SHORT PULSED LASERS FOR MATERIALS MODIFICATION, CHARACTERIZATION AND SYNTHESIS

Short-Pulsed Laser Techniques for Materials Modification, Characterization, and Synthesis

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The use of short-pulsed lasers, especially femtosecond lasers, has enabled machining for materials modification, characterization, and synthesis in a range of fields. Moreover, femtosecond laser machining has matured significantly to widespread use in commercial settings. High material removal rates and low heat deposition into material are attractive qualities of this technique and, when coupled with a microscope system, provide scalability across length scales spanning a few micrometers to millimeters and beyond. The use of this approach as part of the process for testing small-scale mechanical properties is comparatively less explored, and questions regarding microstructural modification, best practices, and integration with other common or conventional techniques remain. The scope of this special topic aims to highlight the increasing importance of short-pulsed laser–material interactions and novel applications. It is clear that this topic will continue to grow and develop to the point that these methods will be added to the permanent toolkit in material science research and development efforts.

Small et al. studied the effects of laser processing on steel fabricated using powder metallurgy in “Precision Modification of Microstructure and Properties through Laser Engraving.” Their study utilizes several characterization techniques, including optical microscopy and electron backscatter diffraction, coupled with computational fluid dynamics modeling to evaluate the heat profile and damage to the underlying microstructure. The authors found that careful control of laser process parameters is key to optimizing surface processing by controlling deleterious microstructural features.

J. Gigax and P. Hosemann are Guest Editors for the topic Short-Pulsed Lasers for Materials Modification, Characterization, and Synthesis in this issue.

Hosemann et al. used a novel approach with positron lifetime spectroscopy to characterize subsurface defects generated by femtosecond laser machining in silicon. Their study, “Defect Characterization Using Positron Annihilation Spectroscopy on Laser-Ablated Surfaces,” explores the impact of laser process parameters on Si. Single-crystal silicon wafers were exposed to a decade range of femtosecond laser power and compared against polished wafers. Positron annihilation spectroscopy is commonly used to characterize vacancy-type defects in materials and was used principally in this study to explore the production of vacancies, vacancy clusters, and larger pores up to 1 μm below the incident surface. Their results indicate that increasing laser power increases the size of the pores, with the depth extending beyond the positron range. The authors caution that the use femtosecond laser ablation to pattern a surface is accompanied by subsurface defects that may negatively influence other material properties, such as corrosion resistance.

Dong et al., in their study, “Femtosecond Laser Machining of Micromechanical Tensile Test Specimens,” explore an approach to performing mechanical testing at millimeter and submillimeter length scales. The authors took a novel approach in this study by utilizing two approaches to fabricating small-scale specimens. The first was a more traditional approach using through cuts to form an SSJ2 geometry with a trapezoidal cross-section. The second was to use a lathe machining approach to form round cross-section specimens. Comparisons against bulk-scale tensile bars indicate good agreement with samples of small grain sizes, suggesting this as a viable approach for rapid-throughput mechanical property evaluation. The authors note that variations between the macroscale and smaller-scale tensile tests warrant additional investigation and optimization into the load frames used for testing and fabrication process.

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In the paper, “Demonstration of a High-Throughput Tensile Testing Technique Using Femtosecond Laser-Fabricated Tensile Bars in AISI 316 and Additively Manufactured Grade 91 Steel,” Harvey et al. set out to demonstrate the viability of using femtosecond laser machining as part of a high-throughput tensile testing approach. The principal motivation, noted by the authors, is to provide a more accurate picture of the response of highly heterogeneous systems, such as additively manufactured materials. Testing on submillimeter length scales provides a direct picture of how small printed features, such as lattice struts, behave under loading. Using 316L as a benchmark, the technique was proven to be both repeatable and accurate. Leveraging the same approach, additively manufactured grade 91 steel was examined and found to exhibit a wide range of tensile properties. The authors note that deliberate selection of tensile sizes should be considered to avoid undersampling the microstructure for future tests. However, the approach with a tensile fabrication and test time of only 4 min and a solid repeatability makes this technique truly high throughput.

Jelinek et al. focused on optimizing laser process parameters to minimize the appearance of laser-induced periodic structures on the laser-incident surface in “A Perspective to Control Laser-Induced Periodic Surface Structure Formation at Glancing-Incident Femtosecond Laser-Processed Surface.” Processing specimens with femtosecond laser ablation in a vacuum environment minimizes redeposition of debris and provides a clean surface to characterize using conventional electron microscopy

techniques. However, periodic structures caused by the incident femtosecond laser pulse can negatively affect image quality of the microstructure. The authors provide a generalized approach to minimizing this effect. The careful selection of process parameters provides an improved view of the underlying microstructure, requiring less postprocess cleanup.

Echlin et al. showcase a novel characterization system in “Recent Developments in Femtosecond Laser-Enabled TriBeam Systems.” Here, the authors demonstrate equipment, developed in collaboration with Thermo Fisher Scientific, containing a femtosecond laser coupled with a dual focused ion beam and secondary electron microscope. This unique equipment is capable of sectioning length scales from a few nanometers to millimeters. Moreover, this equipment is one of the few with the capability to serial section and image cubic millimeter volumes with submicrometer accuracy. The authors have demonstrated the unique capability by imaging a wide range of material systems including biomaterials, metals, and composites.

All titles and authors of the articles published under this topic “Short-Pulsed Lasers for Materials Modification, Characterization, and Synthesis” in the December 2021 issue (vol. 73, no. 12) of *JOM* can be accessed via the journal’s page at: <http://link.springer.com/journal/11837/73/12/page/1>.

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