proceedings

Abstract

Microfluidic Cuvette for Near-Infrared Spectroscopy †

Zoltán Szabó [1], Kitti Pankász [1], János Bozorádi [1], Orsolya Hakkel [1], Szabolcs Bella [2], Bianka Fabinyi [3], Sandro Meucci [3] and Péter Fürjes [1,*]

1 Institute of Technical Physics and Materials Science, HUN-REN Centre for Energy Research, Konkoly Thege Miklós Str. 29–33, H-1121 Budapest, Hungary; szabo.zoltan@ek.hun-ren.hu (Z.S.); pankasz.kitti@ek.hun-ren.hu (K.P.); bozoradi.janos@ek.hun-ren.hu (J.B.); hakkel.orsolya@ek.hun-ren.hu (O.H.)

2 Aedus Space Ltd., Józsefhegyi Str. 28–30, H-1025 Budapest, Hungary; szabolcs.bella@aedusspace.com

3 Micronit BV, Colosseum 15, NL-7521 PV Enschede, The Netherlands; bianka.fabinyi@micronit.com (B.F.); sandro.meucci@micronit.com (S.M.)

* Correspondence: furjes.peter@ek.hun-ren.hu

† Presented at the XXXV EUROSENSORS Conference, Lecce, Italy, 10–13 September 2023.

Abstract: We intend to develop an in situ near-infrared spectroscopic solution for monitoring the nutrient composition (e.g., lactate concentration) in microfluidic channels of organ-on-chip devices. In this work, the effects of the geometry, surface quality, and architecture of the micro-volume cuvettes were characterized and optimized considering the signal-to-noise ratio and sensitivity of the proposed spectroscopic method in case of aqueous solutions. The applicability of the micro-volume near-infrared spectroscopy method using this specially designed microfluidic cuvette was proven.

Keywords: near-infrared spectroscopy; microfluidics; cell culture media; organ-on-chip

Citation: Szabó, Z.; Pankász, K.; Bozorádi, J.; Hakkel, O.; Bella, S.; Fabinyi, B.; Meucci, S.; Fürjes, P. Microfluidic Cuvette for Near-Infrared Spectroscopy. *Proceedings* **2024**, 97, 209. https://doi.org/10.3390/proceedings2024097209

Academic Editors: Pietro Siciliano and Luca Francioso

Published: 6 May 2024

1. Introduction

The concentration of molecular markers—such as relevant amino acids, carbohydrates, and drugs—is an important signal of the metabolic or chemical processes unfolding in organ-on-chip applications. In recent years, advanced and miniaturized sources, detectors, and spectrometers have proven the applicability of optical spectroscopy to be an excellent tool for the analysis of different sample compositions or chemical reactions. Infrared (IR) spectroscopy is based on the identification of the transition between discrete vibrational energy levels of molecules caused by absorption photon energies. Accordingly, absorption spectra are related to the specific molecular bonds (wavelength) and the amount of the targeted molecules (intensity). Infrared spectroscopy combined with microfluidic sample transport and preparation can be a powerful, in situ analysis method for continuous monitoring of complex cell culture media and for revealing the molecular fingerprints of the relevant molecular contents. Based on the spectral characteristics, the molecular concentration in the sample could be determined; however, the architecture, the geometry, and the optical parameters of the structural materials (glass, poly-dimethylsiloxane (PDMS), cyclo-olefin polymer/copolymer (COP/COC), etc.) of the microfluidic system have to be considered [1].

2. Materials and Methods

Polymeric microfluidic cuvettes were fabricated through CNC milling and also through hot embossing techniques using microstructured molds. The channel depth was varied between 50 µm and 200 µm. Suitable transreflectance architecture was created by coating the backside of the microfluidic chip or the inner surface of the channels with 150 nm thick vacuum-evaporated aluminum. The channels were sealed with glass and COP slides using double-sided adhesive. The optical measurements were carried out in the wavelength range of 950–1690 nm using an Avantes spectrophotometer (Avantes BV, Apeldoorn, The Netherlands) combined with an optical fiber waveguide for excitation and detection.

3. Discussion

The sample volume effect was characterized by comparison of the spectral transmittances of benchmark aqueous solutions (ethanol–water; lactate–water) measured in a standard macroscopic cuvette and in microfluidics. In the case of the microfluidic cuvettes, the transmittance and transreflectance mode spectral analyses were also elaborated upon. The IR absorbance of water with a wavelength over 1400 nm causes significant deterioration of the signal-to-noise ratio and this effect could be eliminated by using microfluidic cuvettes with radically shorter pathways, as highlighted in Figure 1. Considering the volume-dependent sensitivity of the method (Lambert–Beer law), the ideal channel depths were investigated by testing varying chamber depths between 50 μm and 200 μm.

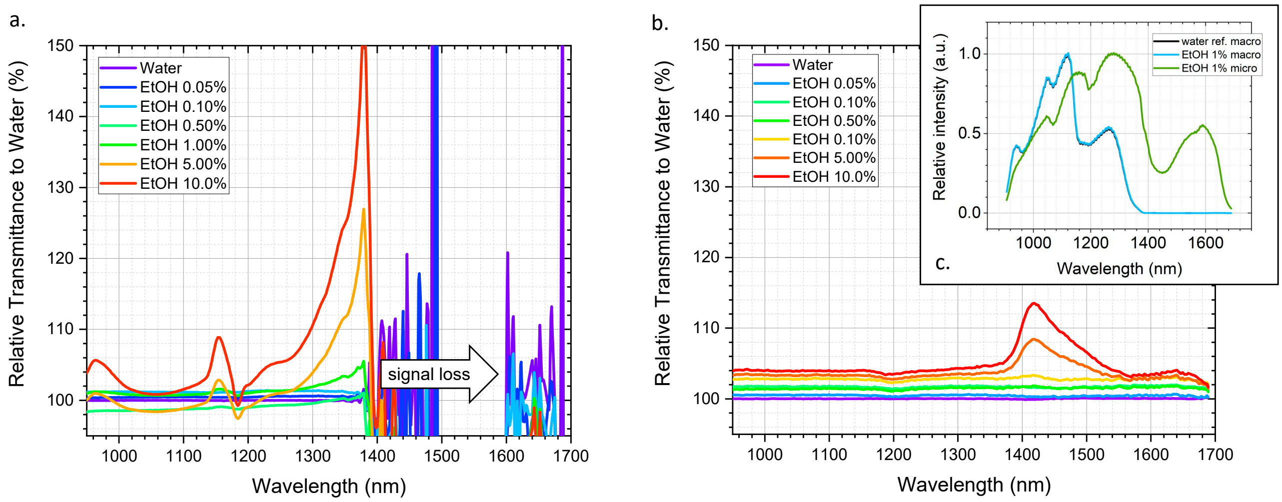

Figure 1. Concentration-dependent near-IR transmittance spectra for ethanol solutions (0.05, 0.1, 0.5, 1.0, 5.0, 10% v/v) compared to water as a reference in macroscopic (**a**) and microfluidic (**b**) HE (100 μm, transmittance) cuvettes. Relative intensities (**c**) demonstrate a signal loss over a wavelength of 1400 nm.

Considering the proposed application, the positioning of the fluidic connections, and the optical setup, the transreflective measurement mode was selected. Accordingly, specular reflectance was applied for analysis, although in this case the effects of the structural materials, the surface finishing of the microfluidic cuvettes, and the placement of the reflective metal layer (in-channel or backside) needed to be considered. The scattering effects causing intensity loss were decreased by the enhanced surface quality of the hot embossing (HE) technique. The in-channel reflective layer was proven to be advantageous, although in case of backside metallization, the spectral absorbance of the structural materials has to be noted.

OoC-compatible microfluidic cuvettes were designed and manufactured for transreflectance mode optical measurements with adequate material properties, excellent surface quality, and a suitable architecture. By decreasing the optical path, the specific absorbance of water could be decreased, resulting in an increase in the signal-to-noise ratio.

Author Contributions: Z.S., B.F., S.M., S.B. and P.F. were responsible for the design and manufacturing of the microfluidic cuvette compatible with the system architecture. Z.S., K.P., J.B. and O.H. implemented the optical spectroscopy. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the ECSEL JU and the National Research, Development and Innovation Fund (NKFIA) via More4Medical H2020-ECSEL-2019-IA-876190 (www.moore4medical.eu, accessed on 11 April 2024) grant.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available in this manuscript.

Conflicts of Interest: The authors, Aedus Space Ltd. and Micronit BV declare no conflicts of interest.

Reference

1. Perro, A.; Lebourdon, G.; Henry, S.; Lecomte, S.; Servant, L.; Marre, S. Combining microfluidics and FT-IR spectroscopy: Towards spatially resolved information on chemical processes. *React. Chem. Eng.* **2016**, *1*, 577–594. [CrossRef]