High-speed image analysis of melted ejecta during visible nanosecond ablation of Aluminium

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Abstract: High-speed image analysis is used in conjunction with profilometry measurement to determine the behaviour of Aluminium samples exposed to nanosecond laser pulses in the region 1~40Jcm^{-2}. Results are discussed with a view to understanding dominant ablation mechanisms.

OCIS codes: (140.3390) Laser materials processing; (110.2960) Image analysis

The dominant mechanisms during nanosecond ablation of metals are; *vaporisation* (direct thermal vaporisation from a melt pool); *pressure induced melt displacement* (radial displacement of material due to pressure created by the ablation front) & *explosive melt ejection* (violent ejection of molten droplets from the surface caused by superheating and subsequent homogeneous nucleation). In order to develop a complete predictive capability for such ablation it is necessary to determine the fluence thresholds for each of these mechanisms. To this end, this work studies the nature of material removal from an Aluminium sample within the fluence region 1~40Jcm^{-2} via high-speed image analysis.

The output of a copper laser oscillator (λ = 511nm & 578mn) was first passed through a length of optical fibre and then subsequently amplified to give pulse energies ~1mJ. This technique allowed the beam profile at the far field of a100mmfl drill lens to resemble a top hat in preference to the conventional Airy Disc. Single pulses of various energies were utilised to ablate material from a polished aluminium substrate placed at the focal plane of the drill lens, with each incident pulse falling on an untouched portion of the surface. A typical crater created at a high energy (~1.3mJ) is shown in Figure 1.

Greyscale images (Figure 2) of material droplets ejected from the surface were obtained using a high-speed camera with a 5ns Nd: YAG light sheet illumination at a time delay of ~3μs after each incident laser pulse. Each image was taken under different energy conditions at a constant spot radius (~40μm) and analysed with a custom built LabVIEW module to determine the volume of ejected material. In addition, the volume removal of each crater was analysed with profilometry, allowing an evaluation of the total removed volume and the volume removed in the form of melted droplets.

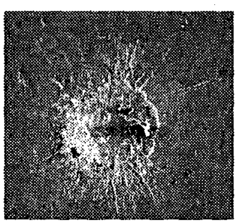

Figure 1: Typical SEM of an ablation crater (F~35Jcm^{-2})

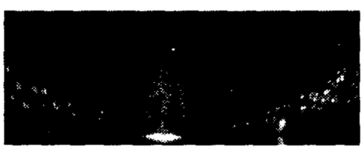

Figure 2: Typical High-speed image capturing ejected melt (F~35Jcm^{-2})

As seen in Figure 3 the profilometry data show the onset of material removal at a fluence of ~ $2Jcm^{-2}$. A volumetric removal of ~ 1×10^{-9} cm^3 is rapidly attained, remaining constant with fluence until ~ $15Jcm^{-2}$ where the removal begins to increase linearly. The high-speed image analysis shows minimal material removal at low fluences, with material removal beginning at $10\text{-}15Jcm^{-2}$ then increasing linearly at higher fluences.

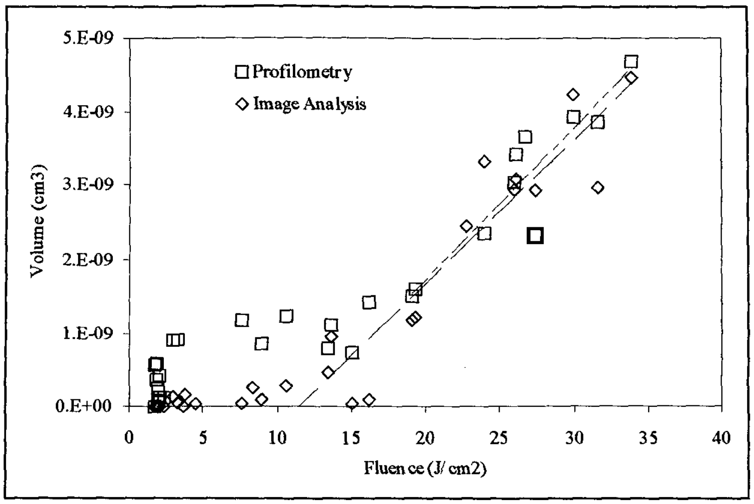

Figure 3: Volume removal with fluence showing the evolution of the total material removal (Profilometry) and the volume removed as melted droplets (Image Analysis)

At fluences > $15Jcm^{-2}$ the total volume removed as measured by profilometry is shown to correspond well to that visibly removed in droplet form, indicating that most of the volume is removed due to the melt expulsion regime. However, in the lower fluence region ($<10Jcm^{-2}$), minimal material removal in droplet form is observed requiring that the total material removal be accounted for by a different ablation regime; namely vaporisation or melt displacement. As vaporisation is a purely thermal process it is expected to increase linearly with incident energy, behaviour not consistent with the profilometry dataset in the region $2\text{-}15Jcm^{-2}$. It is likely then, that the cause of the discrepancy between the two datasets is localised material removal due to melt displacement. Under this regime while the material is not ejected, and therefore is not observed in the high-speed images, it is displaced and will manifest as material removal evaluated via profilometry. The results of this work will be discussed and evaluated within the current framework of understanding of the dominant mechanisms during nanosecond ablation of metals.