STAINLESS STEEL FOIL PERFORATION

Application note

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INTRODUCTION

Foil perforation can be exploited for numerous tasks and applications, electronic circuitry, optical surfaces and apertures and mechanical filters are just a few that can be mentioned. Until recently this task would have been done by employing mechanical tools or long-pulsed lasers. The technical advances in femtosecond laser technology are making femtosecond laser machining of thin metallic coatings or foils a feasible solution when high quality features of a few micrometers are necessary.

Objective. The objective of the experiments presented here is to repeatability produce holes of ~1 micrometer diameter in stainless steel foil of 10 um thickness.

Keywords: femtosecond, thin, foil, metal, perforation, drilling.

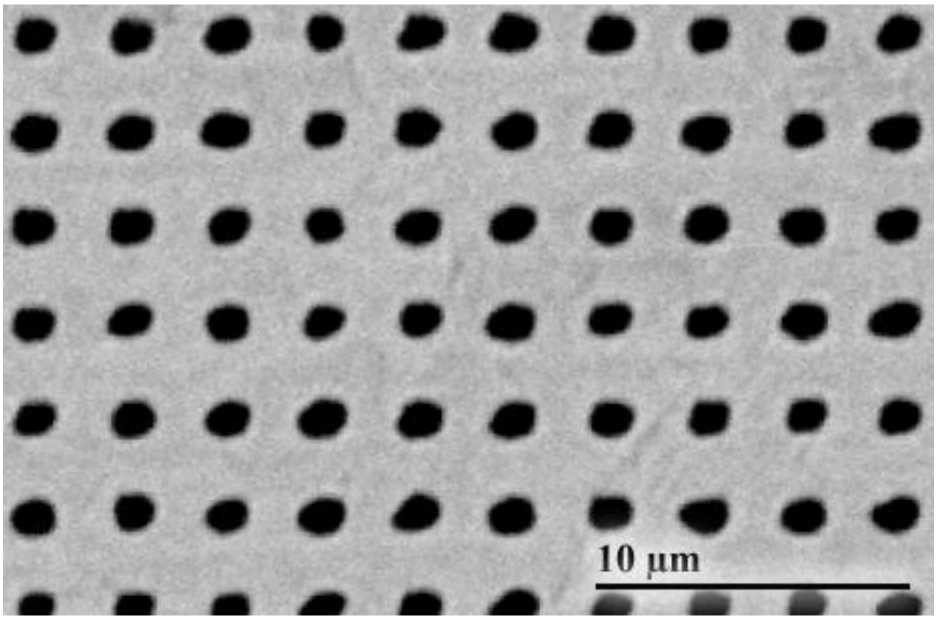


Fig. 1 Precise micro holes drilling (down to 1 μm diameter).

A hole drilling in metals is perhaps one of the first commercial applications of laser technology. Fuel injectors and inkjet print heads have benefited from laser drilling in the past. There are, however, many more applications for laser-machined through-holes that have not yet been feasible or haven't even been discovered. Nanosecond lasers have been and are still used for such tasks. The nanosecond approach is not without its drawbacks. Compared to characteristic durations of laser radiation interaction with metals, nanosecond pulses are considered to be long. The laser pulse lasts well into the material removal stage and exactly because of this high material removal rates are possible. The downside of this same temporal character of nanosecond pulse machining has been discussed extensively in the related scientific literature. The material is heated comparatively slowly, energy has a lot of time to diffuse into the surrounding area before the affected spot is heated enough for material removal to occur. This produces a large heat affected zone (HAZ) and a lot of molten matter is ejected and deposited on the surface of the fabricated article. Also, because the pulse lasts into the removal stage, the ejected vapor or plasma plume is further heated by the laser pulse, radiation is absorbed in the plume instead of being deposited into the machined object. The produced plasma plume interacts with the surface, this brings about mostly negative consequences (although it can sometimes be exploited for deep channel fabrication).

Nowadays picoseconds lasers offer high power for industrial scale fabrication and their pulse length can be tailored for metal fabrication because the characteristic durations of lattice heating are in the region of several to several tens of picoseconds. However for the smallest features and the least amount of heating and collateral damage the shortest pulses have been shown to give the best results. Femtosecond lasers do not yet rival picoseconds systems in delivered power, but with their parameters and industrial robustness improving steadily, femtosecond metal machining seems destined to reach maturity in industry in the foreseeable future. Moreover, not all applications require average powers into the tens or hundreds of watts, so niche applications can already be found for femtosecond systems that can prove to be fit for industry.

EXPERIMENTAL SETUP AND PROCEDURE

The sample was 10 um thick stainless steel foil (steel grade - SAE 304). Pieces of foil that were used for the experiments were glued to a glass substrate with a water-soluble adhesive to ensure flatness and stability of the fabricated surface for the duration of the experiment.

Experiments were carried out using FemtoLab femtosecond laser microfabrication system (Altechna) incorporating Yb:KGW femtosecond laser Pharos (Light Conversion), harmonics generator Hiro (Light Conversion), high precision sample positioning system (Aerotech) all of which is integrated by SCA (System Control Application, Altechna) software. Holes 5 um and 3 um apart were formed with various pulses-per-spot numbers and pulse energies, different focus positioning schemes and pulse repetition rates. An aspheric AR coated lens of 4 mm focal length was used to focus the Gaussian beam on the samples.

After fabrication the samples were rinsed in an ultrasonic bath in pure H2O for 5 minutes, during this procedure the foil was released from the glass substrate, also the arrays of holes that lacked mechanical robustness to withstand ultrasonic agitation were destroyed, providing an additional criterion for the selection of a suitable fabrication parameter set.

After ultrasonic cleaning the samples were flattened between two glass microscope slides for observation through an optical microscope, frontal illumination allowed analysis of the front and back surfaces while back illumination gave a clear indication of whether the machined features were through-holes and also showed the consistency of hole diameter and machining repeatability. Samples were further inspected by a scanning electron microscope.

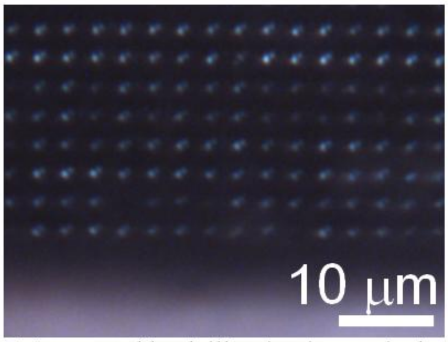
RESULTS

As it can be expected, when pulse energy was too high, hole diameter was increased due to the threshold nature of laser ablation and Gaussian beam intensity distribution. Too many pulses per spot had the same effect due to damage incubation and accumulation and surface modification by previous pulses. In most cases this resulted in total destruction of the fabricated region when produced holes became large enough to overlap or critically reduce mechanical strength of the resulting metallic net. Pulse energies or pulse repetition numbers that were too low failed to produce through-holes of failed to do this in a repeatable manner. High pulse repetition rates resulted in heating and localized melting, although in all cases some deformation of the fabricated region was observer. Also significant amount of removed material were deposited on the sample, although the deposited debris was not molten, but rather oxidized. The front surface also exhibited oxide formation, but the exit side of the holes was clean, without any observable heat damage. This suggests that apart from the film of oxidized steel, the foil was perforated with high quality and thermal effects are being kept at a minimum during such fabrication.

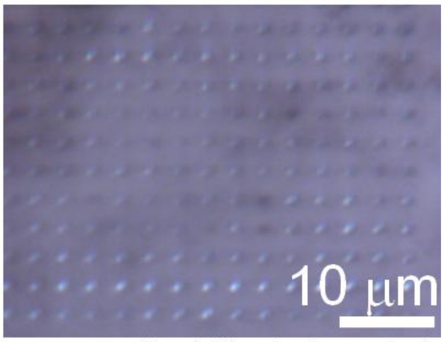
Two sets of parameters have been selected according to the best results obtained, features produced in these test can be seen in figures 2 and 3, explanations are given in captions accompanying the images.

CONCLUSIONS AND FUTURE OUTLOOK

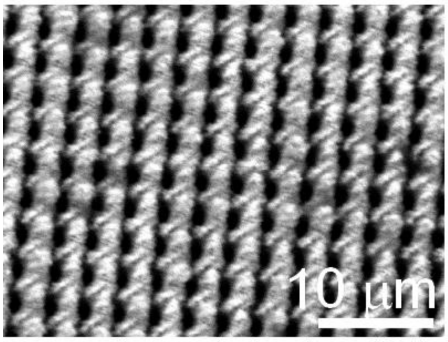
These tests indicate that high-precision perforation is indeed possible, and these exists a region of optimum balance between pulse energy and number of pulses per spot than enables drilling of micrometer-sized holes without noticeable or at least significant heating. Also it becomes clear, that pulse repetition rate in the high-kilohertz region starts to become a major determining factor for machining quality and repeatability. If femtosecond perforation of thin materials is to be adopted by industry on a large scale, it needs to provide industrial throughput and reliability, as well as cost effectiveness. There already exist several techniques for making the process faster. These include pattern projection by multiple beam interference, diffractive beam splitting, the use of microlens arrays and multiple samples machining after beam splitting and focusing through multiple objectives.



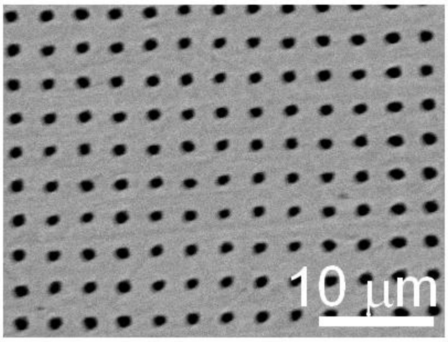
1. Front and back illumination optical micrograph of perforated foil, front surface.



2. Front and back illumination optical micrograph of perforated foil, back surface.

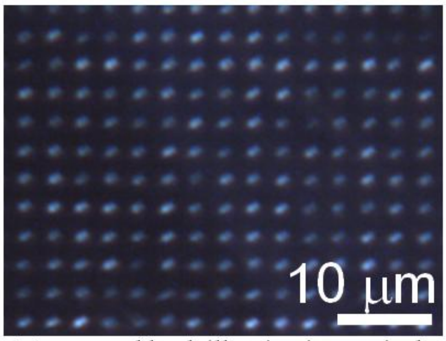


3. SEM micrograph of perforated foil, front surface.



4. SEM micrograph of perforated foil, back surface.

Fig. 2 Hole diameter 1 um, holes form a grid with 3 um periodicity.



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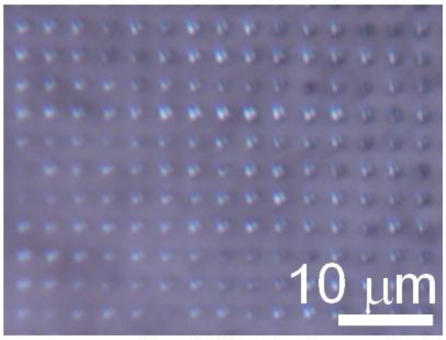
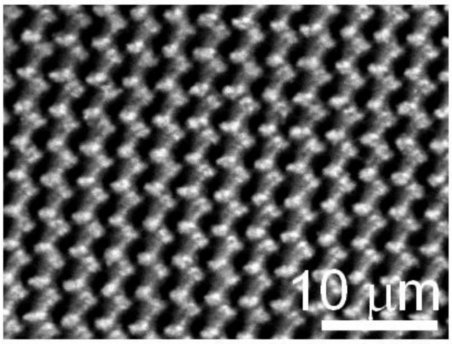


2. Front and back illumination optical micrograph of perforated foil, back surface.



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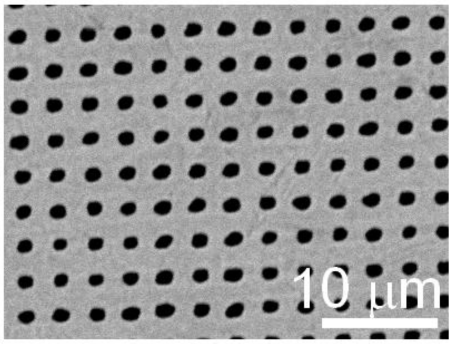

4. SEM micrograph of perforated foil, back surface.

Fig. 3 Hole diameter 1,3 um, holes form a grid with 3 um periodicity.

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