Laser ablation studied using Pulsed Digital Holographic Interferometry

Laser ablation is the process of removing material from a solid or a liquid surface by irradiating it with a laser beam. It has a lot of applications including modification of the physical or chemical microstructure of materials, microhole drilling, art conservation and thin film deposition. Pulsed Digital Holographic Interferometry is used to increase the understanding of the laser ablation process in a time resolved manner. Numerical data of the integrated refractive index field is calculated and presented as phase maps showing the propagation of the shock wave and the plume generated by the process. Radon inversion is used to estimate the 3D refractive index fields measured from the projections assuming rotational symmetry. From the refractive index the density and electron number density can be calculated.

Experimental setup and procedure
Pulses of the fundamental wavelength (1064 nm) of the pulsed Nd:YAG –laser is used to ablate a polycrystalline Boron Nitride (PCBN) target and the frequency doubled light (532 nm, green) is used for the measurement. The green light is split by a beam splitter (BS1). The reflected part is reflected by mirror M1, expanded by a negative lens (NL), collimated by lens (L2) and used to illuminate a diffuser (D) after it passes along the target (PCBN). The light that passes the beam splitter BS1 is used as reference beam (R). The object light from the diffuser (O) interferes with the reference light (R) on the CCD-detector, thus recording a digital hologram. Pulsed Digital holograms for different short times after the 1064 nm laser beam starts to ablate the target are recorded. The ablation process creates a strong shock wave and may also create a plasma in the region close to the target. These changes cause changes in refractive index which in our measurements will show up as phase changes in the recorded holograms. These phase changes are calculated and presented as phase maps.

The shock wave radius as a function of time for different power densities at the target surface is shown in the figure. The experimental results were fitted to the point explosion model given by:

\[ r = \frac{\xi E_0}{\rho_0 E} \left( \frac{1}{2} \right)^{1/5} \left( \frac{1}{t} \right)^{2/5} \]

where \( r \) is the shock wave radius at a certain time \( t \), \( E \) is the released energy, \( \xi \) is a constant close to unity and \( \rho_0 \) is the undisturbed density of the ambient gas. The ratio between the energy converted to a shock wave and the incident energy was calculated. This conversion efficiency was in the order of 80 % for the PCBN material.

Radon inversion has been used to estimate the 3D refractive index fields. (a) Refractive index field at \( Z = 0.15 \) mm and a time delay of 530 ns. (b) Refractive index profiles at \( Y = 0.057 \) mm and \( Z = 0.7 \) mm for different time delays, at a power density of 4.2 GW/cm². (c) Shock front density calculated from the reconstructed data and that calculated using the point explosion model at a power density of 4.2 GW/cm².

Conclusion
- Pulsed digital holographic interferometry is a promising technique to study laser ablation processes.
- The energy conversion efficiency can be calculated using experimental results and the point explosion model.
- The 3D refractive index field can be reconstructed and the shock wave density and electron number density can be calculated.
- Different materials and laser parameters like wavelength, focusing, number of pulses can be studied in combinations with other techniques.

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