

Water-Jet Waveguide for Fluorescence Spectroscopy

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1 Introduction

This paper reports an optofluidic water-jet waveguide used for laser-induced fluorescence spectroscopy. In this common analytical technique, the sensitivity depends on the ratio between the fluorescent signal and the background signal. The signal intensity is essentially related to the collection efficiency of the detection optics, whereas the background signal (noise) has two main contributions: the excitation source scattering and the fluorescence arising from non-analyte substances that the light source encounters along its path. In order to increase the signal-to-background ratio, recently, a great effort has been addressed towards the development of novel optical excitation/detection configuration [1–4]. In this paper an innovative configuration is proposed, where a high-speed water stream produced by means of a microchannel acts at the same time as the solution to analyse and the collecting optical waveguide.

Water-jet waveguides are sometimes used in laser cutting device [5], and very few examples in fluorescence spectroscopy applications have been proposed, however, without fully exploiting the great advantage of this device [6, 7]. Furthermore, the few configurations proposed in literature require bulky optic and fluidic device with careful alignment procedure. Our configuration allows to minimize the pump contribution in the detected signal and to avoid any problem related to non-analyte fluorescence arising, for instance, from the walls of the flow cell typically used in this spectroscopic technique. In addition the configuration proposed is auto-aligned and integrated as the water-jet waveguide is directly coupled with the receiving optical fibre which collects the fluorescence light to a low-cost minispectrophotometer.

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2 Liquid-Jet Sensor

Figure 1 shows a schematic of the device. The optofluidic sensor has one inlet, for the liquid analyte, connected to a small microchannel used to create the liquid stream that falls directly onto the collecting fibre optic. The exciting light impinges orthogonally to the water stream in order to minimize the pump component into the detected signal. The fluorescence photons, arising from the analyte, are captured by total internal reflection and transported along the liquid jet to a multimode optical fibre centred with analyte stream.

The fabrication processes have been performed by direct milling a 3 mm thick layer of polymethylmethacrylate (PMMA). A long channel (that acts as a microfluidic channel and as groove for the collecting optical fibre) has been milled using a milling tool with $254 \pm 12.7 \mu\text{m}$ diameter. The fluidic inlet port has been realized by means of an $800 \mu\text{m}$ diameter drilling tool. Then, the substrate has been bonded to another layer of PMMA by means of a solvent-assisted bonding procedure. The following step has been to cut the chip by a micromilling machine in order to obtain an open region (24 mm wide and 10 mm high) where the jet waveguide flows allowing a length of the jet up to 10 mm. Subsequently, in order to excite the water stream from the backside, a 7 mm hole has been opened at the rear of the device. This exciting direction allows to minimize the scattering of the light refracted by the cylindrical liquid jet. This device layout ensures a perfect self-alignment between the collecting optical fibre and the liquid jet.

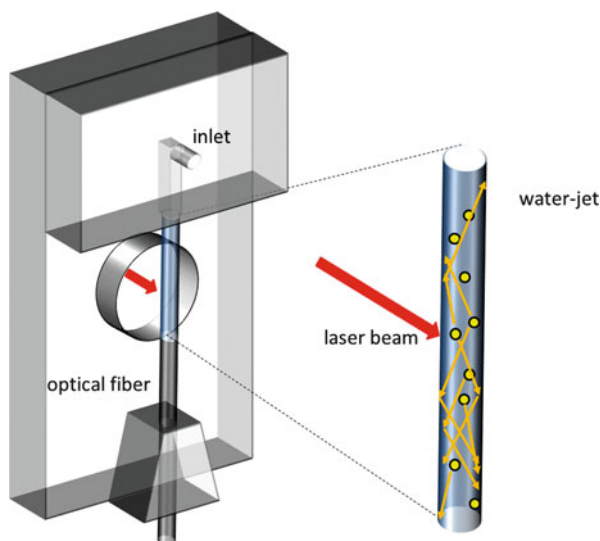


Fig. 1 Schematic of the optofluidic water-jet waveguide. The fluorescence arising from analytes in the water jet is confined in the jet waveguide and collected by a multimodal optical fibre

3 Experimental Results

For the device characterization, a collimated laser diode emitting at 640 nm has been used to excite aqueous solutions containing Cy5 dye concentration ranging over more than three orders of magnitude, from 8.67×10^{-10} M to 1.69×10^{-6} M. The corresponding calibration curve is reported in Fig. 2 where measurements have been obtained considering spectra between 646 nm and 850 nm (the observed fluorescence emission area). The measured limit of detection (LOD) has been 2.56 nM. This LOD value is very competitive also if compared to liquid core waveguides [8, 9] or considering innovative sensors devoted to similar applications [4]. This result is achieved thanks to the very optically smooth side walls due to the surface tension in liquid jet and the high fluorescence collection efficiency of a water stream waveguide. As the current-collecting optical fibre (NA=0.22) and the minispectrometer (NA=0.22) do not perfectly match the water cylinder cross section, a further increasing of the collection efficiency by direct coupling the falling jet waveguides to a photodetector by a high-numerical aperture fibre should be possible. In order to explore this solution, in a filter-free approach, the integral of the previously measured spectra has been evaluated on the whole detection range (350–1,000 nm). The obtained values (in Fig. 3) similar to the ones obtained by a silicon photodiode clearly attest that a filter-free detection is possible with a limit of detection of 6.11 nM.

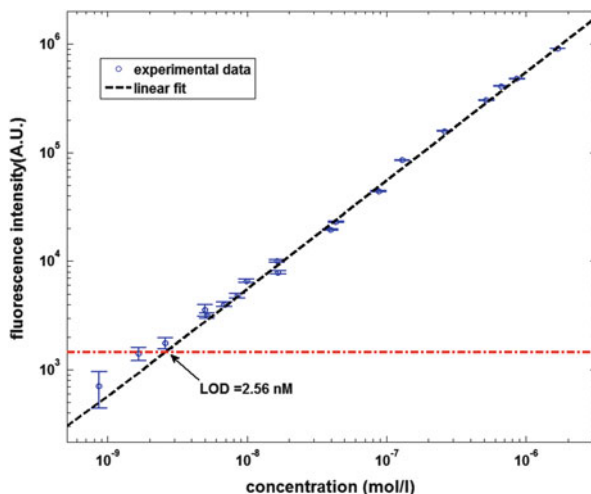


Fig. 2 Calibration curves for Cy5 solutions in the range $[8.67 \times 10^{-10} - 1.69 \times 10^{-6}]$ mol/l

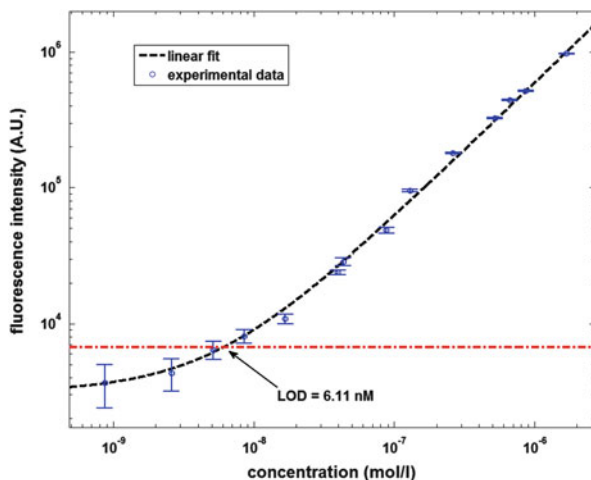


Fig. 3 Calibration curves of the devices in a filter-free detection configuration. The limit of detection is 6.11 nM

4 Conclusions

A water stream waveguide sensor for fluorescence spectroscopy of liquid solution has been developed. The waveguiding nature of a water stream improves the optical performances of the system avoiding usual drawbacks related to the flow cell presence or to the autofluorescence of the chip materials. A direct coupling with the collecting optical fibre allows a perfect integration with pigtail detectors. Fluorescence measurements of Cy5 solution had shown an LOD of 2.56 nM, and proof-of-concept of filter-free measurements has been demonstrated. The reported LOD, the high level of integration, and the compact size of the device are a clear indication that this sensor is potentially useful for environmental monitoring activity, providing online analysis of the concentration of various molecular species.

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