Optical Fiber Technology 28 (2016) 28–37

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Regular Articles

Excitation efficiency of a side-pumped fiberized fluorescent dye microcapillary

Veselin Vladev *, Tinko Eftimov, Stefan Nedev

Faculty of Physics and Engineering Technologies, Plovdiv University "Paisii Hilendarski" Photonics Laboratory, 24 Tsar Asen St., Plovdiv 4000, Bulgaria

ARTICLE INFO

Article history:
Received 4 March 2015
Revised 18 September 2015
Available online 22 January 2016

Keywords:
Fluorescence spectra
Micro-capillary
Rhodamine 6G in glycerin
Angle-polished fiber
Glass ferrule
Reflective aluminium coating

ABSTRACT

In the present work we study the dependence of fluorescence spectra for different pump source characteristics on the length of a micro-capillary filled with a fluorescent dye solution. A standard fiber-optic glass ferrule with two parallel 125 μm inner diameter holes serving as capillary structures has been studied. One of the holes of the ferrule was filled with a solution of Rhodamine 6G in glycerin, while in the second hole an angle-polished single-mode pump optical fiber was placed. Experiments with pump fibers polished at 20°, 25°, 30°, 35°, 40° and 45° with a reflective aluminium coating have been conducted. The analysis of the experimental data shows differences in the behavior of the fluorescent spectra at different polished angles. Theoretical calculations for pump ray trajectories as well as overall power transmission for pump fibers polished at different angles have been made. The results show that the proposed construction could be used in optofluidic chemical and biosensors, microfluidic lasers or as a compact fluorescent source compatible with fiber-optic components.

1. Introduction

Angle-polished optical fibers have been used to deliver and collect light in sensors [1], like a micro-mirror in scanning systems for imaging bio-engineered tissues [2], with reflective gold coating for side pumped fiber-optic lasers [3]. They have been successfully used as excitation source of fluorescing thin film polymers for a TNT vapor detection device [4].

In previous papers we studied the dependence of fluorescence spectra on the length of micro-capillary structures filled with fluorescent dye solutions [5]. Compatibility with fiber optic up-tapers and microstructured optical fibers have been demonstrated [6,7]. The present work is a continuation of the experiments from previous studies of a new micro-capillary construction for side-pumping of fluorescent dye solutions [8]. The objective of this work is to study the fluorescent spectral behavior of a dye-filled micro-capillary which is side-pumped by optical fibers angle-polished at 20°, 25°, 30°, 35°, 40°, 45° and coated with an aluminium reflective film, to perform theoretical calculations for pumping ray trajectories and to identify the efficient polishing angle excitation conditions. The results obtained can help optimize side-pumping efficiency using optical fibers for a number of applications such as optofluidic biosensors [9] and microfluidic dye lasers [10].

2. Experimental details

2.1. Experimental setup and capillary structure used

Schematic view of the experimental set-up with the components used is presented in Fig. 1.

A glass ferrule which is a standard fiber-optic component was used as a microcapillary structure for optical fiber alignment. A front and a side picture of the ferrule are shown in Figs. 2 and 3, respectively. It represents a glass cylinder with a 2.3 mm outside diameter, a 10.4 mm length, and two parallel 125 μm holes along its length. The holes increase in size at one end in order to facilitate insertion of the optical fibers. The distance between holes is approximately equal to the holes diameter.

The ferrule was cleaned with ethanol and allowed to dry until it evaporates. Then one of the holes was filled with the prepared fluorescent solution.

2.2. Fluorescent solution

Rhodamine 6G (R6G) dissolved in glycerin was used as a fluorescent medium. It was prepared via a serial dilution of an appropriate quantity of R6G dissolved in ethanol and then mixed with glycerin to give the desired concentration after ethanol evaporation. The R6G concentration in the samples was 4.10^{-4} M. Ethanol absolute and glycerin of 99.89% purity (sulfates 0.0002%, chlorides 0.0001%, heavy metals 5 ppm) were used for the analysis.

* Corresponding author.
E-mail address: v.p.vladev@abv.bg (V. Vladev).

http://dx.doi.org/10.1016/j.yofte.2016.01.007
1068-5200/

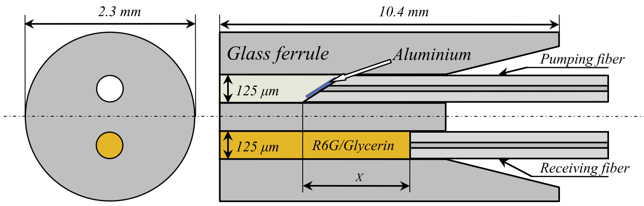

Fig. 1. Schematic view of the experimental setup.

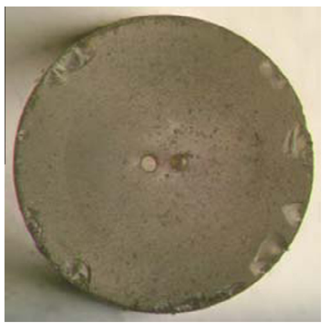

Fig. 2. A front view of a glass ferrule.

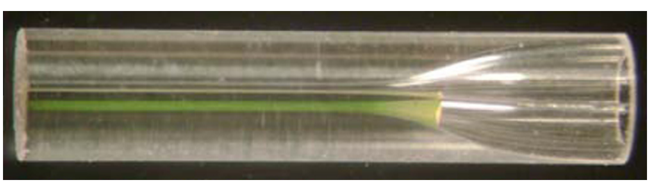

Fig. 3. Side view of a glass ferrule.

2.3. Pumping and receiving components

A receiving optical fiber (RF) SMF-28 with a flat facet is placed in the filled hole for registration of the fluorescent signal by a CCD spectrometer (AvaSpec 2048, Avantes) having a 200 μm slit.

The sample mounted in the holder and the receiving fiber are fixed to a micropositioner having three linear displacements and two tilts.

The fluorescent medium is side-pumped along the filled hole with the help of an angle-polished pumping optical fiber (PF) SMF-28, single-mode above 1260 nm and placed in the empty hole. The PF was coupled to a continuous wave diode-pumped solid-state (DPSS) Nd:YAG laser emitting at $\lambda_{pump} = 532$ nm. It was placed and fixed in a syringe needle holder (Fig. 4), then placed on a single-axis micropositioner.

With the help of a micrometric screw of the single-axis micropositioner the PF was moved along the hole. Thus the distance x between pumping and receiving positions was varied.

The two micropositioners mentioned above, the single-axis and the one having three linear displacements, were mounted upon an optical table then placed under optical microscope observation.

2.4. PFs preparation procedures

The performance of pumping fiber facets with angles 20°, 25°, 30°, 35°, 40° and 45° were next studied. The SMF-28 fiber stacks mounted and fixed in syringe needle holders were polished at the above angles using a FibrMet polishing machine for optical fibers (Fig. 5). Polishing goes through four stages by using four standard polishing papers with decreasing sizes of the grain which are respectively 30 μm, 15 μm, 9 μm and 3 μm.

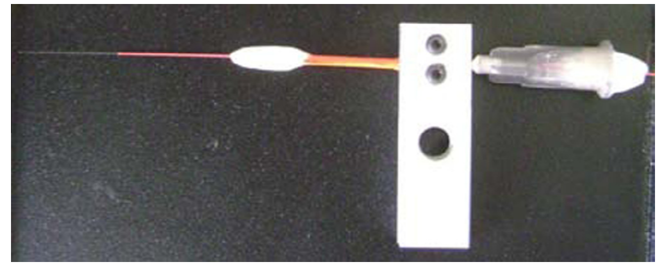

Fig. 4. A pumping optical fiber in a syringe needle holder.

Then a thin aluminium film with a 99.999% purity was deposited upon the polished facets using thermal evaporation in a vacuum chamber. The schematic view of the vacuum chamber used for aluminium deposition is shown in Fig. 6. An optical microscope picture of a syringe needle holder with seven optical fibers polished at a 30° angle with deposited aluminium is presented in Fig. 7.

The thus prepared reflective aluminium coating directs the pump laser light to the fluorescent solution. The final view of a PF facet polished at a 20° angle with pump laser light through it is shown in Fig. 8(a). The shown pumping fibers in Fig. 8 (b) and (c) are with facets polished at 25° and 30° respectively, at which thickness of the reflective coating is not enough to fully reflect the pump light. The two light spots of the facets of each fiber are the points in which light is reflected from the mirror surface (in this case partial reflection).

The pump spot shapes of all PFs polished at corresponding angles in the hole filled with fluorescent medium can be seen in Fig. 9. The location of the receiving fiber is on the right side of each picture. The diameter of the filled hole equal to 125 μm is shown in the figure. At our estimate the transverse dimension of the base spot (with maximum power) has ≈ 37 μm width.

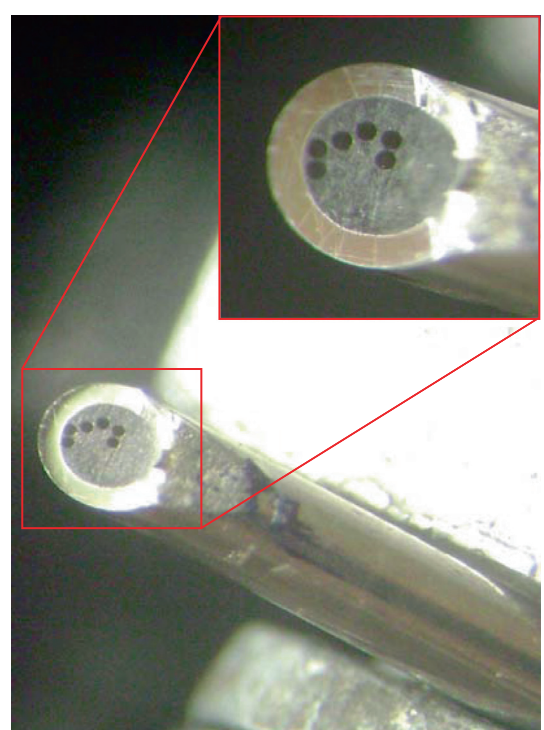

Fig. 5. A fiber stack mounted and fixed in a syringe needle holder polished at a 45° angle.