

Controlling Femtosecond Laser Ablation of Germanium for Laser Polishing Applications

L. L. Taylor¹, J. Xu², T. R. Smith³, M. Pomerantz³, J. C. Lambropoulos^{2,3,4}, and J. Qiao^{1,*}

¹Rochester Institute of Technology, Chester F. Carlson Center for Imaging Science, Rochester NY USA

University of Rochester ²Department of Mechanical Engineering, ³Materials Science Program,

⁴Laboratory for Laser Energetics, Rochester NY USA

qiao@cis.rit.edu

Abstract: Sensitivity of femtosecond laser ablation to laser parameters was investigated to evaluate controllability of germanium material removal. A processing metric was determined, enabling a method to control laser polishing with flexible combinations of laser parameters. © 2018 The Author(s)

OCIS codes: (140.3390) Laser materials processing; (140.7090) Ultrafast lasers; (220.4610) Optical fabrication

1. Introduction

Femtosecond lasers enable non-thermal, ablation-based removal of material and, therefore, polishing of optical components with high precision. However, if laser parameters such as pulse energy, repetition rate, and scan speed are not optimized to accommodate the thermal properties of the material, unwanted thermal effects such as melting, oxidation, and material pileup can occur [1]. Thermal artifacts on surfaces are detrimental for laser polishing applications which require precision material removal and high surface quality. Optimum laser parameters must be determined to effectively control the ablation volume and/or rate, especially for polishing freeform optics with rotationally non-symmetric, complex surface geometries [2].

To achieve deterministic femtosecond laser polishing, we investigate the controllability of femtosecond laser ablation of germanium (Ge) relative to variation of laser parameters. A processing metric which considers the combined effect of laser parameters on ablation volume was determined and used to evaluate the controllability and select sets of optimal laser parameters for polishing of Ge.

2. Experimental determination of the Ge ablation threshold

The ablation threshold is defined as the fluence above which a laser pulse can effectively remove material. It is critical to determine this threshold to ensure effective ablation-based laser polishing. The impact of pulse energy on single-shot laser ablation of Ge was investigated to determine the ablation threshold for ~300-fs laser pulses at a wavelength of 1030 nm.

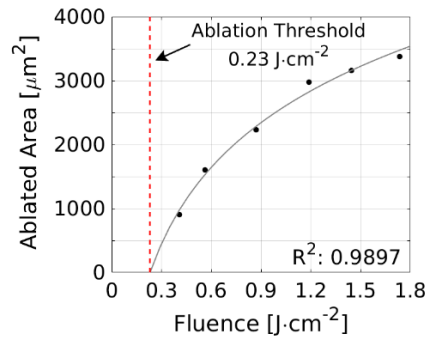


Fig. 1. Ablated crater area versus laser fluence for single-shot ablation of Ge with a 66-μm laser spot. The fitted line corresponds to Eq. 1 and the ablation threshold fluence was determined to be 0.23 J·cm⁻².

Figure 1 illustrates the relationship between the experimentally-determined ablated crater area measured by an optical profiler (Zygo NewView 600) and the peak fluence of the Gaussian laser pulse. The ablation threshold was determined by fitting the experimental data shown in Fig. 1 using Eq. 1 [3,4].

$$A_{ablated} = \frac{\pi \cdot w_0^2}{2} \cdot \ln \left[\frac{F_{laser}}{F_{threshold}} \right] \quad (1)$$

In Eq. 1, $A_{ablated}$ is the area of the ablation crater measured at the Ge surface, $w_0 = 33 \mu\text{m}$ and F_{laser} are the respective $1/e^2$ radius and peak fluence of the Gaussian laser pulse, and $F_{threshold}$ is the corresponding ablation threshold fluence. The ablation threshold of Ge was found to be 0.23 J·cm⁻².

3. Evaluating the controllability of femtosecond laser ablation

For laser polishing applications, it is critical to determine the controllability of non-thermal ablation. Ablation sensitivity tests were conducted in a line-scan configuration to determine the isolated effect of pulse energy, repetition rate, and scan speed on the removal depth and volume of Ge.

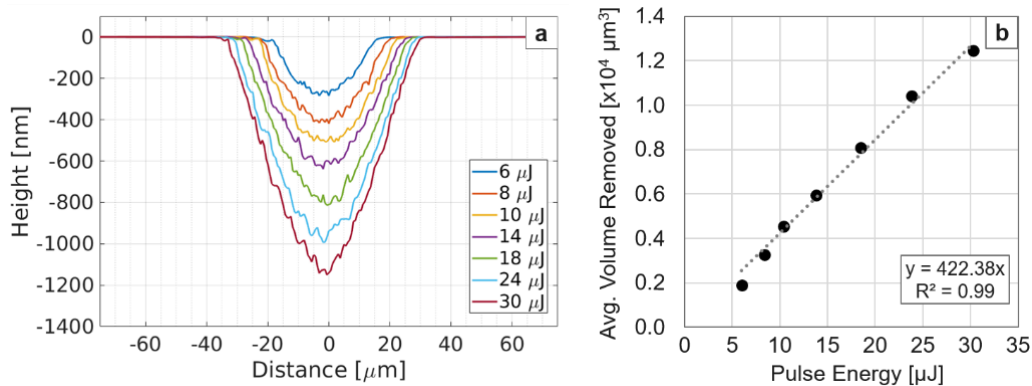


Fig. 2. (a) Average line profiles over a 300-μm scan length achieved using various pulse energies and (b) the corresponding material removal volumes.

Figure 2 presents ablation sensitivity to pulse energy. Figure 2(a) shows that the average profiles of ablated lines follow the Gaussian spatial shape of the focused pulses and the ablation depth changes from 285 to 1150 nm when varying pulse energy from 6 to 30 μJ. Figure 2(b) shows that the ablation volume can be controlled linearly with increasing pulse energy. The repetition rate and scan speed were respectively fixed at 250 kHz and 1.5 m/s to isolate the effect of pulse energy on material removal. The ablation sensitivity to repetition rate and scan speed will be presented.

A processing metric describing the amount of energy deposited per unit length along the scan direction [*energy deposited per unit length (J/m) = pulse energy (J) × repetition rate (1/s) / scan speed (m/s)*] was determined to compare material removal achieved using different combinations of laser parameter settings. The comparison result demonstrates that consistent material removal volumes can be attained with different combinations of laser parameters, paving the way for achieving flexible laser polishing configurations. Results on the ablation evaluation using this processing metric and the corresponding laser-polished surface quality will be presented.

4. Conclusion

Ablation sensitivity to laser pulse energy, repetition rate, and scan speed was investigated to evaluate the threshold for non-thermal ablation of Ge and controllability of femtosecond laser polishing. Controllable material removal was achieved by varying the laser polishing parameters, e.g. pulse energy linearly controls the ablation volume. A processing metric was determined to evaluate and compare the ablation volumes achieved by different combinations of laser polishing parameters. The metric will allow flexible selection of laser parameters for deterministic, optimized laser polishing applications.

This Research was supported by the NSF I/UCRC Center for Freeform Optics (IIP-1338877 and IIP-1338898).

- [1] L. L. Taylor, J. Qiao, and J. Qiao, "Optimization of Femtosecond Laser Processing of Silicon via Numerical Modeling," *Opt. Mater. Express* **6**, 2745–2758 (2016).
- [2] K. Fuerschbach, J. P. Rolland, and K. P. Thompson, "A New Family of Optical Systems Employing ϕ -Polynomial Surfaces," *Opt. Express* **19**, 21919 (2011).
- [3] J. M. Liu, "Simple Technique for Measurements of Pulsed Gaussian-Beam Spot Sizes," *Opt. Lett.* **7**, 196–198 (1982).
- [4] J. Thorstensen and S. E. Foss, "Temperature Dependent Ablation Threshold in Silicon Using Ultrashort Laser Pulses," *J. Appl. Phys.* **112**, 103514 (2012).