Fabrication of Optical Fiber Diffusors Using Femtosecond Lasers

Photodynamic therapy, laser-induced thermotherapy or endovenous laser treatment used in the fields of oncology and dermatology are medical laser applications where a well-defined volume of tissue must be irradiated over a length of up to several centimeters inside the human body. An optical fiber is used to deliver the light into the human tissue. One significant challenge is decoupling the light at the fiber's end and uniformly illuminating the tissue volume. Polymer diffusors can be attached to the fiber tip for this purpose, but a critical point to consider is that even a small malfunction at the interface between fiber and diffusor can cause a fusion of the material and disrupt the uniformity of illumination. A more promising and robust approach is to directly modify the fiber's end to achieve homogenous light decoupling from the fiber.

Recently, an ablative femtosecond process for fabrication of a fiber diffusor has been developed at the research center for micro-technology at the Applied University in Dornbirn, Austria in collaboration with Spectra-Physics. A fiber diffusor is fabricated using the Spirit® 1040-8 SHG femtosecond laser from Spectra-Physics by creating a series of defects on the fiber's surface (see Figures 2 and 3). These defects penetrate into the fiber's core, inhibiting the total internal reflection at the interface between core and cladding so that the light is scattered and decoupled at the roughened surface. The characteristic of the light decoupling along the fiber and the transmission through the fiber was modelled as a function of the number of defects using a Monte Carlo method. The simulation was also used to find a strategy for calculating the correct defect dimensions for fabricating a homogeneously emitting optical fiber diffusor with a length of several centimeters. Based on these simulation results, a diffusor was fabricated with a series of 111 defects in a line having footprint of 250 µm x 250 µm with a 250 µm space in between the overall diffusor's length of 55.5 mm. Figure 4 shows the decoupling efficiency profile along this linearized diffusor. The decoupling efficiency profile of the linearized diffusor has a maximum deviation of only ±1.7% of the mean value along its 55.5 mm length. Figure 5 is photograph of the fiber diffusor showing uniform decoupling along the 55.5 mm diffusor length.

Further details of this work can be found at Johannes Gratt, Matthias Domke, Ronald Sroka "**Fabrication of homogeneously emitting optical fiber diffusors using fs-laser ablation**" Proc. SPIE 9740-22, 2016

Figure 1: Spirit® 1040-8 SHG is an industrial femtosecond laser.

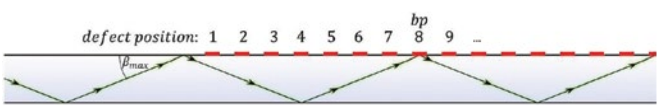

Figure 2: Diagram of a modified optical fiber. An optical ray trace is shown with the maximum possible angle of incidence for light propagation due to total internal reflection. Rays with greater angles are not propagated in the optical fiber.

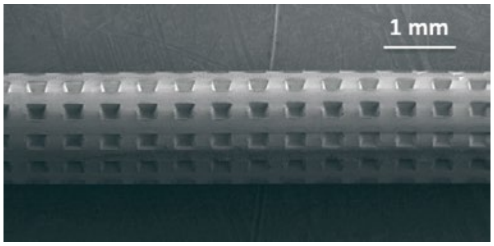

Figure 3: SEM (scanning electron micrograph) image showing a detailed view of a modified area. Shown are machined defects with a footprint of 250 x 250 µm and a depth of 65 µm. The bottom surface is in the fiber core so that light is decoupled because the total internal reflection is prevented.

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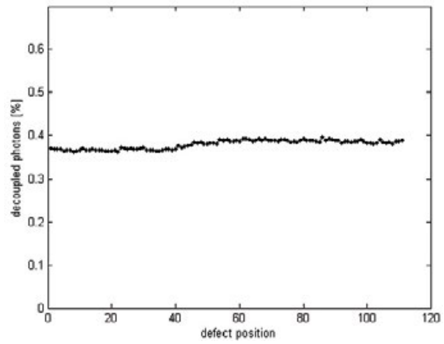

Figure 4: Decoupled photons per defect at the linearized diffusor. Number of defects N=111, footprint = 250 x 250 µm, pitch = 500 µm.

Figure 5: Photograph of an optical fiber diffusor with a length of 55.5 mm fabricated with the Spirit femtosecond laser. Light is decoupled out of the optical fiber at the modified areas and results in a uniformly diffused illumination.

PRODUCTS: *SPIRIT AND SPIRIT ONE*

The Spirit® femtosecond laser is a flexible, high repetition rate one box ultrafast amplifier. With direct diode pumped technology developed by Spectra-Physics, Spirit's innovative and simple architecture offers truly unique performance.

The Spirit platform offers impressive versatility to serve the needs of scientific and industrial customers. The laser's high average power (>16 W) and high repetition rate enable high throughput applications in material processing and micromachining. Pulse energy and repetition rate adjustability (single shot – 1 MHz) make the Spirit laser ideal for medical device manufacturing and femtosecond micromachining. The amplifier is optimized for one factory calibrated repetition rate between 100/200/400 kHz (40 µJ) and 1 MHz (4/8/16 µJ), depending on the laser model. This basic repetition rate can be chosen by the customer. Additional pre-set repetition rates are optional and can be configured in the factory during assembly upon request. The integrated pulse picker offers the possibility for fast pulse selection and power control by an analog input signal. This simplifies the integration of the laser and offers fast process throughput.

	Spirit 1040-4	Spirit 1040-4-SHG	Spirit CS 1040-4	Spirit 1040-8	Spirit 1040-8-SHG	Spirit CS 1040-8	Spirit 1040-16	Spirit 1040-16-SHG
Wavelength	1040 nm ±5 nm							
Output Power[2] at 1040 nm	>4 W			>8 W			>16 W	
Pulse Energy at 1040 nm	>40 µJ at 100 kHz			>40 µJ at 200 kHz			>40 µJ at 400 kHz	
Wavelength (SHG)	N/A	520 nm ±3 nm	N/A	N/A	520 nm ±3 nm	N/A	N/A	520 nm ±3 nm
Pulse Duration	<400 fs							

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