Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 120 (2015) 1071 – 1074

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2015

Optical particle detection in liquid suspensions with a hybrid integrated microsystem

I. Bernat[a]*, J.J. Gonzalez-Murillo[a], L. Fonseca[b], M. Moreno[a], A. Romano-Rodriguez[a]

[a]Department of Electronics, University of Barcelona, 08028 Barcelona, Spain.

[b]Institute of Microelectronics of Barcelona -CNM-CSIC, Campus UAB, 08193 Bellaterra, Spain

Abstract

A compact, robust and portable system for optical particle detection in liquid suspensions, achieved through the hybrid integration of commercial components, such as VCSELs and microlenses, in a silicon micromachined structure is presented. We demonstrate the feasibility of fabricating a device providing up to 4 collimated laser beams, with the ability of detecting and distinguishing microparticles of several diameters, even in mixed suspensions. This optical microsystem represents an alternative design for microflow cytometers based on optical fibres, and is aligned with the current tendency set by the Point-of-care devices.

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: VCSEL; microlens; silicon micromachining; optical flow cytometry.

1. Introduction and Optical Design.

Since 1990 the interest in LoC (Lab-on-Chip) and μTAs (Micro Total Analysis) biosensors has increased considerably. A large number of these sensors are devoted to count the amount of cells or particles in a sample, for in many biological applications, it is necessary to know this data. Miniaturization and integration of optical components in LoC devices has become an important issue to deal with. The goal is to obtain efficient coupling and focusing of light into the interrogation window, whether it be with fiber optics (off-chip approximation) or with the integration of optical sources and detectors as close as possible to the area of interest (on-chip approximation) [1,2].

* Corresponding author. Tel.: +34-934039146; fax: +34-934021148.
E-mail address: ibernat@el.ub.edu

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015
doi:10.1016/j.proeng.2015.08.763

In this work we present the design, fabrication and testing of a miniaturized package suitable for detection of microparticles with a diameter in the range of tens of microns. Two subsystems has been developed: i) a robust device based on hybrid integration of VCSELs (Vertical Cavity Surface Emitting Laser) coupled with a microlens array and ii) a microfluidic platform with PDMS fabricated channels for microparticle flowing, as an approach to a flow cytometer [3].

1.1. Optical components

VCSELs from "ULM Photonics" are commercialized in dies forming linear arrays of 4 or 12 lasers, with a pitch of 250µm. They emit at λ=850nm, with a circular emission area of 20µm diameter and divergence angle of 30º. Anode and Cathode contacts are in the top side, which is an advantage for the wire-bonding.

A comercial microlens array from "SUSS MicroOptics" has been selected in order to correct the divergence and to allow the focusing or collimating of the light beams in the detection area [4]. The circular microlenses are fabricated in fused silica, present a focal length of 1.063mm, a radius of curvature ROC=0.487mm and also the same pitch of 250µm, which allows a good alignment between the centers of lenses and the VCSEL. The total dimensions of the array are 10x10x1.2mm. In Fig. 1 (a) and (b) we show these commercial components and the proposed hybrid assembly to package them, Fig. 1 (c). The spacer (yellow color), defines the real position of the microlens array (at the top, blue color) with respect to the VCSELs array (at the bottom, red color) over the silicon base (gray color).

1.2. Design and simulation

Optical simulations have been performed in order to define the most suitable relative positions of the optical elements for a collimated scenario, with the aim of obtaining a spot of reduced dimensions. Fig.2 (a) is a layout of the proposed and implemented design optimized with ZEMAX® software. From left to right:

- Punctual emitters representing the VCSELs in RGB colors and the microlenses array.
- PDMS microfluidic channel of 2mm thickness and refractive index of 1.47, and glass substrate of 1mm thickness with a refractive index of 1.51.
- The microfluidic channel, in pink color, is 150µm height, 200µm width for the top side and 225µm for the bottom side. The difference in the width for top and bottom sides creates a more real channel with non-parallel side walls and simulates possible light reflections on these walls. Details of this microchannel design can be appreciated in Fig. 2 (b).

Fig. 2 (c) is the result of a particular simulation of light intensity in the photodetector located at the center of the microchannel. While the white circle corresponds to the collimated spot, it can also be observed the shadow effect produced by a particle of 50µm diameter placed in the center of the microchannel. Black lines appear due to the absence of light because of the refracted light in the non-vertical walls of the microchannel. Two variables were defined for the analysis: $d_{V\text{-}D}$ as the distance between VCSELs and detector #2, and $d_{V\text{-}L}$ representing the distance between VCSELs and microlenses. For a practical manipulation of the experimental set-up and the allocation of microfluidic platform, $d_{V\text{-}D}$ was fixed to 18mm, and after simulations, optimum position of the elements resulted in $d_{V\text{-}L}$=1.118mm, delivering a minimum spot radius of 116µm.

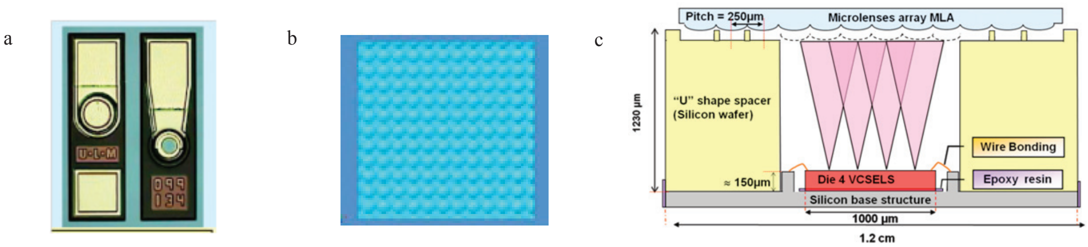

Fig. 1. (a) VCSEL from "ULMphotonics"; (b) microlens array form "SUSS Microoptics"; (c) cross-section of the fabricated structure.

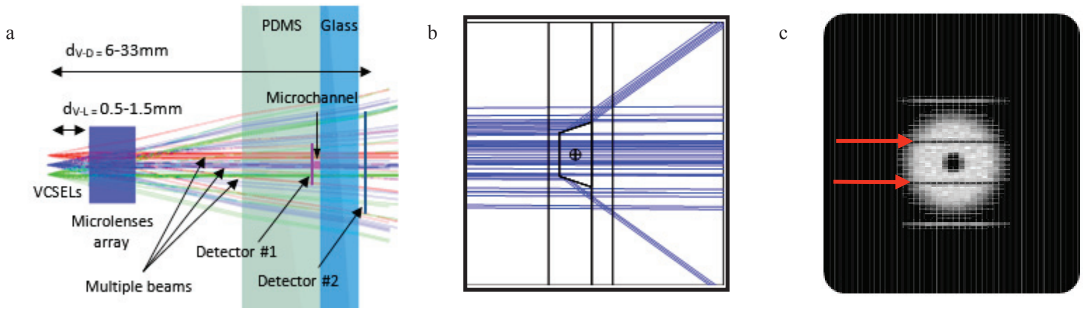

Fig. 2. (a) Layout of the optical system to simulate; (b) detail of ray tracing in the microfluidic channel; (c) impacts in a photodetector.

2. Fabrication and alignment.

Firstly, VCSELs and the microlenses were assembled and aligned. From Fig.1 (c), silicon base (gray color) and U-shaped spacer (yellow color) were fabricated through silicon micromachining technology. In the silicon base, a cavity with a height of 150µm was created in order to place the VCSELs and to fix the U-shaped spacer. U-shaped spacer has a thickness of 1.23mm, to accomplish the optical requirements of the system, and was fabricated in a special silicon wafer with a non-standard thickness, using Deep RIE to achieve a total etching of the wafer. Fig. 3 (a) is a photograph of the final processed silicon base and spacer. Aluminum contacts were also fabricated in the base, for the wire-bonding between VCSEL and the external power paths and contacts (Fig. 3 (b)). The packaging of the final device on a PCB is shown on Fig.3 (c).

Fig. 4 (a), (b) and (c) show how microlenses were actively aligned, before being fixed to the optical spacer [5]. Fig. 4 (d) presents the results of the testing of the collimation effect of the fabricated microsystem. The laser spots were captured with a commercial ½" CMOS camera of 1280x 1024 pixels (EO-1312BL – Edmund Optics) at several distances. For the range $d_{V\text{-}D}$=3-9mm the radius of the spot is 124µm; at $d_{V\text{-}D}$=1cm, radius becomes 130µm and at $d_{V\text{-}D}$=3cm radius increases to 213µm. So, from 1cm to 3cm we estimate a divergence of 0.234º.

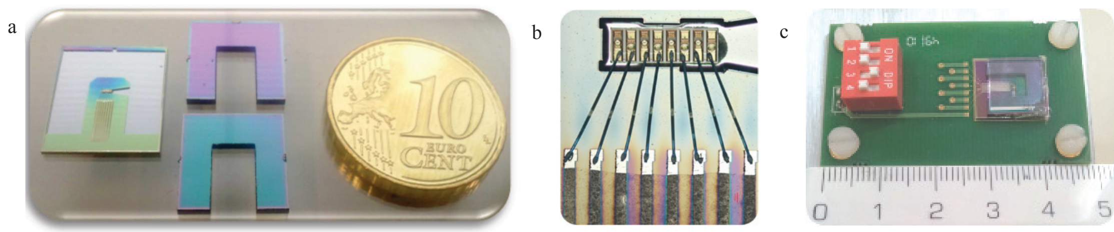

Fig. 3. (a) Silicon base and "U-shaped" spacer, previous to be assembled; (b) wire-bonding connections between VCSELs and electric paths; (c) miniaturized system mounted on a PCB.

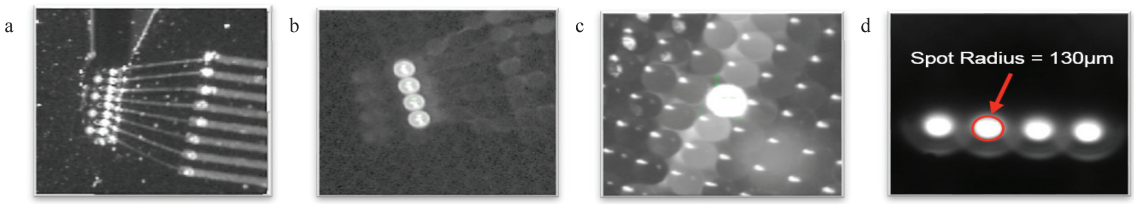

Fig. 4. (a) Four IR VCSEL turned-ON to actively align the microlenses; (b) IR VCSELs active after lens alignment; (c) one IR VCSEL active, view at lens focal plane; (d) collimated laser spots at a distance of 10mm.

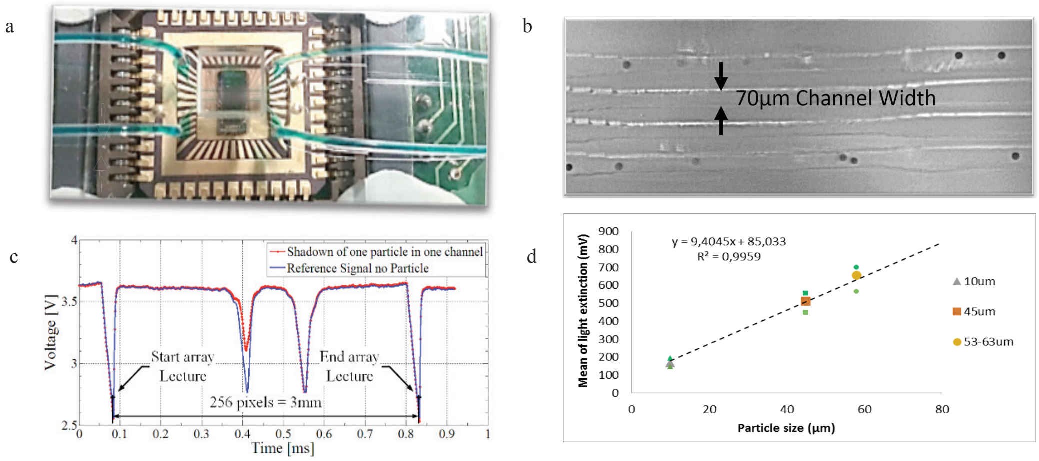

Fig. 5. (a) Microfluidic channels over photodetector array of 256 pixels; (b) four parallell microchannels with 70µm width at the center of detection; (c) signal acquisition from the array with two VCSELS turned-on; (d) light extinction for different particle sizes.

3. In flow particle detection.

Microfluidic channels were fabricated in PDMS with soft lithography techniques [6]. The height of the channels is 100µm. Particles flow through these channels until they are confined into a detection window of 70µm width. Each channel must be centered in relation to one VCSEL, so their pitch distance should be also 250µm. We have worked with 10µm to 60µm diameter black polystyrene beads from "Polyscience®". Motion of the particles is achieved by pressure driven flow at 10µL/min. Photograph of Fig. 5 (b) is an example of 4 channels with particles of 45µm of diameter flowing in the flowing in the external channels (top and bottom).

As detector we have used a 0.35µm CMOS photodetector array of 256 pixels, with a pixel pitch of 10µm; the total length of the array is approximately 3mm. The electronics board includes a microcontroller that governs the digital control signals and the integration time of the array. The analog output of the array is captured with an external NI-USB-6251 acquisition board, working at 1Ms/s, for a posterior post-processing in a computer. The reading time of the array is around 800µs, as it is seen in Fig. 5 (c), where the extreme VCSELS are turned-ON. The blue signal is the output for no particle in the detection area, and the red signal is the variation caused by the shadow of a particle in the channel.

Finally, detection experimental results prove that discrimination of particles with different sizes (10µm, 45µm and 53-63µm) is possible. Mean values of light extinction signal amplitudes are well defined in differentiated ranges according to particle size, with low dispersion and excellent CV as is shown in the Fig. 5 (d).

Acknowledgements

This research has been possible thanks to the Spanish project TEC2009-12456, GICSERV Program: 6th call (NGG-190) and TEC2013-48147-C6-1-R.

References

[1] Sang Uk Son et al., Micro-cell counter using photoconductance of boron diffued resistor (BDR),Sensors and actuators A 111 (2004), 100-106.
[2] T. D. Chung, H. C. Kim, Recent advances in miniaturized microfluidic flow cytometry for clinical use, ELECTROPHORESIS, vol. 28 (2007).
[3] HT. Chen, Y.Wang, Optical microflow cytometer for particle counting, sizing and fluorescence detection, Microfluidic nanofluidic (2009).
[4] B. Kuswandi et al., Optical sensing systems for microfluidic devices: a review, Analytica Chimica Acta 601 (2007) 141-155.
[5] M. Mohaupt, E. Beckert et al., Alignment Procedures for Micro-optics, 5th IFIP WG 5.5 International Precision Assembly Seminar Proceedings (2010) 143-150. , 2010. O H. Zappe, Fundamentals of micro-optics, Cambridge University Press, 2010.
[6] K. E. Herold, A. Rasooly, Lab on a Chip Technology, Volume 1: Fabrication and Microfluidics, Horizon Scientific Press, 2009.