Cleaning KrF Laser Pulses with Plasma Mirrors

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Motivation

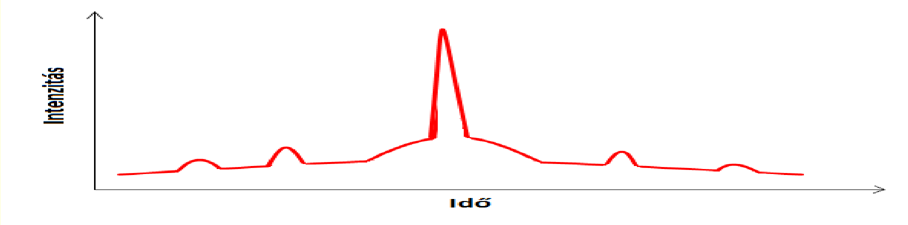
Plasma mirrors are the most efficient cleaning tools in the generation of ultrahigh contrast ultrashort laser pulses.

Idea (1991 Kapteyn et al.): Only the leading edge of the ultrashort pulse is above plasma threshold, i.e. prepulses and pedestals are transmitted by a transparent target, the short pulse is reflected and „cleaned”.

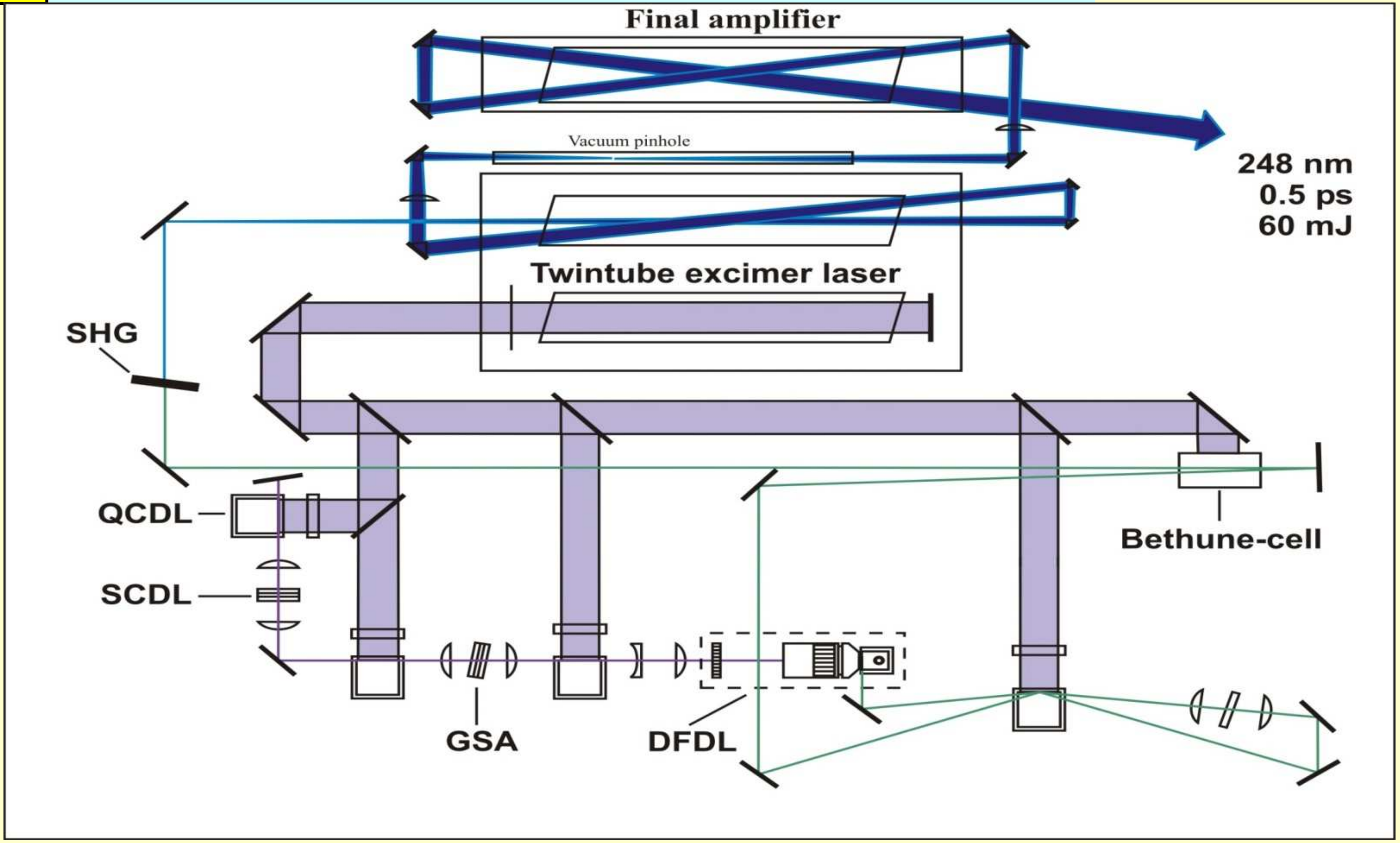
Plasma mirrors allowed more than 10 orders of magnitude contrast for Ti-sapphire (infrared lasers) allowing surface harmonics generation up to several keV (Dromey et al.).

The ultrashort KrF laser of the HILL laboratory is based on direct amplification. Only ASE prepulse is present – partially suppressed by off-axis amplification.
But: Surface photoionization by the 5eV KrF photons must be avoided,
prepulses < 10^7 W/cm^2 needed.

Uses: high-intensity interactions (>10^{17} W/cm^2)
low intensities (material studies, ablation)



The upgraded KrF system

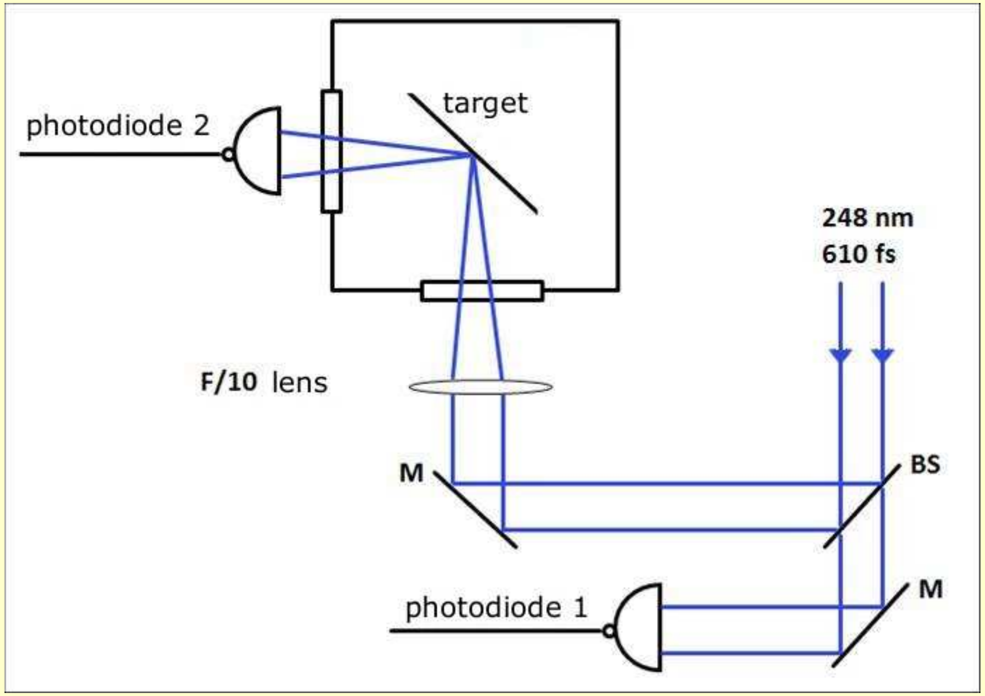


High energy contrast (>100) due to the spatial filter.

But: the ASE going through the pinhole is further amplified and focused into a small spot → the contrast is worse in focus (10^{18} to 10^{9} W/cm^{2}) → photoionization is present in case of interaction with solids.

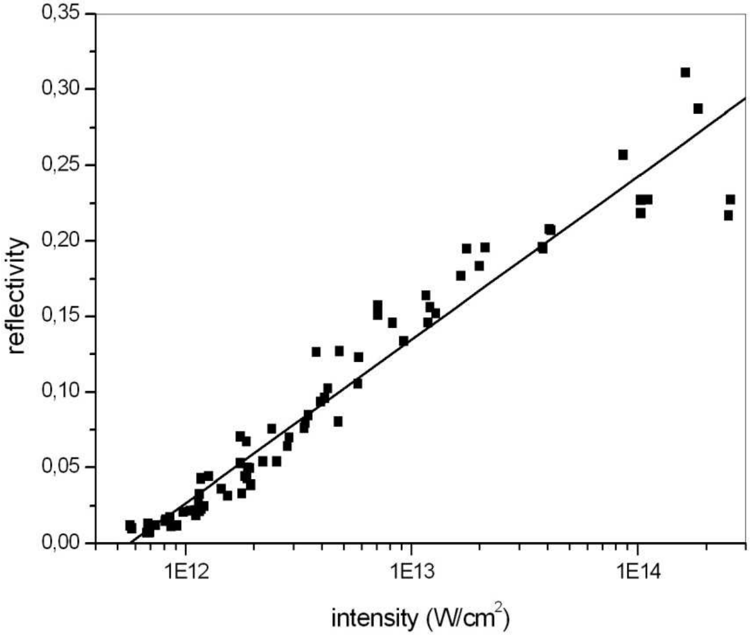
Better for ablation studies, worse for high-power.

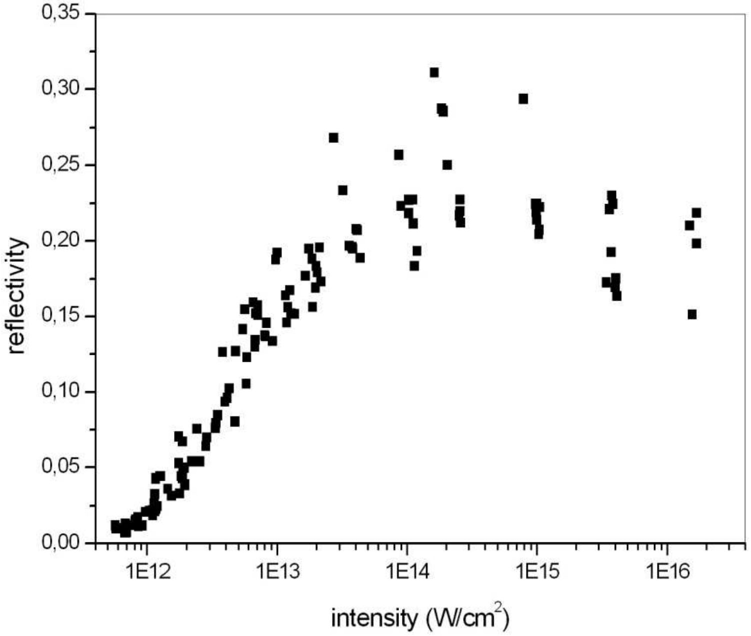
Experimental arrangement



Arrangement for the study of plasma mirror effect.
The laser beam is s-polarized.
The target is AR-coated.
Intensity variation by moving the lens.
First experiments were carried out with 45° angle of incidence.

Reflectivity increase and saturation



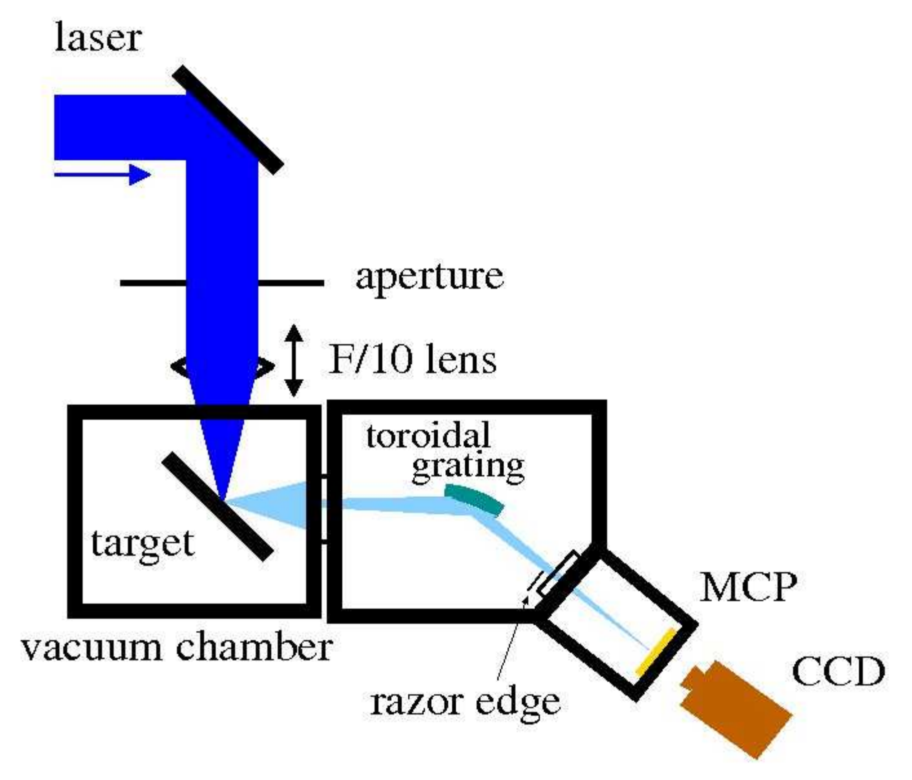


At 45° angle of incidence reflectivity starts to increase logaritmically above the plasma threshold (10^{12} W/cm^2) and it saturates above 10^{14} W/cm^2 intensity.

The maximal reflectivity was ~35%.

It is lower than that observed earlier (Fedosejevs et al.) with a 250fs pulse due to the longer duration, larger plasma, more collisional absorption.

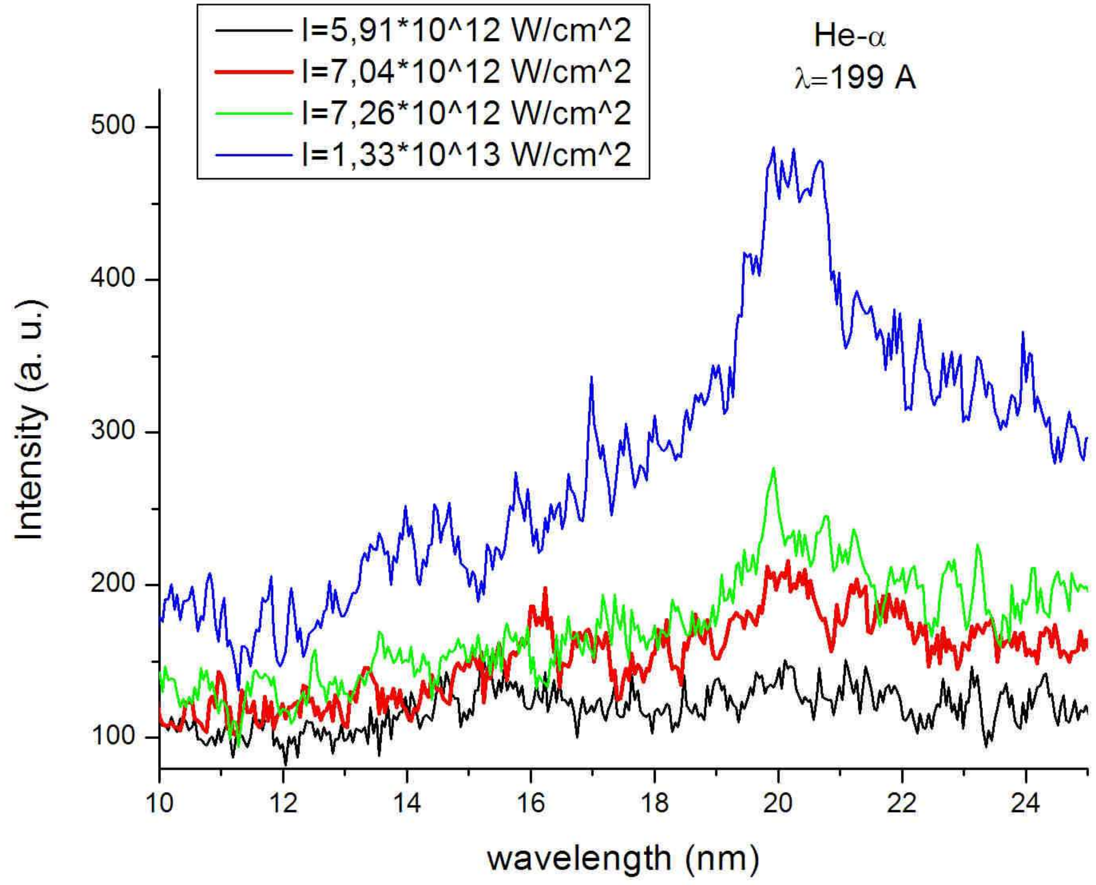
Spectroscopical measurement of the plasma parameters for optimal reflection



VUV spectroscopy of LiF (low-Z) target shows the increasing ionization with increasing intensity.

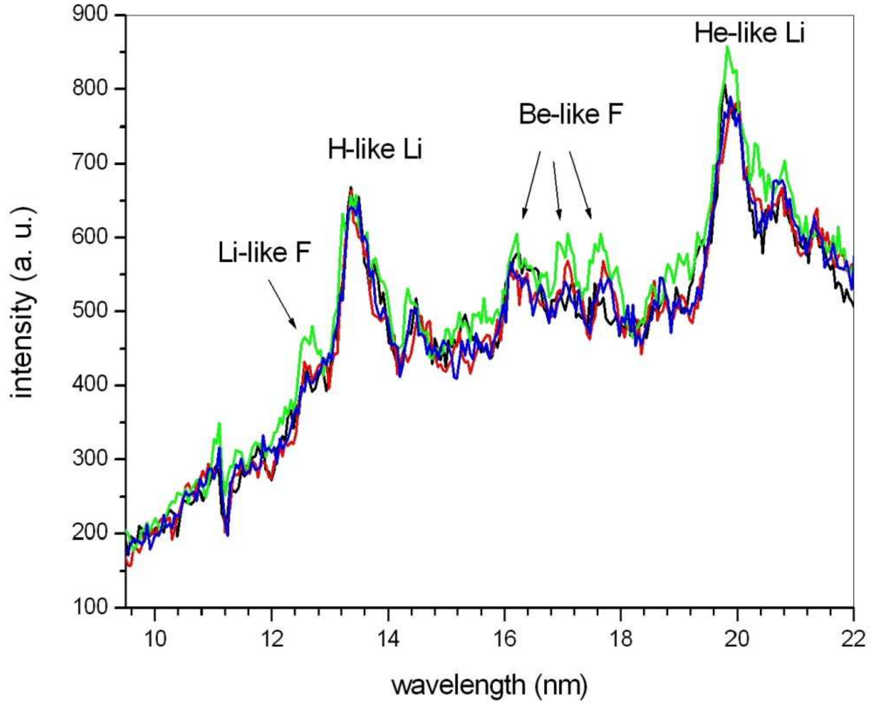
The 10-30nm spectra
(Li K-shell, F L-shell) follows the temperature evolution up to the appearing nonlinear behaviour,
i.e. harmonics generation above
10^{14}W/cm^2.

LiF spectra above plasma threshold



Whereas below 10^{13}W/cm^2 hardly any structure is visible, the Li He-α line appears. The satellites from the neutral Li are also visible above 200 Å giving a broadening of the line. It corresponds to a temperature of 5eV according to the collisional radiative model NOMAD of Yu. Ralchenko for 2-component materials.

Spectral properties near saturation



10^{14}W/cm^2

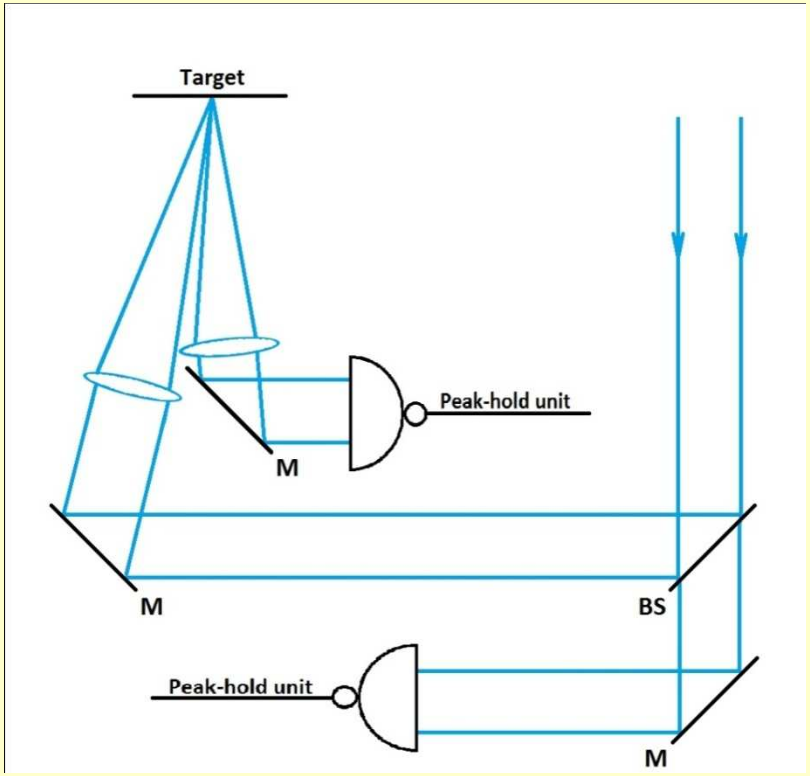
Above 5×10^{13} W/cm^2 the Ly-α intensity becomes as intense as the He-like feature, corresponding to ~20 eV temperature (coll.-rad. model).

Also the second ionization potential of Li is 75.638 eV, from which a temperature of 25 eV can be estimated.

The appearance of Be- and B-like fluorine lines around 14 and 16 nm give the same temperature. This is the optimum temperature for the plasma mirror effect.

(D. Salzmann: Atomic Physics in Hot Plasmas)

Experimental arrangement for near perpendicular angle of incidence



The laser beam is s-polarized.

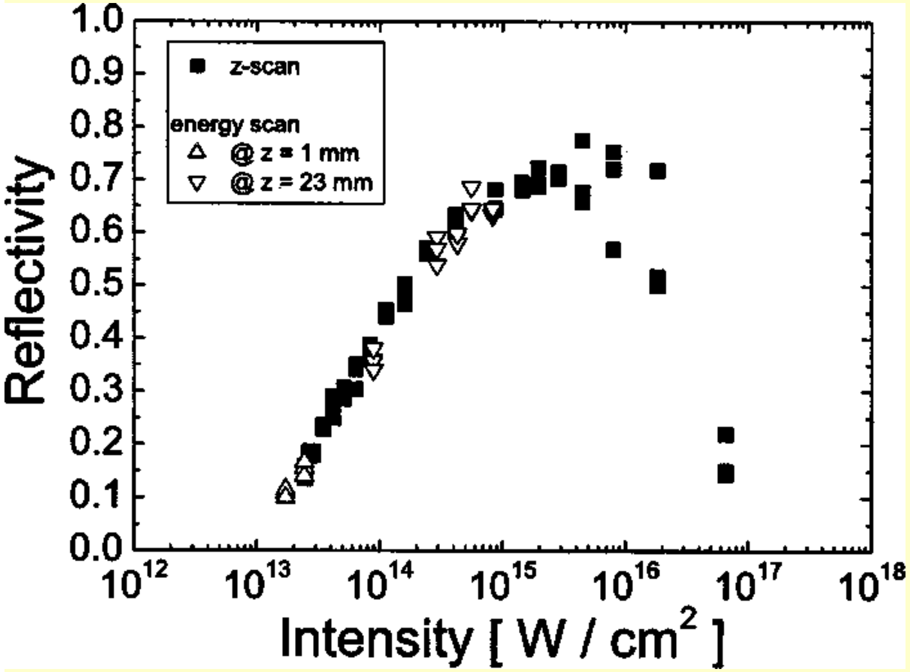
The target is AR-coated, each shot on fresh surface.

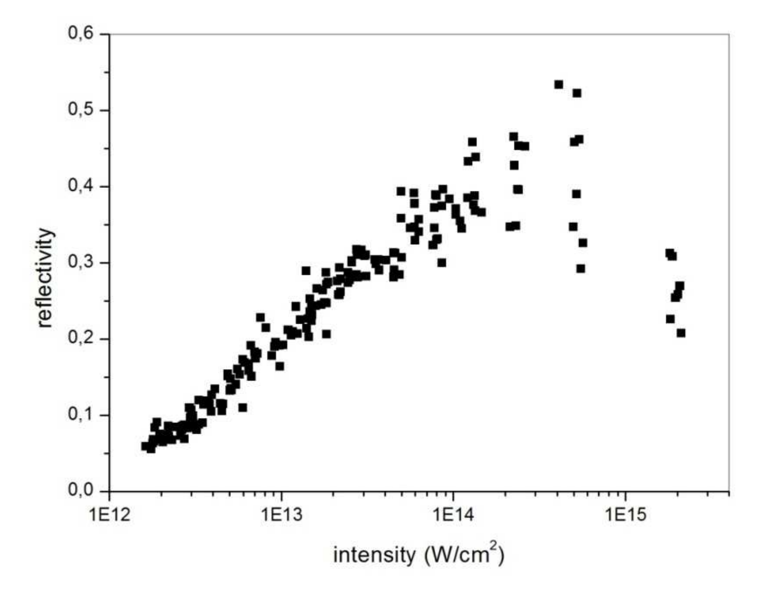
Intensity variation by moving the focusing lens.

Experiments with 12.4° and 8.2° angle of incidence.

The detectors are equipped with peak-hold detectors and microprocessors and fiber coupled in order to reduce noises.

Comparison with Ti-sapphire plasma mirror





Specular reflectivity for a pulse duration of 500 fs and an angle of incidence of 19°. Ti-sapphire laser.
Ziener et al, J. Appl. Phys.
93, 768 (2003)

Nearly 50% reflectivity was obtained for a pulse duration of 620fs with 12.4° angle of incidence, using a KrF laser!

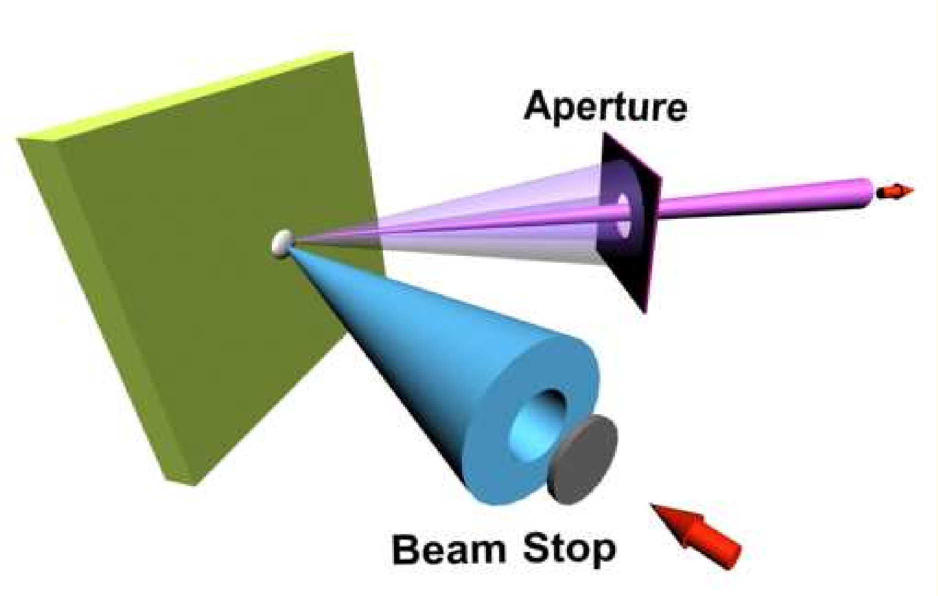
Methods for applications

- The observed reflectivity makes the direct application for high-power experiments difficult, but even in this form it can well be used for material studies (e.g. ablation) in which case the total energy is not critical.
- It is expected that after pulse compression to ~100 fs pulse duration the reflectivity becomes higher, and plasma mirror suppresses prepulses from compression, too.
- Using the plasma mirror before the last amplifier in case of higher amplifier may be a good compromise. As KrF amplifiers work in saturation, it does not cause a significant energy loss. On the other hand during the single pass of the last amplifier no significant ASE prepulse is generated, as it is linearly amplified.

Application possibilities

In case of applying the plasma mirror before the last amplifier, we expect practically no energy losses and higher contrast and better beam quality because of the diffraction-limited properties. A beam-stop - aperture arrangement may even result in spatial filtering of the beam and the use of not-coated targets for plasma mirror.

The mirror has to be placed into the (diffraction-limited) focal spot, then there is no structure in it. It is a secondary source of radiation, i.e. A spatial filter, cleaning the beam from high spatial frequency components.



KrF lasers remain attractive short-pulse drivers for clean x-ray generation experiments.

Summary

- Plasma mirror effect was demonstrated for KrF lasers.
- The optimum intensity was determined to be ~10^{14}W/cm^2, corresponding to a plasma temperature of 20-25eV.
- The maximum reflectivity of ~50% was reached, i.e. according to the expectations lower than for the infrared radiation.
- Methods for direct applications and configurations for using it before the final amplifier are considered.