11.15 CFI4

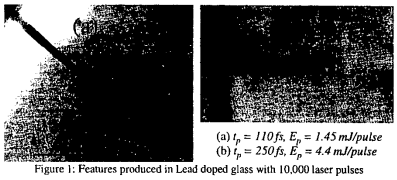
Femtosecond micro-machining at atmospheric pressure near air-ionization threshold

Lawrence Shah, Martin Richardson, Jesse Tawney, and Kathleen Richardson

Laser Plasma Laboratory, School of Optics & CREOL, University of Central Florida
4000 Central Florida Blvd, Orlando, FL 32816-2700, USA.
Tel: 407 823 6819 Fax: 407 823 3570 Email: mcr@creol.ucf.edu

Femtosecond laser pulses are capable of producing very small features (on the order of 1 μm) without significantly modifying the surrounding bulk material. Furthermore, it is well known that these pulses produce very smooth and deterministic features when compared with conventional laser processing [1]. Since it is common for intensities to exceed 10^{15} W/cm^2 during femtosecond ablation, several experiments have been performed at low pressures (< 10^{-3} mbar) in order to avoid unwanted nonlinear reactions with the surrounding atmosphere. However processing in ambient atmospheric conditions would be preferable for femtosecond laser processing to be useful in commercial applications We are therefore making a detailed study of femtosecond and subnanosecond ablation in glasses, ceramics, carbon composite, and metals in order to determine the influence of air on characteristics such as penetration rate and surface quality

Thus far, we have been able to produce repeatable features (between 50 and 75 μm in diameter), without evidence of significant thermal or mechanical shock to the surrounding material, in several dielectric materials using femtosecond laser pulse ablation in air. We have performed several experiments with laser intensities both above and below the threshold for visible plasma generation in air. In these experiments, no degradation of feature quality or reduction in ablation rate has been observed as a result of air ionization. In Figure 1, the feature produced using femtosecond laser pulses is both longer and smoother than the feature produced using subnanosecond laser pulses under similar experimental conditions. Moreover Fig.1(a) shows that features with aspect ratios > 40:1 can be produced with femtosecond laser pulses. More recent experiments conducted with a variety of metal foils have yielded comparable results. We are now studying the complex nature of the plasma/air interaction mechanisms and how they influence the ablation process. These machining experiments have been performed using the laser output from a Ti:Sapphire/Cr:LiSAF femtosecond laser system, producing 110 fs (FWHM) laser pulses with ~1 mJ/pulse compressed and 250 ps (FHWM) laser pulses at ~3 mJ/pulse uncompressed, at 845 nm. The laser output is focused by a 20 cm focal length fused silica lens onto the target material, which is positioned by a precision 3-axis micrometer stage.



(a) t_p = 110 fs, E_p = 1.45 mJ/pulse
(b) t_p = 250 fs, E_p = 4.4 mJ/pulse

Figure 1: Features produced in Lead doped glass with 10,000 laser pulses

In addition to optical and scanning electron microscopic analysis, we will report on optical probe experiments and chemical analysis of the debris created during femtosecond processing. These studies will help in understanding the influence of the ambient atmosphere on plasma propagation through the target material and on the chemical reactions occurring after the impact of the femtosecond pulse. These studies are critical to assessing the commercial utility of femtosecond laser processing for various materials.

Reference:

1. C, Momma, B.N. Chichkov, S Nolte, F. von Alvensleben, A. Tünnermann, H. Welling, B Wellegehausen. Opt. Comm. **129**: 134 (1996).

11.30 CFI5 (Invited)

Theory for ablation and structural changes induced by femtosecond pulses

Martin E. Garcia

Institute for Theoretical Physics, Freie Universitaet Berlin,
Arnimallee 14, 14195 Berlin, Germany

We present a theoretical description of the interaction of carbon with ultrashort laser pulses. Bond-breaking mechanisms, nonequilibrium phase transitions and ablation are analyzed as a function of duration and intensity of the laser pulses.

We have performed simulations to analyze theoretically the laser induced bond formation and beaking in diamond-bulk, diamond- and graphite films, C_{60} molecular solids, C_{60} clusters and nanotubes.

We describe the coupling between the laser pulse and the electrons as well as their subsequent relaxation dynamics on a microscopic level. In our model the form of the laser pulse, the electron thermalization and, for the case of solids and films, diffusion effects are taken into account explicitly. The relaxation dynamics of the atomic degrees of freedom are considered by performing molecular dynamics simulations.

We show that ultrafast nonequilibrium phase transitions, like the graphitization of diamond, the melting of diamond and graphite, the fragmentation of C_{60} and the deformation of nanotubes occur for a wide range of laser intensities and durations. We analyze the mechanisms of these processes and also present a systematic study of the graphitization and ablation thresholds.

For the case of graphite, we find two distinct ablation thresholds corresponding to different microscopic processes. The first threshold (lower intensities) corresponds to successive ejection of graphite layers, as shown in the figure. The second threshold (higher intensities) indicates the onset for bond breaking and corresponds to the destruction of the graphite sheets. As a consequence of this process small fragments are emitted.

Figure: *Snapshot of a graphite film 860 fs after irradiation by a ultrashort laser pulse (duration 20fs, absorbed energy 2.4 eV/atom).*