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A Portable Biochemical Analysis System Integrated with Microcapillary Electrophoresis and Microplasma Emission Spectroscopy

Takanori Ichiki, Toru Koidesawa, Masahiko Watanabe, Tatekazu Ujiie and Yasuhiro Horiike[1]

Bio-Nano Electronics Research Center, Toyo University
2100 Kujirai, Kawagoe 350-8585, Japan
Phone:+81-49-239-1351 Fax:+81-49-239-1351 E-mail: ichiki@eng.toyo.ac.jp
Department of Materials Science, School of Engineering, The University of Tokyo[1]
7-3-1 Hongo, Bunkyo-ku, Japan

1. Introduction

In recent years, microfabricated analysis systems on chips have been enthusiastically developed for various applications such as clinical, environmental and biological analysis. Among these, microcapillary electrophoresis (μCE) chips have been extensively studied for high-speed separation of ingredients in the slight amount of the liquid sample. However, the small sample volume often suffers from the short of detection sensitivity. For the establishment of a portable biochemical analysis system with superior detection sensitivity, we have been developing a system that integrates the microcapillary electrophoresis (μCE) and miniaturized inductively coupled plasma - optical emission spectroscopy (ICP-OES) as schematically shown in Fig. 1. Hereby ingredients of the sample separated on a microcapillary electrophoresis chip are sequentially sprayed into the high-density micro plasma source allocated beside it, and are detected via the emission from the plasma [2, 3]. In this paper, we report the development of a VHF-driven high-density microplasma chip and a planar-type micronebulizer, which is an essential interface of a μCE/ICP-OES system, in detail.

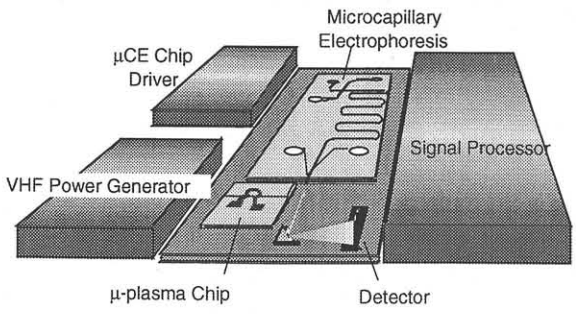

Fig. 1 Schematics of a μCE/ICP-OES integrated system.

2. Microcapillary Electrophoresis and Micro-nebulizer Chip

Channel patterns for microcapillary electrophoresis and a micronebulizer were etched onto the 30 by 30 mm quartz plate using deep plasma etching technology as typically shown in Fig. 2 [1]. After dipping into the 1% diluted HF solution, a microfabricated quartz plate was bonded with another plate having ports for the liquid sample or gas injection, closing the channels. For the connection with gas supply lines, fine copper tubes were attached to the chip using epoxy glue. As schematically illustrated in Fig. 3, high voltages were applied between both ends of the microcapillary lying at the center of the chip in order to induce electroosmotic flow, and nebulizer gas was injected from both sides of the outlet head of the central channel to blow out the outflowing liquid sample. Operation test was carried out in the following sequence. At first nebulizer gas was introduced at the flow rate of 4.7 sccm, and then sample was loaded without biasing the capillary. The sample used was 20 mM phosphate buffer (pH=9.1) with the slight addition of 0.1 mM rhodamine B for sensitive imaging using fluorescence microscopy. Without applying high voltages the liquid flow stopped just at the outlet of the capillary with 8 μm width due to the surface tension. Then the liquid sample flew out on applying a high voltage and

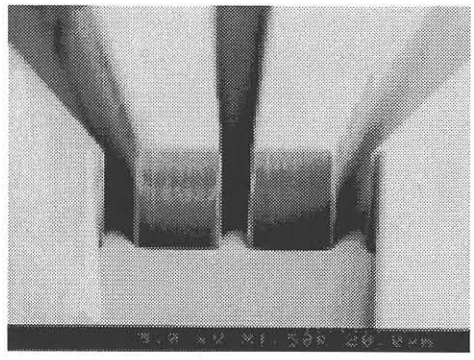

Fig. 2 An SEM photo of the outlet nozzle of the micronebulizer etched into the quartz plate.

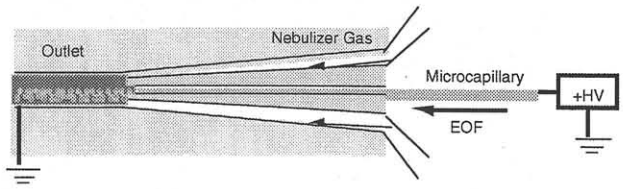

Fig. 3 Operation principles of a micronebulizer.

was atomized by nebulizer gas. The linearity of sprayed sample volume against the applied voltage for electrokinetic pumping was confirmed via the measurement of fluorescent intensity from the sprayed rhodamine B as shown in Fig. 4.

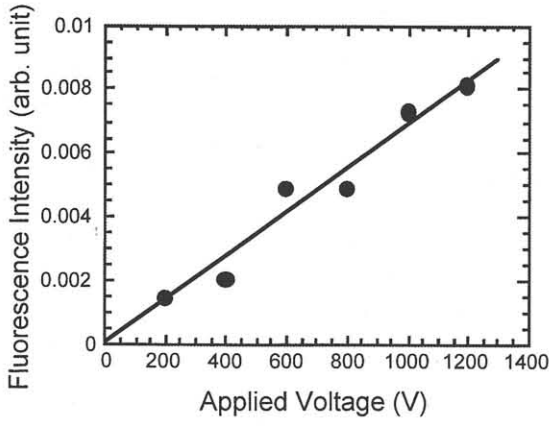

Fig. 4 Fluorescence intensity from sprayed rhodamine B measured with the increase of driving voltages for electrokinetic pumping.

3. VHF-driven Microplasma Chip

A miniaturized planar antenna with the inner diameter of 2 mm was fabricated on a 30 by 30 mm quartz chip using optical lithography and copper plating technology. The dimension of the discharge tube located under the antenna was 1 by 1 by 30 mm. Atmospheric-pressure argon inductively coupled plasmas were successfully produced at the 100-MHz VHF power no more than 3 W. The plasma density evaluated from the Stark broadening of H_β emission peak width was proved to be higher than $10^{14}cm^{-3}$ at the VHF power of a few tens watt. Then the plasma temperature exceeds 6000K. Figure 5 shows the typical electron density distribution of an Ar microplasma. Thus the localized power coupling to the

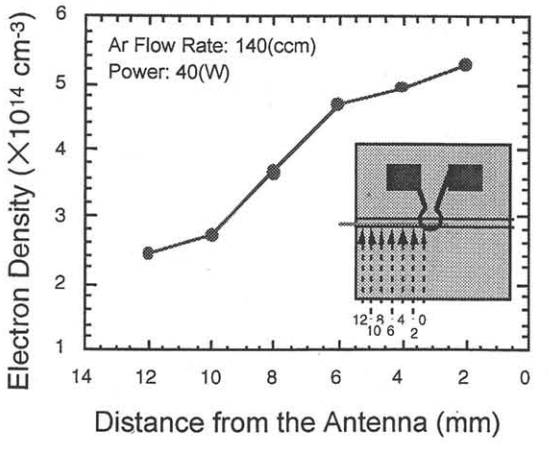

Fig. 5 Electron density of atmospheric-pressure argon microplasmas measured along the distance from the antenna.

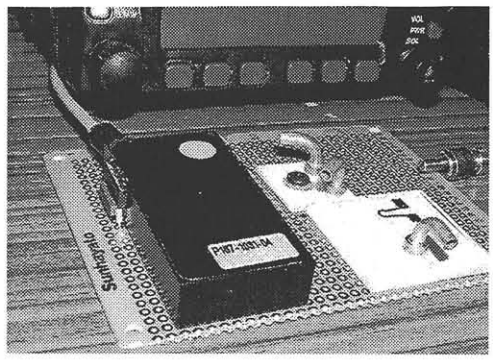

Fig. 6 A microplasma chip, a micronebulizer chip and a miniaturized optical spectroscope module mounted on a board. A compact VHF transmitter is also seen in the photo.

small space allows us to attain high-density and high-temperature plasmas comparable to those used in the commercially available ICP emission analysis apparatus of bench-top size even using a compact VHF generator like a car radio transmitter. Furthermore the low consumption of electric power and gas is a great advantage for the portable analysis system as demonstrated in Fig. 6.

4. Conclusions

For the establishment of a portable biochemical analysis system with high detection sensitivity, a VHF-driven high-density microplasma source and a planar-type micronebulizer interface have been developed based on a chip technology. Successful operation of all the essential elements for this system has been confirmed. Furthermore, their low consumption of electric power and gas under proper operation conditions ensures to integrate the whole analytical system in a portable size and weight.

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