ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB153

LASER MICROFABRICATION FOR ACCELERATOR APPLICATIONS

S. Antipov, S. Kuzikov, Euclid Techlabs LLC, Solon, OH, USA
A. A. Vikharev, Institute of Applied Physics, Nizhny Novgorod, Russia

Abstract

Laser microfabrication allows high precision ablation of materials at sub-mm scale. When laser pulse length is shorter than about 10 picoseconds the heat affected zone is minimized and ablation occurs without melting. Workpieces processed in this fashion exhibit less structural damage and are expected to have a higher damage thresholds. In this paper we will review several case studies of laser-microfabricated components for accelerator and x-ray applications. Ablated materials include diamond, quartz, tungsten, copper, YAG:Ce and silicon.

INTRODUCTION

In the past few years, laser micromachining has made impressive improvements in terms of accuracy, scalability, and surface finish. Furthermore, the availability of extremely short pulse, femtosecond lasers has made possible ablation without melting. Surfaces processed in this fashion exhibit less structural damage, and are expected to have a very high optical damage threshold. We use a fs-laser ablation system for the production (Fig. 1) of various accelerator – related components from field emitters to CO_2 laser gratings.

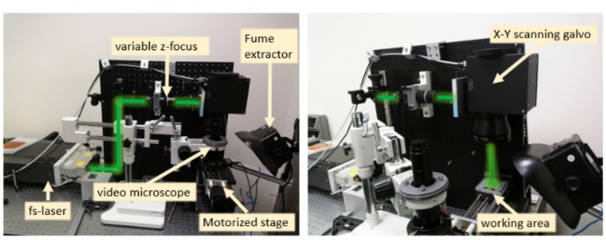

Figure 1: Femtosecond laser ablation system.

The fs micromachining unit is depicted in Fig. 1. It consists of a femtosecond laser and a motorized mirrors at allow pre-programmed rastering of the laser across the sample surface. Sub-micron precision can be achieved in special cases.

FIELD EMITTER MICROMACHINING

In collaboration with Argonne Wakefield Accelerator Facility we produce field emitter fiducials (Fig. 2) on an insertable cathode plug. The goal of this exercise is to track field emission from a known set of sources (microfabricated needles). Using these field emitters an electron imaging beamline is calibrated. This beamline is used to identify and track dark current sources on cathode plugs. Figure 2 shows simulation compared to the actual measurement.

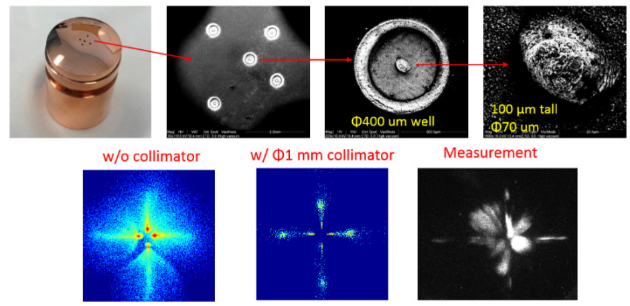

Figure 2: Schematics of a single-grating interferometry setup, showing the wavefront propagating through a checkerboard grating (a) without and (b) with the distortion from a sample.

PEPPER POT FOR EMITTANCE MEASUREMENT

Another standard application of laser micromachining is fabrication of periodic arrays of holes (pepper pots) for beam emittance measurement. A high Z material like Tungsten is used for pepper pots.

Depending on expected beam parameters a customization of the pepper pot arrays may be required. Figure 3 shows an example of multiple pepper pots created on the same tungsten sheet.

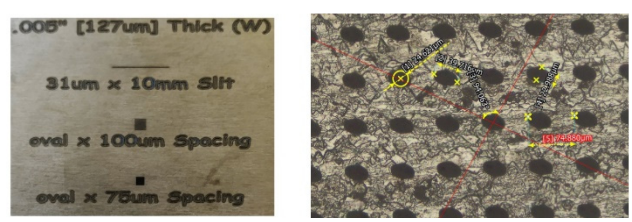

Figure 3: Laser drilled arrays of holes in tungsten.

COMPRESSION GRATING FOR CO_2 LASER

The invention of CPA was a dramatic breakthrough in the field of solid-state laser technology, and it is expected that its effect on gas lasers will be equally strong. Accelerator Test Facility considers the CPA as a main route for the upgrade of their terawatt CO_2 laser [1]. They stretch the beam after the optical parametric amplifier, amplify it further and compress at the final stage with diffraction gratings.

Traditional etched gratings allow for large aperture devices but suffer from losses and poor diffraction efficiency. Secondary coatings can improve the efficiency but they decrease an optical damage threshold. Ruled ("master") metallic gratings have high damage threshold and high efficiency, but are extremely expensive. Replicated gratings

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB153

are relatively inexpensive but suffer from low damage threshold.

While it is possible to shape the beam intensity distribution to yield blazed grating geometry we will show below, that an equally high if not higher (Fig. 4) diffraction efficiency can be achieved with quasi-sine wave grating surface like that one produced on a sample cut (Figs. 4 and 5). Diffraction gratings are widely used in mm-wave community for high power gyrotron beam polarization control [2].

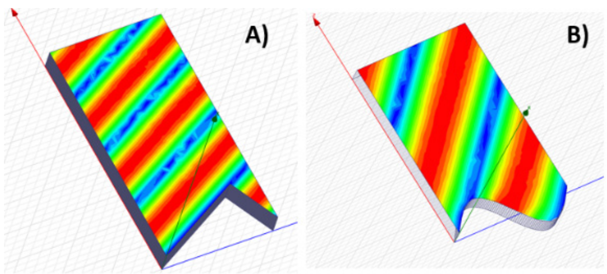

Figure 4: Simulations of grating performance. Electric field distribution. A) triangular grating and B) sinusoidal grating.

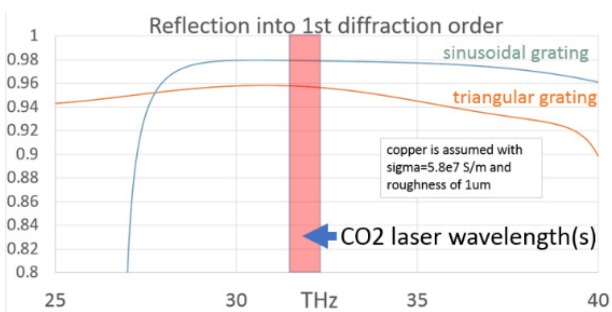

Figure 5: Comparison of grating efficiency (simulation).

In the case of mm-wave devices gratings can be CNC machined with virtually any shape, while optical and near infrared gratings are ruled with knife and triangular shape is easier for the knife profiling. High power gyrotron community tries to avoid sharp corners as those lead to field enhancement and possibility of breakdown. Following the same logic we consider a sine-like grating pattern for breakdown resiliency. We had simulated both cases. As the system is periodic, only one period of grating can be simulated. Figure 4 shows the field distribution on A) blazed grating and B) sinusoidal grating.

Figure 5 compares grating efficiency into first diffraction order. While triangular grating has wider bandwidth, sinusoidal grating has higher efficiency for the same material and assumed surface roughness. CO_2 laser bandwidth (Fig. 5, shaded red) is rather narrow and sinusoidal grating has higher efficiency in that region.

We fabricated a sample by laser ablating copper (Fig. 6). The required periodicity of 15 microns had been achieved.

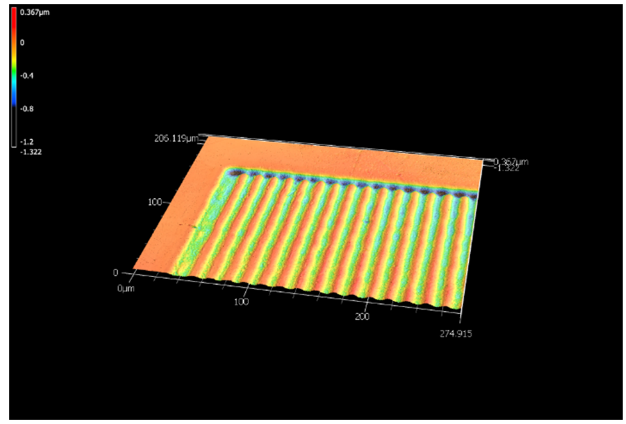

Figure 6: Metrology of a compression grating sample.

REFERENCES

[1] I.V. Pogorelsky and I. Ben-Zvi, "Brookhaven National Laboratory's Accelerator Test Facility – Research Highlights and Plans", Brookhaven National Laboratory, Upton, NY, USA, Rep. BNL-104414-2014-CP, Sep. 2013.

[2] F. Zhang *et al.*, "Experiment study of a dual-polarizer for HL–2M electron cyclotron resonant heating systems", *Fusion Engineering and Design*, vol. 122, pp. 16-20, 2017. doi:10.1016/j.fusengdes.2017.09.015