Proceedings of CLEO-2000 (Conf. On Lasers and Electro-Optics)

Short pulse laser-induced optical damage and fracto-emission of amorphous, diamond-like carbon

K. Sokolowski-Tinten and D. von der Linde
Institute for Laser-and Plasmaphysics, University of Essen, 45117 Essen, Germany
Phone:+49-201-183-2570, Fax: +49-201-183-2120, e-mail: kst@ilp.physik.uni-essen.de

M.P. Siegal and D.L. Overmyer
Sandia National Laboratories, Albuquerque, NM 87185-1421, USA

Abstract: Short pulse laser damage and ablation of amorphous, diamond-like carbon films is investigated. Material removal is due to fracture of the film and ejection of large fragments, which exhibit a broadband emission of microsecond duration.

OCIS Codes: 350.0350 Other areas of optics, 350.1820 Damage, 320.0320 Ultrafast optics, 320.7130 Ultrafast processes in condensed matter, including semiconductors.

Ablation of solids by ultrafast lasers attracts increasing interest, in particular with respect to potential applications of such lasers in material processing. In a number of experiments advantages of ultrashort pulses have been demonstrated, however the understanding of the fundamental physical processes is still incomplete. For semiconductors and metals we have shown recently [1] that near-threshold ablation with ultrashort laser pulses exhibits a material-independent, *universal* behavior. Removal of material is brought about by hydrodynamic expansion of the laser-generated hot, pressurized matter followed by decomposition into a two-phase, liquid-gas mixture.

In this work we concentrate on the distinct ablation behavior of a specific material system, namely thin films of amorphous, diamond-like carbon. 50nm films with densities close to that of crystalline diamond have been grown on quartz and silicon substrates by nanosecond pulsed laser deposition (PLD) [2]. Ablation is initiated by irradiating the surface with single 120fs laser pulses at 620nm. An example of the typical surface morphology after irradiation is depicted in the microscope picture in the left part of Fig. 1.

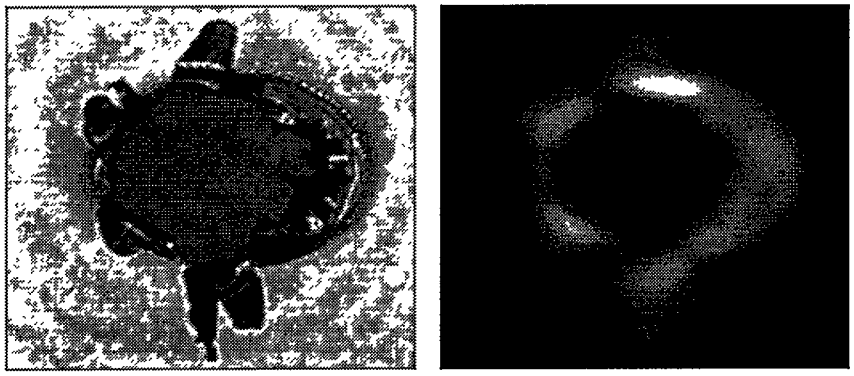

Fig. 1: Left: Microscope image of the final surface morphology after fs-laser irradiation; right: image of the surface obtained with the light which is emitted by the ejected fragments.

Obviously laser irradiation in this case does not lead to a phase transformation of the excited material to the gas phase. Instead the visual impression of the final surface morphology indicates mechanical fracture as the damage mechanism. This process exhibits a well-defined fluence threshold of 220mJ/cm^2. Near the threshold, at the periphery of the crater, the material seems only lifted from the substrate and forms a periodic surface structure. For higher fluences the film is completely removed, and large fragments, tens of μm in size, are ejected and deposited in and around the ablation region. As can be seen in the left part of Fig. 1 these fragments are the source of a strong optical emission (visible to the bare eye!). Preliminary measurements with different color filters show that the emitted light covers a broad spectral range (from the

DISCLAIMER

blue to the near-infrared). The emission is directly related to the fragmentation process, but occurs *after* deposition of the fragments on a μs-time scale, as confirmed by explicit time-dependent measurements. Therefore, simple thermal emission due to laser heating could be ruled as an explanation because this should be strongest just after the excitation when the temperature of the material is highest.

We believe that the peculiar damage behavior is related to the high internal stresses of the films due to the PLD-growth process [3]. Impulsive heating with an ultrashort laser pulse sufficiently reduces the adhesion forces and the film is removed from the subtrate *without* phase transition to the gas phase. Relaxation of the internal stresses leads then to destruction of the film, ejection of the fragments and the μs emission. To our knowledge this is the first observation of the so-called *fracto-emission* or *triboluminescence* [4] at the surface of a laser-irradiated material. It should be noted that for higher fluences, above ≈400mJ/cm^2, we do not observe fragmentation and fracto-emission, but the material-independent *universal* ablation behavior reported in [1].

This work was supported in part by Sandia National Laboratories, US DOE under contract No. DE-ACO4-94AL85000.

[1] K. Sokolowski-Tinten, J. Bialkowski, A. Cavalleri, D. von der Linde, A. Oparin, J. Meyer-ter-Vehn, and S.I. Anisimov, "Transient States of Matter during Short Pulse Laser Ablation ", Phys. Rev. Lett. **81**, 224-227 (1998).

[2] M.P. Siegal, L.J. Martinez-Miranda, H.J. DiNardo, D.R. Tallant, J.C. Barbour, and P. Newcomer Provencio, "Characterization of amorphous carbon films grown by pulsed-laser depostion", in High Power Laser Ablation, C.R. Phipps, (ed.), Proc. SPIE **3343**, 885-894 (1998).

[3] Y. Lifshitz, S.R. Kasi, and J.W. Rabelais, "Subplanation model for film groth from hyperthermal species: application to diamond", Phys. Rev. Lett. **62**, 1290-1293 (1983).

[4] A.J. Walton, "Triboluminescence", Adv. in Phys. **26**, 887-948 (1977).