A POLYMERIC MICRO-OPTIC DEVICE FOR THE DETECTION OF MICROFLUIDIC FLOW SPATIAL PROFILE

F.Sapuppo[1*] **, A. Llobera**[2]**, F. Schembri**[1]**, M.Bucolo**[1]
[1] *Dipartimento di Ingegneria Elettrica, Elettronica e dei Sistemi, Università di Catania, ITALY* and
[2] *Institut de Microelectrònica de Barcelona, (IMB-CNM, CSIC), SPAIN*

ABSTRACT

This paper reports a miniaturized device for a spatially distributed characterization of microfluidic two-phase flow, exploiting a multi-wavelength optical signal. The device implements four optical windows (slits) which, superimposed on the centerline of a microfluidic channel, collect flow-related information through specific wavelengths. An advanced polymeric micro-optic design is used to guide and merge spatially distributed information into a single output signal, which maintains memory of the spatial coordinates by using the wavelengths as fingerprints of the slits' positions.

KEYWORDS: Multi-wavelength, Prism, Total Internal Reflection (TIR), Velocimetry.

INTRODUCTION

Phenomena occurring in microfluidic devices, such as DNA processing, particle encapsulation, and fluids mixing, or the analysis of *in vivo* conditions, such as red blood cell (RBC) flow and platelet motion in the microcirculation, involve the visualization of cells, gas bubbles, or liquid droplet transport through micrometric channels. The need, therefore, has arisen for accurate two-phase flow characterization at the microscale level, requiring noninvasiveness, real-time performance and good spatial resolution.

Technological solutions for the optical detection of flow, based on polymeric micro-optics, were previously reported [1][2]. Such micro-optic interfaces were considered as a valid alternative to microscopy and as optical detection devices to be integrated in velocimetry techniques for two-phase flow, as in the Dual Slit methodology [3]. These solutions provide information on the average flow over a single area using white light transillumination. They were applied in *in vitro* microfluidic devices and in *in vivo* microcirculatory observation on animal preparations [2][4].

The novelty of the device presently proposed is its capability to obtain a single multi-wavelength optical signal offering dynamic information about spatially distributed flow profiles.

EXPERIMENTAL

The device is realized through a micro-molding technique [5] exploiting the PDMS/air interface and the difference in refraction index ($n_{air}=1$, $n_{PDMS}=1.41$) to generate total internal reflection (TIR)[6].

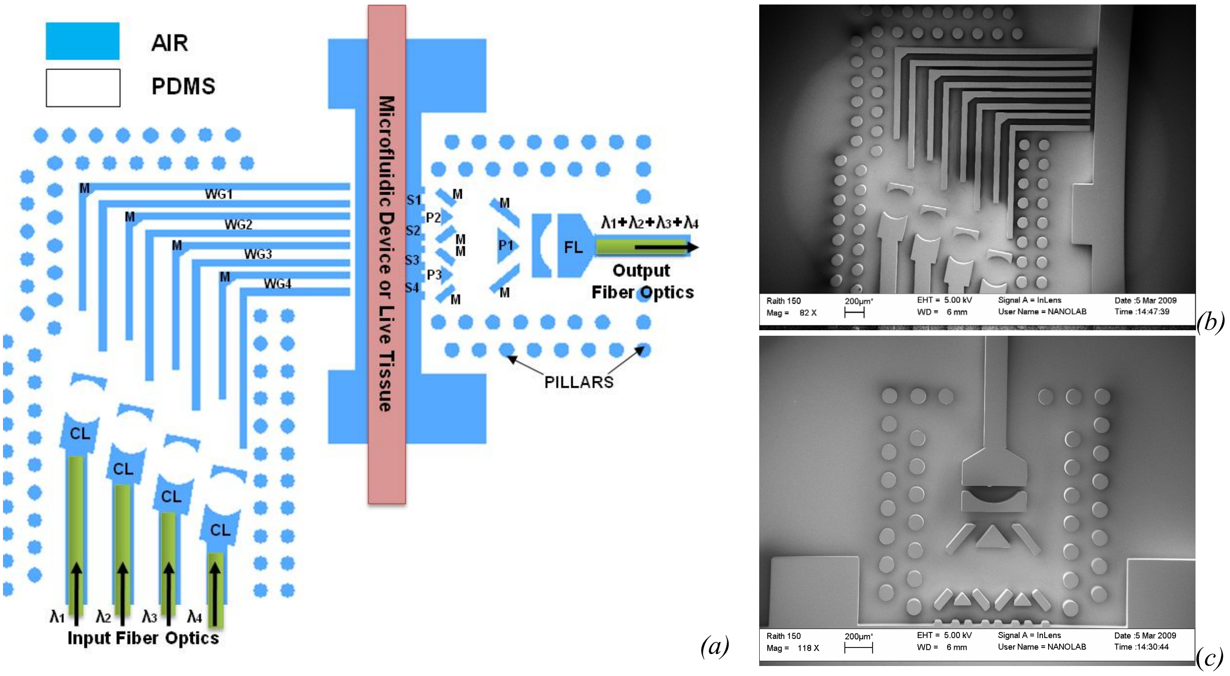

Figure 1: Micro-Optic Device. (a) Design: Collimating Lenses (CL). Mirror (M); Waveguides (WG1,2,3,4). Optical Windows/Slits (S1,S2,S3,S4=70µm). Prisms (P1,P2,P3). Focusing Lens(FL). Pillars with 100µm diameter. (b)(c) SEM images of the device SU8 master.

The advanced design, in Figure 1, involves two parts: 1) an interface between the four fiber optic inputs with differing light wavelengths (λ_1, λ_2, λ_3, λ_4) and the microfluidic channel, and 2) the merging device for the detection of the flow dependant optical signal. In the first part, collimating lenses (CL) are used to correct the numerical aperture (N.A.) of the fiber optics. Light is then guided through waveguides (WG 1,2,3, and 4) including mirrors (M) for light reorientation. The four beams are thus directed to four areas on the centerline of the microfluidic channel carrying two-phase flow, and after transmission they are captured, in the second part, by the four windows (slits – S 1,2,3, and 4). The beams are then merged by the prisms (P 1,2, and 3), while mirrors (M) are again needed for light reorientation, towards the fiber optic output. A focusing lens (FL) is used to match the N.A. of the fiber optic output. Circular air pillars are included in the design to protect the optical path from external light. In addition, self-alignment systems are disposed to facilitate the fiber optics insertion.

Optical simulations were performed (TracePro® ,Lambda Research Corp.) to validate and optimize the design. The resulting light path is shown in Figure 2.

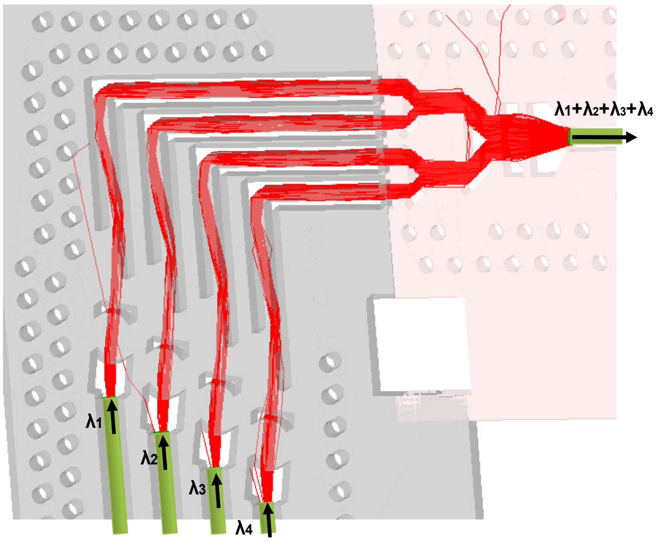

Figure 2: Ray tracing simulation of the propagating light through a device with Slits (S 1,2,3,4)=75µm. Refractive index: n_{air}=1, n_{PDMS}=1.41. Input fiber optics with N.A. =0.22.

RESULTS AND DISCUSSION

Experiments were carried out superimposing the micro-optic device on a serpentine microfluidic y-junction mixer (640X640µm section) with an ethanol-air two-phase flow (Figure 3). Two fiber-coupled lasers and two LEDs (λ_1=405nm, λ_2=470nm, λ_3=525nm, λ_4=639nm) were used as sources and a spectrophotometer was connected to the fiber optic output to collect the light for analysis.

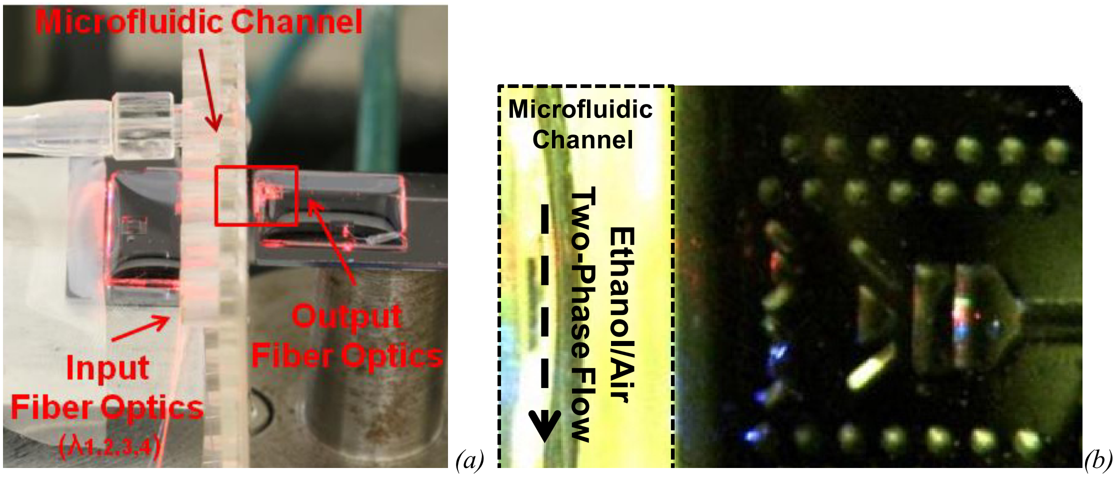

Figure 3: Multi-wavelength detection of two-phase flow. (a) Photo of the Experimental Setup: the PDMS micro-optic devices were positioned on fragments of silicon wafer as mechanical support. (b) Microscopy details of the merging device in the red rectangle in (a).

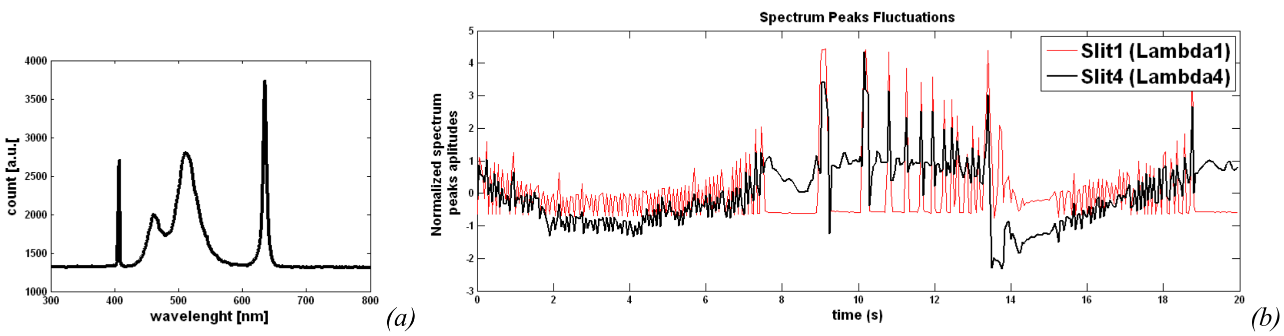

Figure 4: Dynamic spectral analysis of the output optical signal over a 20s experiment on a two-phase flow with constant air inflow and sinusoidal ethanol inflow. (a) Spectrum. (b) Dynamic study of the peaks related to the external slits(S1,S4), respectively detecting λ1 and λ4.

Static power measurements were performed to evaluate the efficiency of the device. The output spectrum (Figure 4(a)) was then dynamically captured and post-processed to detect amplitude fluctuations of the spectrum peaks for the four wavelengths. Figure 4(b) exhibits the trends in time of the peaks' amplitude for the two external slits [S1(λ_1), S4(λ_4)] in relation to an experiment with constant ethanol inflow (4µL/s), and sinusoidal air inflow (minimum: 20ul/s, maximum: 60ul/s, period Tp=10s). In such trends both the amplitude and the time lag between fluctuations are modulated by the air inflow.

CONCLUSION

The design of the polymeric device presently proposed for spatial distributed flow monitoring represents a miniaturization and optimization of advanced macroscopic optic designs. Its main feature is represented by the extraction of an optical signal which provides information on flow profile, respecting the spatial distribution of the information and exploiting the wavelength as a fingerprint of the spatial position. Possible applications are wide and range from droplet and digital microfluidics to the *in vivo* investigation of fluids' flow in the microcirculation. This development demonstrates the possibility of integrating well-known and widely-used optical flow monitoring systems for microfluidics, providing, in the long term, a disposable interface for live mammalian tissues.

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REFERENCES:

[1] M. Bucolo, V. J. Cadarso, J. Esteve, L. Fortuna, A. Llobera, F. Sapuppo, and F. Schembri, A Disposable Micro-Electro-Optical Interface For Flow Monitoring In Bio-Microfluidics, Micro Total Analysis Systems 2008, pp. 1579-1581, (2008).

[2] F. Sapuppo, A. Llobera, F. Schembri, M. Intaglietta,V. J. Cadarso, M. Bucolo, A polymeric micro-optical interface for flow monitoring in biomicrofluidics, Biomicrofluidics 4, 024108 (2010).

[3] F. Sapuppo, M. Bucolo, M. Intaglietta, P. C. Johnson, L. Fortuna and P. Arena, "An Improved Instrument for Real-Time Measurement of Blood Velocity in Microvessels", IEEE Transaction on Instrumentation and Measurement,Vol.56(6),pp:2663,2671, (2007).

[4] F. Sapuppo, F. Schembri, L. Fortuna, M.Bucolo, "Microfluidic Circuits and Systems", Circuits and Systems Magazine IEEE, Vol.9 (3), pp. 6-19, (2009).

[5] D.C. Duffy, J. Cooper McDonald, O.J.A. Schueller, and G.M. Whitesides, Rapid Prototyping of Microfluidic Systems in Poly(dimethylsiloxane), Anal. Chem., 70, 4974-4984, (1998).

[6] A Llobera, S Demming, R Wilke, S Büttgenbach Multiple internal reflection poly(dimethylsiloxane) systems for optical sensing, Lab Chip. Nov ;7 (11):1560-1566 17960286 (P,S,E,B,D), (2007)

CONTACT

*F.Sapuppo, tel: +39 095 7382603; fsapuppo@diees.unict.it