EPJ Web of Conferences **266**, 13012 (2022)
EOSAM 2022
https://doi.org/10.1051/epjconf/202226613012

Micro-reactors fabricated by Subaquatic indirect Laser-Induced Plasma-Assisted Ablation on soda-lime glass substrates.

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Abstract. Synchronization control of complex systems is a field that emerged with huge interest and aims to study new possible routes to synchronization in networks of non-locally coupled chemical oscillators. Light can be used to stimulate these systems and to be able to synchronize the different micro-reactors involved in the complex system. To this end, transparent reactors with good optical qualities are needed. Glass is the most appropriated material to be used for fabricating the micro-reactors. Subaquatic indirect Laser-Induced Plasma-Assisted Ablation is presented as a laser technique that combines underwater ablation with shock waves as a potential technique for fabricating these micro-reactors by using a Nd:YVO_4 laser.

1 Introduction

The phenomenon of synchronization among coupled oscillators is quite common in natural and man-made systems. It occurs in cooperative crowd effects [1,2] while in non-living physical systems synchronization is seen, for example, in arrays of Josephson junctions and semiconductor lasers [3, 4]. Last, systems of coupled chemical reactions provide representative examples in chemistry [5]. The coupling of these oscillators using light pulses at different intensities, increasing, or decreasing their frequency so the oscillators can adapt to each other and synchronize their signal, offers a huge potential in the field. However, to use light for this purpose, the microreactor needs to exhibit optical transparency in the excitation at the visible wavelength range. Thus, glass is a good candidate to be used for this kind of microreactors due to its robustness and chemical resistance.

During the last decades laser technologies have received high attention due to its versatility to perform different kind of structures for a wide variety of applications. Moreover, it is a non-contact method that implies no thermal or mechanical deformation of the sample if properly used. The speed of the process and its low cost, once the equipment is installed, as well as the non-toxicity of the process, make them a good option to fabricate many devices [6 -7]. Soda-lime glass substrates are used in this work to manufacture with a nanosecond IR laser these microreactors. Subaquatic indirect Laser-Induced Plasma-Assisted Ablation is used to achieve the dimension needed for the micro-reactor as well to obtain straight walls, that cannot be obtained with other laser-based techniques. Micro-reactors with dimensions of 3 mm radius and 2 mm depth are presented. An initial study on the synchronization of complex system is showed.

1.1 Fabrication of microreactors on sode-lime glass with a nanosecond IR laser.

The technique used in this work for fabricating micro-reactors over soda-lime glass substrates corresponds with the setup presented in the Fig.1. An Infrared Nd:YVO_4 laser pulsed in the nanosecond regime, with a pulse duration around 20 ns, is focused using a flat field lens on the surface of a metallic target. The glass substrate is located over this metallic target, but not in direct contact with it. To avoid the shift of the glass substrate during the laser processing due to the shock waves, two weights are used to fix it. This setup in introduced in water, in such a way the debris can escape from the inner of the structures that are being performed in the glass. The water also helps to reduce the increasing of the temperature due to the absorption of the energy of the laser in the nanosecond regime. With this technique micro-reactors with diameter of 3 mm and depth of 2 mm, with straight walls (Fig. 2).

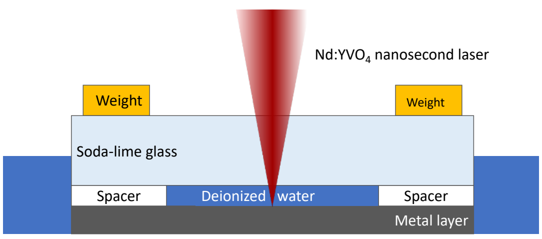

Fig. 1. Setup used for the SLIPAA technique.

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2 Preliminary studies on micro-reactor

Each "micro-reactor" contains a photo-sensitive chemical oscillator, composed of ruthenium gel and the Belousov-Zhabotinsky reaction. In the surface of the gel, the chemicals react, and the gel changes its color from orange to transparent (and viceversa) via a redox mechanism in the form of a wave, giving raise to periodic oscillations of colour. By varying the light intensity that we use to illuminate the reactor and due to the photosensitivity of the chemical reaction, we can modify the frequency of the oscillations. The idea is to couple the different oscillators using light pulses at different intensities, increasing, or decreasing their frequency so the oscillators can adapt to each other and synchronize their signal.

Fig. 2. a) photography of an array of micro-reactors and b) microscopic image of the up-side view of a micro-reactor, fabricated by SLIPAA

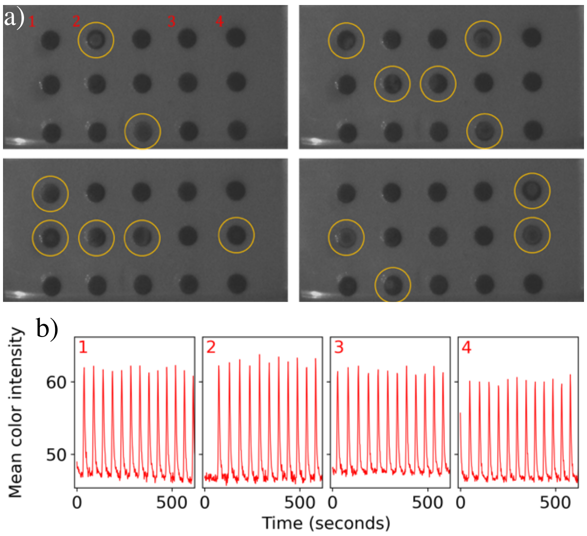

Fig. 3. From left to right and from top to bottom, consecutive images of the emerging oscillations in the micro-reactors. a) yellowed circle is drawn on the reactors where an oscillation is taking place. b) Measured time signals from the marked "micro-reactors" 1 to 4.

Figure 3 presents a picture of the reactor with a set of chemical oscillators. Yellow circles in Figure 3a) mark those oscillators that are experiencing an excitation peak. Different snapshots correspond with different moments of the experiment. Figure 3b) shows the evolution of the excitation state of several oscillators (those marked with red numbers).

In Figure 4a, a synchronization experiment is presented with some preliminary results. The leading oscillator is located at the center of the field of vision (Figure 4a) and periodically triggers a luminous pulse over the three other chemical oscillators in the picture. The excitation pulses, as recorded directly from the light intensity in the images, are plotted in Figure 4b. Note that after some transient time the three slave oscillators fully synchronize with the leading oscillator (marked with dashed black lines).

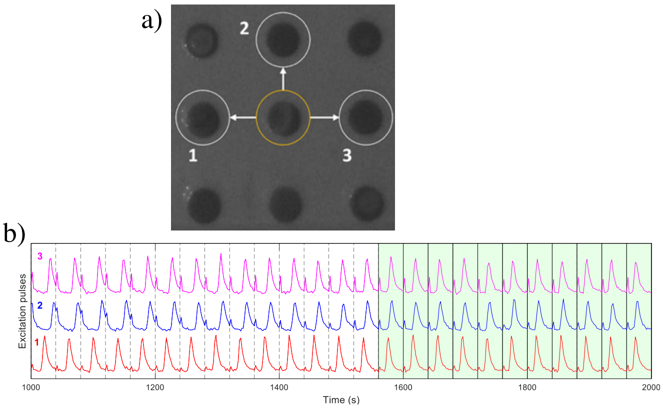

Fig. 4. Network of coupled chemical oscillators. When the central oscillator is activated, a shadowed pulse is projected (panel a) onto the oscillators of its network (marked in white in panel a). b) Excitation pulses in the slave oscillators synchronized after some transient.

3. Conclusions.

Micro-reactors for analysing the synchronization of complex systems with light have been fabricated by a subaquatic laser ablation, using a metal foil to generate the plasma and shock waves responsible of the ablation on soda-lime glass substrates. Results of the experiments carried out with these micro-reactors for synchronization of complex systems induced by light, prove that the micro-reactor arrays fabricated by SLIPAA are good enough.

References

1. Z. N´eda, E. Ravasz, Y. Brechet, and A.-L. Barab´asi, Nature **403**, 849–850 (2000).
2. H. Rheingold, Smart Mobs: The Next Social Revolution (Basic Books, 2003)
3. E. Goldobin, D. Koelle, R. Kleiner, and R. G. Mints, Physical Review Letters **107**, 227001 (2011).
4. D. V. Ramana Reddy, A. Sen, and G. L. Johnston, Physical Review Letters **80**, 5109–5112 (1998).
5. G. Ertl, Science **254**, 1750–1755 (1991).
6. J. R. Vázquez De Aldana, P. Moreno, and L. Roso, Opt. Mater., vol. 34, no. 3, 572–578, (2012).
7. M. Malinauskas, A. Zukauskas S. Hasegawa, Y. Hayasaki, V.Mizeikis, R. Buividas, and S. Juodkazis, Light Sci. Appl., **5**, e16133-e16147, (2016).

This work has been d supported by the Agencia Estatal de Investigación, under contract RTI2018-097063-B-100 and the Consellería de Educación Xunta de Galicia/FEDER under contracts ED431B 2020/29 and ED481D-2021-019, Spain.