Microfluidic devices and Gigahertz sensor applied to measurements of liquid mixtures concentration

Salomão Moraes da Silva Junior, Johan Stiens, Stanislav Moshkalev, Jacobus Willibrordus Swart, Alexander Flacker, Yuchen Zhang, Vladimir Matvejev, Werner Vandermeiren and Cathleen de Tandt

salomaomoraes@yahoo.com.br; jstiens@etrovub.be; stanisla@ccs.unicamp.br; jacobus@fee.unicamp.br; alexflacker@gmail.com; vmatveje@etrovub.be; yzhang@etrovub.be; wvanderm@etrovub.be; cdtandt@etrovub.be

Abstract: *This paper reports on the performance of a sub-THz liquid sensor tool coupled to a microfluidic platform. Non-invasive, non-destructive and on-line measurements are demonstrated for the determination of ethanol concentration controlling by micromixer device. We have developed a label-free chemical sensing methodology coupling a sub-terahertz sensor technology in microfluidic devices fabricated on glass and polydimethylsiloxane. We demonstrated on-line sensing and control of ethanol concentration on demand. The THz-microfluidic sensing strategy represents a versatile tool for fast and easy integration in microfluidic devices, for concentration detection and linear control of binary mixtures concentration in a contactless mode using in-flow regime environment in micro channel.*

Key-Words*: THz sensor; Microfluidic device; Passive Micromixer; Ethanol concentration; Linear control.*

Introduction: Techniques used to characterize liquid composition is of fundamental importance for Chemistry and Life Sciences [1]. The scientific community has increased the interest for studies about interactions of liquid-liquid in reactive mixtures, learning more on reaction dynamic and non-linearity aspects involving them [2][3], in particular in binary mixtures of water-alcohol. The frequency from 10^{10} to 10^{13} Hz range allows sensors for such interrogation in a label-free manner through electromagnetic measurements of small permittivity changes, as demonstrated for variety applications [4]. THz-based sensing schemes is usually associated with low-energy events such as inter- and intramolecular hydrogen bonding. Those mechanisms make THz sensing and spectroscopy an ideal non-invasive, contactless detection and characterization tool for a broad range of substances, including pharmaceutical applications [5], drugs [8], explosives [5] and biomolecules [1]. The Microfluidics technology allows the manipulation of very small volumes of fluids inside microchannels. It takes advantages in using much less reagents [7], using low-cost materials and fabrication, miniaturized, portable and reusable devices, faster temperature change [8], ease in applying higher electric fields, occupied area of few square centimeters, reactions in system in flow, potentially to follow reaction interaction running in real time. It is possible to perform high throughput chemical reactions, such as mixing, separation, heating and detection [9]. We developed a flexible platform for performing microfluidic experiments with an embedded spectroscopic sensor, with a view to enabling contactless investigation and non-invasive on-line characterization of chemical mixing processes. We demonstrated such capabilities through various measurements in a microfluidic environment operating in laminar flow, with Reynolds number smaller than 13.54. Small Reynolds number reduces a predominance generates by inertial forces over viscous forces, while big Peclet number increases the advection mechanism [10]. These results mean that, if the device and fluids are designed properly, perfectly with same dimensions and symmetry, then it allows controlling the distribution of the species by input of the mass flow rate. Because of this, carefully determined devices requirements are very important and can affect directly the results. In this work, particularly we used a capillary tube integrated into a low-loss waveguide cavity and attached to the outlet of a microfluidic device. The measurements with THz sensor were performed to detect water/alcohol mixtures concentration. This type of coupling takes advantage of a non-invasive, non-destructive, on-line detection, good sensitivity for small detection window, height dimension of hundreds of micrometers, using small liquid volume of 1.40 µl inside of the microchip.

Experimental: The microfluidic devices used in this work were fabricated using conventional microfabrication techniques, such, wet etching, conventional and soft lithography, sealing by PDMS and plasma oxygen treatment.

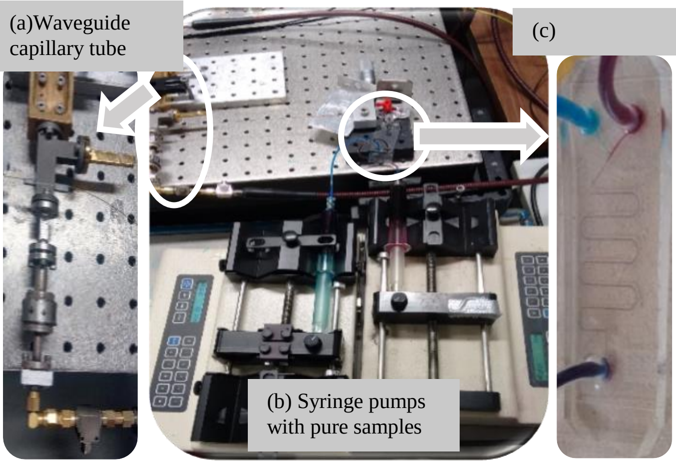

Fig.1 – Experimental setup. (a) Capillary tube integrated into a wave guide. (b) Syringe pumps and flow rate control. (c) Micromixer with blue dye color (ethanol), red dye color (in water) and purple as real liquid mixture along the microchannel.

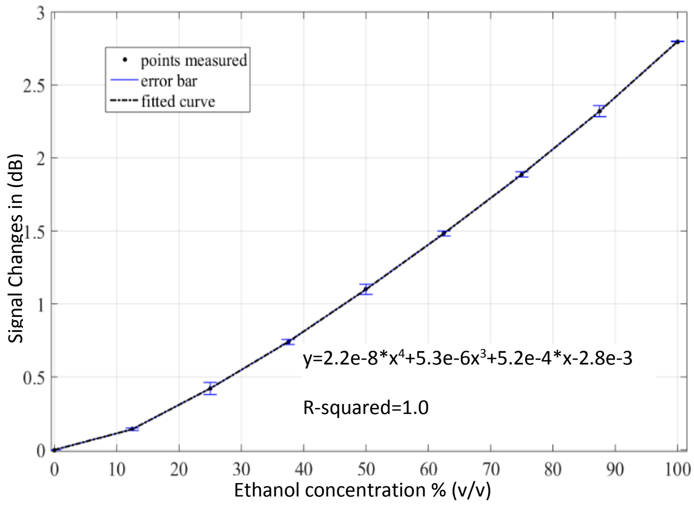

Fig.2 - SubTHz sensor response versus ethanol concentration.

Conclusion: We have presented a method for convenient on-line determination of ethanol concentration, using THz sensor coupled in microfluidic platform, for linear generation and control of binary mixtures concentration. The mixing reaction was predominantly controlled by advection with Re smaller than 13.54 and *Pe* bigger than 25700. As demonstrated in a concept-proof for water-alcohol mixtures, we detected equivalent concentrations between 9.35% and 70.80%. Results showed a good accordance between concentration generation and control of mixtures with small variation of 0.32% between alcohol concentrations required on demand and those measured on-line. The THz-microfluidic sensing strategy represents concentration detection and linear control of binary mixtures concentration in a contactless mode using in-flow regime environment. Due to this flexibility, this system could be used for the beverage and chemistry industries, to perform measuring and controlling in line in small samples. Future perspectives include liquid spectroscopy in real time, sensing and following the chemical reactions in loco along the microchannels.

References and acknowledgements:

Acknowledgements: The authors acknowledge Unicamp - FEEC, CCSNano, IFGW-LAMULT, CNPEM-LNLS, FAPEAM, BeMundus, Project Horizon 2020, Vrije Universiteit of Brussel (VUB) and LAMI-ETRO team.

Refererences: [1] Siegel, P. H., “Terahertz Technology in Biology and Medicine,” IEEE Trans. Microwave Theory Tech., vol. 52, no 10, pp. 2438-2447, 2004. [2] Juurinen, I.; Water-Ethanol Mixtures by Molecular Dynamics and X-Ray Compton Scattering, inPrograta-tutkielnalam Theoreettinem Fysiika, Universitas Helsigiensis, Institutum Phisicum, 2009. [3] P. Siegel, Terahertz technology, IEEE Transactions on Microwave Theory Technology 50 (2002) 910-928. [4] F. C. De Lucia, “THz spectrocopy-techniques and aplications,”in IEEE MTT-S Int. Microwave Symp. Dig., vol. 3, jun. 2002, pp. 1579-1582. [5] A.G. Davies, A.D. Burnett, W. Fan, E.H. Linfield, J.E. Cunningham, Terahertz spectroscopy of explosives and drugs, Materials Today 11 (2008) 18-26. [6] Matvejev, V., Zhang, Y.; Stiens, J.; “Integrated waveguide structure for highly sensitive THz spectroscopy of Nano-liter liquids in capillary tubes”, Progress In Electromagnetics Research, Vol. 121, 89-101, 2011. [7] Whitesides, G. M. “The origins and future of microfluidic.” Nature, Vol. 447. n.27.368 – 373, 2006. [8] Kakuta, N., et. al. Simultaneous imaging of temperature and concentration of ethanol-water mixtures in microchannel using near-infrared dual-wavelength absorption technique, Meas. Sci. Techno. 27 (2016) 115401 (12pp). [9] Squires, T.M., Quake, S. R. “Microfluidics:Fluid physics at nanoliter scal”, Reviews of Modern Physics, Vol. 77, No. 3, 2005. [10] Madou, M. J. “Fundamentals of Microfabrication: The Science of Miniaturization.” CRC Press. Washington, USA. 2ed. 2002.