Optics and Lasers in Engineering 91 (2017) 24–29

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Studies on surface pitting during laser assisted removal of translucent ellipsoidal particulates from metallic substrates

Bijoy Sugathan[a,b], J.Padma Nilaya[a], V.P.Mahadevan Pillai[b], D.J. Biswas[a,*]

[a] Laser and Plasma Technology Division, BARC, Mumbai 400085, India
[b] Department of Optoelectronics, University of Kerala, Karyavattom, Thiruvananthapuram 695581, India

ARTICLE INFO

Keywords:
Laser assisted cleaning
Field enhanced surface absorption
Ellipsoidal particulates
Pitting depth
Surface topography

ABSTRACT

We report on the manifestation of field enhanced surface absorption during laser assisted removal of translucent particulates of ellipsoidal geometry from a metallic substrate surface. The surface pitting caused due to this effect has been experimentally probed as a function of the ratio of minor to major axis of the ellipsoid and the behavioral trend has been theoretically interpreted by invoking the principle of geometrical optics. The study also includes the effect of fluence and wavelength of the incident coherent radiation on the surface pitting. Probing of the surface topography has helped gain insight into the formation of multiple pits by a single particulate following its removal post laser exposure.

1. Introduction

Laser assisted surface cleaning has decided advantage over conventional methods [1,2] as it is a dry process generating very little secondary waste, can be performed in a remote manner, and can be very well controlled to remove the contamination selectively without altering the substrate surface properties [3]. No wonder that laser cleaning has found wide application in areas pertaining to semiconductor industry [4], art restoration [5], nuclear [6] and aerospace [7] industry etc. Further, the controlled manner in which surface contamination layers can be removed by judicious choice of laser parameters [8] makes this technique more versatile. The duration of the laser pulse, in particular, needs to be carefully chosen depending on the nature of the contamination. In case of fixed contamination, the exposure of the surface to ultrafast pulses results in swift transformation of the thin contamination layer into hot and dense plasma [9] often termed as cold ablation as there is barely any time for the transfer of the absorbed laser energy from the extremely hot electrons to the lattice. In the case of loose surface contamination, for which the laser induced thermal stress is responsible for the generation of cleaning force [3], the pulse duration is long enough for the rapid transfer of the absorbed laser energy into the bulk. Consideration of various relaxation time constants involved generally identifies microsecond to nanosec pulses suitable for removal of loose particulates and picosecond to sub picosec pulses suitable for removal of fixed contamination. We have chosen a coherent source capable of delivering pulses ranging from 1.5 to 0.3 ns for the present study of laser assisted removal of loose contamination. There are however instances wherein even exposure by microsecond [10] and nanosec [11] pulses have led to removal of fixed contamination, in particular, when a compromise has been made between the ablation rate and quality of cleaning [12]. It is important to note here, in the context of laser cleaning of loose particulates, that transparent/semi-transparent contaminant particulates can act as focusing media and enhance the intensity of the incident radiation underneath the particulates. The increased intensity leads to enhanced absorption by the substrate [13] causing surface pitting as a result of ablation even when the incident laser intensity is well below the ablation threshold [13–15]. While the substrate ablation due to optical field enhancement is an undesired effect in the cleaning process, it can be gainfully employed in diverse areas e.g., surface nano-patterning [16–18], optical trap assisted nano-patterning [19] nanophotonics [20] and biomedicine [21]. In our previous works on this subject, we provided experimental signature of increased surface cleaning efficiency as a result of field enhanced surface absorption [13] and studied surface pitting as a function of both the fluence and wavelength of the incident coherent radiation [22]. In this communication, we have extended the characterization domain of pitting by way of including the size of the particulates and the corresponding depth of pitting in addition to the dependence on laser fluence and wavelength. Further, the research to this end until now has been confined to spherical or hemispherical particulates [16,17], and our work on particulates predominantly of ellipsoidal geometry represents an additional contribution to this emerging area of laser assisted surface patterning.

* Corresponding author.
E-mail address: dhruba8biswas@gmail.com (D.J. Biswas).

http://dx.doi.org/10.1016/j.optlaseng.2016.11.009
Received 3 August 2016; Received in revised form 29 October 2016; Accepted 7 November 2016
0143-8166/

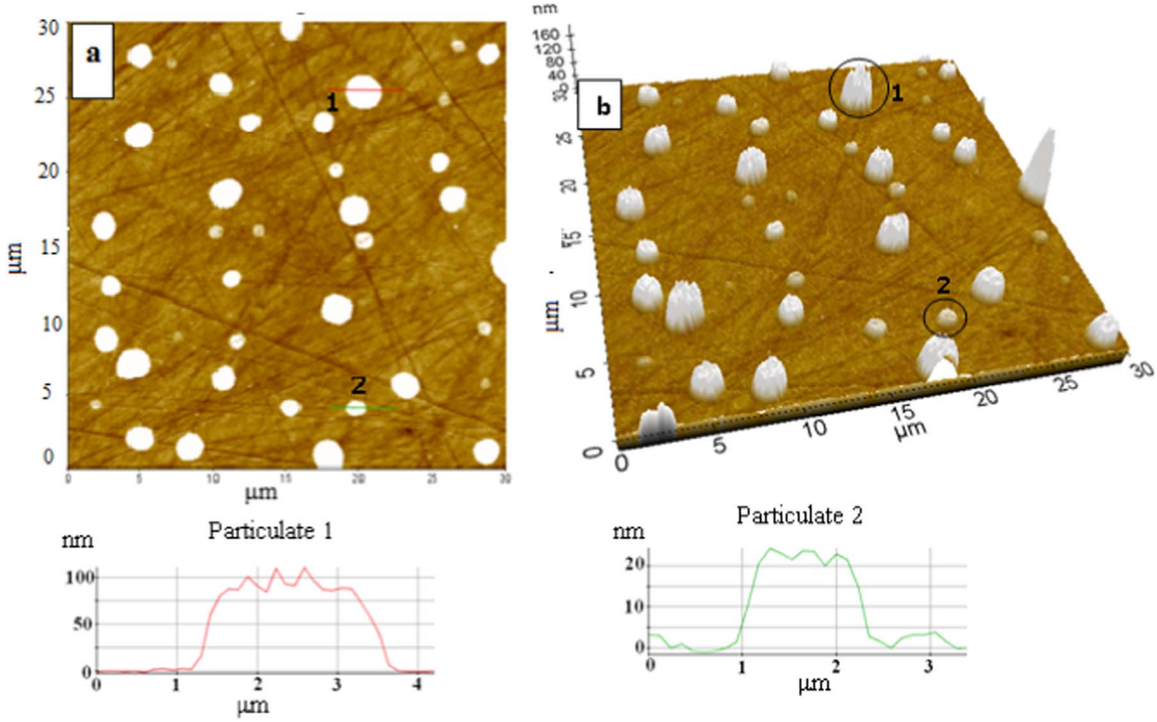

Fig. 1. AFM micrograph of the SS surface simulated with Cs contamination showing a typical distribution of particulates in 2D and 3D views (Fig. 1a and b respectively). The insets show the surface topography of two randomly chosen particulates 1 and 2 that have also been identified in the AFM images.

2. Experimental

The particulate contamination was simulated by depositing aq.$CsNO_3$ on optically polished stainless steel (SS) substrates (Surface flatness: λ/4 at visible wavelength and s/d 40-20) over a diameter of ~4 mm. The air dried samples were inspected using an optical microscope (Carl Zeiss, A2M) and its surface topography carried out by means of an AFM (XE100, Park Systems). The molar strength of the aqueous solution was so controlled as to result in the formation of particulates with sizes primarily lying in the range of several microns. A typical AFM image of such a contaminated surface is shown in Fig. 1 in both 2D (trace a) and 3D (trace b) from where it is evident that the particulate's size can be scaled approximately to 1–3 µm. The surface undulations of the particulates as well as their ellipsoidal shape are also clearly revealed in the surface topography of two randomly chosen particulates shown in the inset of this figure. The schematic diagram of the experimental setup used for characterization of laser induced surface pitting is as shown in Fig. 2.

An Nd-YAG laser (Model-SL 332-T, Ekspla), capable of delivering spatially flat topped pulses of duration variable from 300 ps to 1500 ps on the fundamental and higher harmonics was employed as the irradiation source. The maximum energy obtainable from the laser on the fundamental is ~200 mJ/pulse over a diameter of 8 mm. The pulse to pulse stability and the poynting stability were respectively ~4% and 50 µrad at 1064 nm. The typical spatial burn pattern and temporal profile of the laser emission are depicted in the traces of Fig. 3.

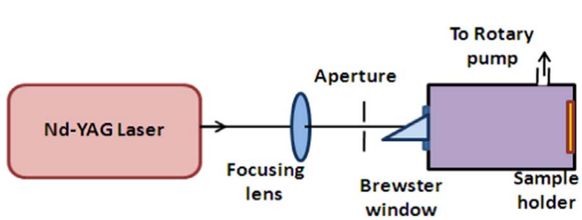

Fig. 2. Schematic diagram of the experimental set-up used for characterization of laser induced surface pitting.

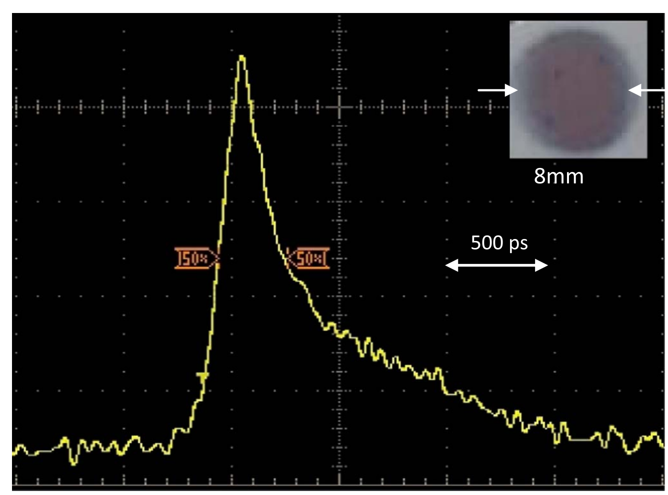

Fig. 3. The temporal profile of the laser pulse used for this experiment. The inset shows the typical spatial profile of the laser beam as recorded on a thermal sensitive paper.

A Perspex chamber was vacuum sealed by the sample holder at one end and a BaF_2 Brewster window on the other end that allowed coupling of the polarised emission from the laser without any attenuation. A rotary pump connected to the chamber was kept on during the experiment to prevent any redeposition of the removed particulates. The substrate surfaces, prior to and after laser exposure, were examined employing the aforementioned optical and atomic force microscopes. As contaminant particulates deposited on the substrate cannot be made exactly identical in size by this method of sample preparation, it is essential to evolve a way to correlate a particulate and its signature on the substrate surface following its removal post laser exposure. Taking advantage of the surface imperfections as a signature, an intuitive technique, that allowed probing the same region of the sample surface before and after laser irradiation, was made use of to relate the particulates and the corresponding pitting on the laser