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FEMTOSECOND LASER MICROFABRICATION FOR ADVANCED ACCELERATOR APPLICATIONS

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Abstract

Femtosecond laser microfabrication allows for precise dimension control and reduced thermal stress of the machined materials. It can be applied to a wide range of materials from copper to diamond. Combined with secondary operations like polishing, laser microfabrication can be utilized in various state of the art components required for the AAC community. In this paper, we will review several applications of laser microfabrication for Advanced Accelerator research and development. These will include wakefield structures (corrugated metal and dielectric loaded), plasma capillaries, x-ray refractive optics, high power laser optical components: mirrors, phase plates.

INTRODUCTION

In recent years, laser micromachining has made impressive advancements in terms of accuracy, scalability, and surface finish. Furthermore, the availability of extremely short pulse, femtosecond lasers now makes possible the process of ablation without melting. Surfaces processed in this manner exhibit less structural damage, and are expected to have a very high optical damage threshold. We developed an in-house femtosecond laser ablation system for the production of diamond lenses and phase plates [1]. We propose to use this approach (fs laser ablation) for the production of various accelerator – related components, from field emission cathodes to high frequency RF components to CO2 laser diffraction optical elements. A combination of galvanometer-controlled ("galvo") mirror scanning and high precision translation stages allows for large-scale grating production, limited only by the translation range of the stage.

In this paper we will review the laser ablation microfabrication process and present several accelerator applications of this fabrication technique.

LASER ABLATION

Laser ablation is a complex multiparameter process. In our laser cutter layout, we have a 50–100 kHz repetition rate, ~ 200 fs pulse length laser, operating in the second harmonic (515 nm). This laser passes through two key optical elements. One is a motorized lens, which allows focus adjustment in the range of 4 mm. The second unit consists of computer-controlled "galvo" mirrors with a so-called theta lens, which rasters the laser beam on the worktable (Fig 1). It is the interplay of the galvo mirror motion along with computer-controlled signal for the laser to fire or delay firing, and the specifics of the mirror motion control, that consists not only of steady movement, but also acceleration, deceleration and settling effects, that make the process incredibly complex and flexible.

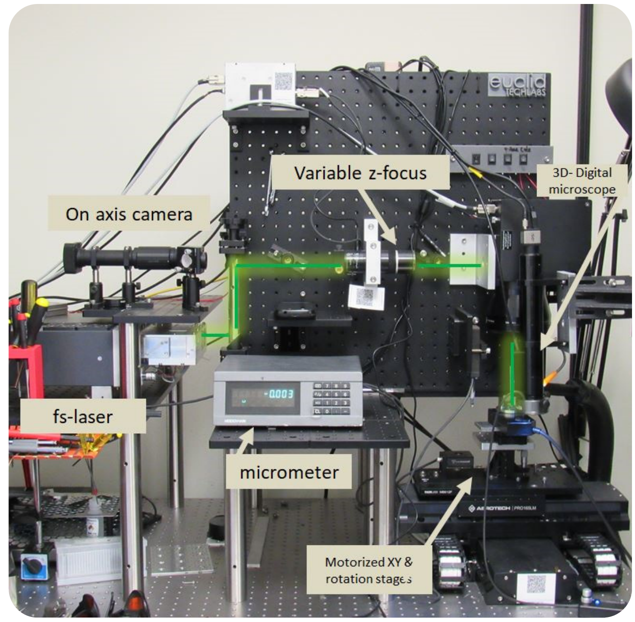

Figure 1: Femtosecond laser ablation system.

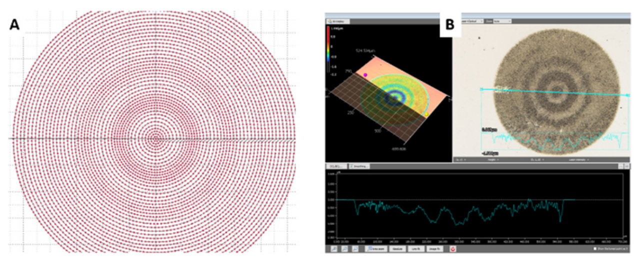

Figure 2: A. Laser ablation pattern. B. Metrology of ablated profile in diamond.

Typical ablation script is a path of the laser rastering created to produce specific ablation features at desired locations. Most geometries are produced by layering basic shapes (circles, squares, etc.) that are field with laser path lines. A more sophisticated strategy can involve variable density path lines for micron-level feature control (Fig 2). The single point ablation regime allows the ability to reproduce a specific set of ablation craters on the surface of different materials. An example of copper ablation with a random point pattern for high-power mirror reflectivity control is shown on Fig. 3. The typical size of the crater is a 10-micron aperture with quarter micron depth. There are number of considerations that are accounted for in the ablation scripting: layer decomposition, symmetrization of ablation with respect to the inherently elliptical laser spot, structure edge effects, kerf, laser delay and corresponding under or over exposure of the work piece to the laser beam, incorporation and synchronization of external motorization and focal plane adjustment during laser cutting procedure.

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We utilize confocal scanning laser microscopy [2] for in-house metrology and iterative fabrication.

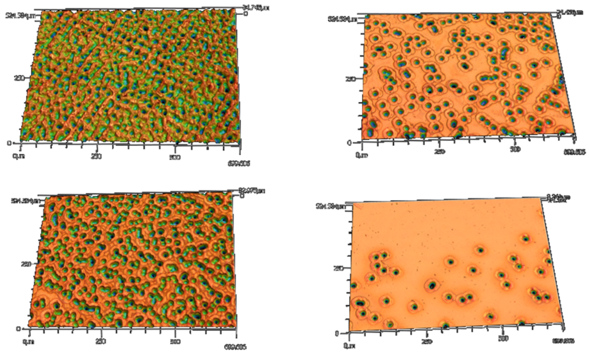

Figure 3: Mirror apodization: random points ablation on copper mirror for CO2 laser.

EXAMPLES OF ACCELERATOR APPLICATIONS

Femtosecond laser ablation relies on extremely high peak power (~100MW) within a pulse to evaporate material. For this reason, any material can be processed with this technique including ceramics, ultra-hard metal alloys, carbides, and diamond. We routinely ablate copper for several applications. One is for an array of field emitters (Fig. 4). In this figure, an array of 100-micron tall, 50-micron wide copper needles are ablated with 1 mm periodicity. This sample was used to calibrate the emission spot imaging system at Argonne Cathode Test stand [3].

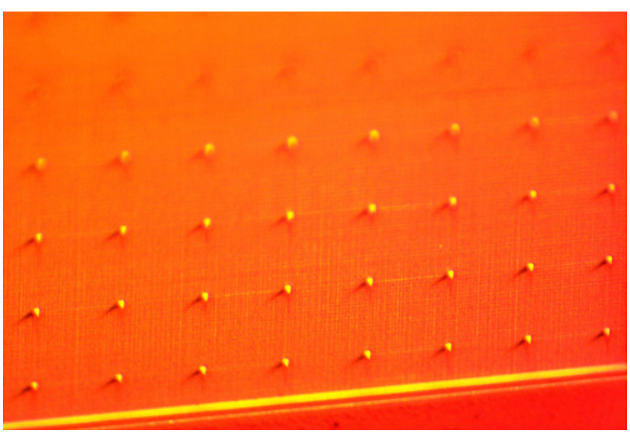

Figure 4: Field emission needle array on copper.

Custom mm-size parabolic mirrors with a 1-micron shape error are produced for final focusing of high-power broadband THz pulses [4, 5]. These are shown in Fig. 5A along with a mm-size off-axis paraboloid, Fig. 5B.

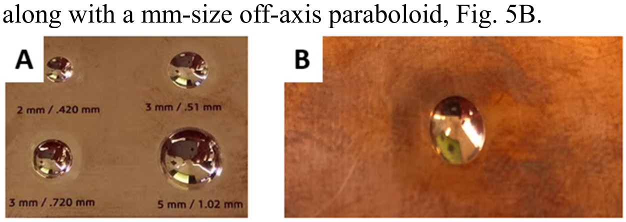

Figure 5: Custom parabolic micro-mirrors, laser ablated and polished. A) Normal incidence, B) Off-axis.

Micron-size feature control allows laser microfabrication to be used in sub-mm wave component designs. An example being linear to circular polarization converter (Fig 6). In this device, incoming linearly polarized radiation reflects from top and bottom edges of the grating. The depth of the grating is tuned to create a proper phase shift that forms a circular polarization of the wave at a design frequency of 275 GHz.

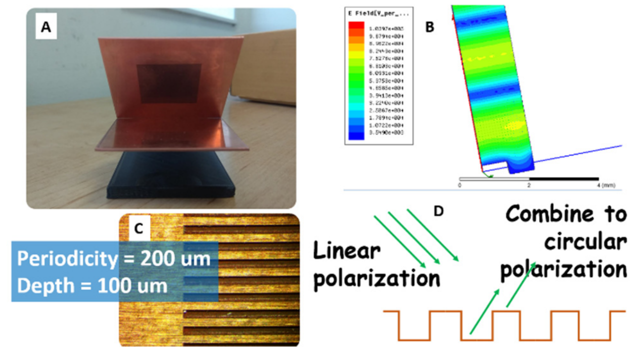

Figure 6: Linear to Circular polarization converter at 275 GHz. A) Fabricated device – polarization isolator, B) simulation of the grating operation, C) Microscope image of lasercut grating in copper, D) Principle of operation.

Another example of laser microfabricated structure is a photonic band gap accelerating waveguide at 300 GHz. This structure is an array of plates shown in Fig. 7. High resistivity float zone silicon is used in this application, as it has extremely low loss tangent in the sum-mm frequency range (1e-3). Concentric rings form a Bragg condition for the TM01-like mode, providing confinement without the metal wall. Such structure can have a high shunt impedance due to reduction of Ohmic losses at high frequency [6].

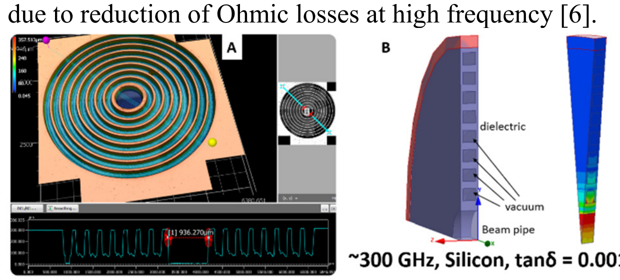

Figure 7: Photonic band gap accelerating structure for 300 GHz. A. Ablation of silicon, metrology. B. Microwave design of the structure.

CONCLUSION

Femtosecond laser ablation is a promising fabrication method for a variety of accelerator applications. Precise dimension control and the extremely wide range of materials that can be processed by this technology make it suitable for field emission cathode applications, and fabrication of broadband mirrors, transmission windows and accelerating structures from the sub-mm to the infrared range.

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