Laser Machining of a Multicore Fibre for Multipoint in vivo Illumination and Collection

Laser machining of a multicore fibre for multipoint *in vivo* illumination and collection

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Abstract: Ultrafast laser pulses are used to machine a multicore fibre (MCF), such that different MCF cores emit light at different positions. This can be applied to many biomedical applications, such as distributed sensing.

Introduction

Delivery of light into patients is a core requirement of novel diagnosis and treatment. Optical fibres are applied in a wide range of scenarios, enabling compact and flexible endoscopic instrumentation with integrated light emission. The advantage of optical fibres as opposed to, for instance, integrated LEDs is that the insertable clinical instrument (often disposable) remains simple while the external light source can be complex and easily varied. Here, we tackle the challenge of medically appropriate fibres which can, on demand, deliver light to tissue at many individual locations along the length. We intend this as an enabling technology in novel medical diagnosis, treatment and imaging.

Laser micro-ablation of PMMA multicore optical fibres

Transmitted, reflected, and scattered light resulting from light-tissue interaction is used for medical diagnostics. Efficient transport and delivery of light is important for deep tissue imaging applications. Commonly in such cases, light delivery through optical fibres employs an end-to-end approach to deliver light to the targeted area. For multiple light exit points, large fibre bundles need to be used causing damage to the targeted tissue areas during insertion. In this paper, we demonstrate femtosecond micromachining [1] of PMMA-based multicore imaging optical fibre creating multiple exit points of light along a single compact fibre for biomedical applications. This approach uniquely enables the each of these points to be excited individually.

Experimental details: A femtosecond laser operating at 1030 nm (Menlo systems) is used to ablate the selected regions of a plastic optical fibre (POF). Fig.1 (a) Illustrates the fabrication set up. The diameter of the imaging fibre is 1.5 mm contains 7400 individual core elements each with ≈ 30 µm radii (fig.1 (b & c)). The repetition rate of the laser was 500 kHz with an average power 270 mW. The fibre is attached to a high precision 3D translation stage and the laser pulses were focussed onto the fibre with an aspheric lens of NA 0.4. The laser machined microstructures were formed by translating the stages to predefined distances and focusing the laser pulses on the fibre with high accuracy and control.

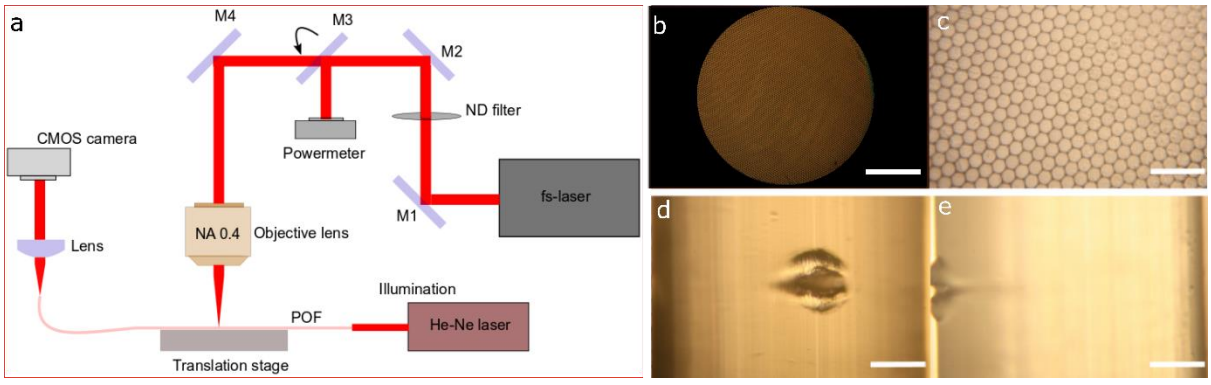

Fig 1. a) fs-direct writing setup. M1-M4 are mirrors. b & c) Micrographs of the imaging fibre. d) Top view of a microstructure formed by laser exposure. f) side view of the microstructure. Scale bars 300 µm.

In order to investigate the fibre ablation, the proximal end of the fibre was flood illuminated with a He-Ne laser. With the distal end imaged onto a CMOS camera, real-time fibre ablation is observed and controlled. Fig.1 (d & e) shows the top and side view micrographs of a microstructure formed by the laser exposure. 12 micro-slots were

machined into the side of the MCF at 20 mm intervals along the MCF by carefully moving the fibre along X, Y, and Z axes. To characterise the machined microstructures in terms of throughput (the amount of light side scattered out of the MCF), light at 780 nm is butt-coupled onto individual cores using a single-mode fibre (SMF) which was placed on an X-Y-Z micro-flexure stage. Light was delivered to each microstructure serially by moving the SMF along the proximal end of the POF. A CCD camera is used to image each microstructure and to optimise the light coupling. The CCD images of the fibre (fig.2 (a), obtained by proximal end all core flood illumination) and three side emitting fibre points along the fibre (fig.2 (b-d), selection by butt-coupling) are shown. For each micro-slot, a cutback power measurement was performed. The throughputs of the micro-slots were measured by comparing the optical power remaining in the fibre just after (about 1 cm) and before the micro-voids, therefore quantifying the light output coupling efficiency. Fig. 2(e) presents throughput of the 12 microstructures along the fibre ranging from 84 % to 96%, the highest achievable throughput for a side firing fibre reported so far.

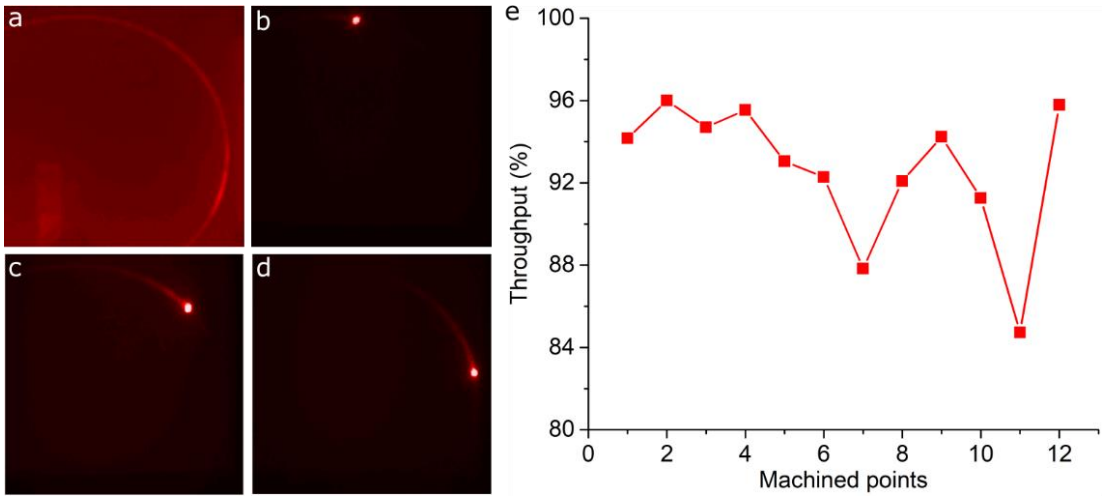

Fig 2. a) CCD image of the fibre. b - d) CCD images showing the light emission from three micro-slots under individual coupling conditions. e) Throughput of the micro-slots obtained from the cutback measurements.

Biophotonic applications

The high throughput side emitting geometry allows a choice of light emission location over the fibre length, and can be employed in biomedical sensing, imaging, and treatment. As an example, in photobiomodulation [2] applications, delivering light to large areas of tissues or organs for photophysical and photochemical studies is an essential criteria. The discrete emission of light is also potentially enabling in medical diagnostics, enabling spectroscopic investigation at many points along a medical device throughout an organ or extended tissue structures. During medical device placement, for instance central venous catheter placement, light emission along the device length could be viewed through the skin, the high throughput multi exit point fibre could replace the current optical fibre bundles. For medical device placement deeper in the body, in which light must transit through significant scattering biological media, the discrete sources of light act as known points which can be located serially. In particular, we can use short pulsed emission from the point sources one at time with time resolved techniques to observe light scattering from the discrete locations. Using 2D time-resolved imaging cameras, NIR light scattered deep from the tissue can be monitored and used for both optical tomography [3] and medical device location [4]. By creating light emission at desired points, we observe the full path of inserted optical fibre devices.

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