Spectral properties of plasma mirrors generated by KrF lasers

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Introduction

KrF lasers provide a perspective alternative in inertial confinement and fast ignition fusion schemes as driver lasers [1,2]. The advantage of their short wavelength (248 nm) results in longer plasma penetration depth and thus, higher absorption with the mitigation of parametric instabilities. A further consequence of the short wavelength is that the interactions can still be considered as nonrelativistic, even at high $>10^{18}$ W/cm^2 intensities.

Short pulse KrF lasers are based on gas discharge systems which enable their use as direct amplifiers. For the amplification of the short (~ 100 fs) seed pulse (2ω of a dye laser, or the third harmonic of a Ti:sapphire laser) in the excimer amplifier, no additional pulse compression is neccesary, thus the laser pulse background can solely be attributed to Amplified Spontaneous Emission (ASE).

The new Fourier filtering technique enables us to increase the contrast to 12 orders of magnitude, thus the 700 fs pulse can interact with an initially steep, solid profile [3]. Absorption and spectral measurements of the reflected pulse were carried out with the upgraded laser system into which this technique was implemented. Such investigations may further highlight the relevance of the intensity contrast as an important laser parameter in other laser-plasma experiments, too.

Methods

The short (700 fs) KrF pulses were provided by an updated Szatmári-type hybrid dye-excimer laser system [4]. The 500 fs pulse length 497 nm central wavelength, 200 μJ dye laser pulses were frequency doubled in a BBO crystal, which was tuned to 248.5 nm, i.e. to the center of the KrF amplification bandwidth. Next, the UV seed pulse is sent into the six pass excimer amplifier chain.. The first stage of the nonlinear Fourier filtering is the preimaging with low numerical aperture (I) which is applied after the first pass. After the second pass stage II - i.e. the nonlinear part with the gas jet - is applied. Applying and omitting the Fourier filtering allowed us to adjust the intensity contrast from 5.5×10^5 to 10^{12} (low and high contrast cases). These are the first high intensity laser plasma experiments which were conducted by this new contrast improving method.

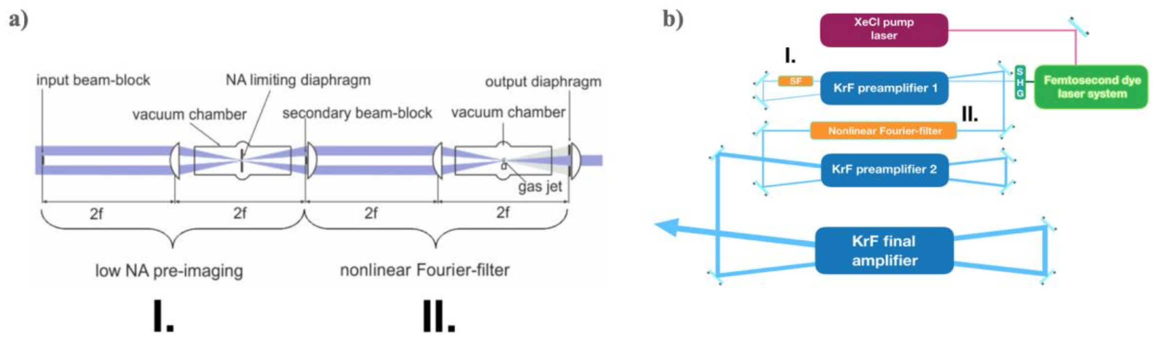

Fig. 1. Scheme of the nonlinear Fourier-filter [3], and that of the laser system [5].

At the end of the amplifier chain, the horizontally polarized pulse had a 4.5 cm x 4.5 cm cross section, and ~80 mJ pulse energy, while possessing a slight (~3.5 x 10^{-5} fs^{-2}) positive chirp. Up to 1.15 · 10^{18} W/cm^2 intensities were achieved by tight (f/3) focusing with an off axis parabolic mirror (30°, SORL). The focal spot had a FWHM size of 1.85 ± 0.1 μm in the horizontal, and 1.95 ± 0.1 μm in the vertical dimension. The ASE spot size was >1.5 mm without the filtering, and drastically reduced to about ~7 μm when it was used. The laser intensity could be varied using an aperture, with a simultaneous focal spot size measurement for each incident beam size. This allowed us to stay in the Fourier-plane throughout the experiment, and to scan an intensity range of more thant three orders of magnitude (10^{15} W/cm^2 to 1.15 · 10^{18} W/cm^2).

The targets were float glass plates with 500 nm thick gold or boron coating, fabricated with standard vacuum evaporation technique. Surface morphology of the targets was controlled, and showed a <λ/5 smoothness.

The p-polarized laser pulses had 45° angle of incidence and the reflected main pulse was first collimated and sent out of the vacuum chamber. For reflectivity measurements the pulse energies were determined using a callibrated energy meter. In the same time the reflected pulses were sent to a spectrometer with a resolution of 0.0027 nm for spectral characterization. For focal plane diagnostics and total x-ray yield measurements, an (IRD AXUV-100) x-ray sensitive photodiode with a 2 μm Al filter was placed viewing the front side of the target (~ 30 cm).

Results

Laser plasma reflectivity measurements were carried out as a function of intensity and intensity contrast. At lower intensities (10^{15} W/cm^2 to 10^{16} W/cm^2) our findings confirm earlier results [6,7]. It should be noted that even at moderate intensities reflectivity is significantly lower for low contrast pulses, and this difference decreases with increasing intensities (Fig. 2). Experiments from early 2000's demonstrated that even an ASE prepulse intensity of 10^8 W/cm^2 can cause photoemission and surface perturbations, all of which can modify the resulting reflectivity of the main pulse [8]. At the highest intensities, the ASE intensity reaches > 10^{12} W/cm^2, well above the breakdown limit of many dielectrics. The resulting long scale-length preplasma (>λ/L=30) interacts with the main pulse, resulting in low reflectivity, especially in the case of gold targets and low contrast pulses.

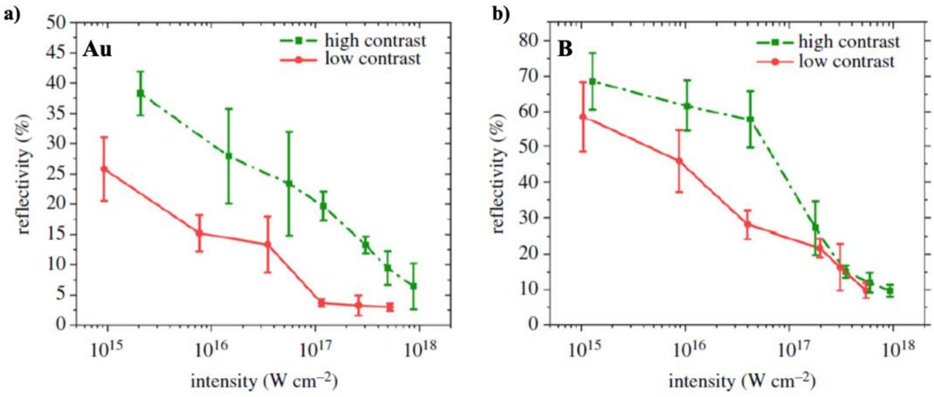

Fig. 2. Reflectivity measurments from a gold (a), and boron laser plasmas (b) [9].

The question arises, what mechanism could be responsible for the low reflectivity with high contrast pulses at high intensities. It should be mentioned that the rising part of the 700 fs long main pulses can produce intensities up to 10^{14} W/cm^2 1 ps before the peak, thus generating in a 0.1 λ preplasma. The relatively large angle of incidence favours resonance-absorption as well, but for the highest intensities the Brunel-absorption - or vacuum-heating - may alone give an 80% contribution. No well defined limit exists between the mentioned mechanisms, thus we suspect that in our recent experiments both collisionless effects takes place together with collisional absorption in the preplasma..

An interesting result is the laser intensity- and contrast-dependence of expansion velocity of the reflecting critical surface. During the experiments only blue-shifts were observed in the Doppler-spectrum, thus the plasma always expanded in the incident laser's direction. It is evident that cleaner pulses have a positive effect on the expansion velocity (Fig. 3).

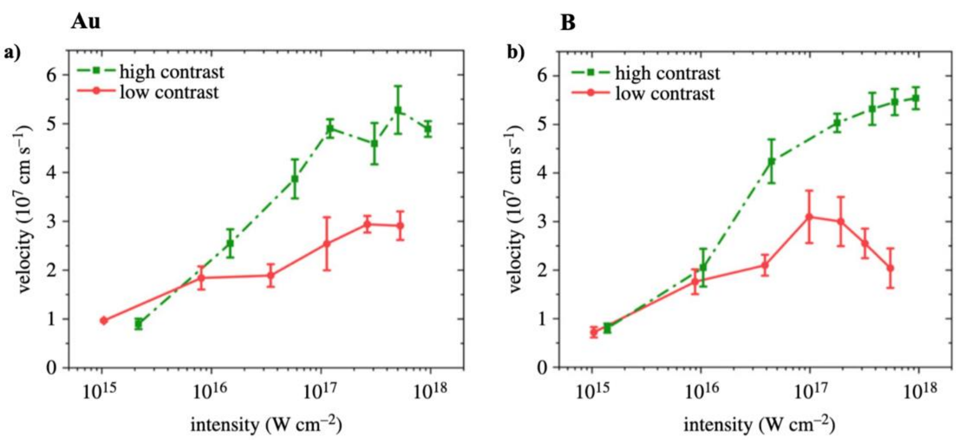

Fig.3. Expansion velocities for gold (a), and boron (b) laser plasmas. The velocities were derived from the nonrelativistic Doppler-formula [9].

A simple interpretation can be made of the results with boron targets at the highest intensities. Assuming purely Brunel-mechanism: $A = \frac{I_{abs}}{I_0} = 8\frac{v_{osc}}{c}sin^3\theta$, the electron oscillation velocity can be expressed as: $v_{osc} = \frac{e|E|}{m\omega} = \frac{e}{m\omega}\sqrt{\frac{8\pi I_0}{c}}$. This can be attributed to an electron temperature of 11 keV, and a corresponding ion acoustic velocity of $7.3 \cdot 10^7$ cm/s. The velocity gained from light pressure acting into the opposite direction can be written as $v_L = \frac{p}{\rho\delta}\tau \approx 1.1 \cdot 10^7 cm/s$, where p= I/c = 330 Mbar is the light pressure, τ is the half of the pulse length (350 fs), and ρ is the density. An estimated $\delta = \lambda/5$ is given as scale length. The difference of these values corresponds to the Doppler-derived velocities with good accuracy. The estimated acceleration of the critical surface block can also be given, with a value of $1.6 \cdot 10^{17}$g, which is the largest macroscopic acceleration achieved at this wavelength.

Funding

This work was carried out within the framework of the EUROFUSION Consortium and has received funding from the Euratom research and training programme 2014–2018 and 2019–2020 under grant agreement 633053. The views and opinions expressed herein do not necessarily reflect those of the EuropeanCommission. The support of the European Social Fund EFOP-3.6.2-16-2017-00005 - ‘Ultrafast physicalprocesses in atoms, molecules, nanostructures and biological systems’ is acknowledged, too.

References

[1] Obenschain SP, Colombant DG, Schmitt AJ, Sethian JD, McGeoch MW. Phys. Plasmas 13 (2006)

[2] Betti R, Zhou C. Phys. Plasmas 12, 110702 (2005)

[3] B. Gilicze, R. Dajka, I. B. Földes, S. Szatmári. Optics Express 25(17), 20791 (2017)

[4] B. Gilicze, Zs. Homik, S. Szatmári. Optics Express 27(12):17377-17386 (2019)

[5] Zs. Kovács, B. Gilicze, S. Szatmári, I. B. Földes. Front. Phys. 8:321. (2020)

[6] U. Teubner, J. Bergmann, B. Wonterghem, F. P. Schäfer, R. Sauerbrey. Phys. Rev. Lett. 70, 794 (1993)

[7] R. Fedosejevs, R. Ottmann, R. Sigel, G. Kühnle, S. Szatmári, F. P.Schäfer. Phys. Rev. Lett. 64, 1250–1253 (1990)

[8] I. B. Földes, J. S. Bakos, K. Gál, Z. Juhász, M. Kedves, G. Kocsis, S. Szatmári, G. Veres Laser Phys. 10, 264–269 (2000)

[9] Zs. Kovács, K. Bali, B. Gilicze, S. Szatmári, I. B. Földes. Phil.Trans.R.Soc. A378, 0043 (2020)