FATIGUE OF OPTICAL RESISTANCE IN DIELECTRIC COATINGS: INVESTIGATION OF SINGLE PULSE CONTRIBUTION USING DIGITAL HOLOGRAPHY WITH HIGH TEMPORAL RESOLUTION

Evelina Drobužaitė, Linas Smalakys, Balys Momgaudis, Andrius Melninkaitis

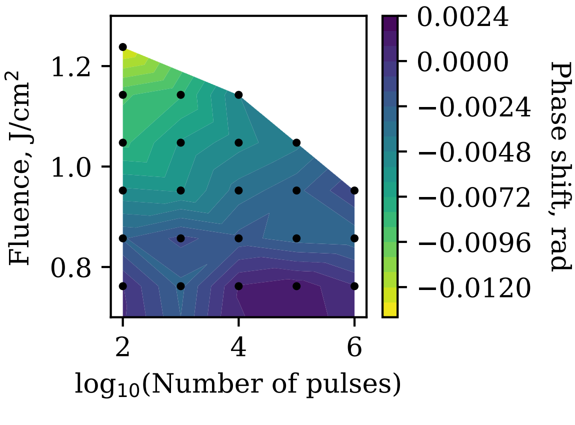
Laser Research Center, Department of Physics, Vilnius University, Lithuania
evelina.drobuzaite@ff.stud.vu.lt

Laser Induced Damage Threshold (LIDT) is a physical characteristic of optical component which defines a critical power or peak fluence of laser irradiation causing irreversible changes in materials structure. Optical materials exhibit LIDT fatigue effect: LIDT of dielectric materials for multiple pulse exposures is lower compared to single-pulse illumination [1]. It is essential to understand mechanisms that create optical fatigue in order to precisely predict multiple pulse damage threshold. Knowledge on damage threshold dependence on pulse quantity would lead to faster, less expensive and guaranteed way of predicting optical components fatigue behaviour which is necessary in order to create reliable optical systems.

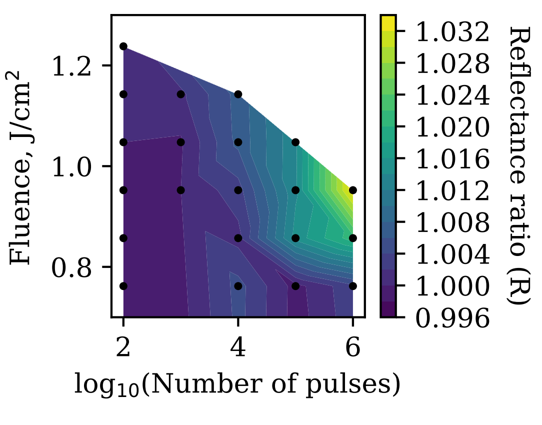
In this work we did an investigation of optical fatigue effect using digital holography experimental setup which provides high spatial and temporal resolution phase and amplitude contrast pictures [2]. Also, defect pictures were taken with a Nomarski microscope. Optical fatigue effect was seen as a red spot appearing in Nomarski microscope pictures and as negative phase shift in phase contrast image. This experiment was done with a zirconium dioxide thin film on silicon dioxide substrate (ZrO_2/SiO_2). Sample was exposed to different pulse fluences from $0,19\,J/cm^2$ to $1,24\,J/cm^2$ and to different pulse quantities from 10^2 to 10^6. Experiments were carried out using 316 fs 1030 nm pump and 26 fs 539 nm probe pulses. We compared signals from phase contrast images with signals from Nomarski microscope reflectance pictures Fig. 1.

As can be seen in Fig. 1 (a) the negative phase shift is decreasing with increasing number of pulses. Different dependence on number of pulses is seen in Fig. 1 (b), signal is increasing with increasing number of pulses. These dependencies Fig. 1 indicate existence of two defect states: long-lived and short-lived. Short-lived defect states create negative phase shift and are generated with each pulse but through relaxation process between pulses turn into long-lived states. Long-lived states create positive phase shift but there is no relaxation, so, these states accumulate in a material. Long-lived defect state accumulation in Nomarski pictures is seen as brighter red spot formation and as negative phase shift decrease in phase contrast images Fig. 1.

According to Lorentz model for bound electrons short-lived state resonance frequency is higher and long-lived state resonance frequency is lower than probe frequency (2,3 eV). It is known that defect states in zirconium dioxide (ZrO_2) are created by oxygen vacancies and their resonance frequencies are in agreement with our results [3]. In conclusion, optical fatigue in zirconium dioxide (ZrO_2) is caused by accumulation of long-lived oxygen vacancy states.



(a) Phase shift dependence on pulse energy and number of pulses.



(b) Nomarski microscope reflectance picture R chanel dependence on pulse fluence and number of pulses.

Fig. 1. Signals from phase contrast images and from Nomarski reflectance pictures.

[1] A. E. Chmel, Fatigue laser-induced damage in transparent material, Materials Science and Engineering B, **49**(3), 175-190 (1900).
[2] N. Šiaulys, L. Gallais, A. Melninkaitis, Direct holographic imaging of ultrafast laser damage process in thin films, Optics Letters, **39**(2), 2164- 2167 (2014).
[3] T. V. Perevalov, D. V. Gulyaev, V. S. Aliev et al., The origin of 2,7 eV blue luminescence band in zirconium oxide, Journal of Applied Physics, **116**(24), 2-6 (2014).