Measuring subsurface damage on optical glass

J. Neauport[1], C. Ambard[2], O. Cahuc[3], P. Cormont[1], N. Darbois[1], P. Darnis[3], R. Laheurte[3], S. Lambert[2], C. Maunier[1]
[1] *CEA CESTA, BP2, France*
[2] *CEA Le Ripault, France*
[3] *I2M Site ENSCBP, France*

Jerome.neauport@projet-lmj.org

Abstract

Measurement of subsurface damage (SSD) of ground optical surfaces is of major concern in the assessment of high damage threshold fused silica optics for high power laser applications. We herein detail some of the measurement principles we have tested and compared to measure SSD depth, distribution and shape on various optical surfaces from diamond ground to loose abrasive fine ground surfaces. Two types of measurements are compared and discussed: destructive methods and non destructive methods. We evidence in peculiar that trying to link roughness peak to peak to SSD depth can only be performed for a fixed set of manufacturing conditions.

1 Introduction

Fusion class high power laser facilities such as Megajoule laser (LMJ) [1] or National Ignition Facility (NIF) [2] will focus more than 1 MJ of energy at the wavelength of 0.351 µm, in the center of a target chamber. Optics used to convey, focus or shape the laser beam in the final optic assembly of these systems are large fused silica components operating in transmission. When exposed to fluences of some joules per square centimeter at the wavelength of 0.351 µm with nanosecond pulse duration, fused silica optics can exhibit localized surface damage. Damaged sites grow exponentially after further laser exposition and therefore dramatically limit the optic lifetime. It has been evidenced that residual subsurface damage existing in polished fused silica is likely to be the principal cause of damage. Consequently, important efforts were made by the community to develop and qualify methods to measure SSD at the various stages of the polishing process of fused silica. We herein report on our efforts in this field.

2 Destructive methods

We investigated a destructive method based on the utilization of HF acid etching [3]. It consists in the following of the surface topology of the part during the etching process in order to give access to the depth of the SSD. We compared this method with other destructive methods to demonstrate a good concordance [3]. Results are presented in Table 1. We evidence a fairly good concordance between the difference measurement methods.

Table 1: Comparison of different SSD measurement methods (MRF Dimpling, ,HF acid etching with or w/o inductively coupled plasma measurement, MRF taper polishing) on various diamond ground samples with different diamond wheels (S1, S2: D181 / S3 to S9: D64 / S10, S11: D20). All quantities are expressed in microns

S/N	9.1 R_t [6]	MRF Dimpling	HF dissolution & Roughness	HF dissolution & ICP	MRF taper microscopy / confocal
S1	119.02	111.1	-	-	-
S2	87.99	-	117.9	110	-
S3	26.93	24.2	-	-	-
S4	26.39	-	-	-	21 / 28
S5	21.84	-	20.4	25	-
S6	55.69	51.9	-	-	-
S7	56.23	-	35.7	52	-
S8	2.64	-	-	-	2 / 2
S9	11.19	-	9.3	14	-
S10	12.01	-	-	-	7 / 10
S11	8.55	-	8.2	9.5	-

Moreover we also used this HF etching principle to address the question of the possible relation existing between surface roughness and SSD depth on grounded [3, 4], fine grounded, or loose abrasive lapped fused silica [5]. For each grinding or lapping configuration, various slurries or diamond wheels and manufacturing parameters were used in order to voluntary change SSD depth. Table 2 summarizes the k factor obtained during these different experiments, where k is defined as $SSD_{depth} = k. Rt$, Rt being the roughness peak to peak.

We clearly see that despite previously published results [6], for a given SSD measurement method, the k factor can be modified by a factor of about 2. But within a given manufacturing process (same machine, kinematics …), the k factor is found to be fairly constant (especially in the case of loose abrasive grinding).

Table 2: Comparison of different k factors on diamond ground or loose abrasive lapped fused silica samples. Measurements performed using the HF etching method.

Sample manufacturing process	k	Ref.
Diamond grinding on a SCHNEIDER SLG100 grinder (D181, D64, D20 wheels)	8,5 ± 2.4	[3]
Diamond grinding on an OPTOTECH SMP500 CNC (D126, D64 wheels)	4.4 ± 1	[4]
Loose abrasive lapped samples. Lapping performed on a LOGITECH PM5, cast iron plate, alumina or SiC slurries.	3.3 ± 0.5	[5]

3 "Non destructive" methods

We also investigated non destructive methods based on fluorescence confocal microscopy as a tool to measure subsurface damage on fused silica optics at various manufacturing stages. Fluorescence confocal microscopy was performed with an excitation at the wavelength of 405 nm on fixed abrasive diamond grinded fused silica samples [7]. Figure 1 presents the result obtained on a diamond ground surface.

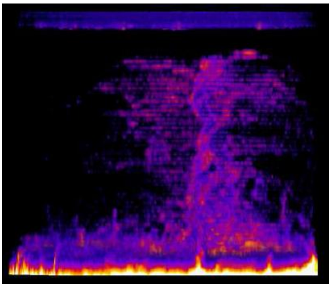

Figure 1: Confocal microscopy image in fluorescence mode (acquisition in the 435 nm – 661 nm spectral range, excitation at 405 nm) of a D181 diamond ground surface. Analyzed area is 227 μm^3. Ground surface is at the bottom (Ra=1.22 μm, Rt=16.9 μm). Sample was thinned down by acid etching to allow measurement (etched surface is at the top). Subsurface crack can be seen with brittle like structures and SSD depth is approx. 190 µm.

Although the SSD depth measured by this way shows good concordance with the one obtained by the HF etching method, confocal microscopy imposes a rather difficult preparation of the sample that makes such measurement painful in an industrial context. For this reason, our recent efforts focus on the use of Abbott Firestone parameters computed from roughness profile as an indicator of subsurface fracturation [4].

Conclusions

We evidenced, using fused silica sample manufactured by different processes (diamond grinding, loose abrasive lapping), that linking SSD depth to surface roughness with a universal constant is illusive. Depth has to be measured for each new manufacturing configuration. We also demonstrate a relatively good concordance between various SSD measurement methods.

References:

[1] M. L. André, "Status of the LMJ project," in Solid state lasers for application to Inertial Confinement Fusion: Second Annual International Conference, M. L. André, ed., Proc. SPIE 3047, 38-42 (1996).

[2] W. H. Lowdermilk, "Status of the National Ignition Facility project," in Solid state lasers for application to Inertial Confinement Fusion: Second Annual International Conference, M. L. André, ed., Proc. SPIE 3047, 16-37 (1996).

[3] J. Neauport, C. Ambard, P. Cormont, N. Darbois, J. Destribats, C. Luitot, O. Rondeau, “ Subsurface damage measurement of ground fused silica parts by HF etching techniques”, Optics Express, Vol. 17, Iss. 22 (2009)

[4] R. Laheurte, P. Darnis, N. Darbois, O. Cahuc, J. Neauport, "Subsurface damage distribution characterization of ground surfaces using Abbott Firestone curves", submitted to Optics Express.

[5] J. Neauport, J. Destribats, C. Maunier, C. Ambard, P. Cormont, B. Pintault, O. Rondeau, "Loose abrasive slurries for optical glass lapping", Applied Optics Vol. 49, No. 31 (2010)

[6] T. Suratwala, L. Wong, P. Miller, M. D. Feit, J. Menapace, R. Steele, P. Davis, and D. Walmer, “Subsurface mechanical damage distributions during grinding of fused silica,” J. Non-Cryst. Solids 352, 5601–5617 (2006)

[7] J. Neauport, P. Cormont, P. Legros, C. Ambard, J. Destribats, “Subsurface damage fluorescence of grinded fused silica optics” Optics Express Vol. 17, Iss. 5, pp. 3543–3554 (2009)