Novel Technique for the CO_2 Laser Fabrication of Optical Devices with Sub-Micrometer Ablation Depth Precision

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Abstract *We present novel techniques for the processing of fibre end face and cladding surfaces using a 9.6 µm CO_2 laser. We investigate the effects of pulse duration on process parameters.*

Introduction

Laser processing of glass for the fabrication of optical components has been an area of great interest for the telecommunications and laser industries as it can facilitate rapid, reproducible and precise production of devices with laser polished surface qualities.

In this article we demonstrate a novel technique that achieves sub-micrometer control over ablation depth using a 9.6 µm CO_2 laser, and we then demonstrate the advantages of our technique in fabricating flat angle optical fibre cleaves and cladding mode strippers.

Background

Cleaving of optical fibres is of critical importance for the telecommunications and fibre laser industries[1]. Mechanical cleaving through crack propagation can provide excellent results but can suffer from poor reproducibility, and difficulties in cleaving complex optical fibres. Techniques such as polishing can achieve excellent reproducible results, but take a significant time to achieve.

Currently CO_2 laser cleaving techniques are limited to the fabrication of cleaves for free space propagation, or for providing cleave angles suitable for subsequent mechanical polishing.[1-3]

The removal of pump light from the cladding is usually achieved by a high refractive index polymer coating on the cladding of the optical fibre. In the case of high power lasers the power in the cladding mode can be significant and can destroy the polymer coating. All-glass structures have been previously demonstrated for scattering the cladding radiation[4], and we demonstrate the applicability of our approach to fabricating similar structures.

We have demonstrated angle cleaves with a surface variation of less than 1.6 µm over 340 µm of optical fibre cross section. We also present a rapid fabrication technique that is able to modify the surface of the cladding in order to remove power from the cladding modes of a double clad fibre. We investigate the refractive index of the core and demonstrate that insignificant heating or diffusion occurs.

Approach

The attenuation of radiation from a CO_2 laser in silica has a strong wavelength and temperature dependence[5]. In this work a 100 W, pulse width modulated (PWM), CO_2 laser operating at a fixed wavelength of 9.6 µm was used to allow processing in the ablation regime. The use of a 9.6 µm laser allows melting and surface reflow processes to be avoided. This strategy limits any residual heating, thereby avoiding dopant diffusion in the core.

A ZnSe Aspheric lens of focal length 25 mm was used to focus the laser onto an optical fibre which was suspended at an angle θ from vertical, and mounted on a four axis micrometer controlled stage, as shown in Fig. 1.

The experiment was setup such that the pivot point of the fibre coincided with the location of the CO_2 laser beam waist. The fabrication process was monitored using a microscope camera.

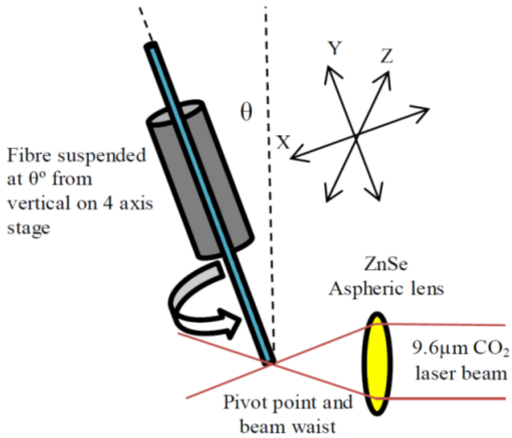

Fig. 1: Experimental setup. A 9.6 µm CO_2 laser beam is focused onto the suspended optical fibre.

The optical fibre was aligned to the CO_2 laser beam waist using a co-propagating green laser for coarse alignment. Fine alignment was achieved by observing the orientation and depth of ablation with respect to the fibre core through the microscope camera.

Ablation Depth

The ablation depth of the CO_2 laser was investigated as a function of pulse width for two pulse repetition frequencies of 50 and 100 Hz.

A 400 µm optical fibre suspended at 5.9º was rotated at 50 revolutions per minute (RPM) while being irradiated with CO_2 laser pulses of initial duration 20 µs to cleave the fibre. The displacement of the fibre edge as a function of increasing pulse width up to 400 µs was then measured using the in-situ microscope camera as shown in Fig. 2.

The slopes of the graphs for pulse durations of less than 150 µs in Fig. 2 show that by varying the pulse duration by 1 µs an ablation depth resolution of ~150 nm can be achieved.

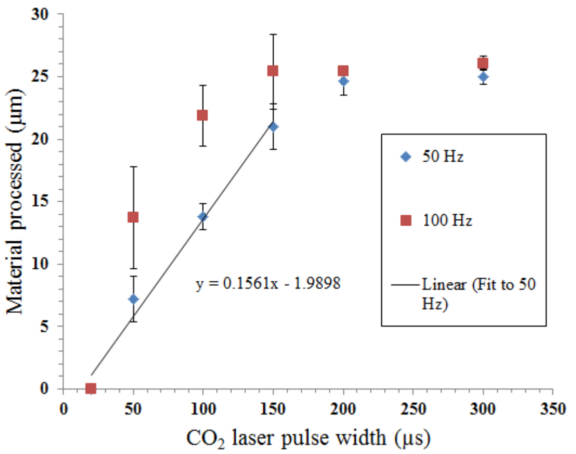

Fig. 2: Material ablated as a function of CO_2 laser pulse width at 50 and 100 Hz pulse repetition rates. The error bars are from the standard deviation of 3 measurements for each point and are largely attributed to end float movement of the optical fibre during processing as well as optical resolution.

For a precise measurement of the ablation depth as a function of pulse duration, a ramp height profile was machined onto the end of a 400 µm diameter optical fibre by linearly varying the pulse width as a function of fibre rotation angle from 90 µs to 120 µs.

The resulting profile was measured interferometrically using a Nyfors Cleave Meter 3D and is shown in Fig. 3. This profile displayed a maximum height of ~4.4 µm, and an ablation depth per microsecond of pulse width variation of 148 nm, which is in agreement with the processing resolution implied by the results shown in Fig. 2.

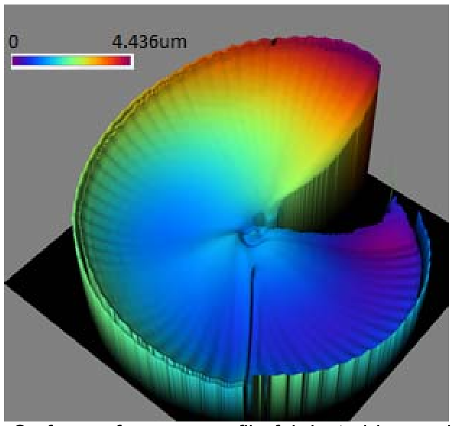

Fig. 3: Surface of a ramp profile fabricated by varying the CO_2 laser pulse width during the ablation of a 400 µm diameter optical fibre suspended at 5.9º from vertical, as reconstructed from interference pattern.

Fibre Cleaving

The cleaving of optical fibres was achieved through the rotation of the fibre at 50 RPM while it was irradiated with pulses of constant duration (~ 90 µs). It was found that by increasing the angle θ, from vertical, the surface variation across the fibre reached a minimum value as shown in Fig. 4. As the angle was decreased from its value at this minimum, the ablation process generated an increasingly concave surface profile. In contrast, as the angle was increased a convex surface profile was produced.

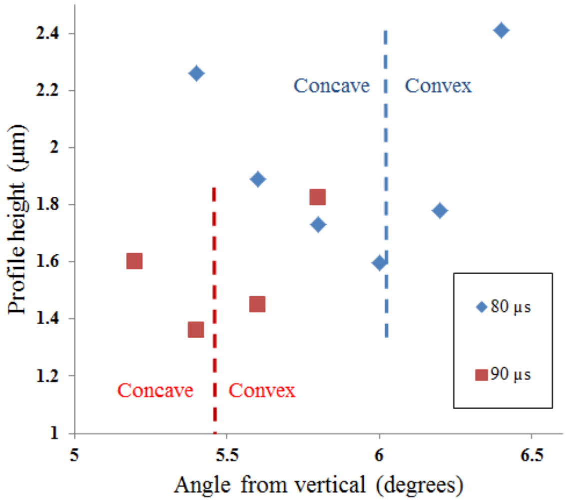

Fig. 4: Material ablated as a function of CO_2 laser pulse width at pulse repetition rates of 50 Hz and 100 Hz for a 400 µm outer diameter optical fibre suspended at an angle θ from the vertical. The stationary points are where the profiles transform from concave to convex for increasing angle.

Using the optimum angle found through the minimum point of the graph in Fig. 4, we were able to achieve reproducible cleaves as shown in the microscope camera images in Fig. 5 and Fig. 6. This process resulted in profiles with

~1.6 µm surface variation over a 340 µm region, giving effective cleave angles of less than 0.4°.

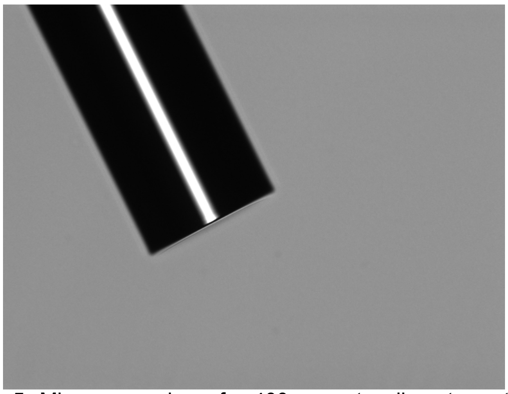

Fig. 5: Microscope view of a 400 µm outer diameter optical fibre cleaved with the CO_2 laser.

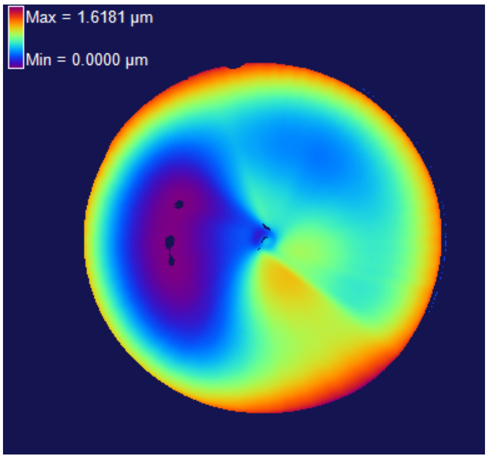

Fig. 6: Surface profile of a 400 µm diameter fibre cleaved by the CO_2 laser.

Cladding Mode Strippers

Cladding strippers were fabricated by ablating material from an optical fibre rotating at 50 RPM while translated vertically at a rate of 100 µm/s, forming a corkscrew profile on the cladding of the optical fibre as shown in Fig. 7.

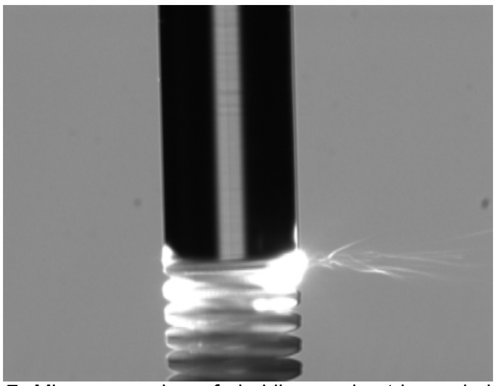

Fig. 7: Microscope view of cladding mode stripper during a fabrication process.

The refractive index profile of the core was measured using an IFA-100 to determine if there had been any significant heating. The refractive index of a processed and an unprocessed fibre are shown in Fig. 8. There was no diffusion observed – any significant heating would have removed the central dip in the fibre.

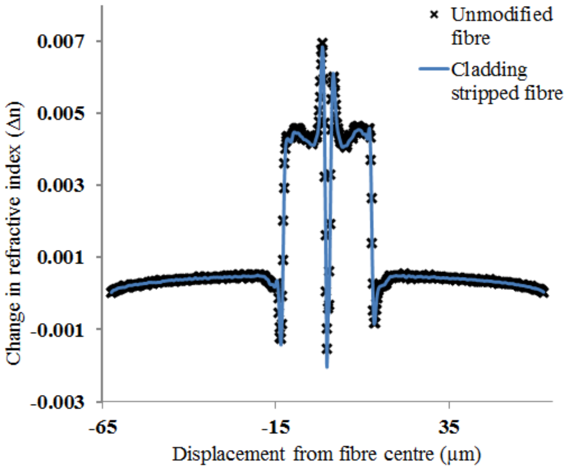

Fig. 8: Comparison between the refractive index profiles of the fibre core from a cladding processed optical fibre and an unprocessed optical fibre.

Summary and Conclusions

We have demonstrated CO_2 laser processing allowing control over ablation depth of material to ~150 nm and the fabrication of flat angle cleaves and cladding mode strippers.

Further improvements to the system such as compensating for the end float motion of the rotating fibre or eliminating this motion entirely should yield a significant improvement in surface quality.

The system currently shows great promise in expanding the capabilities of CO_2 laser processing to devices requiring sub-micron scale ablation capabilities.

References

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