Optoel 2017

2017

X Reunión Española de Optoelectrónica

Comité de Optoelectrónica

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

SEDOPTICA
SOCIEDAD ESPAÑOLA DE ÓPTICA

USC OSA
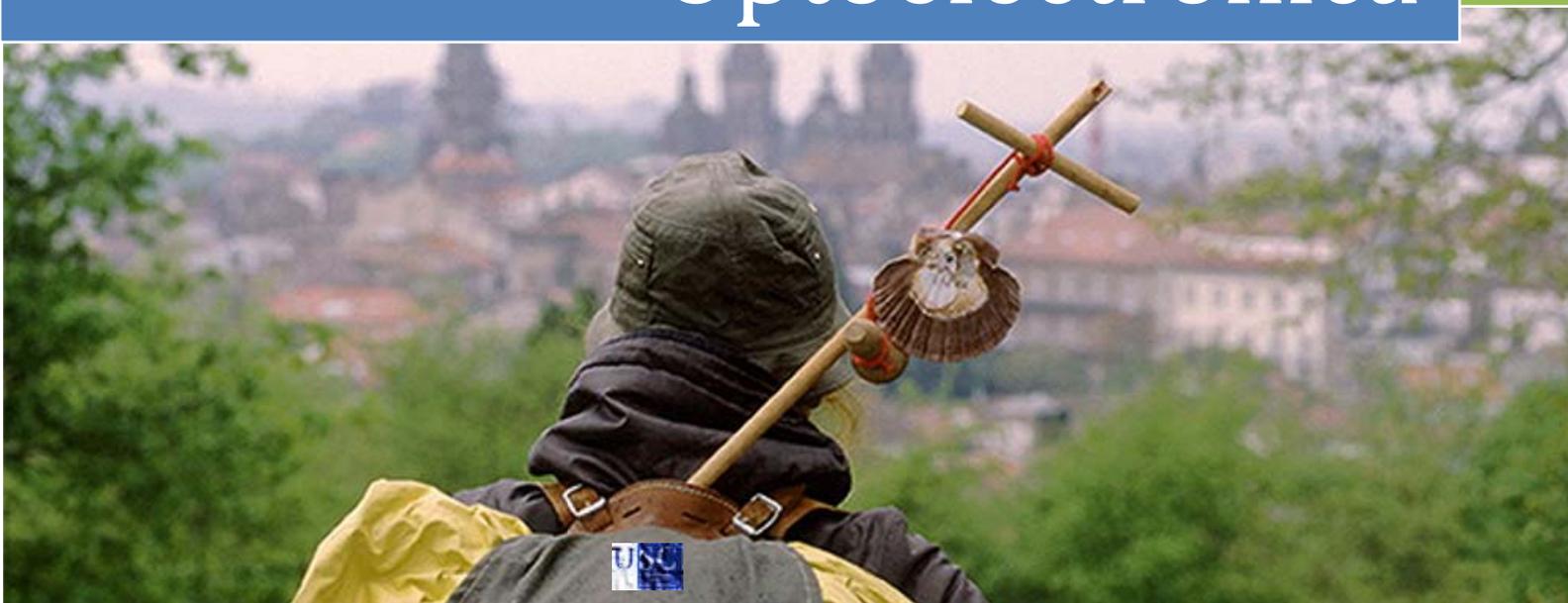Student Chapter

Santiago de Compostela

12-14 Julio de2017

EDITADO POR:

Justo Arines Piferrer

Manuel Blanco Fraga

María Teresa Flores Arias

María del Carmen Bao-Varela

María de la Inmaculada Aymerich López

Femtosecond Laser inscription of diffractive element in optical fiber end-face

David PALLARES-ALDEITURRIAGA [1], Luis RODRIGUEZ-COBO [1,2,3], Rubén RUIZ-LOMBERA [1], Antonio QUINTELA[1,2,3], Jose Miguel LOPEZ-HIGUERA[1,2,3]

1. Grupo de Ingeniería Fotónica, Universidad de Cantabria, Santander, España.
2. Centro de Investigación Biomédica en Red en Bioingeniería Biomateriales y Nanomedicina (CIBER-bbn), Cantabria, España.
3. Instituto de Investigación Sanitaria Valdecilla (IDIVAL), Cantabria, España.

Contact name: David Pallarés Aldeiturriaga (pallaresd@unican.es).

ABSTRACT:

In this work,the potential of femtosecond laser for optical fiber end-face inscription is highlighted by presenting a reliable setup for optical fiber longitudinal writing. This set-up has been used to write 1 dimension diffraction grating at the fiber end-face. Its far field intensity distribution has been measured and compared with simulations assuming rectangular air hole structure of same width and period. By comparing diffraction efficiencies, a first attempt of measuring hole deep is achieved.

Key words: Femtosecond laser, diffraction, optical fiber, far field, FDTD, laser inscription.

1.- Introduction

Femtosecond lasers have attracted many interest in the past decades for its wide brunch of applications in microprocessing field. They are reliable tools for inscription at high micro-resolution without undesired thermal effects because of photon energy absorption occurring on a faster time scale than energy transfer to the lattice [1]. Said precision makes them especially suited for optical fiber and microphotonic devices where they can be used for optical storage or optical element inscription.

Inscription is mainly performed by translating sample transversal or longitudinal to the focusing spot. Longitudinal inscription has limited path due to working distance of focusing lens and degree of spherical aberration caused by substrate changes varies as the depth of focus increases [2]. Both issues make transversal inscription the most extended, however, when desired sample is an optical fiber, longitudinal writing has advantages when inscription is performed at or near its end-face, allowing among other things, effective design of perpendicular patterns. This location has a huge potential for many structures inscription, such as diffractive elements or phase holograms [3].

This work presents a simple experimental set-up for fiber optic end-face micromachining that highlight femtosecond laser potential in optical fiber end-face inscription. This set-up is used to inscribe a diffraction grating at the fiber surface. Resulting far field profile will be compared with simulations.

2.- Setup

With the aim of longitudinal surface writing, a simple set-up has been established. Micromachining is performed with a femtosecond commercial Fiber Laser Chirp Pulse Amplifier (FLCPA) from CALMAR lasers operating at 1030nm, 370fs pulse duration and 120 kHz Pulse Repetition Rate (PRR). Laser pulses are focused through a NA=0.5 objective lens from Mitutoyo converging at fiber end face fixed to a HP 8100FB bare fiber adapter as described in Fig. 1. Adapter is placed in a platform fixed to a
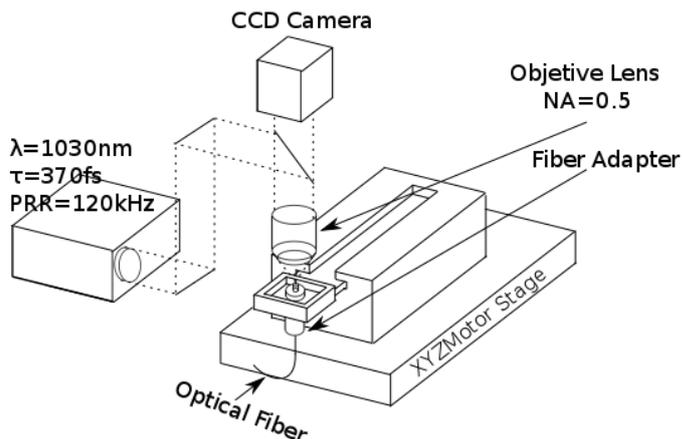
Fig. 1: Set-up diagram for longitudinal and surface writing.

nanoresolution motor stage from Aerotech. For visualizing the fiber position, objective lens collects light emitted from a whitelight source that illuminates the platform and transmits to a CCD Camera.

Further characterization of the samples is performed by a Hamamatsu vidicon camera with Far Field Pattern (FFP) optics. Image formed with this system is analogous to the emission angle distribution projected on the screen on the hemisphere which has the luminous point as its center. Pattern is analyzed with commercial software Lepas-11.

3.- 1 Dimension diffraction grating

Longitudinal writing setup cited in previous section is used to inscribe simple diffractive elements at fiber end-face. Diffraction gratings are inscribed at 0.06mm/s and 310nJ pulse energy. Fig. 2(a) shows the scheme of the resulting binary phase grating. Ten rectangular air holes of thickness d=2.30(21) have been inscribed (TIII [4]) with period a=3.95(23). A CCD camera image of performed inscription is depicted in Fig. 2(b). In order to characterize the output diffraction pattern, the fiber has been illuminated with HP 8168F tunable laser source working at 1550nm capturing its profile with the vidicon.

FFP detailed in Fig. 2(c) exhibits high quality, good symmetry and expected intensity distribution with one visible diffraction order placed at θ_1= 22.23(11)° as depicted in Fig. 2. Following grating equation for normal incidence

$$a \sin \theta_m = m\lambda \qquad (1)$$

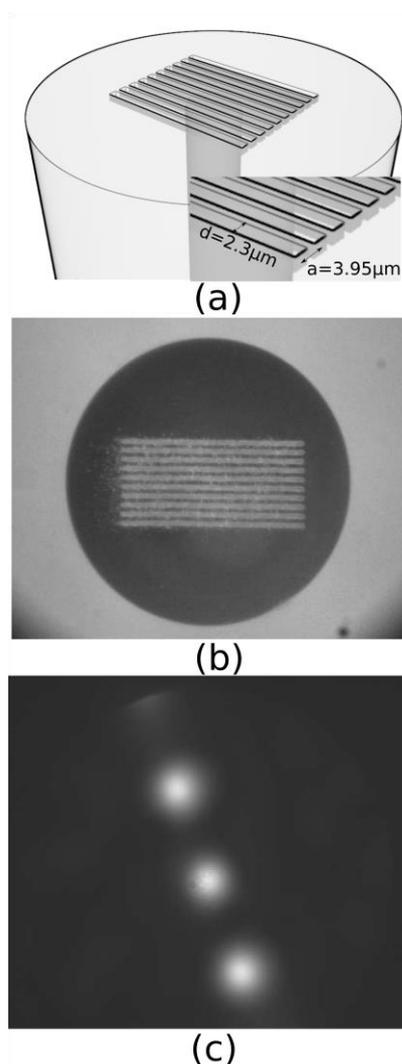*Fig. 2: Scheme of 1-D diffraction grating at fiber end-face with period a=3.95(23) μm and thickness d=2.30(21)μm (a), CCD image of resulting 1-D diffraction grating inscription (b) and its FFP distribution from a 1550 nm laser source (c).*
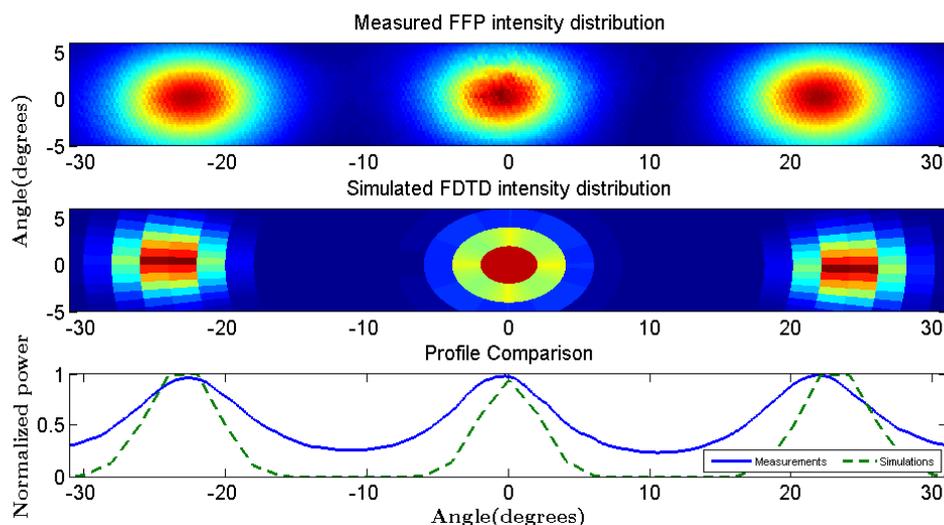
Fig. 3: Angular intensity distribution for FFP measurements and FDTD simulation. Both profiles are compared below.

First order maxima should be placed at $\theta_1=$ 23.1(1.4)º. Being both measurements consistent quantitatively verifies that measured FFP follows expected diffractive pattern. Numerical Aperture (NA) has also been characterized at $1/e^2$ of intensity decay, showing NA=0.169 compared to NA=0.192 of uninscribed SMF28 which is a decay of 12%.

This structure may be easily simulated with commercial software FullWAVE based on Finite Difference Time Domain (FDTD) [5]. Letting hole deep as free parameter, several simulations have been run in order to fit normalized power. First value to fit was 1.2 µm which is a very reasonable value for given pulse energy. Fig. 3 exhibits both FFP and FDTD intensity distribution with their respective linear profile confirming angular position and diffractive efficiency agreement.

Inscribed structure can be used as beamsplitter or Wavelength Division Multiplexer (WDM).

4.- Conclusion

A longitudinal writing set-up for optical fiber end face has been established. This set-up has been used for inscribing 1-D diffraction grating that exhibits a high quality pattern with good symmetry. Assuming surface modification, FDTD simulations have been run suggesting that inscribed holes have a deep of 1.2 µm which is consistent with employed pulse energy. This device has potential applications as beamsplitter and WDM.

Future works may include more complex structures such as 2-D diffraction gratings, binary masks or phase holograms.

References

[1] Chris B SCHAFFER, André BRODEUR, Eric MAZUR, "Laser-induced breakdown and damage in bulk transparent materials induced by tightly focused femtosecond laser pulses", Measurement Science and Technology, 12, Number, 1784-1794, 2001.

[2] Roberto OSELLAME, Giulio CERULLO, Roberta RAMPONI, *"Femtosecond Laser Micromachining: Photonic and Microfluidic Devices in Transparent Materials"* (Springer 2012).

[3] Juha-matti SAVOLAINEN, Lars GRÜNER-NIELSEN, Poul KRISTENSEN, Peter BALLING, "Femtosecond refractive-index tailoring of an optical fiber and phase retrieval from far-field measurements", in proceedings of CLEO: Science and Innovations, CTh4H.2, 2013.

DAVID. PALLARES-ALDEITURRIAGA et al.

[4] Bertrand POUMELLEC, Matthieu LANCRY, Abdelouahed CHAHID-ERRAJI, Peter G. KAZANSKY, "Modification *thresholds* in femtosecond laser processing of pure silica: review of dependencies on laser parameters [Invited]", Optical Materials Express, 1, 4, 766-782, 2011.

[5] Kane S YEE, *"Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media"*, IEEE Transactions on Antennas and Propagation, 14, 3, 302-307, 1966.

DAVID. PALLARES-ALDEITURRIAGA et al.