Real-time characterization of plasma evolution by diffraction imaging

Application Note

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I. Introduction

Femtosecond (fs)-laser ablation is considered as a unique technique for material processing that gives the opportunity for precise micromachining, material synthesis, growth of thin films and others. Such a wide range of technological applications stimulates the interest in the physical processes that accompany laser ablation. When an intense ultrashort laser pulse hits opaque condensed matter, the laser radiation is absorbed within a thin layer of the material and the electromagnetic energy is converted into electronic excitations. The major processes during laser-matter interaction are electron heating by the laser field and the subsequent complex electron dynamics. In case of fs-laser-matter interaction transient material properties such as the density of quasi free electrons and therefore the plasma frequency, the absorption coefficient, and others strongly depend on the parameters of the applied laser field. To observe the time-dependent material response and the plasma evolution on the impact of intense laser pulses, we have developed a pump-probe setup utilizing diffraction of an ultraviolet (UV) probe beam (Figure 1).

II. Experimental setup

Near Infrared (NIR) pulses at 800 nm with a duration of 50 fs generated by a regenerative Ti:Sapphire amplifier system induce strong light-matter interaction. A frequency-doubled fraction of the original NIR beam serves as ultraviolet probe. A motorized linear stage enables a variable time delay up to 2 ns. NIR pump and UV probe pulses are superimposed using a dielectric mirror. The excitation pulses as well as the probe pulses are focused collinearly by a lens with 50 mm focal length onto thin metal foils serving as samples. The transmitted NIR light is blocked with a color filter; the transmitted and diffracted UV light is monitored by the Andor Neo DC152 QC-FI scientific CMOS (sCMOS) image detector in dependence of the delay time between excitation and probe pulse. The Andor Neo sCMOS camera provides a high spatial resolution due to the small pixel size of 6.5 µm and at the same time a high dynamic range as well as a high frame rate. The high spatial resolution is necessary to resolve the diffraction pattern, the high dynamic range is essential to resolve the high intensity differences between the constructive and destructive diffraction features.

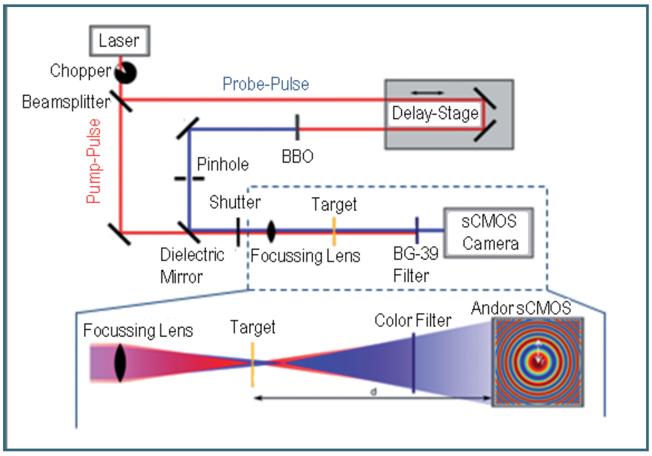

Fig. 1. Schematic experimental setup. A fs-NIR pump pulse induces a plasma within the focus resulting in material ablation. A time delayed and frequency doubled pulse probes the plasma dynamics. The transmitted probe beam which shows characteristic diffraction features is monitored by the Andor Neo sCMOS camera.

III. Results and discussion

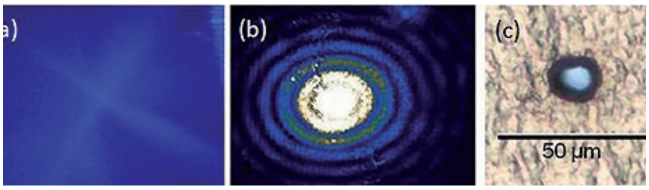

Fig. 2. Laser ablation studies on a 70 nm thick Aluminum foil (a) Diffraction image of the 2 ns time delayed probe pulse, (b) Diffraction pattern after several ms time delay. (c) Optical microscope image of the machined Al foil.

In first experiments a 70 nm thick aluminum (Al) foil was machined with Fourier limited NIR pump pulses. Two ns after the illumination a low intense cross like diffraction image could be recorded (Figure 2a). Only a low number of photons of the probe pulse are transmitted through the excited matter. With ongoing time the plasma should expand. This comes along with a reduced charge carrier density resulting in a decreased plasma frequency. The plasma frequency defines the photon energy above which the plasma becomes increasingly transparent. The diffraction pattern from the final machined structure is shown in Figure 2b. A more or less circular symmetric pattern with at least five observable diffraction orders is recorded. The resulting structure was analyzed by optical microscopy and shows a 10 µm hole. From these first results we can conclude: (i) the optically excited material is at the beginning intransparent for the UV probe (ii) after the excitation the matter density stays high for more than a few nanoseconds still blocking the probe; (iii) the pump pulses produce holes on the micrometer scale. Diffraction patterns of the UV probe from these structures can be observed after the plasma has disappeared. This indicates that at early times the probe pulse is not blocked by a solid foil, but by a dense plasma.

IV. Summary

We have shown that the evolution of a laser induced plasma can be monitored via the time resolved transmission of laser pulses in the UV. The Andor sCMOS is suitable for recording single shot images of the UV beam and weak features resulting from its diffraction. The studies will be extended to investigate the plasma evolution in more detail.

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