Electronic Supplementary Information

Highly sensitive contactless conductivity microchips based on concentric electrodes for flow analysis

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Electrode configurations in C⁴D microchips:

Fig. S1 illustrates the electrode assemblies usually employed for increasing the sensitivity and detectability of C⁴D systems (semicircular and dual top-bottom electrodes), as well as a microdevice incorporating planar electrodes.¹



Fig. S1 Configurations of electrodes in C⁴D microchips aiming the improvement of sensitivity and detectability. Microdevices integrating planar (**a**), semicircular (**b**), and dual top-bottom electrodes (**c**). Images: 1-3, schematic diagrams of the cross section in the detection zones for systems (**a**), (**b**), and (**c**), respectively.

Microfabrication steps:

The steps required for microfabrication of the C⁴D microchip featuring concentric electrodes (designed as C^4D_C) are shown in **Fig. S-2**. The metal deposition process was carried out on the cover plate (planar electrode) and inside the microchannel that was etched in the substrate slide (semiconcentric electrode).



Fig. S-2 Steps for microfabrication of the C^4D_C systems used in this study. **A**, fabrication of the microchannels; **B**, deposition of the semiconcentric electrodes (inside the microchannel); **C**, insulation of the semiconcentric electrodes by SiO₂; **D**, deposition of the planar electrodes; **E**, insulation of the planar electrodes by PDMS; and **F**, sealing of the structure. The steps **B** and **D** are performed simultaneously, as well as **C** and **E** if the dielectric is the same.

Etching of the microchannels and air-trapping zones was performed sequentially with the solutions: *i*) 396 mL H₂O, 54 mL HF, and 270 g NH₄F for 14 min; *ii*) 150 mL H₂O, 150 mL HCl, and 150 mL HF for 3 min; and *iii*) HCl for 1 min under continuous stirring. Following the etching step, substrates were rinsed in excess acetone with the aid of ultrasound, washed with deionized water, and then dried with N₂. The microchannels were fabricated in a cross-format configuration, with 15 and 55-

mm-long channels. The electrodes, in turn, were sputtered at 5 mm from the microchannel extremity. The adopted design presents narrow lines (10.0-mm-length and 0.2-mm-width) connecting the sensing electrodes (0.6-mm-gap and 1.0-mm²-area) and soldering pads at an angle of 45 degrees. After the deposition of the electrodes, the lift-off step was carried out by soaking the substrate in Al-etch, 20% HF, and acetone. Then, the glass slides were washed with deionized water and dried with N₂. Regarding the step for electrical insulation of the electrodes, SiO₂ was deposited by plasma-enhanced chemical vapor deposition (PECVD) featuring *ca*. 200-nm-thickness (in the microchannel top), whereas PDMS was spin-coated at 1,000 rpm for 10 s down to 50- μ m-thickness.

Chemicals and instrumentation:

LiClO₄, NH₄F, NaOH, and sodium phosphate were supplied from Sigma-Aldrich Chemical Co (St. Louis, MO). HF, HCl, acetone, AZ 400K developer, and AZ 4620/4210 resists were obtained from Clariant Corporation (Branchburg, NJ). All chemicals were of analytical grade or at the highest purity commercially available and used as received. All solutions were prepared utilizing deionized water (Milli-Q, Millipore Corp., Bedford, MA) with resistivity no less than 18 MΩ cm.

The instruments used in C⁴D_C microfabrication were: *i)* Karl Suss America Inc. MJB 3 UV 200 photoaligned (Waterbury, VT); *ii)* Headway Research Inc. EC101DT spinner (Garland, TX); *iii)* Oerlikon Balzers BA510 sputter (Schaumburg, IL); *iv)* Vacutec® VPS1500 plasma-enhanced chemical vapor deposition (PECVD) system (Randburg, South Africa); and *v)* O₂ Plasma Technology Inc. PE 80 (Hanover, NH). Microchannel parameters, area of the electrodes, and roughness mean square (RMS) values for glass surfaces were estimated by a Veeco Dektak 2210 profilometer (Branson, MO) with 4- μ m-resolution. Field-emission gun scanning electron microscopy (SEM-FEG) images of the cross section of the sealed microchannel were carried out in a Philips XL 30 microscope (Eindhoven,

Netherlands). This instrument operated with tungsten thermionic filament, 15 kV potential, and secondary electron detector as analytical mode. In order to improve the contrast in the SEM-FEG micrographs, the samples were previously metalized using a Baltec MCS 010 sputter coater (Balzers, Liechtenstein). Finally, the analytical instrumentation required by the C^4D_C measurements consisted of three principal components, namely: *i*) alternating signal generator (Minipa MFG 4202, São Paulo, Brazil); *ii*) conductivity detector, whose electronic circuit was designed according to a previously reported scheme;³ and *iii*) two syringe-pumps for microfluidic handling (New Era Pump Systems Inc. NE-300, Wantagh, NY). Data acquisition was carried out using a software written in LabVIEW[®].

Precision of the glass etching:

In C⁴D_C the dimensions of the microchannel determine the detection cell volume, that is directly associated to the response in conductivity measurements. Thus, the analytical precision of the method is related, among other factors, to the precision of the glass etching; this process presented satisfactory intra- and inter-chip precisions. To evaluate this parameter, microchannels were etched in ten slides of glass and the depth and width (at the opening and bottom of the microchannel) values were measured in four distinct points for each slide (n = 40). The average global values were: $31.3 \pm 0.3 \mu m$ (depth), $178.4 \pm 11.8 \mu m$ (width at the opening), and $73.1 \pm 1.4 \mu m$ (width at the bottom). The relative standard deviations (RSDs) for a same etched glass slide (intra-chip precision) obtained average values equals to: 1.0%, 6.7%, and 1.9% to depth, width at the opening, and width at the bottom of the microchannel, respectively. In addition, considering the average dimensional parameters achieved for the different glass slides (inter-chip precision), the RSDs were: 2.6% (depth), 6.3% (width at the opening), and 2.3% (width at the bottom). Finally, the roughness mean square (RMS) values of the non-etched and etched (microchannels) substrate regions were measured as 0.50 and 0.80 nm, respectively. Regarding the air-

trapping zones, such structures presented $180.7 \pm 7.3 \ \mu\text{m}$ in width and $31.3 \pm 0.9 \ \mu\text{m}$ in depth (n = 10 for a unique slide).

Electrical insulation test of the electrodes:

In C⁴D, there is no faradaic current so that the electrodes, which are insulated by a dielectric, essentially form capacitors with the electrolyte. **Fig. S3** illustrates an electrical model of the C⁴D_C microchip with the following elements: *i*) resistance of the electrolyte solution (R), *ii*) capacitances of the solution and the semiconcentric (C_{SE}) and planar (C_{PE}) electrodes, and *iii*) a third capacitance resulting from the direct capacitive coupling between the electrodes, called stray capacitance (C_o). The latter affects adversely the sensitivity of the method as it increases the background. In general, C⁴D measurements consist on the application of a RF signal to an electrode (excitation electrode, e_{exc}), which generates polarization of dipoles in the dielectric. This phenomenon induces a charge in the solution by forming an interfacial potential. In the region of the second electrode (receiving electrode, e_r) occurs an analogous process to the former, with induction of electric current in e_r .²



Fig. S3 Electric model of the C^4D_C electrode assembly. S, RF signal; D, detector; C_{SE} and C_{PE} , capacitances established between the solution and the semiconcentric and planar electrodes, respectively; e_{exc} and e_r , excitation and receiving electrodes, respectively; C_o , stray capacitance; and R, resistance of the solution.

Characterization of the dielectrics:

Micrographs for SiO₂ and PDMS dielectrics were obtained by atomic force microscopy (AFM) as shown in **Fig. S4**. The measurements were performed employing dielectric-coated glass plates with area of 1.0 cm² in tapping mode with constant force in a Veeco MultiModeTM SPM equipment (Plainview, NJ), containing 512 x 512 pixels of maximum resolution with optical detection. AFM images were collected at room temperature, 1.2 Hz rate, with scans covering an area of 5 μ m x 5 μ m. Both dielectrics presented smooth surfaces, with RMS values of 0.45 (SiO₂) and 0.46 (PDMS) nm. Owing to this smoothness, the electrode sensing area is approximately the same as the geometric area of the electrode.



Fig. S4 AFM images recorded for PDMS membrane (a) and SiO_2 nano-thin film (b). The peaks observed in figure (b) are due to the presence of particulate matter on the SiO_2 surface (the sample was not prepared in clean room).

X-ray photoelectron spectroscopy (XPS) characterized the SiO₂ dielectric film on a Kratos Analytical XSAM HS spectrometer (Spring Valley, NY) operating with non-monochromatic Mg K α radiation (1,253.6 eV in binding energy, E_B). It was necessary to fit the XPS curves due to the low spectral resolution (1.2 ± 0.1 eV). These fittings, which assisted us in the interpretation and characterization of the XPS lines, were processed with the software Winspec (kindly provided by the Laboratoire Interdisciplinaire de Spectroscopie Électronique, installed at Facultés Universitaires Notre-Dame de la Paix, Belgium). Elucidation of the chemical composition of the film followed as previously described.⁴ PECVD-grown SiO₂ film exhibited high purity as illustrated in **Figure S-5**, with the percentage atomic concentrations of 55.6% O, 27.7% Si, 16.1% C, and 0.6% N. The latter is attributed to the deposition process of the dielectric by PECVD, which produces nitrogen as byproduct of the reactions in plasma.⁵ Deposited-vapor oxides present significantly greater uniformity than compounds thermally and chemically grown, representing an advantage when using this approach in electrophoretic separations or as substrate in chemical sensors.⁶



Fig. S5 XPS exploratory spectra (a) and N 1s peak photoemission line (b) recorded for SiO_2 nano-thin film. The E_B values and the percentage relative quantities are listed for each component in figure b.

Tests of electric insulation of the C⁴D electrodes:

The sensitivity and detectability in C⁴D decreases with the thickness of the dielectric. Commonly, the minimum thickness of the dielectric for C⁴D microdevices incorporating electrodes *i*) outside on the microchip lid and *ii*) in the same plane of the sample microchannel range between 100-200 μ m and 0.1-40 μ m, respectively.¹ Furthermore, the coating film should be thick enough to electrically insulate the electrodes from electrolytic solution in order to ensure contactless-mode capacitive measurement. Thereby, the ideal dielectric thickness is related to its minimum value that effectively insulates the electrodes/sample system. Herein, cyclic voltammetry tested the insulation degree of the electrodes. PDMS/SiO₂-coated metal films were used as working electrodes. The voltammograms measured the capacitive current that arises from electrolyte polarization in the double layer;⁷ its absence indicated the effective electrical insulation of the electrodes.

The tests were performed at room temperature using an Eco Chemie Autolab PGSTAT 30 potentiostat (Utrecht, Netherlands). The system presented Ag/AgCl, Pt wire, and PDMS/SiO₂-coated metal films as reference, auxiliary, and working electrodes, respectively. The electrochemical cell volume (500 μ L) was delimited by a piece of PDMS, which was sealed reversibly onto glass upon contact under pressure. The electrode potential was swept in the positive direction between –0.4 and +0.2 V at 0.1 V s⁻¹. The electrolyte solution was phosphate buffer solution (pH 8). The pH was adjusted with 1 mol L⁻¹ NaOH or 1 mol L⁻¹ HCl. Sodium phosphate dibasic and potassium phosphate monobasic were purchased from Sigma-Aldrich Chemical Co.

The voltammograms measured the capacitive current that arises from electrolyte polarization in the double layer;⁷ its absence indicated the effective electrical insulation of the electrodes.

PDMS-coated electrodes

A PDMS membrane with 50-µm-thickness insulated the planar electrodes. Thinner membranes, desirable to achieve greater sensitivity and detectability, were not possible due to limited reproducibility of the deposition process used (spinning).⁸ In this case, we compared the exposed and PDMS-coated Ti/Au films as working electrodes. **Fig. S6 a** shows the voltammetric profiles obtained.

For the exposed Ti/Au films, capacitive currents of 230 nA were detected. For the PDMScoated film, meanwhile, it was not seen any measurable capacitive current, or at least, no current larger than 3.0 nA, which is the lower limit-range of the potentiostat (10 nA at full scale).



Fig. S6 Cyclic voltammograms of 0.2 mol L^{-1} phosphate solution (pH 8.0) employing Ti/Au films exposed and insulated by 50-µm-thickness PDMS as working electrode (**a**) and Cr/Al films insulated by different thickness of SiO₂ as working electrodes (**b**).

SiO₂-coated electrodes

The semiconcentric electrodes were insulated by a SiO_2 nano-thin film. The ideal thickness was studied by testing the insulation degree of Cr/Al films using SiO_2 in different thicknesses, namely: 100, 150, and 200 nm (at the microchannel top/center). The voltammetry profiles recorded for different thickness of SiO_2 are illustrated in **Fig. S6 b**.

For 100 and 150 nm SiO_2 we could still observe capacitive currents in the order of 40 and 20 nA, respectively. For 200 nm, meanwhile, any capacitive current at levels larger than 5 nA were observed; such value is below the lower limit-range of the potentiostat.

As consequence of the electric insulation tests, the thicknesses of 50 μ m (PDMS) and 200 nm (SiO₂, in the microchannel center) were adopted for insulation of the planar and semiconcentric electrodes, respectively, in the fabrication of the C⁴D_C microchips.

Flow analysis procedure:

The signals were recorded flowing either water or saline solution by two external syringe pumps through the microfluidic channels. First, water was circulated for approximately 5 min for signal stabilization. Once a stable signal was obtained, samples were introduced generating a potential change on the receiving electrode. Next, water was added resulting in a decrease of the signal nearly to its initial value. The analytical responses recorded in this study were associated to the signal difference after stabilization of the signal from the sample and its baseline (water) values. All measurements were taken at 20 μ L min⁻¹ flow rate, 90 s sampling time, and at room temperature. In this study we actuated manually the syringe-pumps. Nevertheless, for higher precision assays, software-controlled valves could be employed. Finally, micropipette tips were used as reservoirs for buffer and sample solutions, which were fixed by epoxy glue on the substrate.

Optimization of the C⁴D parameters:

To achieve an optimized performance for each electrode configuration, we used LiClO₄ standards (1.0 mmol L⁻¹, 0.5, and 0.3 μ mol L⁻¹ for C⁴D_P, C⁴D_S, and C⁴D_C, respectively) in flow analyses to select the optimum transduction parameters of frequency (kHz) and excitation voltage (V_P. P). In this case, signal-to-noise (S/N) ratios were achieved in function of the frequency under different voltage values. The detectability levels measured for C⁴D_P, C⁴D_S, and C⁴D_C microchips using LiClO₄ was calculated based on S/N ratio = 3. For construction of the analytical curves, five measurements for each concentration level were accomplished. Regarding the repeatability analyses, analytical signals were obtained using four microdevices at different days and by different operators; five measurements were performed for each microchip.

Fig. S7 depicts the S/N ratios in function of frequency under different voltage values. The behavior recorded to all electrodes is quite similar to that reported in literature for conventional

capillary ⁹ and microchip electrophoresis.¹⁰ As can be seen in this figure, there is a maximum S/N ratio indicating the optimum operating frequency. Additionally, this maximum increased and shifted to lower frequencies as V_{P-P} increased. The optimum frequencies obtained were smaller for electrodes containing greater area. This fact is in agreement to the related theory.¹ The highest values were 10 (C⁴D_P), 5 (C⁴D_S), and 2 kHz (C⁴D_C). Regarding to the excitation voltage, its optimum value was 10.0 V_{P-P} for all microchips.



Fig. S7 Optimization of the C⁴D parameters. Variations of the S/N ratio in function of frequency under different potentials using C⁴D_P (**a**), C⁴D_S (**b**), and C⁴D_C (**c**) microchips to 1,000.0, 0.5, and 0.3 μ mol L⁻¹ LiClO₄ standards, respectively. The optimum operating frequency is highlighted for each potential. The colors specified in (**a**) for the different peak-to-peak potentials are the same in (**b**) and (**c**). Conditions: 20 μ L min⁻¹ flow rate and 90 s salt-injection time.

Analytical curves:

For construction of the analytical curves, five measurements for each concentration level were accomplished. The achieved results are shown in **Fig. S8**.



Fig. S8 Sensitivity and detectability test. Analytical curves achieved for LiClO₄ standards using C^4D_P (**a**), C^4D_S (**a**,**b**), and C^4D_C (**a**,**b**) microchips. In figure (**a**), the logarithm was applied to signal and concentration in order to visualize all the obtained curves. Conditions: 20 µL min⁻¹ flow rate, 90 s salt-injection time, 10 (C^4D_P), 5 (C^4D_S), and 2 kHz (C^4D_C) in frequency and 10 V_{P-P} potential.

Repeatability test:

The C⁴D_C presented satisfactory intra-chip precision and repeatability levels. Such parameters were evaluated by flow analyses with 25 nmol L⁻¹ LiClO₄ in water employing C⁴D_C microchips. **Fig. S9** shows the average analytical signals obtained with four microdevices at different days and by different operators; each microchip performed five measurements. The experimental was carried out as described in **Fig. S8**, with the same conditions for flow and detection settings. The relative standard deviations (RSDs) shown in **Table S1** indicate that the microfabrication process and, thus, the developed device presented good precision and repeatability.



Fig. S9 Average signals obtained for 25 nmol L^{-1} LiClO₄ using C^4D_C microchips at different days and by different operators (distinct color sets). Conditions: 20 μ L min⁻¹ flow rate, 90 s sampling time, 2 kHz frequency, and 10 V_{P-P} potential.

Table S1 RSDs for intra-chip precision and the repeatability of the method. Data refer to the signals obtained for 25 nmol L⁻¹ LiClO₄ using C⁴D_C microchips in different days (n = 5). Conditions: same as shown in **Fig. S8**

	Intra-chip precision (%) †	Repeatability (%) ‡	
Microdevice 1	7.7 and 6.4	-	
Microdevice 2	14.3 and 7.7	-	
Microdevice 3	12.6 and 9.7	-	
Microdevice 4	8.4 and 13.3	-	
-	-	13.7	

[†]Calculated regarding the data achieved for each microchip in two different analysis days;

[‡]Overall variability calculated from all obtained signals – repetitions for different chips in different days.

Calculation of the capacitances:

Capacitance of the planar electrode/PDMS/solution system

The capacitance (C) represents the ability of a system in accumulating charges (q) under a given

applied potential (V). Mathematically:¹¹

$$C = \frac{q}{V} \tag{1}$$

In C⁴D there is no faradaic current so that the electrode/dielectric/solution systems present behavior similar to a capacitor. The planar electrode is characterized as a parallel plate capacitor. Considering the Gauss's law to mathematical description of *C*. When the plates (electrode and solution in C⁴D) are very close to each other, we can neglect the edge effect of the electric field. Therefore, the electric field will be linear throughout the Gaussian surface. In this case, the capacitance for the planar electrode (*C_P*) is given by:¹¹

$$C_{P} = \frac{\varepsilon_{PDMS}\varepsilon_{o}A_{P}}{d_{P}}$$
⁽²⁾

being ε_{PDMS} the dielectric constant of the PDMS membrane that insulates the electrode, ε_o the permittivity constant of the free space (8.85 pF m⁻¹), A_P the area of the planar electrode, and d_P the distance between electrode and solution representing, thus, the thickness of the PDMS dielectric.

Capacitance of the semiconcentric electrode/SiO₂/solution system

For calculation of the capacitance (C_S) in this situation, seven capacitors connected in parallel are considered for characterization of the semiconcentric electrode/SiO₂/solution system as shown in **Fig. S10**.

Based on **Fig. S10**, *C*_S will be given by:

$$C_S = \sum_{i=1}^7 C_i \tag{3}$$

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Fig. S10 Capacitors representing the semiconcentric electrode/SiO₂/solution system.

Assuming symmetry between the left and right parts of the capacitor, we have that: $C_1 = C_7$, $C_2 = C_6$, and $C_3 = C_5$. Other contour conditions taken into account include: *i*) electric field linear throughout all detection cell, *ii*) thickness of the dielectric constant for each capacitor, and *iii*) distribution of the thin films (electrode and SiO₂) in the etched microchannel as a geometry in which $C_1/C_4/C_7$ and $C_2/C_3/C_5/C_6$ can be characterized by parallel plate and cylindrical capacitors, respectively (see **Figure 2** in the main text and **Fig. S9**). Thereby, neglecting the roughness of the electrode and dielectric surfaces, we will have:¹¹

$$C_1 = \frac{\varepsilon_{SiO2}\varepsilon_o A_1}{d_1}, \quad C_1 = C_7 \tag{4}$$

$$C_2 = \frac{2\pi}{n} \varepsilon_{SiO2} \varepsilon_o \frac{L}{\ln\left(\frac{d_2 - a}{a}\right)}, \quad C_2 = C_6 \tag{5}$$

$$C_{3} = \frac{2\pi}{m} \varepsilon_{SiO2} \varepsilon_{o} \frac{L}{\ln\left(\frac{d_{3}-a}{a}\right)}, \quad C_{3} = C_{5}$$
(6)

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$$C_4 = \frac{\varepsilon_{SiO2}\varepsilon_o A_4}{d_4} \tag{7}$$

being ε_{SiO2} the dielectric constant of the SiO₂ film that insulates the electrode, A_i/d_i the parameters of area and dielectric thickness considered for each region of the capacitor shown in the **Fig. S10**, *L* the length of the external plate, and *a* the radius of the internal plate of the cylindrical capacitor. From the equations (4–7), the capacitance of the semiconcentric electrode/SiO₂/solution system will be:

$$C_{S} = \frac{2\varepsilon_{SiO2}\varepsilon_{o}A_{1}}{d_{1}} + \frac{4\pi}{n}\varepsilon_{SiO2}\varepsilon_{o}\frac{L}{\ln\left(\frac{d_{2}-a}{a}\right)} + \frac{4\pi}{m}\varepsilon_{SiO2}\varepsilon_{o}\frac{L}{\ln\left(\frac{d_{3}-a}{a}\right)} + \frac{\varepsilon_{SiO2}\varepsilon_{o}A_{4}}{d_{4}}$$
(8)

As can be observed in equation (8), C_S increases linearly with the electrode area ($A \alpha L$, being $A = 2\pi rL$). On the other hand, the contribution of the dielectric thickness for the changes in the capacitance is more pronounced; C_S increases with the reduction of the natural logarithm of the thickness for C_2 , C_3 , C_5 , and C_6 . Additionally, this change is linear for C_1 , C_4 , and C_7 .

Capacitance of the concentric electrode/SiO₂/solution system

As shown in **Fig. S3**, the capacitance related to the concentric electrode/SiO₂/solution system (C_C) is given by:

$$C_c = C_P + C_S \tag{9}$$

Substituting (2) and (8) in (9):

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$$C_{C} = \frac{\varepsilon_{PDMS}\varepsilon_{o}A_{P}}{d_{P}} + \frac{2\varepsilon_{SiO2}\varepsilon_{o}A_{I}}{d_{1}} + \frac{4\pi}{n}\varepsilon_{SiO2}\varepsilon_{o}\frac{L}{\ln\left(\frac{d_{2}-a}{a}\right)} + \frac{4\pi}{m}\varepsilon_{SiO2}\varepsilon_{o}\frac{L}{\ln\left(\frac{d_{3}-a}{a}\right)} + \frac{\varepsilon_{SiO2}\varepsilon_{o}A_{4}}{d_{4}}$$
(10)

LOD values described in literature using C⁴D and pressure-driven flow:

Separation Method	Analytes and Samples	Dielectric [†]	LOD $(\mu mol L^{-1})^{\mathfrak{t}}$	Reference
Gas diffusion	Total inorganic carbon	1,333.5 μm PTFE [*]	0.6	12
	Total inorganic carbonate	5 µm polyimide	19	13
	Calcium carbonate in cement	600 µm PEEK*	2.5	14
	Ammonium in rainwater	170 μm fused-silica	0.8	15
	Inorganic carbon in estuary	600 µm Teflon	120	16
HPLC	Peptides	340 µm fused-silica	0.04	17
	Proteins	340 µm fused-silica	0.21	17
	Fatty acids in vegetable oils	110 µm fused-silica	$352 \ge 10^3$	18
	Fatty acids in vegetable oils	110 µm fused-silica	1.1	19
	Organic acids	675 μm fused-silica	0.7	20
Ion chromatography	Inorganic anions	215 µm fused-silica	12	21
	Inorganic cations in water samples	500 µm PEEK	0.15	22
	Inorganic cations in water samples	290 µm fused-silica	0.8	23
	Inorganic anions	240 µm fused-silica	1.2	24

Table S2 LOD values reported in literature for methods based on C⁴D and pressure-driven flow

 † The thicknesses of each dielectric film are presented at μm unit;

[£] Only the lower obtained values are shown;

* Abbreviations: polytetrafluoroethylene, PTFE, and polyether ether ketone, PEEK.



Fig. S11 Analytical signals achieved for LiClO₄ standards using C^4D_P (a), C^4D_S (b), and C^4D_C (c) microchips. Conditions: 20 mL min⁻¹ flow rate, 90 s salt injection time, 10 (C^4D_P), 5 (C^4D_P), and 2 kHz (C^4D_C) frequency, and 10 V_{P-P} potential.

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