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Extended Abstract

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New approaches to characterize the properties of femtosecond laser filament

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Formation of femtosecond laser filamentation is mainly induced by the dynamic balance between nonlinear self-focusing and plasma defocusing effect. Its potential application in lightning control and remote sensing is closely related to the properties of filamentation, which makes it important to characterize them. For example, much effort has been paid on diagnostics of the laser intensity and electron density in filament using electrical conductivity measurement, quantitative fluorescence emission measurement and transverse or longitudinal interferometry, etc. In this contribution, we present two new approaches to measure the properties of filament. Firstly, laser intensity and its distribution has been quantified based on the dependence of sample ablation threshold on angle of incidence. Experimental results on laser ablation threshold of gold sample with angle of incidence have been presented. The peak intensity in filament is found to be strongly related to the external focusing of the laser beam. It is measured to be about 55TW/cm2 in loose focusing which is in good agreement with previous work. Secondly, electron density and its temporal evolution have been studied based on a new single shot electromagnetic induction method. The transient magnetic field is detected by an induction coil and the current as well as electron density was estimated from the time dependent electromotive force signal. The experimental results show its advantages in obtain reliable temporal evolution of the electron density with reduced noise and interference compared with traditional electrical conductivity method.

Femtosecond laser fabrication has grown to be a major method of extreme manufacturing because of the extreme energy density and spatial and temporal scales of femtosecond lasers. The physical effects and the mechanism of interaction between femtosecond lasers and materials are distinct from those in traditional processes. The nonlinear and nonequilibrium effects of the interaction have given rise to new concepts, principles, and methods, such as femtosecond pulse durations are shorter than many physical/chemical characteristic times, which permits manipulating, adjusting, or interfering with electron dynamics. These new concepts and methods have broad application prospects in micro/nanofabrication, chemical synthesis, material processing, quantum control, and other related fields. This review discusses the cutting-edge theories, methods, measurements, and applications of femtosecond lasers to micro/nano-manufacturing. The key to future development of femtosecond laser manufacturing lies in revealing its fabrication mechanism from the electronic level and precisely regulating the electronic dynamics. The methods of femtosecond laser fabrication mainly include femtosecond laser direct writing, femtosecond laser time/space shaping, femtosecond laser frequency modulation such as second harmonic generation or OPA, and femtosecond-laser-induced chemical reaction. These fabrication methods have greatly expanded the range of applications of femtosecond laser fabrication and have made it possible to process any material and construct complicated 3D structures.

In recent years, ultrafast laser micro/nano-manufacturing has become one of the frontiers in the development of manufacturing technology because ultrafast lasers can change the states and properties of materials through the interaction with them and they can be used to control materials for processing from micron to nanometer scales or across scales. Femtosecond lasers tend to impose extreme conditions in the interaction with target materials because of the ultrashort temporal scales (~ 10−15 s) and the high energy density (> 1014 W/cm2) while they can be focused into nanometer spatial dimensions (~ 10−9 m). Because of these characteristics, femtosecond lasers can process almost any material with high quality and high precision, and realize three-dimensional complex structure fabrication. The nonlinear (multiphoton, etc.) absorption of a femtosecond laser enables it to break through the limitations of traditional fabrication methods, and fabrication accuracy currently stands at 1/50 of the diffraction limit. The nonequilibrium (interelectron nonequilibrium, electron-to-lattice nonequilibrium, etc.) absorption and nonthermal phase transitions (Coulomb explosion, electrostatic stripping, etc.) of femtosecond lasers can minimize heat-affected zones, cracks, and recast layers, which greatly improves the quality of fabrication. In addition, no mask, vacuum, or reactive gas environment is needed in femtosecond laser fabrication. Furthermore, the process generates particularly low amounts of waste compared with traditional methods and does not cause pollution. These characteristics of femtosecond lasers have led to the development of new manufacturing concepts, principles, methods, and techniques, which support a large number of manufacturing applications, such as process and automation technology, information technology, telecommunications technology, biotechnology, and the pharmaceuticals, aerospace, and environmental industries.

Owing to the advantages of femtosecond lasers and the newly developed fabrication methods, femtosecond laser fabrication has become an irreplaceable manufacturing method in many application areas such as the processing of special functional surfaces, biological tissue or cells, and high-aspect-ratio microholes. For example, microholes with aspect ratios greater than 1000:1 have been fabricated on transparent materials. The fabrication of high-aspect-ratio microholes on metallic materials remains challenging because of their high reflection rate.

Bottom Note: *This work is partly presented at New Frontiers in Optics, Photonics, Lasers and Communication Systems, May 13, 2019, Tokyo, Japan*