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Interest of singlemode fibers in photonic jet sub-micron laser processing

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Abstract

Laser is a flexible non-contact method, commonly used in industry, to process mechanical pieces, at scale down to 10 µm. Ultrashort pulse lasers make possible to reach smaller size tacking advantage of nonlinear phenomena. Nevertheless, these sources are still too expensive for many potential applications. Rather than concentrating energy in time, this can be done in space, without using microscope objective, but by generating a photonic jet. A photonic jet is a propagative beam concentrated beyond the diffraction limit in the near field of a dielectric object. Initially obtained with microspheres on the sample to process, the phenomena has been recently demonstrated using shaped optical fiber tips, easier to manipulate and without contact with the sample. Whereas multimode fibers have been used until now, we show how singlemode fiber and especially large mode area fiber can achieve the same process with 8 times less power, maintaining a reasonable working distance.

Keywords: Micromachining; submicron laser ablation; photonic jet; shaped optical fiber tip

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1. Introduction

Laser are commonly used in industry for surface marking. Different patterns can be etched on each mechanical part, no contact is required. However, the mark sizes are limited by the optical head resolution. Ultra-short pulse laser can be used to decrease the size taking advantage of the non–linear response of the material [Lecler and Fontaine, 2017]. However, this kind of sources are still quite expensive.

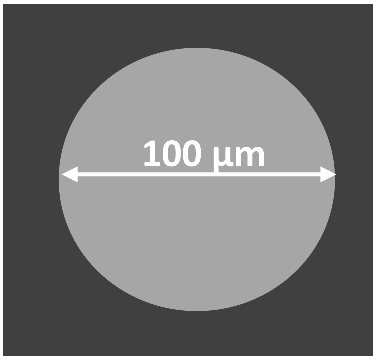
Since 2004, the possibility to concentrate a laser beyond the diffraction limit, in the near field of a dielectric microsphere, has been demonstrated [Taflove 2004, Lecler 2005]. This propagative beam, in which the whole incident power is concentrated on a diameter (Full Width at Half maximum) smaller than a half wavelength, is called photonic jet. Its ability to perform sub-diffraction etching has been experimentally demonstrated [McLeod 2008, Abdurrochman 2014]. However, the micro-bead is not easy to move in a process and the removed material sticks to the sphere. It is the reason why we have worked to demonstrate the possibility to obtain a photonic jet at the end of the shaped optical fiber tip, and thus to have a fiber easier to move and which can be etched without being disturbed by the removal material [Zelgowski 2016, Pierron Lecler 2017].

Using an optical fiber, the photonic jet is only due to the fundamental mode. However, classical singlemode fibers achieve photonic jet too close from the fiber tip. The maximum intensity of a photonic jet having a sub-wavelength diameter is typically located at a distance from the tip smaller than the fiber core diameter. It is why multimode fiber had been used until now. We show in this work that the single mode, Large Mode Area (LMA) optical fiber, is a good solution to benefit from a large enough working distance without energy loss on unwanted higher optical modes.

2. Results

Two optical fibers have been used with different optimized shaped tips. One is a multimode 100-140 silica step-index fiber (fig. 1a), with a 0.22 numerical aperture (NA). The second one is a singlemode pixelated Brag fiber (fig. 1b) with a large mode area. Its equivalent core diameter is around 49 µm (NA = 0.03). This fiber has been realized by the stack and draw technique. The core is made of pure silica (Heraeus Suprasil F300) and the cladding is composed of hetero–structured rings (called "pixels") made of pure silica low index rods and Germanium–doped high index rods [Yehouessi 2015, Vanvincq 2015, Baz 2012]. The two fiber tips have been computed to generate 1 µm laser spot and are described in [Pierron Zelgowski 2017] and [Pierron 2019] respectively.

(a)



(b)

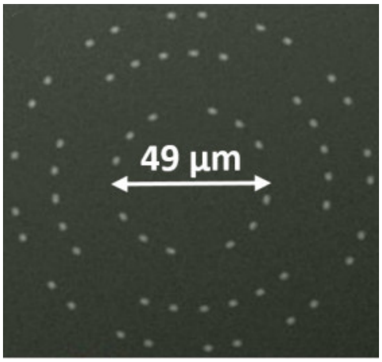


Fig. 1. (a) 100/140 silica multimode step-index fiber; (b) Pixelated Brag fiber cross-section made of three pixelated rings delimiting respectively the core diameter, the first and the second pure silica ring of the cladding - SEM picture.

The two fibers have been used to achieve micro-peaks on a silicon wafer with a 100 ns, 1064 nm, 35 kHz laser. Micro-peaks appear by auto-organization when the power density is just below the ablation threshold [Pierron Pfeiffer 2017]. The minimum required pulse energy to achieve the same micro peaks (FWHM = 1 µm, height = 250 nm) on silicon are given table 1. The LMA shaped fiber tip needs 8 times less energy than the 100-140 multimode one.

Table 1. Minimum required energy to achieve similar 1 µm micro-peak on silicon for the two considered fibers.

Optical fiber	Multimode	LMA
Core diameter	100 µm	49 µm
NA	0.22	0.03
Working distance	100 µm	40 µm
Required pulse energy	17 µJ	2 µJ

3. Conclusion

We have shown that Large Mode Area Optical fibers are good solutions for photonic nanojet marking. Their singlemode nature avoids energy loss in higher mode coupling and their large fiber core allows a working distance big enough so as not to disturb the fiber tip. Micro-peaks have been fabricated with a shaped tip homemade pixelated Brag fiber with a working distance of 40 µm and using 8 times less power than with a 100-140 silica multimode fiber shaped tip. Larger working distances may be obtained in the future using the new Very Large Mode Area Fiber (LMA) [Yehouessi 2016, Jansen 2012].

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