Fiber-coupled fluorescence light source suitable for spectroscopic applications

Veselin Vladev,[*1,2] Tinko Eftimov,[3,2] Stefan Bozhkov,[1] Krastena Nikolova,[1,4] Stefka Minkova,[4] Denitsa Blazheva,[5] Galena Angelova,[5] and Maria Brazkova[5]

[1]*Department of Mathematics, Physics and Information Technologies, Faculty of Economics, Photonics Laboratory, University of Food Technologies, 26 Maritsa blvd., Plovdiv, Bulgaria,*
[2] *Central Laboratory of Applied Physics, Bulgarian Academy of Sciences, 61 Sankt Peterburg blvd., Plovdiv, Bulgaria,*
[3]*Centre de recherche en photonique, Université du Québec en Outaouais, 101 rue Saint-Jean-Bosco, Gatineau, Québec, Canada,*
[4]*Medical University - Varna, 84 Tzar Osvoboditel blvd., Varna, Bulgaria,*
[5]*Department of Biotechnology, Technological faculty, University of Food Technologies, 26 Maritsa blvd., Plovdiv, Bulgaria*

Received July 15, 2022; accepted September 28, 2022; published September 30, 2022

Abstract—An experimental study is presented in the article, of a fluorescent broadband light source fully compatible with optical fibers, for practical application in excitation-emission matrix fluorescence spectroscopy. A fiber optic glass ferrule filled with a solution of Rhodamine 6G in glycerin was used for basic construction of a light source. The ferrule is coupled with optical fibers to illuminate the dye medium and to receive the fluorescent signal. Light spectrum tuning from the source between 528 nm and 660 nm with a shift of 1 nm is achieved by means of a monochromator.

The ability to emit braodband fluorescent light under optical excitation, allows organic fluorescent dyes to find wide practical use in spectroscopy and sensorics.

As a component of active medium they are used in novel optical materials for narrow-band stimulated emission [1]. There is a possibility that the characteristics of their spectrum may be influenced by a variety of factors such as dye concentration, pH, absorbed wavelength, temperature, solvent or impurities [2]. The characteristics of organic dyes allow them to be incorporated into solid and liquid matrices, which allows to create different photonics elements and unique optical sources [3, 4].

With the present experimental work we continue our research on optical fiber compatible structures filled with solutions of organic fluorescent dyes and their use as light sources [5–10]. The specific object of the present article is the fiberized optical structure based on a glass ferrule and its potential application as a broad-band light source for fiber optic sensors with spectral detection [11–12] as well as in excitation-emission matrix (EEM) fluorescence spectroscopy. The latter has been widely used as a powerful technique for determining the purity of complex mixtures, foods for example, or to characterize dissolved organic matter in water and soil [13–14].

* E-mail: v.p.vladev@abv.bg

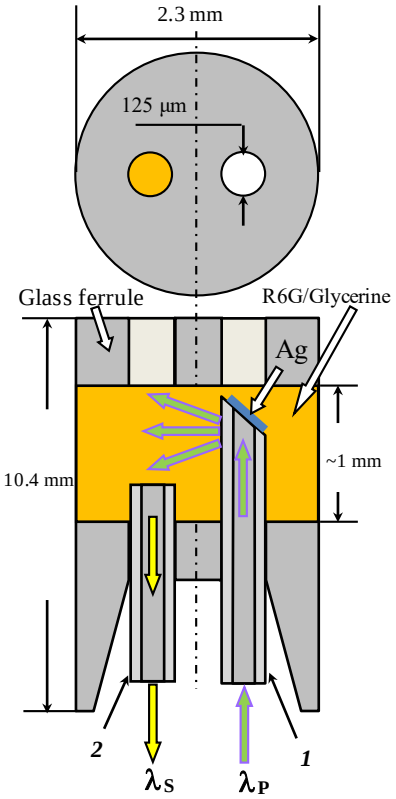

Fig. 1. Schematic view of the ferrule used. Illuminating fiber (denoted by 1), receiving fiber (denoted by 2).

Typically used light sources in fluorescence measurements are light-emitting diodes (LEDs), mercury, xenon and tungsten-halogen lamps. A typical

disadvantage of LEDs is a relatively narrow spectral range they emit, which requires the use of multiple LEDs. Typically, such lamps are expensive and bulky.
Both lamps and LEDs require bulky optics and alignment mechanisms when coupling their radiation in optical fibers. The object of our study is easily coupled with optical fibers and fiber micro-optics, which allows portability and easy alignment of optical systems.

The main structure of the presented broad-band source is a glass ferrule that is a standard fiber-optic component for alignment of optical fibers. The schematic view of the ferrule is presented in Fig.1.

The ferrule has a cylindrical form with an outside diameter of 2.3 mm and a length of 10.4 mm. Along the ferrule length two parallel holes with a diameter of 125 μm are factory made.

To facilitate the filling of the ferrule with a fluorescent solution, approximately a millimeter length section has been machine carved to provide access to two capillary openings. The fluorescent medium used consists of Rhodamine 6G (R6G) dissolved in glycerine with a dye concentration of 1.19×10^{-4} M obtained from a stock solution after dilution. The carved gap is filled with approximately 3 μl of prepared dye solution.

Two fused-silica step-index optical fibers (NA= 0.22, Thorlabs) with 105 μm/125 μm core/cladding diameters are placed in the holes of the ferrule so that their ends are immersed in the dye solution. Before placing the optical fibers, their dipped ends are pre-treated.
The facet of the fiber denoted by 1 is polished at 45 degrees using an optical fiber polishing machine (FibrMet). In the polishing process, diamond polishing papers with a decreasing size of grains were used, respectively 30 μm, 9 μm, 3 μm and 1 μm. The polished facet is coated with a thick layer of silver, which reflects 100% of the incoming light.

The illuminating optical fiber denoted by 1, was coupled to a continuous wave diode-pumped solid-state (DPSS) Nd:YAG laser emitting at $\lambda_P = 532$ nm. Thus, the dye medium is illuminated transversely with respect to the optical axis of the neighbouring fiber denoted by 2. The wavelength of the laser radiation used falls within the maximum absorption curve of Rhodamine 6G.

The facet of optical fiber denoted by 2 was cleaved at the right angle by using a ruby cleaver. This receiving fiber guides the output radiation λ_S from the broad-band source to the monochromator used.

The schematic view of the monochromator and spectrometer used in the experiment are presented in Fig. 2.

For the purpose of the experiment, we assembled a Czerny-Turner monochromator with a diffraction grating. No special slits were used on either the input or the output of the monochromator. The monochromator fiber 1 (MF 1) is set in a kinematic mount on a pylon and delivers the output light from the ferrule to the collimating mirror 1. Both curved aluminium coated mirrors 1 and 2 are fixed on pylons.

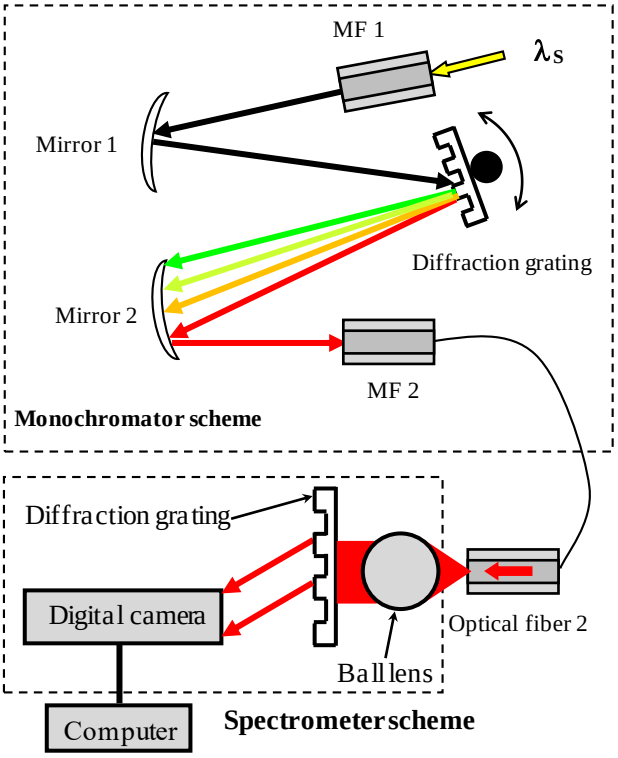

Fig. 2. Schematic view of the monochromator and spectrometer used.

A reflective holographic diffraction grating with a constant of 1.4 μm was used. It was mounted in a holder and placed on a pylon. A rotational micropositioner stage was used to turn the grating (481-A Series, Newport). The station allows precise manual adjustment of 0.1° by means of a screw.

The monochromator fiber 2 (MF 2) is mounted in a holder and fixed to a micropositioner having three linear displacements (ULTRAlign 561D, Newport) and two-axis tilt platform (561-TILT-LH, Newport). The MF2 receives monochromatic light from a focusing mirror 2 and is connected to the spectrometer to observe the wavelength tuning by the monochromator. All composed parts of the monochromator were mounted onto a concrete optical breadboard.

A simple digital camera-based spectrometer was used for the spectral observation of the output signal from the monochromator. It is composed of the MF 2 core (entrance slit = 105 μm), collimating ball lens, transmission diffraction grating with 1350 lines mm^{-1} and a computer connected digital CMOS camera. Thus, the spectral resolution of the spectrometer was found to be 3 nm.

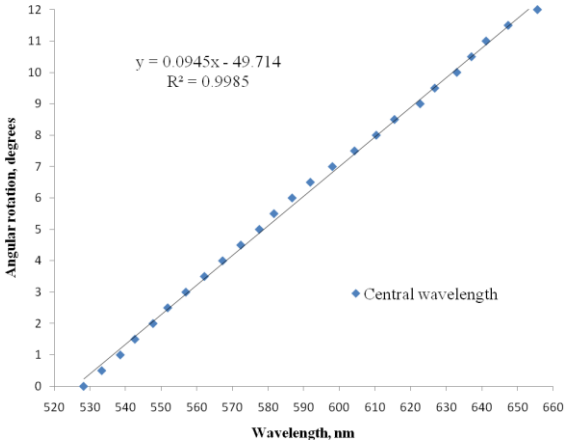

Fig. 3. The monochromator output wavelength change depending on the diffraction grating rotation angle.

A series of spectra were taken at every 0.5° rotation of the grating up to 12.5°. For a starting wavelength of 528 nm, a central wavelength of 660 nm was obtained at 12.5°. Figure 3 presents the dependence of the central wavelength of the monochromator output on the rotation angle of the diffraction grating. The calculations based on the obtained data show that for every 0.1° of rotation there corresponds an approximately 1.1 nm shift in the output wavelength.

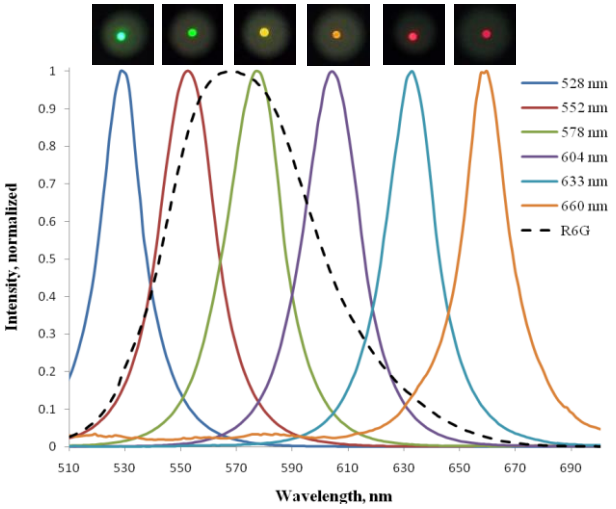

Fig. 4. Output spectra from the monochromator.

Figure 4 shows several spectra obtained from the monochromator, as well as the fluorescence spectrum of the R6G/Glycerine medium used. Pictures from the optical microscope of the MF 2 placed in a temporary holder are also shown in the figure. The pictures correspond to the captured spectra underneath.

As can be seen from the captured spectra shown in the figure above, the output signals from the monochromator are strong enough and the spectral curves are stable. No significant distortions due to noise are observed in the two low-intensity monochromator spectra that fall at either end of the fluorescence signal from the dye medium used.

Based on the obtained experimental data, we can conclude that the investigated fiber-optic structure is suitable for use as a broad-band fluorescent light source. Combining it with a monochromator scheme allows smooth tuning of output fluorescence radiation within the spectrum of the used dye, namely between 528 nm and 660 nm. The resulting radiation from the monochromator is strong enough to be detected by a simple and inexpensive spectrometer that was used in the experiments. The constructed experimental set-up allows smooth light tuning with a step of approximately 1 nm for every 0.1° rotation of the diffraction grating.

The input and output of the monochromator are fiber optic compatible. This allows a rapid change of the light source and connection of a fiber-optic fluorescence detector which uses samples with volumes in the order of microliters. The fluorescent dye can be replaced by another one that emits in a different spectral region.

The obtained results suggest a potential possibility of using the studied broad-band light source in the field of excitation-emission matrix fluorescence spectroscopy.

The authors acknowledge the financial support of "Competition for financial support of basic research projects – 2021", Bulgarian National Science Fund, project KP-06-N58/10.

References

[1] N. Hoinka and T. Fuhrmann-Lieker, Sci. Rep. **9**, 1 (2019).
[2] J. Włodarski, M. Chychłowski, Photonics Lett. Pol. **13**(2), 46 (2021).
[3] J. Żmojda, P. Miluski, M. Kochanowicz, J. Dorosz, A. Baranowska, M. Leśniak and D. Dorosz, Photonics Lett. Pol. **11**(2), 50 (2019).
[4] K. Jakubowski, W. Kerkemeyer, E. Perret, M. Heuberger, R. Hufenus, Mater. Des. **196**, 1 (2020).
[5] V. Vladev, T. Eftimov, Proc. SPIE **8770**, 87700V-1 (2013).
[6] V. Vladev, T. Eftimov, W. Bock, Photonics Lett. Pol. **7**, 41 (2015).
[7] V. Vladev, T. Eftimov, W. Bock, Opt. Comm. **356**, 34 (2015).
[8] V. Vladev, T. Eftimov, S. Nedev, Opt. Fib. Tech. **28**, 28 (2016).
[9] V. Vladev, M. Todorova, V. Slavchev, M. Brazkova, E. Belina, S. Bozhkov, P. Radusheva, J. Phys.: Conf. Ser. **1859**, 1 (2021).
[10] V. P. Vladev, M. M. Todorova, M. S. Brazkova, S. I. Bozhkov, Laser Phys. Lett. **18**, 115103 (2021).
[11] G. Dyankov, T. A. Eftimov, N. Malinowski, E. Belina, H. Kisov, P. Mikulic, W. J. Bock, Opt. Laser Technol. **123**, 1 (2020).
[12] T. Eftimov, G. Dyankov, A. Arapova, P. Kolev and V. Vladev, W4.73, OFS-27, Optical Fiber Sensor Conference – 2022, 29 Aug - 2 Sept., The Westin Alexandria, Alexandria, Virginia, USA. (accepted)
[13] G. Rossi, J. Durek, S. Ojha, O. K. Schlüter, CRFS **4**, 862 (2021).
[14] L. Li, Y. Wang, W. Zhang, S. Yu, X. Wang, N. Gao, Chem. Eng. J. **381**, 1 (2020).

