Novel route to high quality ablation in a range of materials with a 400W single mode continuous wave fiber laser

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Abstract

Low power (up to 500W) single mode Ytterbium fiber lasers operating at 1080nm with a very good beam quality (M^2 ~ 1.10) are routinely used for a range of micromachining applications.

The high brightness of the fiber laser enable high power densities even at modest power levels, which is sufficient for cutting a range of thin metals, capable of welding of various materials including high reflective material and also drilling small holes in metals including aerospace alloys.

To date very little work has been carried out with these lasers for ablation applications. The laser ablation of metals is normally carried out with Q-switched pulsed lasers ranging from microsecond to femtosecond pulse durations, pulse frequencies up to 50 kHz and extremely high peak powers (MW).

In this work, laser ablation of a variety of materials including TBC superalloys used for aerospace has been demonstrated with a single mode fiber laser up to 400W. The paper will investigate the material removal rates and ablation quality.

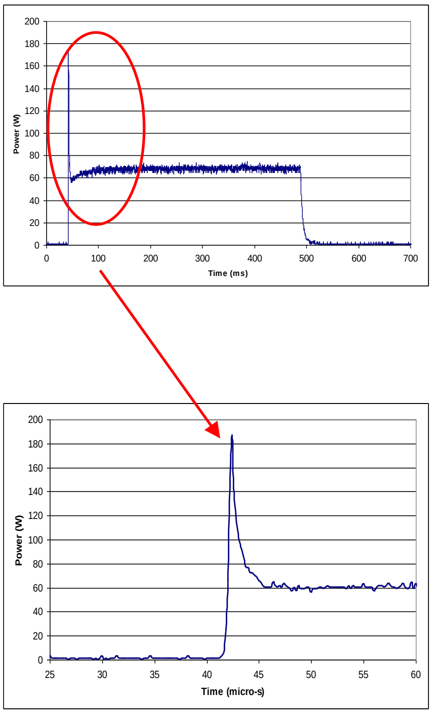
Introduction

The low power fiber lasers are very compact and robust and has an edge over lamp pumped Nd: YAG lasers in terms of beam quality and wall plug efficiency (approx 20%). Current investigations [1-3] show that the single mode fiber laser is an efficient, reliable and compact solution for microcutting and micro joining.

The diode-pumped technology offers low maintenance cycles and high conversion efficiency. Theoretical pump- light conversions of more than 80% are possible [4] but typical optical conversion efficiencies for Ytterbium double-clad fiber lasers are 60-70% [5].

An area where there is a significant difference between lamp-pumped YAG and fiber laser performance is pulsed operation. Lamp-pumped lasers are capable of producing long, multi-ms, pulses with peak powers many times the rated average power of the laser, provided that the duty cycle is sufficiently low. This ability stems from the flash-lamp itself which is often more constrained by the maximum average thermal load than the peak power output.

By contrast, while the semiconductor laser diodes used to pump a fiber laser can be on-off modulated over a wide frequency range as shown in **Fig. 1** (from DC to tens of kHz in most industrial applications), they cannot typically be over-driven for long periods (multi-ms), in the same way as a flash-lamp, without reducing the lifetime of the device to an un-acceptable level.



Initial pulse spike expanded view
duration around 1 microsecond

***Fig. 1*: Fiber laser modulation characteristics**

From an applications perspective this regime can enhance laser material processing in terms of processing speed, weld penetration and cut quality [6].

This paper describes the use of different modulation regimes with the JKFL200 to achieve high material removal rates. The modulation regime can improve the removal rate by eight times compared to running the laser in a purely continuous mode (CW).

The ablation tests were carried out with a 400W single mode Ytterbium fiber laser **(Fig.2)** operating at 1080nm wavelength emits a gaussian beam with an $M^2 < 1.10$ **(Fig. 3).**

The laser was fitted with a JK Lasers' scanning head and the results reported are at an average power

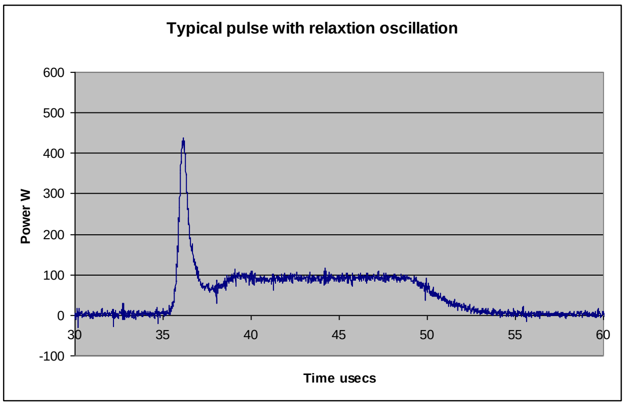


Fig.5: Typical output waveform with relaxation pulse

Fig.2: JK 400W Single mode fiber laser

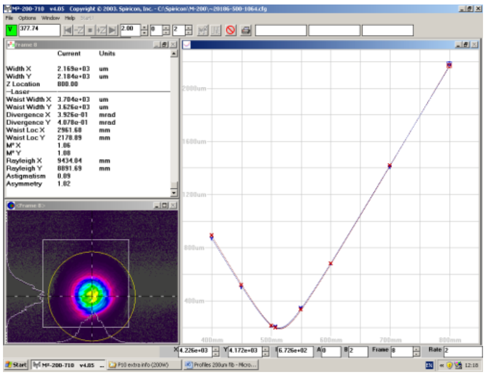


Fig. 3: Beam profile of a 400W SM laser

The laser was operated CW and modulated with a 20-35usec off time at a frequency of 5 kHz + and typical drive waveform is highlighted in **Fig. 4** and pulse is shown in **Fig. 5**.

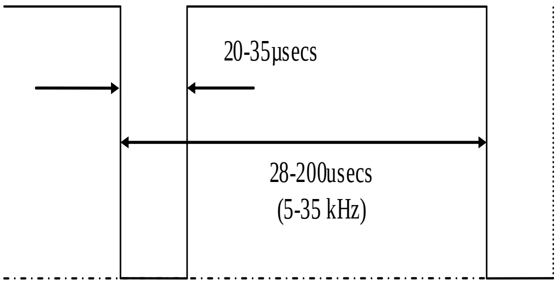


Fig.4: Turning the laser off produces a relaxation pulse typically X4-5 the CW level.

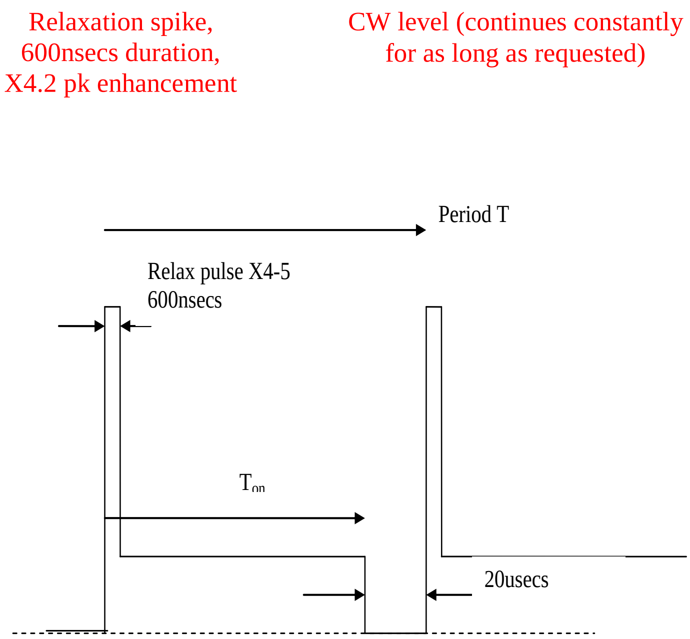


Fig. 6 shows energy calculations in the pulse waveform.

Energy in relax pulse = peak power x duration = 600nsec X 800W = .48mJ

Energy in rest of the pulse = T_{on} x average power = Ton X 200

Fig. 7 shows the estimated percentage the relaxation pulse makes up of the entire waveform and the average power variation with frequency for a 20usec pulse. The graph shows that for frequency of 5 kHz the relaxation pulses only make up 1.3% of the total energy, whereas for 35 kHz frequency it is 28%.

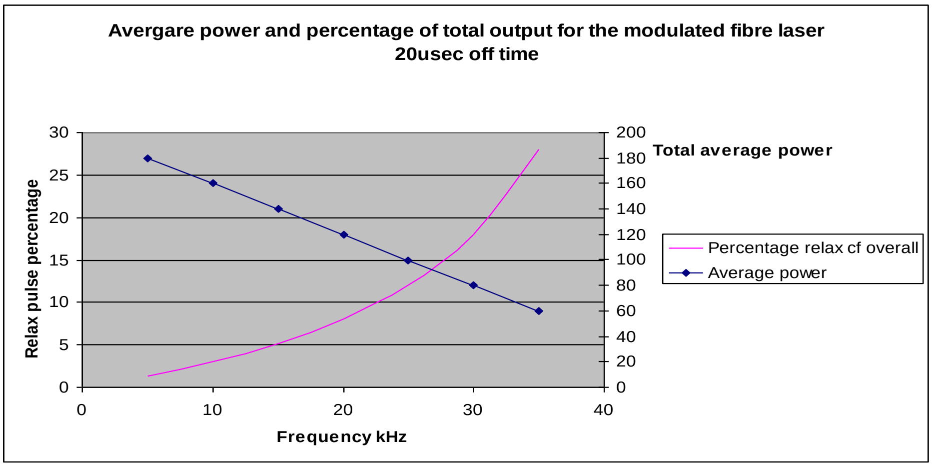


Fig.7: Average power and % of total power for the modulated fiber laser 20µsecs off time

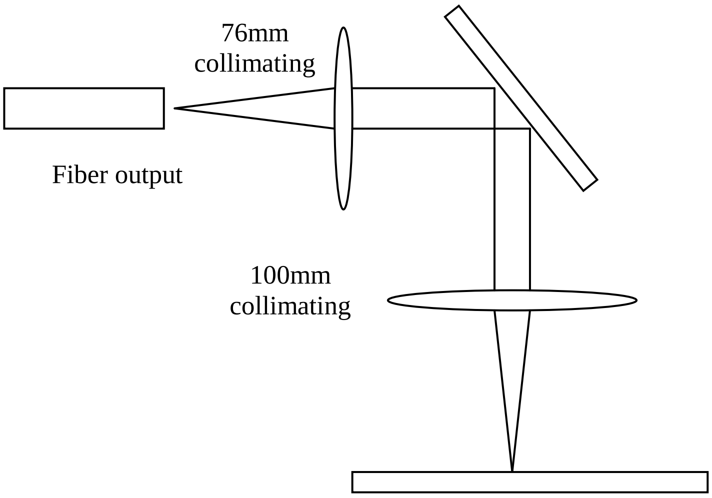
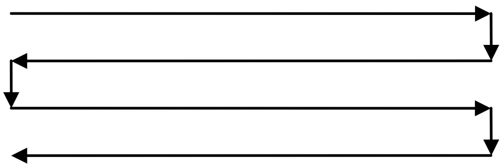


Fig. 8: Optical set up for ablation

Fig.8 shows the optical set up for the ablation experiment. A 4mm square was repetitively scanned with the pattern below:



Speed 1250mm/sec
Step 0.24

The spot sizes used during these tests are highlighted in **Tab 1.**

Tab.1: Spot size and intensities used for the tests

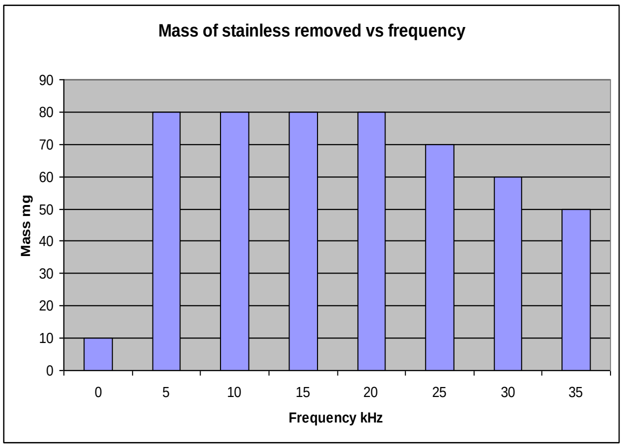
Output	30µm spot	50µm spot
200W CW	$28MW/cm^2$	$10MW/cm^2$
Modulated	$112MW/cm^2$	$40MW/cm^2$

Results and Discussion

Stainless steel

The metal was exposed for 26seconds and weighed before and after to quantify the amount of material removal. Fig. 9 shows mass removed as a function of average power and modulation frequency respectively.

Mass removed as function of frequency



Mass removed as function of average power

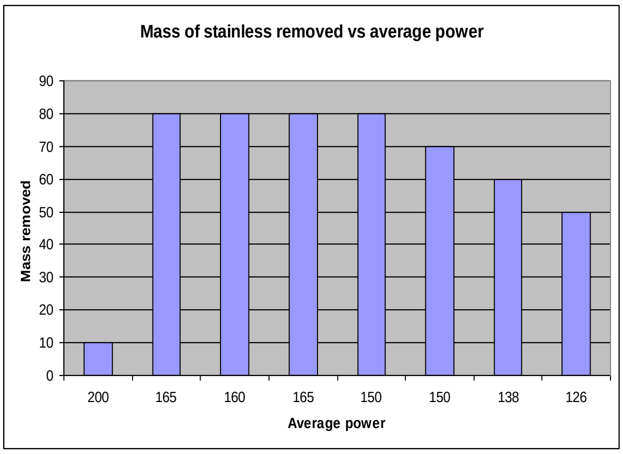
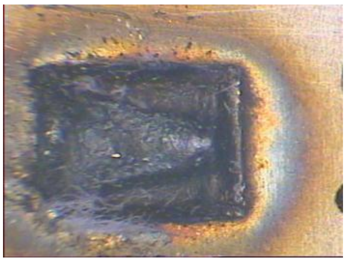


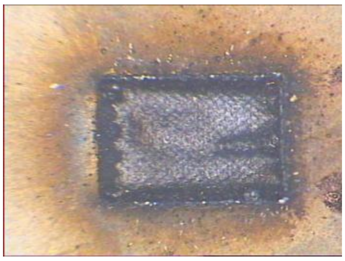
Fig.9: Mass removed in 2mm stainless steel

Results show that mass of 80mg in 26 seconds, which corresponds to 184mg/min or given the density of stainless steel 8030kg/m^3, 8.03mg/mm3. This gives material removal rate of 23mm^3/min. The results also show that in the modulated regime the mass removed is eight times greater than that achieved with a pure CW output.

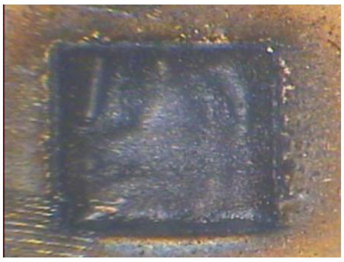
The average power is decreasing due to altering the frequency of the off time of the laser. The increased material removal rate is due the high peak power in the relaxation pulse. **Fig.10** shows photographs of the ablated surfaces at different laser parameters.



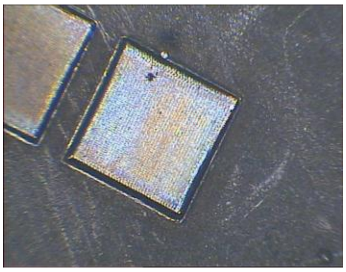
200W, CW, 26 seconds, 50 passes, and 10mg removed. The square is very drossy, not clearly defined and full of reformed material



165W average, 800W peak, 5KHz 165µsec on time and 80mg remove, much shaper defined edges compare to CW



165W average, 800W peak, 15KHz 55µsec on time and 80mg remove, the photograph doesn't illustrate clearly but this was the best finish with the assist gas



165W average, 800W peak, 15KHz 55sec on time and 80mg remove, the photograph doesn't illustrate clearly but this was the best finish with argon shield gas

Fig 10: Ablated surface of 304SS at different laser parameters

TBC Coated materials

Thermal barrier coatings are being widely applied in many types of engines and in aircraft's gas turbines. To increase temperature capability of the engine blades and vanes, a thin coat of a heat-insulating zirconia ceramics is applied on the surface of the blades as a thermal barrier coating.

The cooling of the components causes a pronounced reduction of the metal temperature, which leads to a prolongation of the mechanical component's lifetime. Alternatively, the use of thermal barrier coatings allows raising the process temperature, obtaining thus an increased efficiency.

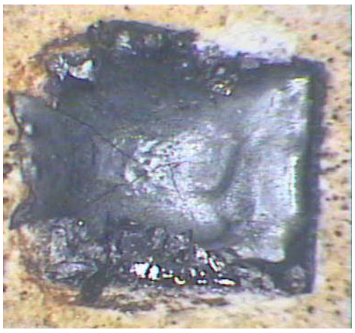
Thermal barrier coatings usually consist of two layers (duplex structure). The first layer, a metallic one, is the so-called bond coat, which protects the basic material against oxidation and corrosion. It also provides a good adhesion to the thermal insulating ceramic layer.

Ceramic coatings such as these are mostly made of yttria partially stabilised zirconia (YSZ), since this material has turned out particularly suitable during the last decades.

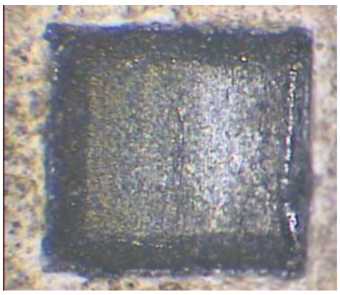
At present, there are two principle methods to apply thermal barrier coatings, one is plasma spraying and the other is electron beam physical vapour deposition (EB-PVD). These methods have been studied excessively to avoid mechanical and adherence problems between coatings and substrate.

Current practice to drill TBC materials is to remove the coating with either a Q-switched pulsed Nd: YAG laser (short pulse width and high peak power) or use pulsed fiber laser.

In this work a CW fiber laser was used to remove the TBC coating on aerospace alloy. **Fig. 11** highlights the results on the coated and Fig **12**. Shows uncoated aerospace materials

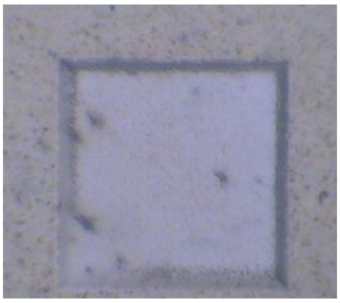


200CW, 26 seconds, very massy with excessive cracking



800W peak, 15 KHz, 26 seconds

800W peak, 15 KHz, 12 passes



800W peak, 15 KHz, 20 passes

Fig 11: Ablated surface of 2mm thick Haynes alloy with 0.5mm thick TBC at different laser parameters

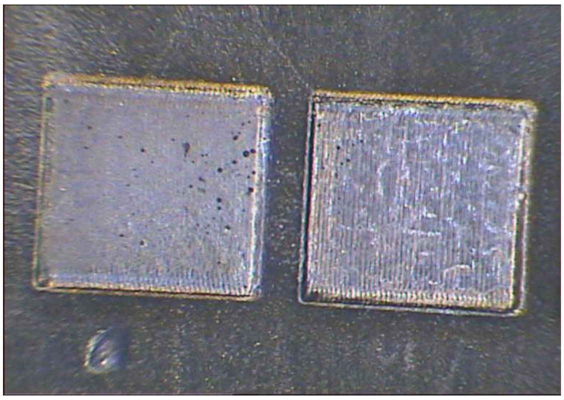


Fig. 12: 3mm HastalloyX alloy, 20 passes (left image) and 40 passes (right image), 15 kHz, 800W peak

Summary

The ablation work with a 400W CW fiber laser has shown that:

- Modulated regime can improve the material removal rate in stainless steel by eight times;

- Removal rate of 184mg/min equiv to 23mm^3/min cf Powerlase paper which quotes 10mm^3/min for a Q-switched laser;

- Better finish in the modulated regime;

- Removes TBC coating cleanly.

References

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[6] Naeem M; Modulation techniques for enhanced material processing using a single mode fiber laser; Conference Proceeding ICALEO 2008, Temecula, CA, USA; October 20-23 October 2008

Biography

Dr. Mohammed Naeem is Materials Process Development Group Leader. He received an MTech degree in metallurgical quality control from Brunel University (UK) in 1981 and a Ph.D. in glass fibre composites from Loughborough University of Technology (UK) in 1985.

He has over 18 years’ experience in support of industrial laser development and has published over 150 papers on laser material processing. He has previously served as Materials Processing Manager and held several important engineering development roles.