Characterization of plasma reflectivity response of optical glasses processed by 34 fs pulses: analysis in the context of ablation parameters

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1.Introduction

One of the methods successfully applied for the improvement of the temporal contrast of ultrashort, high-intensity pulses is the plasma mirror (PM) technique [1]. An advantage of this approach is that it can effectively be utilized in the experiments applying strong-field of intensities higher than 10^{14} W/cm^2 with few cycle pulses, nevertheless, a bottleneck is the damage of the target surface due to the concomitant ablation: when working with high repetition rate, high-intensity systems [2] the target will rapidly be consumed, due to the shot-to-shot reduction of the area available. Commercially available, cheap target materials possessing appropriate plasma mirror characteristics, in best case together with the possibility of surface regeneration are needed to operate these systems. In order to allow a proper choice between attainable candidates, substantial knowledge of the response of the materials to the ablating laser pulse in general and the behavior of the transient reflectivity in particular is necessary.

All papers found in the literature are in accord in describing either the optical response or the ablation characteristics of the materials [3-18]. We did not find attempts to connect both aspects, therefore it is straightforward to expand our knowledge regarding it to properly select the most desirable targets for PM. This work was aimed at the determination of the plasma mirror related properties of three selected optical glasses, Borofloat, BK7 and B270 [19-21] through the measurement of the ablation characteristics and the evolution of the transient reflectivity when processed the glasses by single 34 fs pulses.

2.Experimental

The experimental setup of the single shot measurements is sketched in Fig. 1. The TeWaTi laser system of the department [22] based on a mode-locked Ti:Sapphire oscillator (Spectra-Physics Rainbow™) and a home-made Ti:Sapphire chirped pulse amplifier provided pulses with 34±0.16 fs duration and 1 mJ energy at 800 nm central wavelength with a stability at the output of the amplifier better than 1% RMS for the experiments.

Eleven holes were ablated at each pulse energy. A Veeco DEKTAK-8 stylus profilometer was used to characterize the shape of the ablated holes. The diameter and depth data reported for each energy are averages of measurements performed on the respective 11 holes. The well-known method introduced by Liu [23] was applied to determine the actual diameter of the beam on the sample surface according to the expression:

$$D^2=2w^2\ln(F/F_{th}), \qquad (1)$$

where w is $1/e^2$ beam radius while F and F_{th} stand for the peak and ablation threshold fluences, respectively.

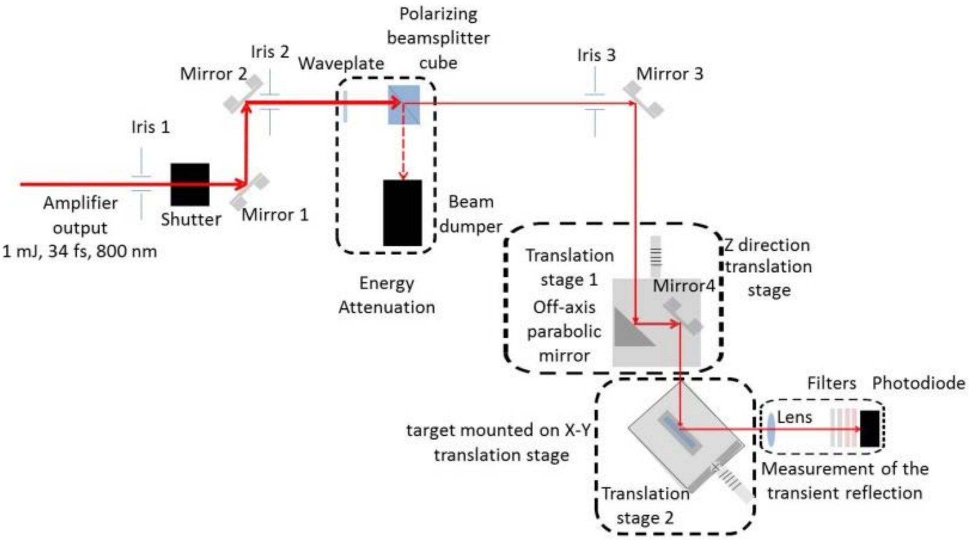

Fig. 1 Scheme of the setup (more details in [24])

3.Results

In Fig. 2 the diameter and the depth of the ablated holes are plotted together with the photodiode signal as a function of laser intensity for the three glass types investigated.

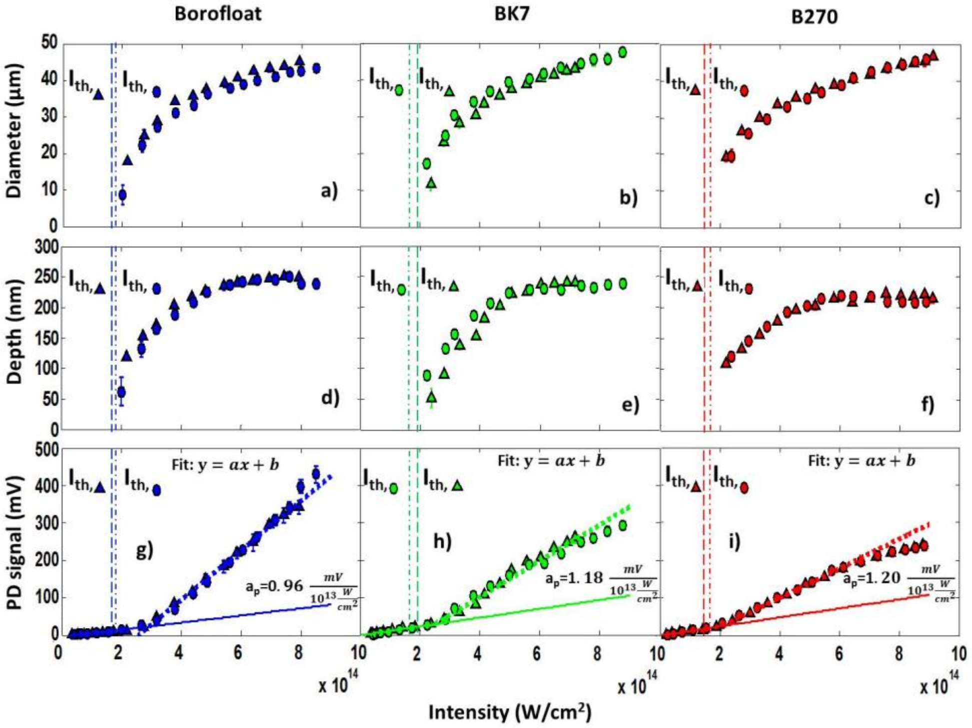

Fig. 2 Evolution of the ablation characteristics: diameter: a)-c) and the depth: d)-f), and the reflectivity g)-i) expressed in terms of photodiode recordings [more details also in [24]], process parameters: 34 ± 0.1 fs pulse duration and 25.5 ± 2 µm spot radius

As seen in Fig. 2 a)-f) very similar ablation characteristics were measured for all three glasses. The ablation threshold intensities (I_{th}), 1.72±0.06 10^{14}, 1.89±0.16 10^{14} and 1.75±0.09 10^{14} W/cm^2 for Borofloat, BK7 and B270, respectively, are equal within measurement error. Above the ablation threshold logarithmic dependence was found for the diameters, while the depths increase with increasing intensity showing saturation. The deviation of the measured reflectivity from the extrapolated permanent one (dotted vs. continuous lines in Fig. 2 g)-i) marks the emergence of the plasma mirror resulting in a steep increase in the reflectivity above the threshold [24]. For Borofloat glass the slope of the increase is the greatest, reaching maximal reflectivity enhancement of 400% distinguishing Borofloat as the most promising PM target. BK7 possesses the second highest slope with 200% increase in reflectivity, while the smallest slope appears for B270, exhibiting an enhancement of 150% only. The puzzling result is that while the glasses behave similarly from the point of view of ablation, the optical responses are different.

Discussion

In a quest for finding an explanation of the differences in the reflectivities, we tried to find any link between the amount of material removed and the evolution of reflectivity. In calculating the volume of the ablated material the shape of the ablated region was assumed to be an elliptic cylinder.

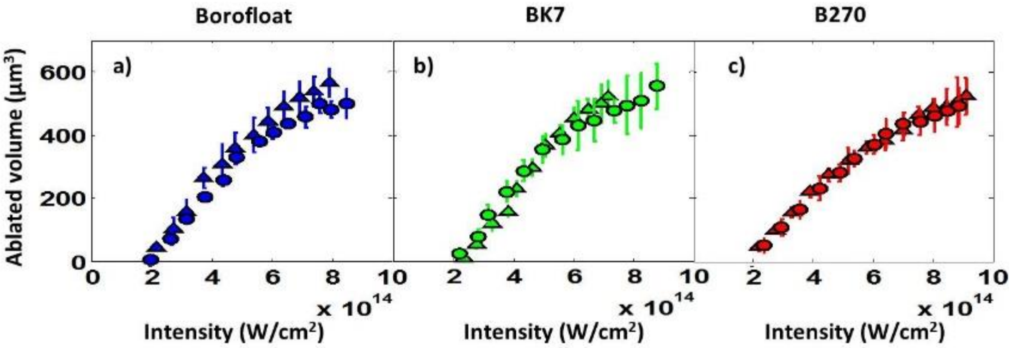

Fig. 3 The ablated volume *vs*. intensity functions for the three glass types

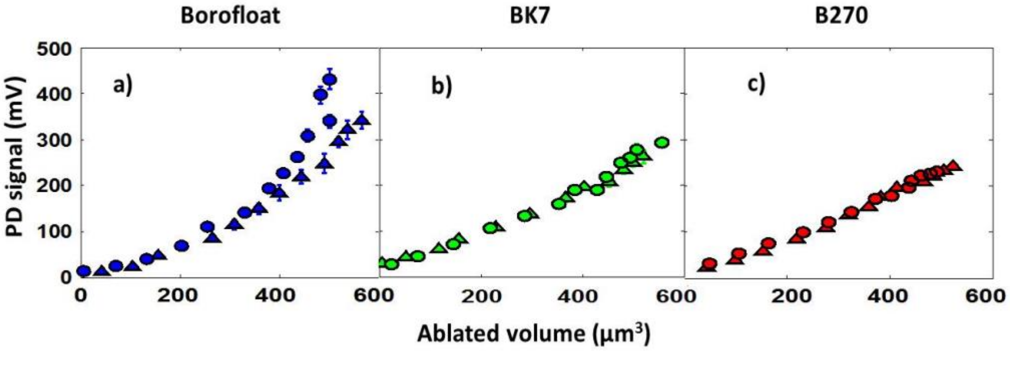

Fig. 4 The evolution of the reflected signal as a function of the ablated volume

The conclusion of the comparison is that while the three glasses behave akin from the point of view of ablation, demonstrated by the similarity of the curves in Fig. 3, their optical response depicted in Fig. 4 is different. As a corollary, it can be stated that the differences in the intensity dependence of the reflectivities cannot be correlated with the dependence of the ablated volume.

As another approach we adopted the idea of Grehn [25] for explaining the composition dependence of the plasma mirror characteristics by the difference in the average dissociation energies of the glasses: we estimated the average number of electrons, n_{av}, participating in the formation of 1 mole glass for describing the composition dependence of the reflectivity. In Table 1 the numbers of electrons calculated according to the molar concentration of all subunits together with the composition of the respective glasses are summarized.

Table 1: Composition and the n_{av} of the investigated glasses and fused silica

Material	**Constituents (wt%)**											**n_{av}**
	SiO_2	B_2O_3	Na_2O	K_2O	CaO	ZnO	BaO	Al_2O_3	As_2O_3	TiO_2	Sb_2O_3	
BOROFLOAT[a]	81	13	4		-	-	-	2	-	-	-	4.19
BK7[b]	70	10	10	6	-	-	3	-	1	-	-	3.91
B270[c]	69	-	8	8	7	4	2	-	-	1	1	3.48

[a]data provided by Schott, [b]data provided by Eksma Optics and [26], [c]data from [27]

Good correlation was found in the variation in the time integrated plasma mirror reflectivity (400%, 200%, 150%) with the n_{av} involved in the glass formation (4.19, 3.91, 3.48) suggesting that this approach offers a plausible explanation for the differences observed in the reflectivity values of the three glasses investigated.

Conclusions

Borofloat, BK7 and B270 glasses behave similarly from the point of view of ablation with intensity thresholds within the 1.7-1.9x10^{14} W/cm^2 domain and analogous evolution of the diameter and the depth of the ablated holes, while the optical response of the glasses is different: Borofloat is the most promising candidate for PM applications due to its highest transient reflectivity values as compared with BK7 and B270. While the difference in the behaviour of the transient reflectivities of the glasses cannot be correlated with their ablation parameters differences in the average number of electrons participating in the formation of 1 mole glass give a reasonable explanation for the differences in the reflectivities. The results of this study may help researchers and engineers to consider optical glasses as cheap alternatives to be used in PM experiments aimed at further improvement in the temporal contrast of the high repetition rate, high-intensity, ultrashort pulsed laser systems.

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