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Microfiber as light source for exciting fluorescence in a polymer optical fiber

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ABSTRACT

We present a new technique for exciting and collecting fluorescence with all-fiber devices, consisting of two different tapered fibers, a microfiber used as illuminating source and a polymer optical fiber where a fluorophore has been deposited and where the fluorescence takes place. We depict the fabrication of the device, characterize its performance and show the feasibility of our approach, the good performance obtained and the possibility of using the flexibility of the illuminating fiber to increase this performance and the compactness of the device.

1. Introduction

In the last years, micro- and nanofibers (MNFs) have attracted considerable interest and have been employed for different applications, notably in the field of sensing. The diameter of a fiber is in this case reduced down to a few micrometers by different methods, thus achieving a high confinement of the light in the narrowed waist with significant extension and intensity of the evanescent field, which is a notable feature for sensing but also, as it is shown in this paper, can be used to provide an illuminating source for fluorescence-based devices [1]. Other applications of MNFs depicted in the literature include: resonators, particle manipulation or filters [2].

In general, their small size, flexibility and sensitivity make possible to produce very compact devices with high performance. Thus, in the field of sensing we find MNFs in varied configurations, such as biconical tapers, optical gratings, circular cavities, Mach-Zehnder interferometers and functionally coated/doped microfibers, among other structures combining them, which are applied to physical and bio/chemical sensing [3].

The fact that light is still guided in the MNF but, at the same time, the reduction of size makes this guiding critical can be used to propose, as we do in this paper, a novel application for these elements, as illuminating sources to excite fluorescence. Fluorescence is one of the most used techniques in bio/chemical sensors [4]. Among the many possibilities existing to develop fiber-based fluorescence sensors, the use of polymer optical fibers (POFs) has been notably increased in the last years, since they have shown a better performance when compared to glass fibers [5], to the point that fiber optic sensors based on POFs have become widespread [6].

While maintaining the same good qualities as glass fibers, POFs present additional advantages: a bigger diameter, easier handling, biocompatibility, good durability and flexibility with a relative low cost [7]. These characteristics make them very suitable for fields such as environmental monitoring [8] and medicine [7], as in these areas budget is a fundamental issue but rough handling and disposability are required. There are some fluorescence-based POF sensors in literature [9,10], but its efficiency depends on the method used for light coupling. In this sense, side-lighting technique improves coupling efficiency with a relatively simple configuration [11–13].

We also opt in this work for POFs as the basis of our configuration. We deposit a fluorophore on the POF and then excite fluorescence with the MNF-based illuminating source. To optimize the performance of the system we also taper the polymer optical fiber and not only the microfiber. This combination of both MNF and POF tapered fibers is a novelty and, as we show in the paper, permits a very good efficiency and a very compact setup,

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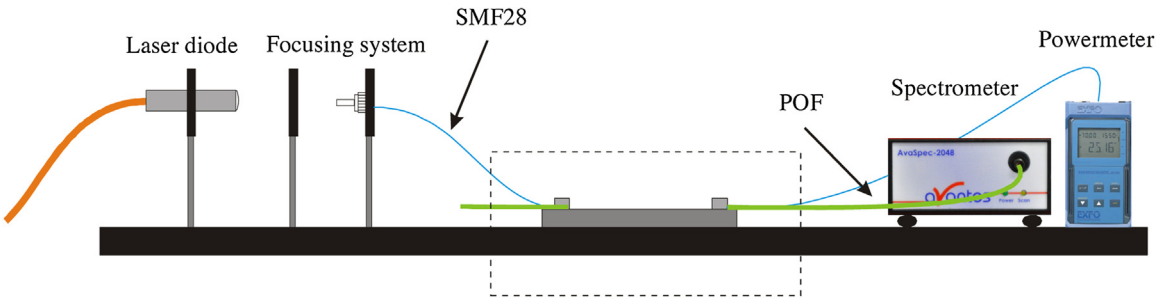

Fig. 1. Scheme of the experimental setup.

ideal characteristics for the development of all-fiber fluorescence sensors.

2. Device fabrication

To produce the illuminating MNF we have started with a standard communication fiber (SMF-28) optimized for transmission in the communication C-band. It is tapered using the traveling-burner technique, where the fiber is oscillatory heated while gently stretched. The amplitude and speed of the oscillation can be automatically controlled to obtain the desired parameters of the fiber, specifically: waist diameter, waist length, profile of the transition regions and total length of the taper. We have been using this technique for several years producing uniform-waist tapers with diameters of the order of 30–40 μm for sensing purposes with extremely good reproducibility and very low losses (around 0.2 dB or smaller). We have checked that this reproducibility is equally good when reducing diameters to smaller values by measuring the final geometry of the tapers. For this application the fiber has been tapered down to a waist diameter of 15 μm, looking for a trade-off between efficiency and mechanical strength. In any case, smaller diameters down to 5 μm can easily be reached with this arrangement. The total length of the tapers is about 52 mm, while the waist length is 10 mm and losses are of the order of 1 dB in the extension of the taper. These are typical values, but the versatility and simplicity of the production setup allows us to change them in a very easy way. As it can be seen here, the proposed reduction of the fiber diameter is enough to permit a good efficiency in the illuminating process with the MNF. When reducing the diameter of the fiber we in principle may expect very fragile, unmanageable devices, but this is not really the case. Of course, one must be careful, especially when retiring the fiber of the tapering machine, trying not to introduce tensions or shearing but fragility is not a real issue with the proper precautions.

In what respects to the other fiber in the device, namely, the POF where the fluorescence will take place, we have used PMMA fibers with an outer diameter of 1 mm and in this case we have tapered them by chemical etching, by immersing the unjacketed fiber in pure acetone [11]. We have reduced the diameter down to 850 μm, which is not a very large reduction, but provides us with an optimum value in terms of mechanical stability and light collection, and also permits us the deposition of the fluorophore in the narrowed region, whose length is of the order of 70 mm, thus increasing the sensing area. Furthermore, a water-based fluorescent yellow-green ink of high quantum yield has been used as fluorophore.

3. Experimental set-up and results

Our main goals in this case are (1) to prove the feasibility of our scheme, that is, to show that fluorescence in the POF can be excited while using the MNF as source and (2) to estimate the efficiency of our approach, while testing several possibilities for the configuration of the device.

In this way, we start with an experimental setup as the one shown in Fig. 1. As light source we use a laser diode with an emission peak in 405 nm (Thorlabs CPS405), whose beam is launched by an optical focusing system into the illuminating fiber. The light emitted in the fluorescence process is collected by the POF and this signal is acquired by a CCD spectrometer (Avantes AvacSpec 2048-2) controlled by a laptop computer. The whole setup is enclosed in a dark container to avoid the presence of any spurious light source.

To permit the excitation of fluorescence in the POF, this fiber and the exciting microfiber can be placed close to one another. To evaluate the importance of the separation (and, in this way, the performance of our method of illumination) we have disposed both fibers in an arrangement where this separation can be accurately varied. Both fibers are attached to micrometric translation stages parallel to one another, and the separation is varied from virtually 0 up to 10 mm. We adjust the integration time of the measures to values of 3 s to optimize the signal as a function of the intensity of the fluorescence (Fig. 2).

In Fig. 3 we show how fluorescence in POF is clearly excited with our setup. Two different distances between exciting and collecting fibers are shown. The intensity of the fluorescent signal obviously decreases with separation but we still have significant signals when the illuminating fiber is several millimeters apart from the POF, thus proving the possibilities of our technique. In fact, as it can be shown in Fig. 4 we have enough fluorescence intensity for values of the order of 4 mm. In Fig. 5 we show the change in the fluorescence maximum with a continuous variation of the distance.

However the very good performance of the technique based on the juxtaposition of the fibers, we have also tested another different approach in which we take advantage of the notable flexibility of the MNF by wrapping it around the POF. It is not very usual that we can have a flexible illuminating source, so this feature can be one of the most important of our setup. In fact, the flexibility of the fiber is increased for a smaller diameter so if we are careful in the wrapping process it can be done without much difficulty and the final result is a quite robust device. Also, by curving the

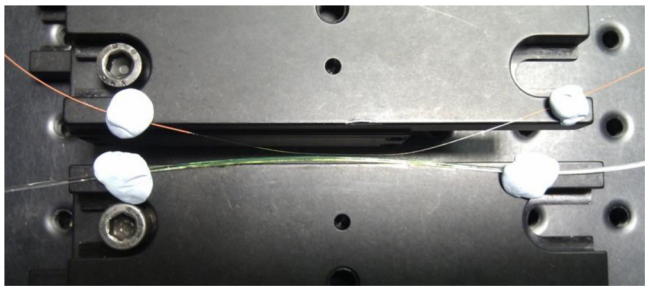

Fig. 2. Detail of the experimental setup showing the translation stages with the fibers attached to them.