

Micromachining of Metals with the Raydiance 1552 nm Ultrashort Pulse Laser System

Abstract

This work demonstrates the potential of the Raydiance Discovery™ System for precision machining of thin-sheet metals used in industrial and medical applications. Material machined included 50 μm Nitinol, 50 μm 316 stainless steel, 25 μm titanium, and tungsten. In all cases, clean and precise features were machined without any apparent thermal effects on the samples. An effective line processing rate of the 50 μm stainless steel was determined to be approximately 3 mm/s.

Background

Micro machining of thin metal sheets has broad application in the medical, semi-conductor and industrial sectors. Specifically, Stent fabrication and semiconductor mask production are two such applications that require high precision and quality machining. The end products can tolerate no heat affected zones (HAZ), cracks, recast material or burrs. Processing defect rates must be low.

Diode-pumped fiber lasers (10 - 50 W, nanosecond pulse duration) offer a relatively low capital and operational cost, a 7 μm resolution limit and a 100:1 aspect ratio. However, due to their relatively long pulse width these lasers exhibit undesirable effects associated with high temperatures. In most instances, the sample must be cooled during the process. Further, multiple post processing steps are required.

Ultrashort pulse (USP) lasers are the new comers in thin metal micromachining. The nonthermal nature of the USP ablation process provides a significant processing advantage by eliminating post-processing steps.

Objective

The objective of this work is to demonstrate precision micromachining in Nitinol, 316 stainless steel, titanium, and tungsten.

Methods

For all results discussed below, a Raydiance Discovery™ System was used (1552 nm, pulse duration 1 ps, variable pulse energy < 13 μJ/pulse, variable repetition rate < 500 kHz). The ablation setup comprised a galvo scanner, linear motion stages, different focusing objectives and lenses, a beam expander, visualization system, and, in some cases, a nitrogen gas purging system. Samples were not temperature controlled in any way.

Hole Drilling in 50 μm Nitinol Sheet

Holes 30 μm and 300 μm in diameter were machined in 50 μm Nitinol sheet. Approximately 2.4 $\mu\text{J}/\text{pulse}$ were delivered on target at 10 kHz. The front side of the sample is shown in **Figure 1**. Very clean machined edges are achievable. The smaller holes were machined with 3.8 $\mu\text{J}/\text{pulse}$ on target and a 40 mm GRADIUM™ lens. SEM analysis of a 30 μm hole, shown in **Figure 2**, reveals no apparent thermal damage to the structure of the material.

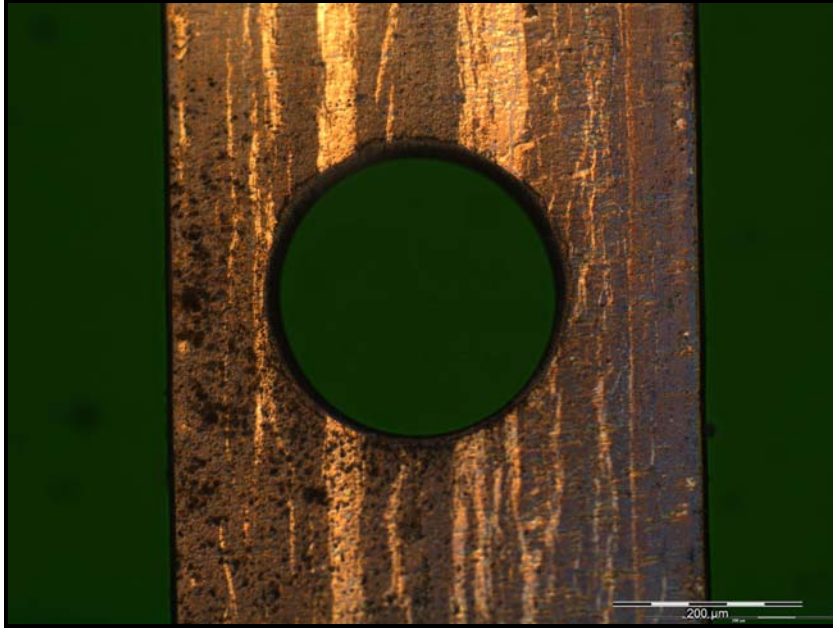


Figure 1: A 300 μm diameter hole drilled in 50 μm Nitinol sheet.

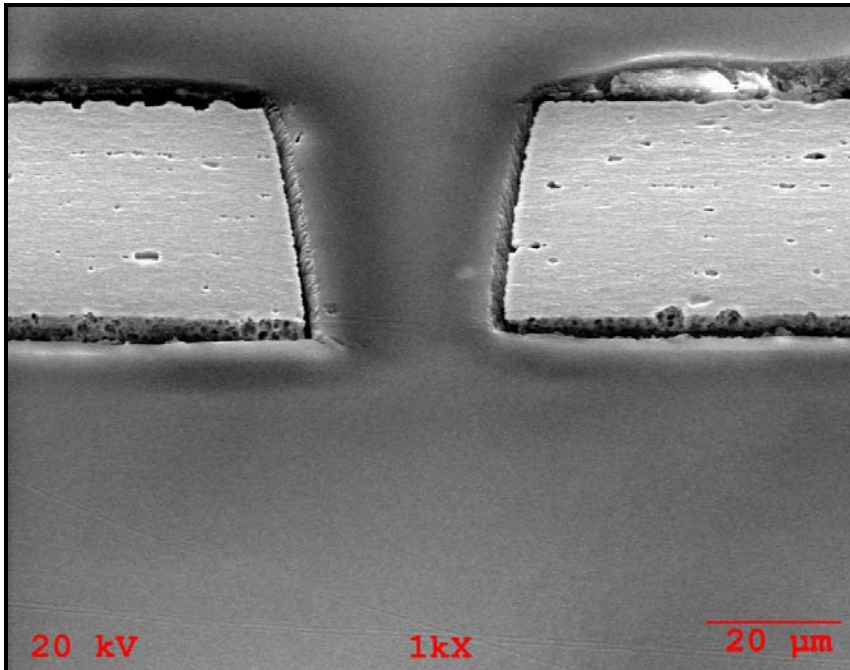


Figure 2: Sideview SEM image of a 30 μm hole drilled in Nitinol. Note that there is no recast or other thermal damage.

Micromachining 50 μm 316 Stainless Steel

A multi-pass cut was made in 50 μm thick 316 stainless steel (10 μJ /pulse on target, 21 kHz). The beam scan rate was 24 mm/sec, and there was no z-indexing. The beam was expanded to 3.5X with a variable telescope ([Special Optics variable telescope 56-30-2-8X-1552](#), AR coated for 1552 nm, 2-8x beam expansion). A 40 mm focal length, gradient lens (GPX15-40DB3) was used. The debris generated around the cut was first cleaned with compressed air and then ultrasonically cleaned. As seen in **Figure 3** sharp angles can be created, which suggests that the process is low temperature and induces very little, if any, mechanical stress. Again, notice that the high NA objective results in taper in the machined feature, which, in turn, appears as the dark area in the image. This is not thermal damage but rather a result of the fact that the microscope camera cannot be in focus over the entire depth of field.

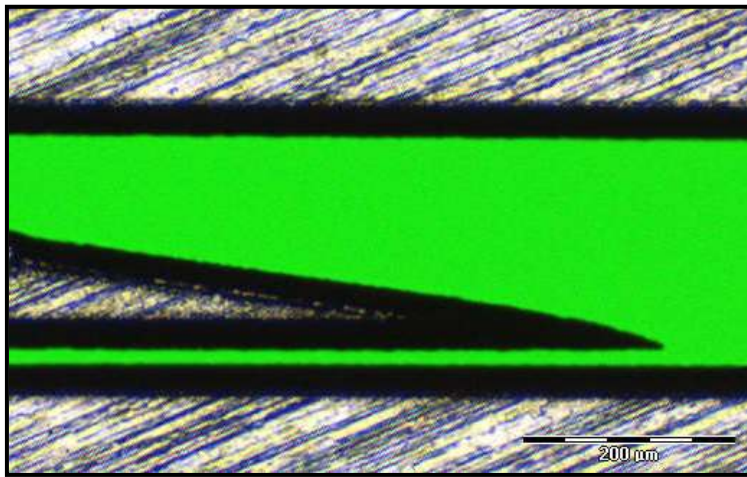


Figure 3: Sharp angles were machined into this 316 stainless steel sheet (50 μm thick).

Other features of similar quality were produced with pulse energies up to 13 μJ /pulse. To determine an approximate processing rate, multiple experiments were done varying scan rate and the number of passes along the same line feature. As one might expect, higher laser scanning rates require more passes to cut through the sample. Best results were obtained with an effective processing rate of approximately 3 mm/s.

Hole Drilling in 316 Stainless Steel

As with the Nitinol, clean 50 μm holes were drilled in the stainless steel. A side view SEM image (**Figure 4**) shows that the grain structure of the remaining material has not been altered by the Raydiance USP processing.

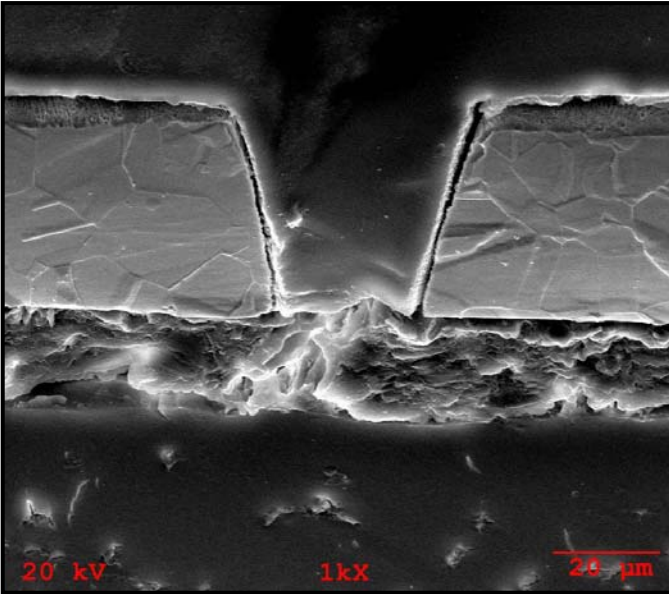


Figure 4: SEM image (side view) of hole machined in 316 stainless steel. (Material below sample is epoxy used in SEM preparation).

Micromachining of 25 μm Titanium Sheet

Cuts of similar quality were also achieved in 25 μm titanium foil. **Figure 5** shows a multi-pass cut with lateral and z-indexing at 24 mm/sec scanning speed (2 μJ /pulse on target, 22.73 kHz). The beam was focused with a [Mitutoyo](#) objective (20X / 0.40 NA, M Plan Apo NIR, $f = 10$), producing a 4 μm spot size. As seen in the figure, sharp angles can be created, which suggests that the process occurs at relatively low temperature and induces little mechanical stress.

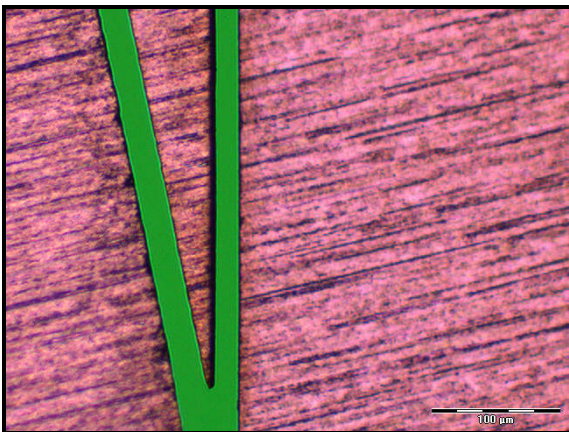


Figure 5: Multi-pass cuts of 25 μm titanium foil.

Tungsten

Clean, precise channels were ablated into tungsten sample below (*Figure 6*). The channel is approximately 276 μm wide and nearly 700 μm deep. As can be seen from the image, the cut is extremely clean, with no burrs or material reflow.

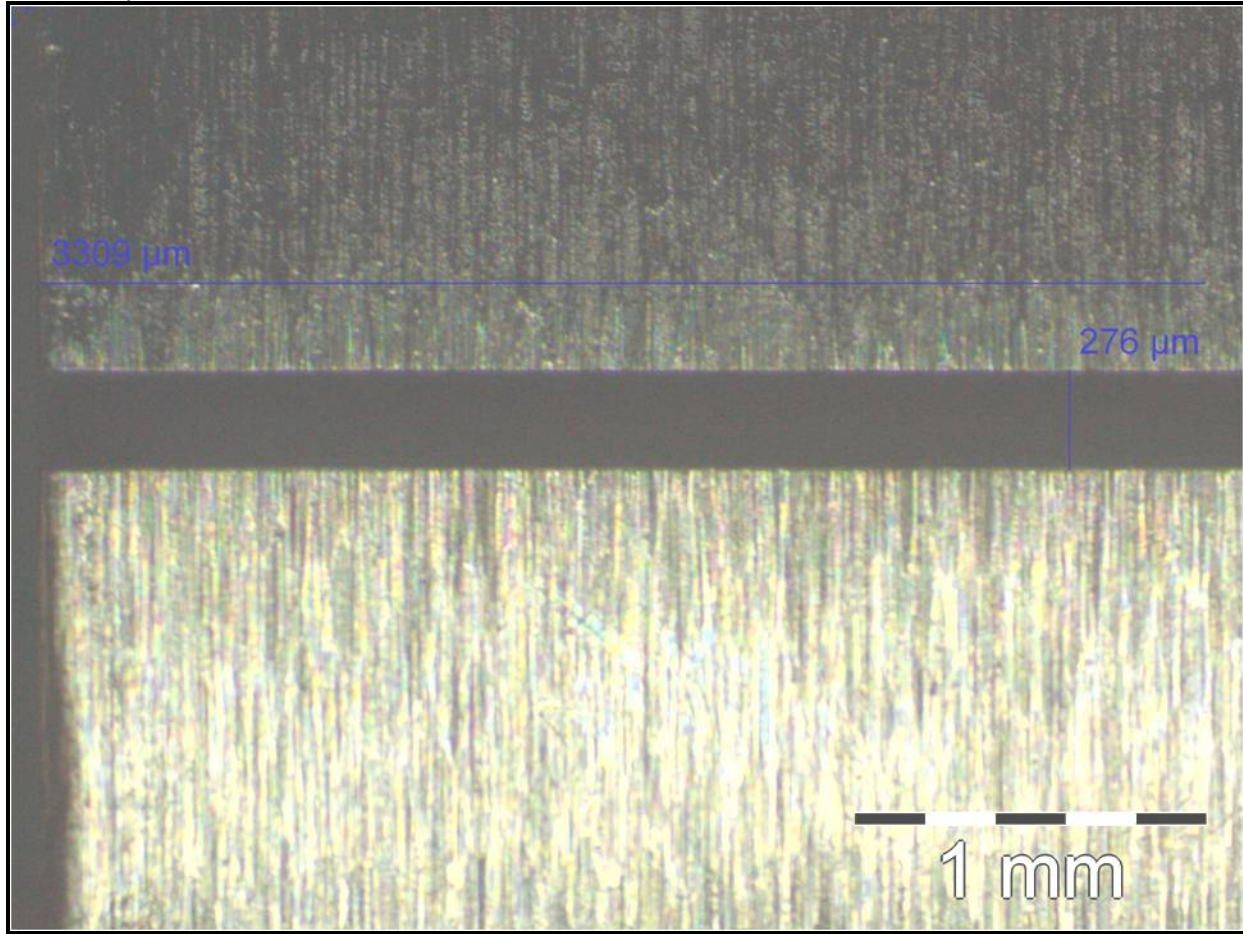


Figure 6: A trench approximately 700 μm deep was machined in this tungsten sample. The channel width is 276 μm .

Conclusion

The Raydiance Discovery system, an ultrashort pulse laser centered at 1552 nm, provides an efficient and precise method for machining many types of metal, including Nitinol, 316 stainless steel, titanium, and tungsten. Fine lines can be machined without thermal effects or changes to the grain structure of the target material.