Shaping the optical fibre output beam by focussed ion beam machining of phase hologram on fibre tip

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Keywords: Microstructured fibers, Laser beam shaping

Abstract

A phase hologram is machined on a commercial single mode optical fibre tip using a focussed ion beam (FIB) system, so that a ring shaped beam emerges from the tip. The output beam from the fibre tip is in general agreement with the model. This suggests that the technique may provide a basis for a ruggedized novel beam shaping method. We expect it to offer compactness, permanent alignment, mechanical robustness, and significant cost reductions when compared to current commercial solutions.

1. Introduction

Attempts on lossless beam shaping go back to 1965[1] and today, its application can be found in material processing, medical procedures, and lithography [2]. With optical fibres as major beam delivery channel, beam shaping through introducing microstructures near the fibre tip have been introduced by Mayeh and Farahi[3], Gu et al.[4], and Tian et al.[5]. In this work, we demonstrate that an arbitrary beam shape can be assigned to the beam emerging from the fibre tip, by machining a hologram on the fibre tip.

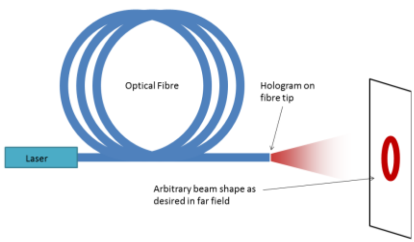

Figure 1: Hologram on the fibre tip.

2. Theory

The wave propagation between a fibre tip and its far field region can be described using the Rayleigh-Sommerfield's diffraction formula[6]. With the Fresnel and Fraunhofer approximations, the expression takes a form of Fourier transform:

$$\mathbf{U}(\mathbf{x},\mathbf{y}) = \frac{\mathbf{1}}{\boldsymbol{i\lambda z}} \boldsymbol{exp}[\frac{\boldsymbol{i\pi}}{\boldsymbol{\lambda z}}(\boldsymbol{x}^2+\boldsymbol{y}^2)] \iint_{-\infty}^{\infty} \boldsymbol{U}(\boldsymbol{\xi},\boldsymbol{\eta}) \boldsymbol{exp}[-\frac{\boldsymbol{i2\pi}}{\boldsymbol{\lambda z}}(\boldsymbol{x\xi}+\boldsymbol{y\eta})] \boldsymbol{d\xi d\eta}$$

where **U(ξ, η)** and **U(x,y)** denote the complex amplitude at fibre tip and its far field region respectively, **λ** the wavelength, **z** the distance between **x-y** plane and **ξ-η** plane.

Field distribution for a single mode fibre tip can be calculated by solving the Maxwell's equation in the cylindrical coordinate systems [7]. An example is shown in figure 2 for a set of parameters for a commercial optical fibre patch chord inferred from the manufacturers' specification, refractive index in glass, and wavelength of 632.8 nm.

Given the desired field distribution in the far field, and at the fibre tip, a phase hologram can be calculated using the Gerchberg-Saxton algorithm[8]. As an example, this calculation for a ring shaped beam is shown in figure 3.

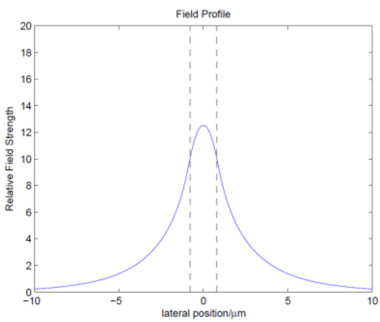

Figure 2: Field profile across a fibre. The dotted line represents the core. Parameters used are NA=0.12, core diameter d=1.8 μm, cladding index n=1.457, λ=632.8 nm.

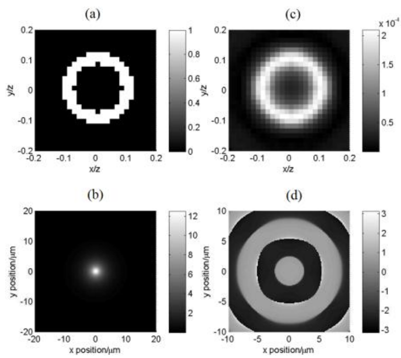

Figure 3: Calculation of hologram for a ring beam. (a) desired far field profile (b) Field profile across fibre (c) Achievable field profile at far field (d) Calculated phase hologram.

3. Experimental Work

In order to demonstrate the concept, the hologram calculated for a ring shaped beam, figure 3, is machined on a commercial optical fibre patch chord. Following Callegari et al's work[9] on machining a Fresnel lens on fibre tip, a FIB system is selected as the machining platform. The hologram shown in figure. 3 consists of phase jumps of π, which for a wavelength of 632.8 nm corresponds to a step of 692 nm. The fibre tip is sputter coated with Au to avoid charging artefacts. Machining took approximately 45 minutes at 30 kV and 200 pA. Following this, any gold coat is removed by FIB machining until the FIB image showed no trace of residual coat, figure 4.

A 632.8 nm He-Ne laser is coupled into the fibre, and the emerging beam is projected onto a rotating disc in order to remove speckle. The disc is then imaged using a camera, figure 5. The ratio of ring radius to distance between the fibre tip and the spinnig disc, R/z was found to be 0.083, compared to the predicted 0.1. The contrast ratio between the ring and the central region is much lower at 1:0.6 as compared to approximately 1:0.02 as predicted. Possible causes of discrepancy includes deviation of phase and amplitude profile from that desired due to surface roughness, residual gold coat, Ga implantation, and non vertical walls. Significant scattering was generated, which could be confirmed with the naked eye. However, it is clear that the output beam shape can be controlled by patterning the fibre tip. With more careful consideration for the issues mentioned above, we expect to be able to assign more complex beam shapes.

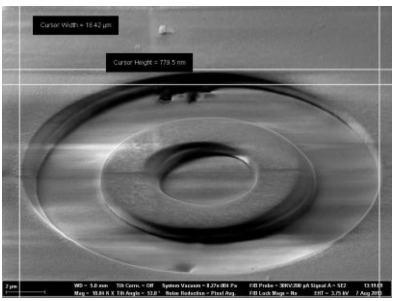

Figure 4: SEM image of the hologram on the fibre tip.

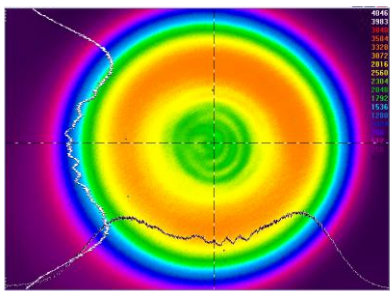

Figure 5: Beam measurement of the output beam. R/z=0.083. Imaged using Spiricon laser beam analyser, model LBA-FW-SCOR20.

4. Conclusions

We have shown that it is possible to shape the output beam from an optical fibre by machining a phase hologram at the fibre tip. Though there is room for improvement, the agreement between the prediction and the eperimental results is encouraging. This suggests that the same technique may provide a basis for a novel beam shaping method. Several issues including power handling capabilities, manufacturing route, and accuracy of the model are likely to be critical in determining in its relavence in the field of beam shaping. However if the development proves to be successful, it is expected to offer a number of advantages over current commercial solutions in its compactness, permanent alignement, mechanical robustness, and significant cost reduction.

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