D-Scan Determination of BK7 Ultrashort Pulses Ablation Parameters Temporal Dependence

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Abstract: The D-Scan technique was used to quickly measure the BK7 ablation threshold for many superpositions and ultrashort pulses temporal widths, allowing the determination of the ablation parameters dependence on the pulses duration.
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Introduction

Incubation effects modify the ultrashort pulses ablation threshold of a material due to the accumulation of defects originated by individual pulses impinging on the same spot. To determine the ablation threshold dependence on the pulses superposition in a material and quantify it by an incubation parameter, the ablation threshold has to be measured for many superpositions usually spanning three or four orders of magnitude.

The determination of the ablation threshold is usually done using the "Zero Damage Method" (ZDM)[1], which requires the complete knowledge of the laser beam geometry and a precise and stable positioning of the sample relative to the laser beam to infer the beam spot size at its surface, and many measurements. To measure the ablation threshold, even for a single superposition, this technique can be experimentally complex, and the determination of the incubation effects requires its repetition for many different pulses superpositions, leading to long working times. Due to these constraints, experimental works usually present results for a small number of superpositions, limiting the comprehension of the defects accumulation mechanisms.

A few years ago we introduced the Diagonal Scan (D-Scan) technique[2, 3], a simple and quick method to measure the ultrashort pulses ablation threshold. In this method, the sample under study is diagonally moved across the waist of a focused pulsed laser beam, and a two-lobed profile with maximum width $2\rho_{max}$ is etched in its surface, and it can be shown [2] that the ablation threshold, F_{th}, is given by:

$$F_{th} = \frac{E_0}{e\pi\rho_{max}^2} \cong 0.117\frac{E_0}{\rho_{max}^2}, \tag{1}$$

where E_0 is the pulse energy. The pulses superposition is given by [3]:

$$N = \vartheta_3\left(0, e^{-\left(\frac{v_y}{f\rho_{max}}\right)^2}\right), \tag{2}$$

where ϑ_3 is the Jacobi Theta function of the third kind, v_y the sample transversal speed and f the laser repetition rate.

Here we use the D-Scan to measure influence of the incubation effects on the ablation threshold of BK7 for pulses duration ranging from 25 to 110 fs, observing the temporal dependence of the ablation parameters.

Experiment and Results

The ablation threshold measurements were performed in two 25 mm diameter, 3 mm thick BK7 glass samples (one of which is shown in Fig. 1), using 200 μJ pulses, centered at 785 nm with 25 fs of minimum duration, in a 4 kHz maximum repetition rate pulse train, from a CPA Ti:Sapphire laser (Femtopower Compact Pro CE-Phase HP/HR, from Femtolasers). The pulses duration (24.8, 38.7, 52.1, 64.6, 72.3, 84.9, and 110.3 fs) were set by detuning the compressor and measured by a FROG.

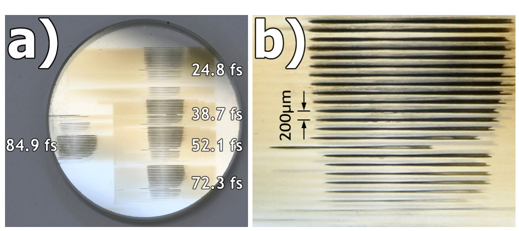

Fig. 1. a) BK7 sample with five groups of D-Scan etched profiles for different pulses durations. b) group etched by 52.1 fs pulses.

The beam was focused by a 75 mm lens, and a 3-axes computer controlled translation stage moved the samples across the beam waist. Various combinations of repetition rates and sample transversal displacement speeds were used to cover superpositions from single shot to more than 10^4 pulses. All measurements were performed in air, in less than 2 hours of laboratory work. The traces widths were measured in an optical microscope.

Each data set was fitted by a model commonly used for dielectrics[4]:

$$F_{th,N} = F_{th,\infty} + \left(F_{th,1} - F_{th,\infty}\right)e^{-k(N-1)}, \tag{3}$$

where $F_{th,1}$ and $F_{th,\infty}$ are the ablation thresholds for a single shot and infinite pulses, respectively, and k is the incubation parameter. Fig. 2 shows the fitting of Eq. (3) to the ablation thresholds obtained for the 72.3 fs pulses.

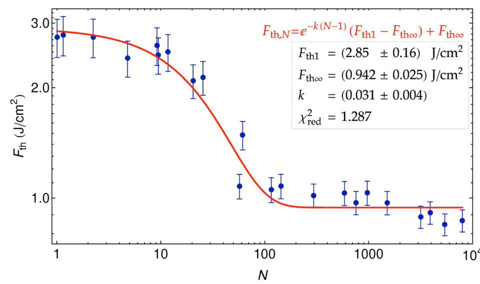

Fig. 2. Ablation threshold dependence on the pulses superposition for 72.3 fs pulses. The line is the fit by Eq. (3).

The ablation parameters ($F_{th,1}$, $F_{th,\infty}$ and k) determined are plotted in Fig. 3 as a function of the pulses duration, and a temporal dependence can be observed.

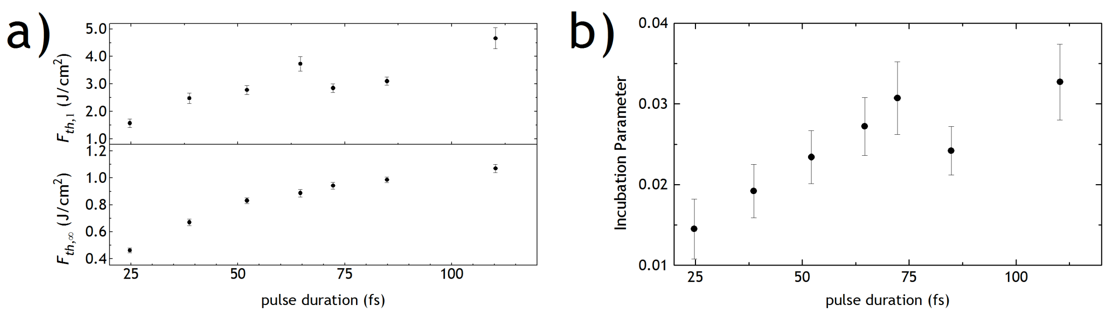

Fig. 3. a) Single shot ($F_{th,1}$) and infinite pulses superposition ($F_{th,\infty}$) ablation thresholds, and b) incubation parameter (k) as a function of the pulse duration.

Conclusions

The D-Scan method allowed the determination, in less than 2 hours, of more than 100 F_{th} values for varying pulses superposition and pulses durations. This large amount of data allows one to confidently choose the model that best describes[4] the ablation parameters dependence on the pulses superposition (defect accumulation). Additionally, as a D-Scan can be performed in a few seconds (at most in a few minutes) makes the results less prone to be affected by laser fluctuations. Such amount of data can be used to study the dynamics of the defects formation under varying parameters such as laser wavelength, pulse chirp, material doping, etc.

We have measured, for the first time to our knowledge, the incubation parameter temporal dependence, and this observed dependence indicates that, as the pulses get longer, the defects density grows faster with the superposition and the ablation threshold saturation occurs for fewer pulses.

Acknowledgements

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