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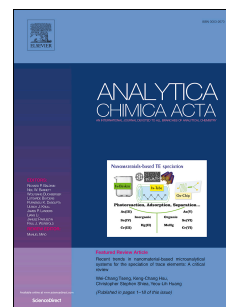
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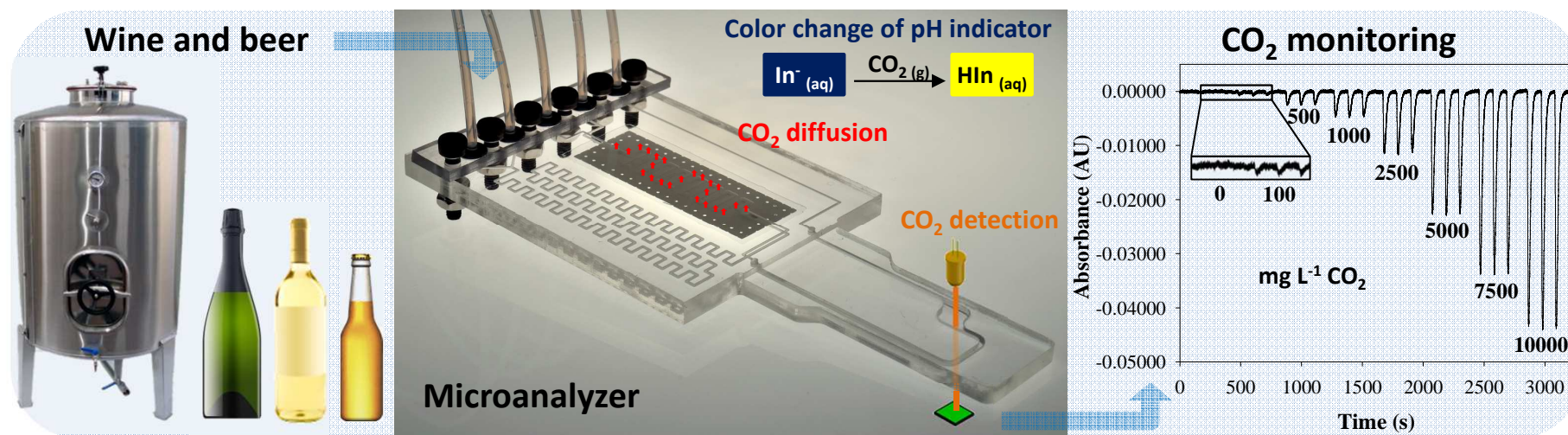
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# **Low cost and compact analytical microsystem for carbon dioxide determination in production processes of wine and beer**

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## **Abstract**

The design, construction and evaluation of a low cost, cyclic olefin copolymer (COC)-based continuous flow microanalyzer, with optical detection, to monitor carbon dioxide in bottled wines and beers as well as in fermentation processes, is presented. The microsystem, constructed by computer numerically controlled (CNC) micromilling and using a multilayer approach, integrates microfluidics, gas-diffusion module and an optical flow-cell in a single polymeric substrate. Its size is slightly bigger than a credit card, exactly 45 x 60 x 4 mm in the microfluidic and diffusion module zone and 22.5 x 40 x 3 mm in the flow-cell zone. The gas-diffusion module is based on a hydrophobic polyvinylidene fluoride (PVDF) membrane, which allows the transfer of the carbon dioxide present in the sample to a bromothymol blue (BTB) pH-sensitive acceptor solution, where the color change is measured optically. The detection system consisted of a LED with an emission peak at 607 nm and a photodiode integrated in a printed circuit board (PCB). The obtained analytical features after the optimization of the microfluidic platform and hydrodynamic variables are a linear range from 255 to 10,000 mg L<sup>-1</sup> of CO<sub>2</sub> and a detection limit of 83 mg L<sup>-1</sup> with a sampling rate of 30 samples h<sup>-1</sup>.

**Keywords:** Lab on a chip, Cyclic Olefin Co-polymer, Miniaturization, Gas-diffusion, Carbon dioxide, Optical detection.

## 1. Introduction

The amount of carbon dioxide (CO<sub>2</sub>) is an important parameter in the monitoring of fermentation process in wines and beers [1] and it is also a factor that affects their organoleptic properties [2,3]. For these reasons, CO<sub>2</sub> is routinely controlled in the production processes of these beverages in wineries and breweries.

There were traditionally three different official methods to determine CO<sub>2</sub> in these samples: the manometric, the enzymatic and the titrimetric, being the last one selected as first option due to its advantages over the others methods [4,5]. This procedure consisted in a titration with sulfuric acid between pH 8.6 and 4.0 of the alkalized CO<sub>2</sub>, using a pH electrode. Despite of its advantages, the titrimetric method shows some difficulties. In order to overcome them, direct measurements of dissolved carbon dioxide, especially those based on electrochemical methods, have also been proposed [6]. However, those methods based on Severinghaus principle show a long response time and sometimes low reproducibility and, in general, they are often expensive, not miniaturized and not easily automatable. As another alternative, automated systems based on continuous flow methodologies with spectrophotometric detection and with gas-diffusion separation step, have been used [7-9]. In this way, different quality parameters such as the analysis time, the sample and reagent consumption and the reproducibility of the measures without the need of skilled laboratory personal, were improved. In these systems, the process to determine CO<sub>2</sub> usually starts when the sample is injected into a carrier solution which is mixed with an acidic donor solution. At that moment, all the inorganic carbon species are converted to CO<sub>2</sub>, which diffuses through a gas-diffusion membrane. Then, a pH-sensitive acceptor stream collects the CO<sub>2</sub> causing a change in the pH which is detected by a change in the absorbance of the acid-base indicator. Nevertheless, these systems present a narrow working range that difficult the determination of CO<sub>2</sub> in beers (about 5000 mg L<sup>-1</sup>) and wines (from about 1000 mg

L<sup>-1</sup> in slightly sparkling up to 12000 mg L<sup>-1</sup> in very highly sparkling wines) [1,8]. In addition, sample and reagent consumption are still too high and the size of the experimental set-up makes them not portable, limiting their use in both discrete in-situ sample analysis and on-line monitoring of fermentation process.

To overcome these drawbacks, the miniaturization of analytical systems can be applied to obtain the so-called micro Total Analysis Systems ( $\mu$ TAS) [10,11]. Among all the different materials that have been used to fabricate these miniaturized analyzers, such as glass, silicon or ceramics [12], polymers offer great advantages over the others. They allow a fast and easy fabrication using inexpensive facilities providing low cost, small and compact microanalyzers. In addition, depending on the polymer employed, they have a good transparency in the UV-Vis range, good mechanical resistance, high chemical inertia against most acids and alkalis and high biocompatibility [13-16]. Furthermore, polymers technology allows the fabrication of microsystems using a multilayer approach in order to obtain tridimensional structures through the use of adhesives between layers in the bonding process. However, when adhesives are used, the obstruction of the microchannels can occur and there may be leaking of liquids or delamination between layers. To overcome these drawbacks, cyclic olefin co-polymer (COC) arises to provide a thermolamination process using the same material substrate as a sealing agent. Thus, taking advantage from the different glass transition temperatures in which COC can be formulated, a hermetic bonding of tridimensional structures can be achieved through the interlink of polymer chains on the surfaces of the layers when they are put together under a certain pressure and temperature [17, 18]. This technology allows also the monolithic integration of other elements such as hydrophobic/hydrophilic polymeric membranes, conductive paths or electrodes into the multilayer COC devices, which permits to integrate different steps of the analytical procedure such as sample dosage, sample pretreatment and separation, mixing, reaction, detection, among others [13,19, 20].

Finally, the advances in optoelectronics, which have let the appearance of new small light sources such as light-emitting diodes (LEDs) [21-25] and small detectors such as photodiodes

[21-24], allow the possibility to reduce the size of the experimental set-up for optical measurements compared to the conventional equipments, making them easily miniaturized [18].

Herein, we propose a low-cost, COC-based microsystem with a gas-diffusion step integrated for the spectrophotometric detection of CO<sub>2</sub> using bromothymol blue (BTB) as pH-sensitive acceptor solution. The microanalyzer integrates microfluidics, gas-diffusion separation step and an optical detection cell. These features, joined to the simplicity of the detection setup, make the entire system easily portable, with a reduced consumption of sample and reagents and a wider linear working range. To demonstrate its applicability, different wine and beer samples have been analyzed.

## 2. Experimental

### 2.1. Reagents and materials

The microanalyzer was fabricated with plaques and foils of COC purchased from Topas Advanced Polymers (Florence, KY, USA) in different grades and thicknesses: Topas 5013 plaques of 500 µm and 1 mm thickness, and Topas 8007 foils of 25 µm and 50 µm thickness.

A hydrophobic membrane made of polyvinylidene fluoride (PVDF) with 150 µm thickness and 0.45µm pore diameter (Millipore) was used to separate the analyte from its sample matrix by gas diffusion.

All reagents employed in this work were of analytical grade. All solutions were prepared in Milli-Q water. Carbon dioxide standard solutions were prepared daily by successive dilutions of a 50,000 mg L<sup>-1</sup> stock of Na<sub>2</sub>CO<sub>3</sub> (Panreac) and degassed. As a donor solution, a 0.2M H<sub>2</sub>SO<sub>4</sub> acidic solution (Sigma-Aldrich), containing 60 mg L<sup>-1</sup> of H<sub>2</sub>O<sub>2</sub> (Panreac) in order to avoid the SO<sub>2</sub> interference by oxidizing it to sulfate [7], was used to convert all inorganic carbon species into carbon dioxide. As an acceptor solution, a 12 mM NaH<sub>2</sub>PO<sub>4</sub>/Na<sub>2</sub>HPO<sub>4</sub> (Panreac) buffer solution (pH 7.6), containing 0.06 mM of BTB (Sigma Aldrich), was used.

### 2.2. Fabrication of the microanalyzer

The fabrication process of COC-based microsystems used, which is based in the lamination of different COC layers with different glass transition temperatures ( $T_g$ ), is described in detail elsewhere [19,20]. Topas 6013 plaques with  $T_g=130\text{ }^{\circ}\text{C}$  were used as fluidic structural layers for the mechanization of all motifs of the design (microchannels and flow cell) and Topas 8007 foils with  $T_g=75\text{ }^{\circ}\text{C}$  were used between them as sealing layers. The fabrication process consists of four main steps: prototype design, fluidic motifs machining, integration of additional non-COC elements (such as electrodes and gas-diffusion membrane) and final lamination. The prototype design was performed with a CAD software (Figure 1) taking into account previous experimental results obtained by our research group and described elsewhere [20]. The microsystem was constructed using five structural layers that, once overlapped, provide the three-dimensional structure required for this application (Figure 1A). The dimensions of the microanalyzer were 45 x 60 x 4 mm in the microfluidic and diffusion module zone and 22.5 x 40 x 3 mm in the flow-cell zone which is inserted into the detection system based on a lock-and-key concept [18] described in the 2.3 *Experimental setup* section. The microfluidics inside the microsystem included three liquid inlets (Figure 3). Two of them converge in a T-shape confluence point. At this point the carrier solution, where the sample is injected, and the  $\text{H}_2\text{SO}_4$  solution are mixed to obtain carbon dioxide from all inorganic carbon species present in the sample following the next chemical reactions:  $\text{CO}_3^{2-}(\text{aq}) + \text{H}^+ \rightleftharpoons \text{HCO}_3^-(\text{aq})$ ,  $\text{HCO}_3^-(\text{aq}) + \text{H}^+ \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$ ,  $\text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{CO}_2(\text{aq}) + \text{H}_2\text{O}$ ,  $\text{CO}_2(\text{aq}) \rightleftharpoons \text{CO}_2(\text{g})$ . The mixed stream is carried to the diffusion membrane unit where, along a meander microchannel, the carbon dioxide diffuses through the PVDF membrane towards the acceptor solution. The BTB pH-indicator acceptor stream sets to pH 7.6 with 12 mM phosphate buffer collects the carbon dioxide diffused changing its absorbance (from blue color to yellow color at wavelength of 607 nm) due to the pH modification induced. Finally, both the donor and the acceptor solutions are carried to the corresponding waste outlets.

All fluidic motifs (holes and channels) were machined onto the polymeric plaques by means of a computer numerically controlled (CNC) micromilling machine (Protomat C100/HF, LPKF,



Spain). The dimensions of the microchannels throughout the microsystem were 0.4 mm wide and 0.3 mm height except in the zone where the diffusion process takes place. In order to maximize the contact area between the donor and acceptor solutions with the diffusion membrane, the dimensions of the channels in both cases were 1 mm wide and 0.1 mm height. The diameter of the detection flow-cell was 4.5 mm with an optical path-length of 1 mm. The total microsystem dead volume was 200  $\mu$ L. In order to increase the lifetime of the gas-diffusion membrane and to prevent its breakage, a non-coincident inlet streams configuration, in the gas diffusion unit, was used [20]. Thus, the stress on the membrane caused by the incidence of the two streams at the same point was avoided.

The integration of the PVDF membrane was made as follows. It was cut, washed with deionized water, dried and placed properly with its more hydrophobic face in contact with the donor solution [20]. As it can be seen (Figure 1B), some holes were made on the external contour of the PVDF membrane to favor the penetration of the sealing foil (Topas 8007) during the lamination process in order to prevent liquid leakage between layers. In order to avoid the flattening of the membrane and the layers deformation during the thermo-compression process as a result of the incorporation of the membrane, an extra 50  $\mu$ m thick Topas 8007 sealing foil with a machined hole with the dimension of the membrane area is placed between the two machined COC layers [19, 20].

COC layers alignment and final lamination was performed in a thermo-compression press (Francisco Camps, Granollers, Spain) at 102 °C and 4 atm using an aluminum support with 4 fiducial alignment pins. Therefore, the whole microsystem acts as a monolithic substrate with the different layers perfectly bonded between them. Finally, fluidic connectors were fixed onto the polymer inlet/outlet ports with a holder and screws (Figure 1B).

### 2.3. Experimental setup

The detection system developed previously by our research group has been described elsewhere [18,24]. It consists in a compact and robust optical reader for microfluidic platforms which is

composed by a structure with a Printed Circuit Board (PCB) for the optical detection electronics and an insertion port, designed with a lock and key concept, to allow a perfect alignment between the light source, the measurement flow-cell and the detector (Figure 2). The PCB structure integrates as a light source a Light Emitting Diode (LED) with an emission peak centered at 607 nm (Kingbright, Taipei, Taiwan) and as a detector, a PIN Hamamatsu S1337-66BR with 33 mm<sup>2</sup> of active area photodiode. The signal generated was acquired by means of a Data Acquisition Card (DAQ) NI USB-6211 from National Instruments (Austin, Texas, US), which transfers the signal from the PCB, via USB interface, to a personal computer, where it is processed using a digital lock-in amplifier. The data collection rate was 10 s<sup>-1</sup>. The use of lock-in amplification allowed to increase the signal-to noise ratio and to work in ambient light conditions avoiding thus the effect of stray light on the measures [18,24].

On the other hand, the continuous flow system setup is shown in Figure 3. It consists of an external peristaltic pump (Minipuls 3, Gilson, Wisconsin, US) using Tygon® tubing (Ismatec, Wertheim, Germany) with 1.14 mm internal diameter and a six-way injection valve (Hamilton MVP, Reno, US). Teflon tubing (Scharlab, S. L., Cambridge, England) of 0.8 mm internal diameter was used to connect the external elements to the microsystem.

### 3. Results and discussion

#### *3.1. Design and optimization of the analytical microsystem*

The main goal of this work is the development of a low cost, simple, selective and robust microanalyzer for the determination of carbon dioxide in bottled wine and beer and in their fermentation processes at breweries or wineries, which monolithically integrates the microfluidic platform, the gas diffusion module and the detection flow-cell. This microsystem has to meet all the requirements for the proposed application, such as easy automation, small size, limited consumption of reagents and a wide working range.

In a previous work [20], the design of the diffusion module was optimized in order to enhance the robustness of the separation process and to increase the lifetime of the PVDF diffusion membrane keeping suitable analytical features such as sensitivity, baseline stability and

detection limit. In this work, variables such as the flow mode (concurrent or countercurrent) and the flow rate ratio between the acceptor and donor solutions inside the diffusion module were tested, concluding that the same configuration previously optimized (countercurrent flow mode and 2:1 donor: acceptor ratio) is also the better choice for the present work. Additionally, the microfluidic structures and the hydrodynamic variables has been designed and optimized respectively to minimize the sample and reagents consumption.

The shape of the flow-cell has also been redesigned and optimized introducing smooth-contour geometries, without any sharp corners, and taking into account the Venturi effect and Bernoulli's principle [26]. Thus, the formation and retention of bubbles was minimized inside the flow-cell. Despite of this, if eventually bubbles appear, their evacuation is favored due to the pressure-velocity difference of the fluid between the flow-cell and the outlet stream (Figure 1Bd). For this reason, noisy and transient signals and baseline drifts related with the presence of bubbles in the flow-cell were avoided, increasing the overall robustness of the microsystem.

In addition, the shape of the microsystem was designed so that it can be inserted into a detection system based on the lock and key concept (Figure 2), allowing a perfect and reversible alignment between the LED, the detection flow-cell and the photodiode and thus, obtaining a robust and compact system, as demonstrated in a previous work [18].

The influence of chemical variables (buffered acceptor solution, acidic donor solution and potential interfering compounds) and hydrodynamic parameters (flow rate and sample injection volume) on the analytical features has also been evaluated using an optimization of each variable individually in order to achieve a compromise between the sensitivity of the analytical measurements, the baseline signal stability, the linear working range, reagent and sample consumption and the sample throughput.

According to the bibliography, bromocresol purple [9], phenol red [27] and bromothymol blue (BTB) [7,19,27-29] have been used as pH-sensitive indicators dissolved in an acceptor stream to determine carbon dioxide in real samples. In this work, BTB dissolved in a phosphate buffer solution was selected because it showed a higher working range [29]. The BTB acceptor

solution was tested at concentrations ranging from 0.03 to 0.08 mM, the phosphate buffer strength was evaluated from 0.1 to 12 mM and the pH of the acceptor stream was evaluated from 7 to 8. The optimal results were obtained using an acceptor solution of BTB 0.06 mM at pH 7.6 with phosphate buffer strength of 12 mM. Using this buffered acceptor solution, the peak height caused by a given CO<sub>2</sub> concentration diminishes compared to that obtained with a non-buffered acceptor solution. This fact means that the higher the buffer strength, the lower the peak height for each CO<sub>2</sub> concentration and the lower the sensitivity, but at the same time it allows enlarging the operative working range [19,28,29]. Taking into account that the aim of the present work is to be able to determine a range of relatively high carbon dioxide concentrations in wines and beers, a very low limit of detection and high sensitivity are not required. In addition, using the buffered acceptor solution, the changes in the pH caused by the absorption of atmospheric carbon dioxide are negligible. Nevertheless, in other applications when very low concentrations of CO<sub>2</sub> have to be determined, non-buffered acceptor solution should be used. In these cases, the absorption of atmospheric carbon dioxide would be a serious problem which can be minimized introducing cartridges of soda lime at the air inlet of the bottles of reagents to completely remove the atmospheric CO<sub>2</sub> [30].

On the other hand, hydrochloric and sulfuric acids were evaluated as donor acidic solutions without obtaining any significant differences between them in terms of peak height. However, sulfuric acid was selected due to that hydrochloric acid can diffuse through the PVDF membrane, since it has a higher vapor pressure, and can change the pH of the acceptor solution. The concentration of H<sub>2</sub>SO<sub>4</sub> donor stream was varied from 0.2 to 0.6 M. The optimal results were obtained with a donor solution of H<sub>2</sub>SO<sub>4</sub> 0.2 M.

Taking into account potential interfering compounds that can be found in these samples, sulfite ion is the only one that has to be taken into account because it is the only chemical compound present in wine samples able to diffuse in an acidic medium, as SO<sub>2</sub>, through the PVDF membrane [7]. Its concentration in wine can be up to 300 mg L<sup>-1</sup> SO<sub>2</sub>. For this reason H<sub>2</sub>O<sub>2</sub> is added to the donor stream in order to assure the total oxidation of SO<sub>2</sub> to SO<sub>4</sub><sup>2-</sup> which cannot

diffuse through the membrane. The concentration of hydrogen peroxide used was optimized elsewhere [7], being 60 mg L<sup>-1</sup>. Therefore, the final composition of the donor stream was 0.2 M of H<sub>2</sub>SO<sub>4</sub> with 60 mg L<sup>-1</sup> of H<sub>2</sub>O<sub>2</sub>. Despite of this, due to SO<sub>2</sub> usually is in less proportion than CO<sub>2</sub> in wine, H<sub>2</sub>O<sub>2</sub> could be suppressed without obtaining significant differences in the results.

Regarding the hydrodynamic parameters, the flow rate of the carrier, the donor and the acceptor streams were varied from 100 to 500 µl min<sup>-1</sup> and the sample injection volume was varied from 25 to 580 µL. A flow rate of 400 µl min<sup>-1</sup> for carrier, donor and acceptor streams and a sample injection volume of 25 µL were considered the optimal parameters.

### 3.2. Analytical performance

Analytical characterization of the microsystem was carried out by successive calibrations obtained using different standard solutions of Na<sub>2</sub>CO<sub>3</sub> from 100 to 10,000 mg L<sup>-1</sup>. Figure 4 shows the recorded signal for one calibration. The obtained equation ( $n = 8$  and 95% confidence) was  $\text{Abs} = -4.45 \cdot 10^{-6} (\pm 2 \cdot 10^{-8}) [\text{CO}_2] + 0 (\pm 1 \cdot 10^{-4})$  with  $r^2 = 0.9999$ . The detection limit, calculated as three times the standard deviation of the blank, was 83 mg L<sup>-1</sup>. The linear working range corresponds from 255 to 10,000 mg L<sup>-1</sup>. Repeatability studies were performed by successive injections of 2,500 and 5,000 mg L<sup>-1</sup> Na<sub>2</sub>CO<sub>3</sub> standard solution. Relative standard deviation ( $n = 6$ , 95% confidence) of the signals were lower than 2% in both cases.

Reproducibility of the results obtained in different days using different reagent solutions was also determined. Mean slope of  $4.38 \cdot 10^{-6}$  with RSD value lower than 2% was achieved, thus demonstrating the reproducible inter-day validation of the microsystem. These results showed the robustness and the reliability of the whole experimental setup. A sampling rate of 30 samples h<sup>-1</sup> was obtained with the optimized experimental conditions.

### 3.3. Real samples analysis

Real samples of wines and beers from different origin were analyzed to validate the proposed microsystem. In order to cover a wide range of carbon dioxide concentrations, slightly sparkling

wines, sparkling wines and beers were analyzed. With the aim of establish an accurate comparison between the results obtained by both methods, before the analysis of the samples, and following the procedure of the reference method [4,5], the bottles were kept at 4 °C, they were opened and their content was immediately treated with 30 mL of 10 M NaOH per liter of sample in order to fix the concentration of CO<sub>2</sub> and avoid its loss. Then the mixtures were allowed to reach room temperature in closed bottles without air before their determination. It is noteworthy that the developed microsystem can analyze real sample without any pretreatment. As it has been stated previously, NaOH was added to allow an accurate comparison between both methods. In the case that NaOH is not used, the longer the bottle is open, the more loss of carbon dioxide there is, so this is an issue to take into account. In the same way, the microsystem is able to determine CO<sub>2</sub> online in fermentation processes in breweries and wineries. Due to the logistic difficulties, these kinds of samples were not determined.

The results obtained with the developed optical microsystem were validated by comparison with the ones obtained with the titrimetric reference method. This procedure, as have already mentioned, consisted in a titration of alkalized CO<sub>2</sub> with sulfuric acid, between pH 8.6 and 4.0, using a pH-meter. The obtained results are shown in Table 1.

As it can be seen, the results of the developed microsystem are not significantly different from the ones obtained with the reference method using the paired t-test ( $t_{\text{calc}} = 1.595$ ;  $t_{\text{tab}} = 2.365$ ;  $t_{\text{calc}} < t_{\text{tab}}$ ). This fact confirms that the proposed analytical microsystem is useful for the determination of carbon dioxide in a wide range of real samples. Furthermore, the achieved precision is better than the one obtained with the reference method and comparable with the precision of other carbon dioxide analyzers reported previously.

#### 4. Conclusions

A low-cost, spectrophotometric microanalyzer for the determination of carbon dioxide in wines and beers, integrating a gas diffusion PVDF membrane, has been developed and applied to real samples. The microsystem is compact and robust and provides a fast response with lower

sample and reagent consumption, wider working range and higher degree of miniaturization than other carbon dioxide analyzers previously reported [1,7]. In addition, the use of a lock and key concept allows the use, as a detection system, of a miniaturized optical reader for microfluidic platforms where the microsystem can be inserted, achieving a perfect alignment between the LED, the detection flow-cell and the photodiode. This approach makes the whole system simple, robust and compact providing a very good precision and repeatability in the measurements performed. In addition, overall features obtained enable also the possibility to use it for on-line fermentation process monitoring.

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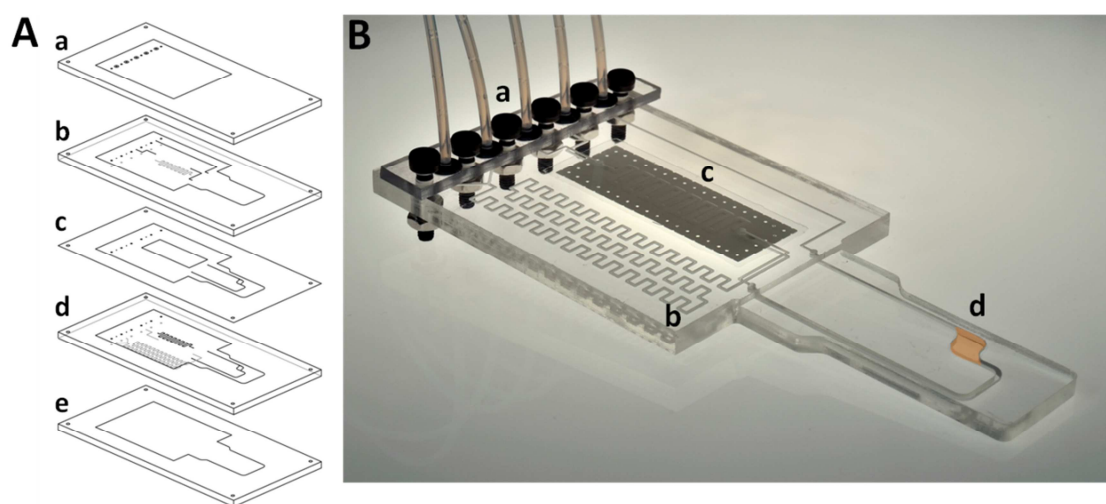
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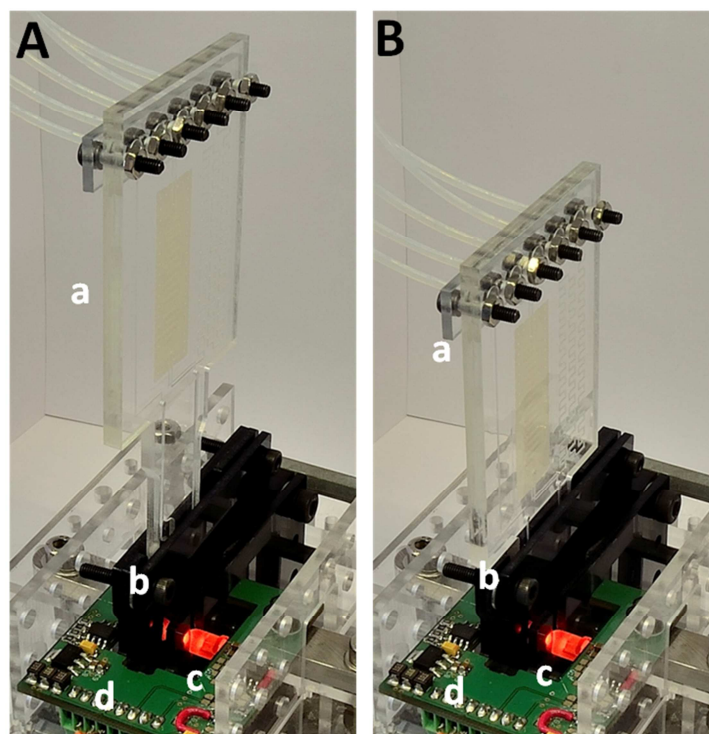


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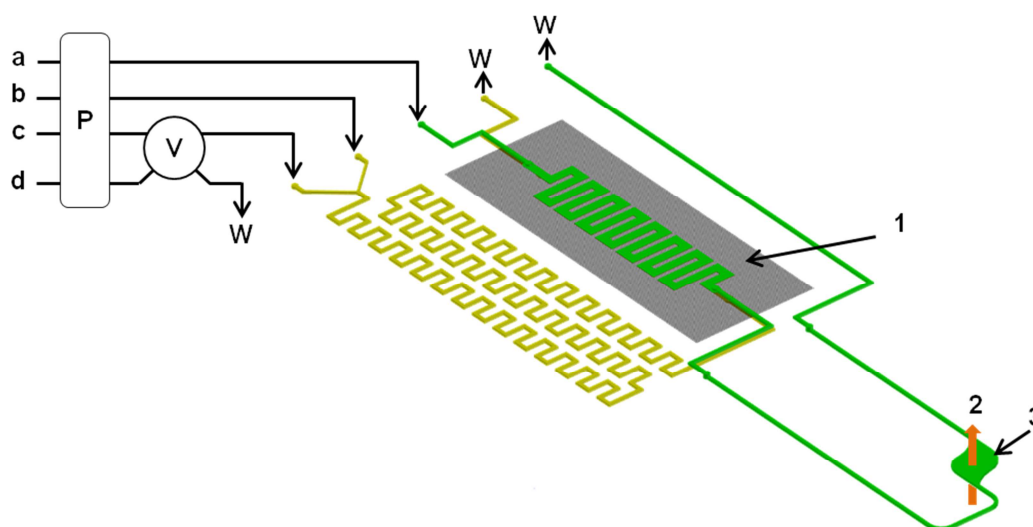
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**Figure 1. A:** Design of the layers of the prototype. Layers a, b, d and e are Topas plaques of 1mm, layer c is Topas foil of 50  $\mu\text{m}$ . Layers b and d have different patterns on both sides, in front, black color, and behind, grey color; **B:** Picture of the final device: **a)** Fluidic connections; **b)** Microfluidics; **c)** PVDF membrane; **d)** Flow-cell depicted in orange color.

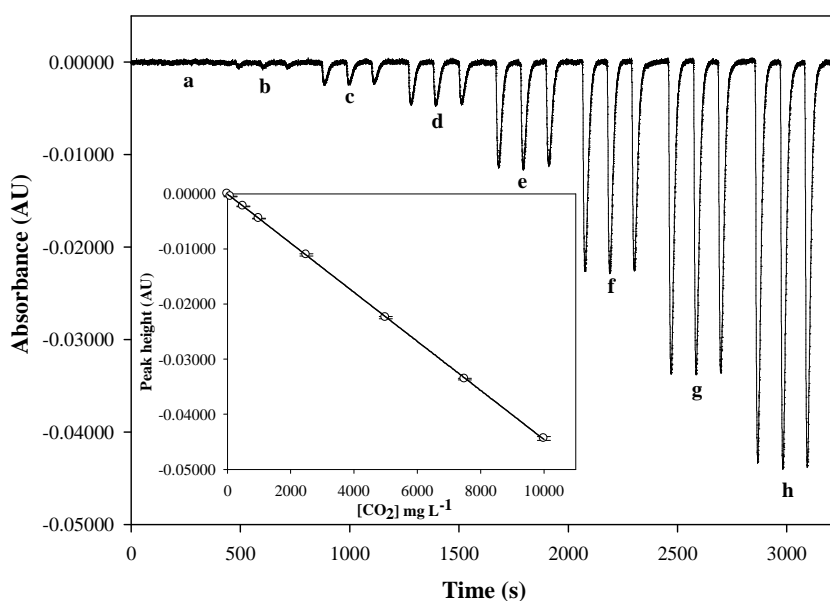


**Figure 2. A and B:** Picture of the microdevice outside and inside the detection system: **a)** microanalyzer; **b)** lock-and-key insertion port integrating a mask with a circular hole that only allows the pass of the light through the flow-cell; **c)** LED at 607 nm; **d)** PCB with the electronics associated to the control and acquisition of the signal.



**Figure 3.** Schematic diagram of microfluidics, detection system and experimental set-up. **a)** BTB buffered acceptor stream **b)** 0.2 M  $\text{H}_2\text{SO}_4$  solution with 60  $\text{mg L}^{-1}$   $\text{H}_2\text{O}_2$ ; **c)**  $\text{H}_2\text{O}$  as carrier

390 solution. **d)** sample; **P)** peristaltic pump; **V)** six-way injection valve; **W)** waste outlets; **1)** PVDF  
 391 membrane; **2)** direction of the light from the LED through the flow-cell; **3)** detection flow-cell;  
 392 yellow color: microchannels under the PVDF membrane; green color: microchannels over the  
 393 PVDF membrane.



**Figure 4.** Signal recording and calibration curve for the microanalyzer using  $\text{Na}_2\text{CO}_3$  standard solutions of  $0 \text{ mg L}^{-1}$ (a),  $100 \text{ mg L}^{-1}$ (b),  $500 \text{ mg L}^{-1}$ (c),  $1,000 \text{ mg L}^{-1}$ (d),  $2,500 \text{ mg L}^{-1}$ (e),  $5,000 \text{ mg L}^{-1}$ (f),  $7,500 \text{ mg L}^{-1}$ (g) and  $10,000 \text{ mg L}^{-1}$ (h).

Table 1

Mean concentration values in  $\text{mg L}^{-1}$  ( $n=4$ , 95%) from the analysis of wine and beer samples using the proposed microsystem.

Sample	Microsystem	Reference method	% error
Spanish sparkling wine	$6700 \pm 100$	$7100 \pm 320$	6
Spanish white slightly sparkling wine	$5000 \pm 200$	$4800 \pm 600$	4
Spanish white slightly sparkling wine	$4500 \pm 200$	$4500 \pm 700$	0
Spanish white slightly	$4100 \pm 200$	$4300 \pm 600$	5

sparkling wine			
Spanish white slightly sparkling wine	$3300 \pm 100$	$3400 \pm 300$	3
Portuguese white slightly sparkling wine	$2900 \pm 200$	$3000 \pm 300$	3
Italian rosé slightly sparkling wine	$5800 \pm 200$	$6000 \pm 300$	3
Spanish beer	$5400 \pm 200$	$5400 \pm 600$	0

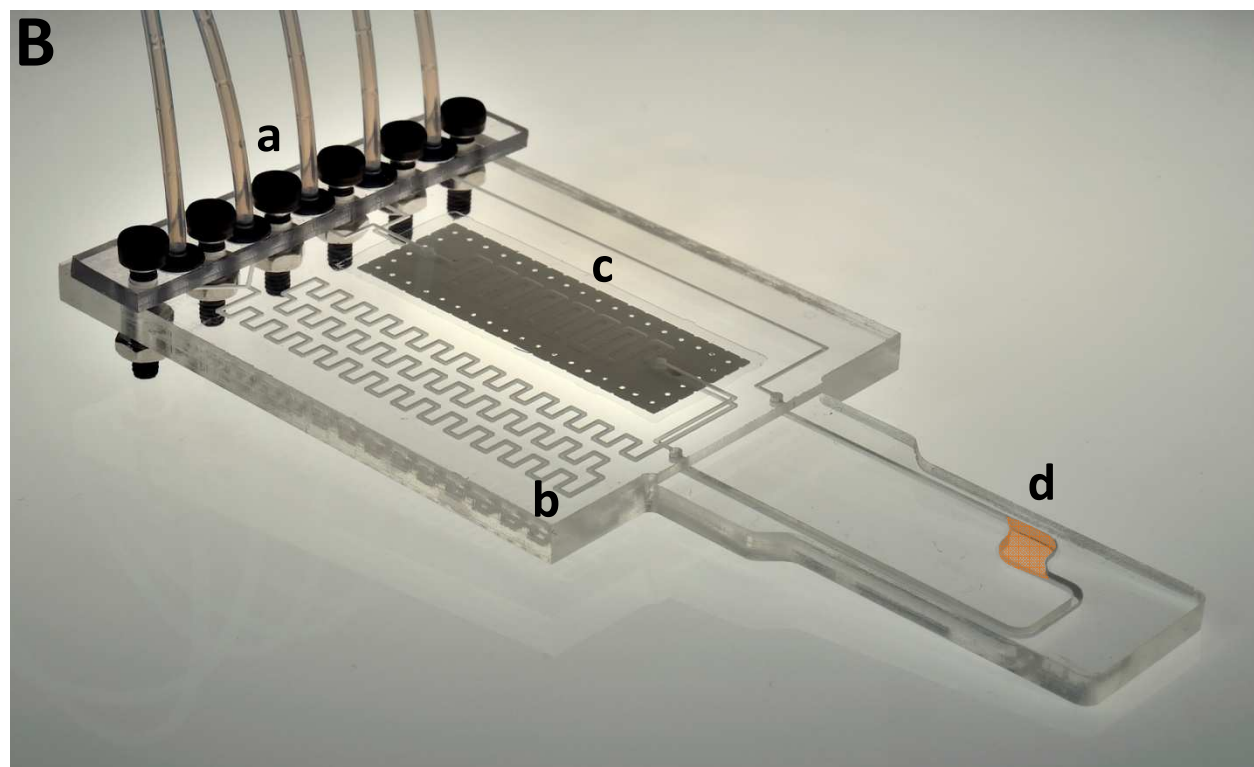
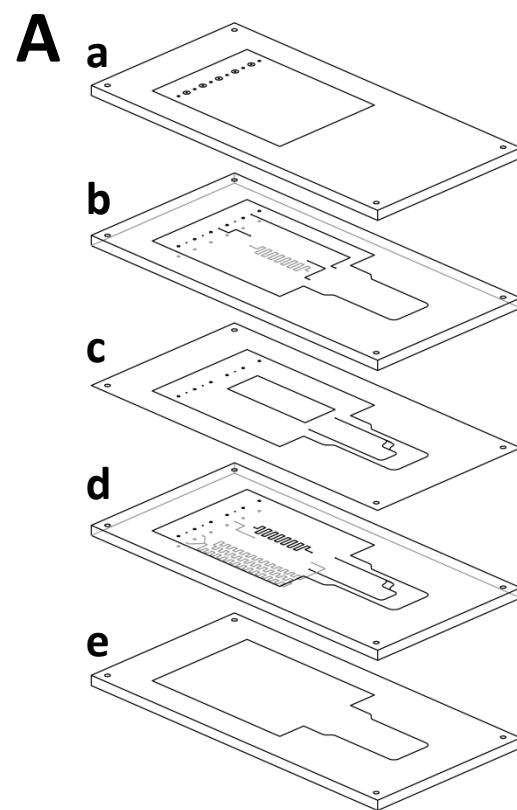
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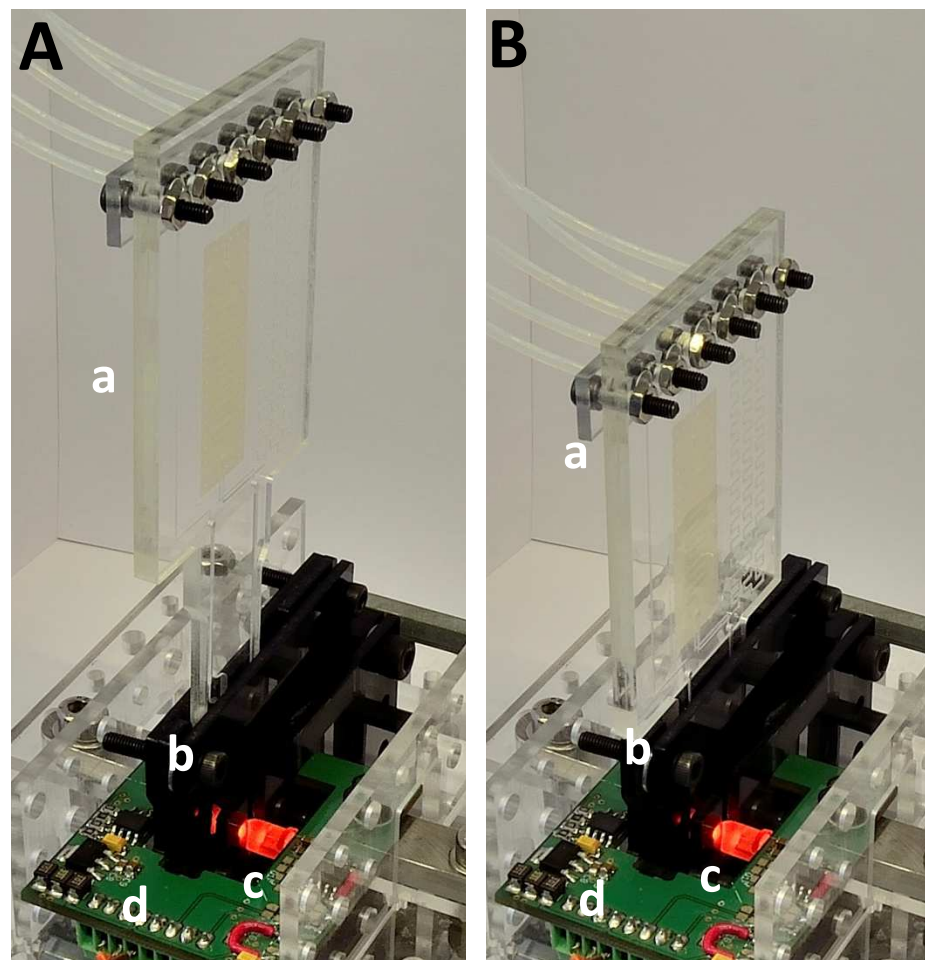
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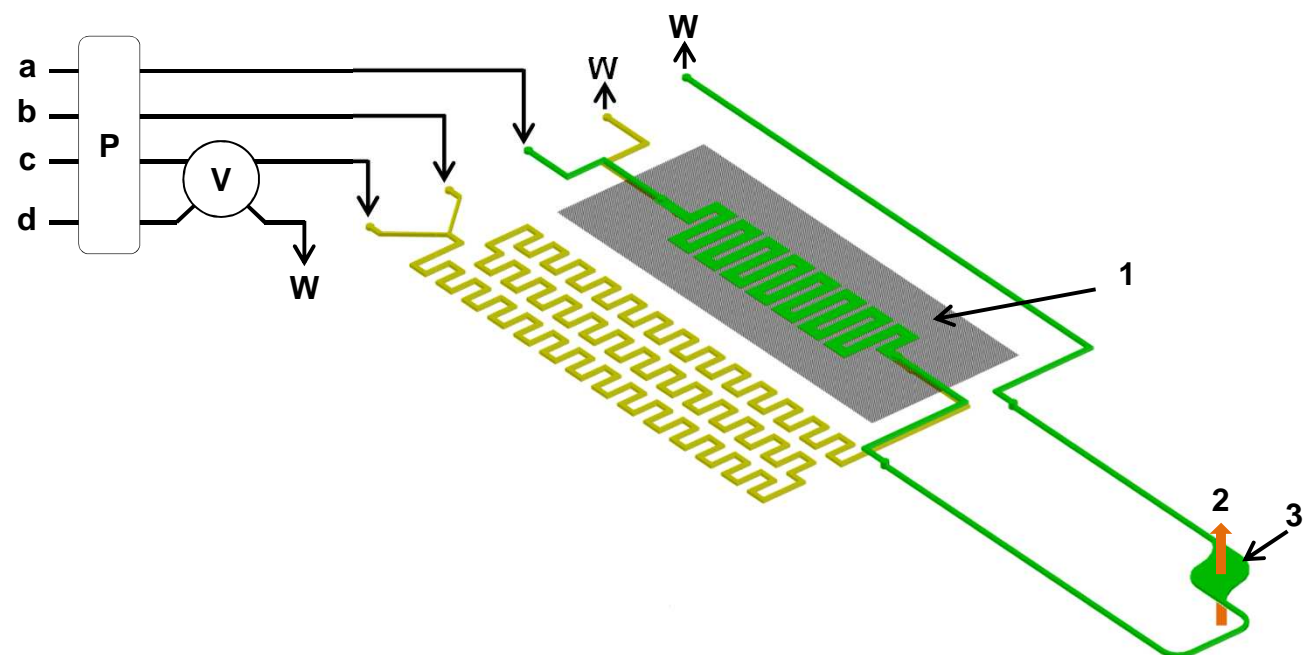
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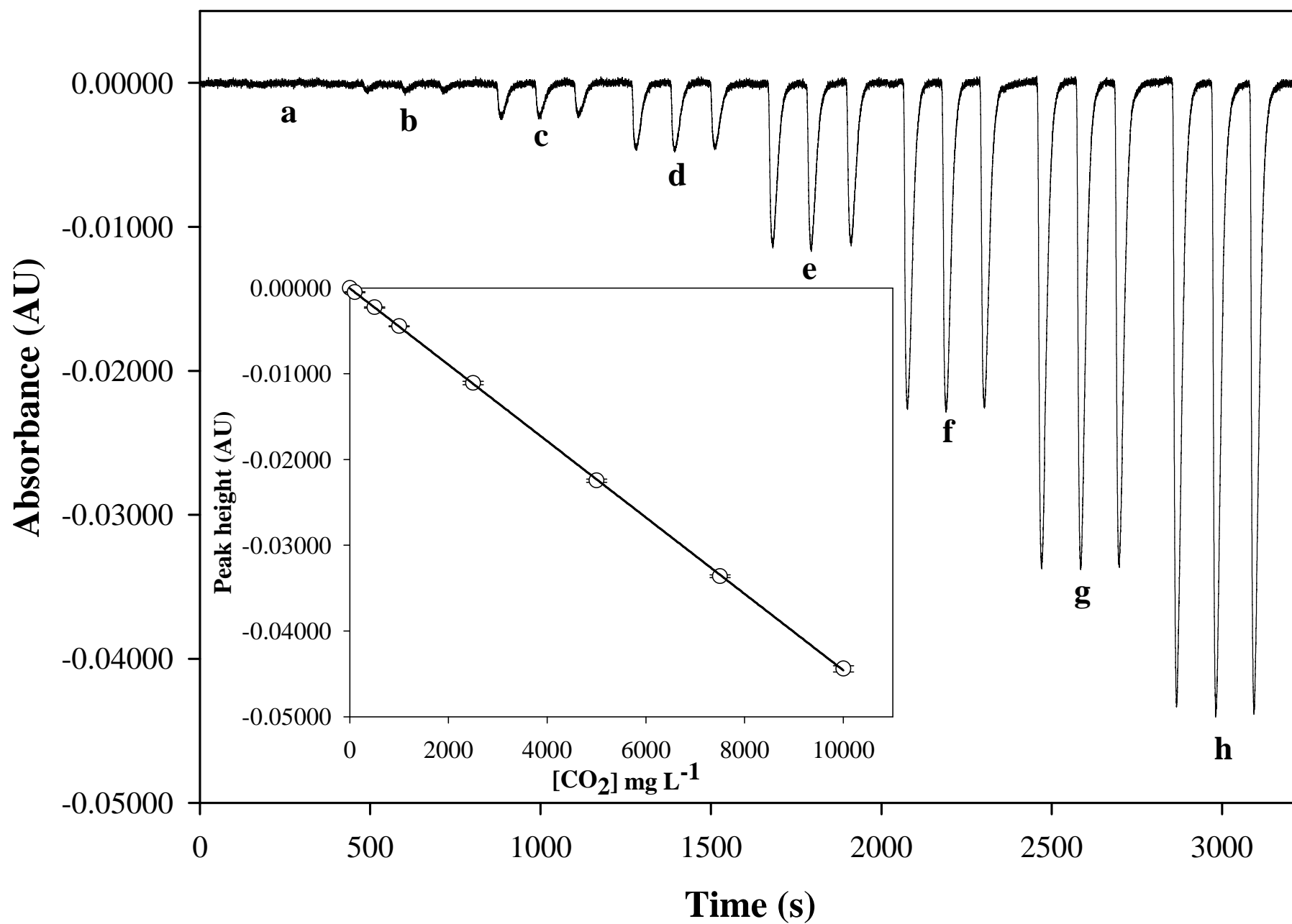












Low cost and compact polymeric analytical microsystem.

Carbon dioxide determination using a gas diffusion step and optical detection

Real wine and beer samples were successfully analyzed

Automatic measurements to monitor production processes of wine and beer could be performed