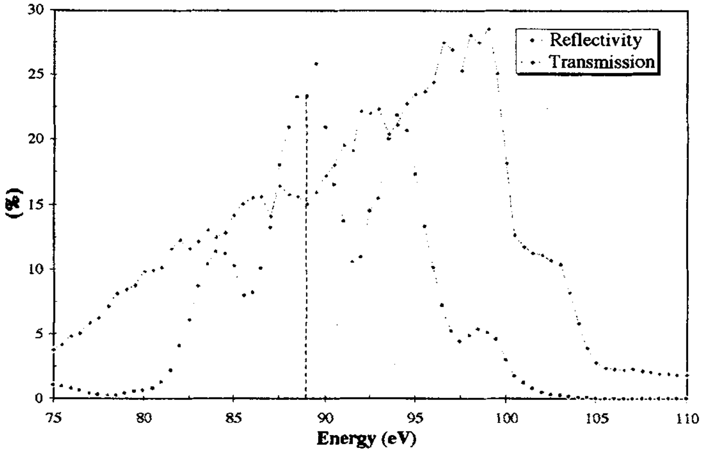

Figure 1. Measured reflectivity and transmission of beamsplitters at 45° incidence.

Due to multilayer structure on both sides of the membrane a Fabry-Perot fringe pattern modulates the reflectivity curve. By adjusting the coating parameters we succeeded in obtaining peak reflectivity close to the x-ray laser wavelength. The beamsplitter flatness has also been measured with a UV Fizeau interferometer and can be estimated to be less than 4100 Å on the whole aperture. The multilayer mirrors of the interferometer consist in 30 layer pairs of Mo/Si and have a measured reflectivity of 33 ± 2 % at normal incidence with a bandpass of ~ 4 Å.

Figure 2 shows the experimental setup we have used to test the Michelson interferometer.

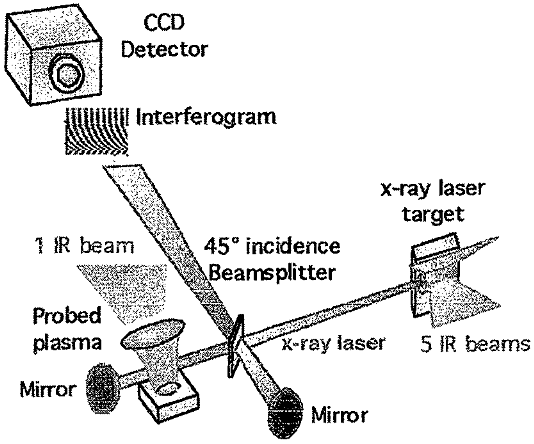

Figure 2. Experimental set-up.

To reduce the multilayer beamsplitter damages by the plasma blow-off we have designed the interferometer such as the distance between the plasma and the mirror is of 20 cm which leads to a total arm length of 70 cm. The interferometer stability is preserved during the pumping by a three-points system.

The x-ray laser crosses the probed plasma only once during its return way (from mirror to the beamsplitter).

Therefore the plasma must be created just after the x-ray laser crosses over the secondary target. The maximum time delay which can be probed is then given by the « beamsplitter-mirror-beamsplitter » distance of 40 cm that is to say ~ 1.3 ns.

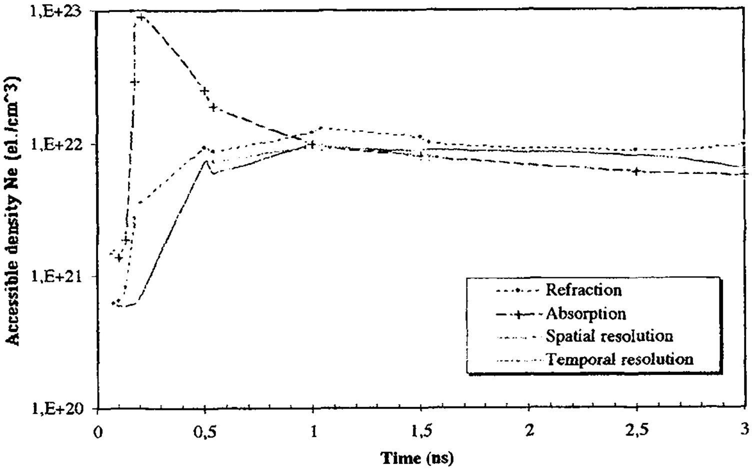

Figure 3. Accessible density for a carbon plasma.

We made preliminary modellings that showed that this delay was sufficient to probe both low Z and high Z plasmas up to high densities (~10^{22} el./cm^3). We used a 1D radiative-hydrodynamic code to describe plasmas and we wrote a post-processor program that calculates the corresponding interferograms. Taking into account the different restricting effects (refraction, absorption, spatial resolution of the detector, temporal resolution), we can estimate the accessible density values versus time and see the interferogram that we would record. Figure 3 shows results concerning a carbon plasma irradiated by an Nd : YAG 130 ps laser pulse at an intensity of 10^{15} W/cm^2. The different curves describe the maximum accessible densities for each limitation effects separated from the others. To obtain the accessible densities field we have to consider the four curves simultaneously.

3. EXPERIMENTAL RESULTS

Figure 4 shows an interferogram recorded in one 40 ps X-ray laser single shot. We can see the active window of the beamsplitter surrounding by its frame (Mo/Si coated too). Over this window we can see fringes in the upper half with a contrast of 23 %. The horizontal dark line in the center is the secondary target (100 µm thick). Note that on this image, the x-ray laser was not collimated so its brightness was no optimized.

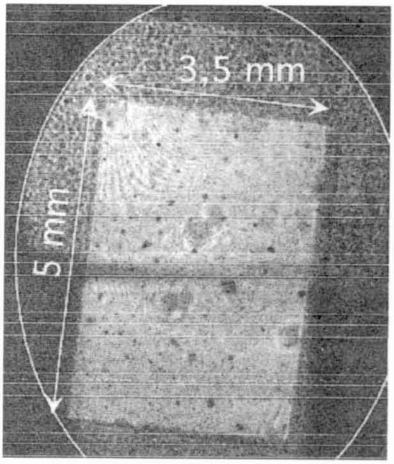

Figure 4. Interferogram recorded without plasmas.

4. CONCLUSION

We have developed and used a x-uv Michelson interferometer. We obtained preliminary results that show fringes with a not optimised contrast. However, some pumping laser problems prevent us to increase fringes contrast and probe plasmas.

Acknowledgements

We would like to thank J. Sobota (Akademie ved Ceske Republiky), FASTEC technology (England) and STEEM group (France) for their contributions.

References

[1] Rus B. et *al.*, Proc. of the 4th International Colloquium on X-Ray lasers, AIP Proceeding, **332** (1994) 152.
[2] Da Silva L. B. et *al.*, X-ray lasers Conference, Lund 1996.