A proposal of new electronics device: micro-total analysis system for capillary electrophoresis

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Abstract: We wish to develop micro-total analysis system (TAS) on a chip, and to make a trial approach to solve the important problem that is to detect ions separated by the electric field. We propose an idea, which is as for rotational motions of dipolar ions, which are affected by the ion atmosphere in outer regions. This is a new kind of the ion-sensitive field effect transistor (ISFET). We wish to develop the ISFET chips, and give more effective, fast and sensitive, capillary electrophoresis is designed in near future.

Keywords: TAS, ISFET, capillary electrophoresis, ion rotations, sensors, biochemical devices

1. BACKGROUND

Nowadays, we can incorporate chemical reactions and the detecting equipments on one chip. The technique is applied to many scientific and engineering fields, especially biological, pharmaceutical, and medical ones. We call the devices micro-TAS (total analysis system) [1]. To realize the micro-TAS, some useful techniques are proposed. We have taken a notice of the following techniques.

One is non-electric plating. By using it, we can plate many metals on insulators; i.e., quartz, plastics, ceramics, and and papers. We can insert palladium thin layers into the inside of papers by the technique. The plating quartz is applied to the quartz crystal microbalance (QCM) [2].

Another is synthesis of an interesting material, silicone gums, (-O-SiR2-O-)n [3]. The poly-dimetyl-siloxane (PDMS) is a kind of the silicone-gums, which is a solid, and at the same time, it operates as if it is liquid. It absorbs gases, and attracts anti-water molecules on the surface. If the PDMS is kept in a vacuum chamber, gas adsorbed in the PDMS is aspirated; then PDMS becomes a strong adsorption reagent. We can make micro pump on a chip.

It has been difficult to detect the DNA's, proteins, sugars, the oligomers, and polymers. It is well known the capillary electrophoresis (CE, [4]) technique makes a breakthrough.
We wish to equip the CE on a micro-TAS, to reduce the cost and to make easy detect of isolate compounds. However, there are many difficult problems on the realization.
In this paper, we show an electrical approach to detect isolated compounds.

2. PROPOSAL OF CAPILLARY ELECTROPHORESIS ON A CHIP

The CE equipments are highly complexes now, and they are costly and large-scale black boxes. We wish to reduce them to small chips. We are now considering the chip would be designed as figure 1.

On the chip in figure 1:

1) The baseboard is an aluminum oxide of 50-100 [mm] squares, whose thickness is 1.6 [mm]. The board is inscribed by diamond blades; a main ditch and some sub-ditches are made. The width is 50-100 [micro-m]. The length of the main ditch is 140-420 [mm], and it is for electrophoresis. The sub-ditches are to generate detection-electrodes for moving ionic molecules. We wish to adopt electrical detections instead of optical absorption detections.

2) Two platinum wire electrodes are put at both edges of the main ditch. Voltage of 0.45-2.8 [kV] is loaded on the electrodes. The high voltages are got by Cockcroft-Walton circuit.

3) The main ditch is filled with electrolytic solutions and a sample. Since high voltage is loaded along the ditch, it should be affixed by a seal film. We use PDMS for the seal. PDMS is insulator and absorbs air.

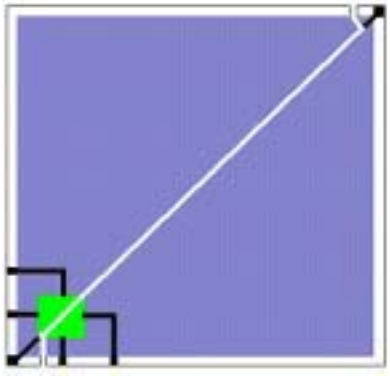

Fig.1 A chip for the capillary electrophoresis.

3. DETECTIONS OF IOLATE IONS

3.1 Ion actions in alternative electric field

It is an important problem to detect the isolated compounds from the capillary electrophoresis. To reduce the detections, we have considered motions of ionic molecules. We make attention to conception of ion-sensitive field effect transistor (ISFET). As for the ISFET's principle, some papers are published [5], and a product, ISFET-pH-sensor [6] is sold. The sensor's response is very rapid because of the principle. We wished to apply the principle to detection for ionic motions; so, we designed a circuit in figure 2.

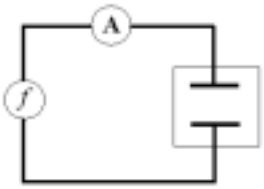

Fig.2 A circuit to detect ion actions.

Where "f" is a sine-wave generator, the frequencies are 1Hz-20KHz. "A" is an ammeter that can be substitution for a digital multi-meter of input impedance is more than 10 mega ohms. A condenser unit is a cell filled up ion-solution, which is constructed of polystyrene resins. The electrodes are brass pins of 3.15mm*7mm. The output voltage of "f" is 1.2[V], which must be low than that of water electrolysis. If not, the brass electrodes are eroded soon.

On the circuit, when there are dipolar ions in the cell, the ions are attracted or repelled for the alternative electric field. The ions are always moved by the field. If we scan the frequency, the motions would be resonant with a special frequency. The resonance gives large electric currents. To suppress convections in the cell solution, we replaced the solution to a gel, and selected amino acids for the dipolar ions. Contents of the amino acid's gel are shown in table 1. We believe that gel is not perfect material for electrophoresis, but it is suitable one to detect ions' vibrations.

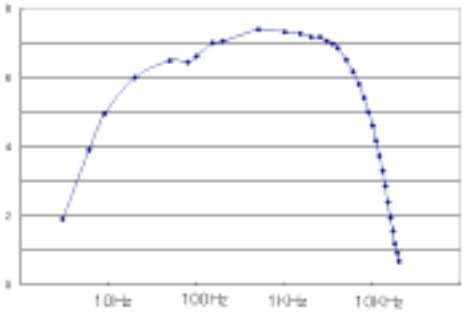

Fig.3 Amplitude ratio of currents for plural amino acids' gel:

The horizontal axis is frequencies of logarithm scales. The vertical axis is the current amplitude; the amplitude curve indicates existence of ionic vibrations.

Table 1. Contents of sample amino-acid gel of 100g

proteins	0.7g	arginine	18mg
Tri-glycerides	0.0g	leucine	17mg
carbohydrates	17.7g	isoleucine	18mg
Na+	38.4mg	valine	21mg
sucrose	0.06g	alanine	600mg

3.2 Dipolar ion rotations

We expand the idea to multi-electrode type, as followings. The phase of alternative currents is shifted by a CR-lowpass-filter. So, we can a rotation electric field in figure 4.

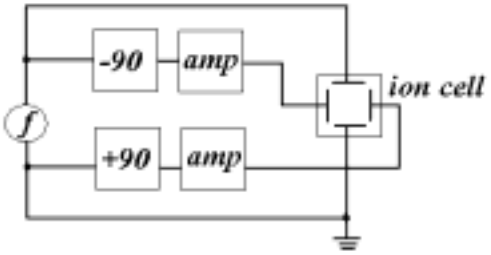

Fig.4 An electric cell loaded rotational electric fields:

Where "f" is a function generator that generates sine waves having various frequencies. "amp" is an amplifier, and "-90" is a delayed phase shifter; the numeric 90 means the shift angle [deg]. The ion cell has 4 electrodes that are arranged symmetrically.

If the alternative fields 0, 90, 180, 270 [deg] were loaded on multi-pole-electrodes, and the fields would give rotational motions of dipolar ions. The "f" unit controls the rotation speed. The rotations absorb electric current at the resonance point. This is a base condition of ISFET. We wish to make the ISFET as two-layers structure on an aluminum oxide board. The partition between the two layers is an ion-transparent film. The absorption current is affected by the ion-atmosphere through the film.

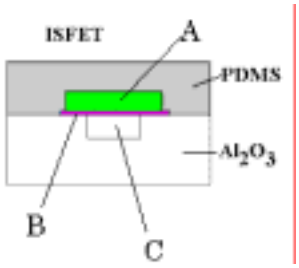

Fig.5 ISFET(Ion Sensitive Field Effect Transistor) based on ion rotations:

Where, PDMS is a sheet of poly-dimetyl-siloxane, Al2O3 is a board of aluminum oxide. "A" is a cell of carrier ions, dipolar ions. "B" is an ion- atmosphere through film. "C" is a capillary ditch on the board.

4. CONCLUSIONS

LSI scale chemical/biological experiment equipments, that is micro-TAS. Where capillary electrophoresis, ion-sensitive FET, electronics, etc., such techniques are connected and make an electronic device. It is a very interesting approach. The capillary electrophoresis is operated on high DC voltages, but ISFET is in low AC. To escape the interaction, capacitors will be required.

We are on a step to develop one chip micro-TAS. In the TAS, it is important problem to detect ions separated by the electric field. We propose an idea, which is as for rotational motions of dipolar ions, which are affected by the ion atmosphere in outer regions. This is a new kind of the ion-sensitive field effect transistor (ISFET).

We wish to develop the ISFET chips, and give more effective, fast and sensitive, capillary electrophoresis is designed in near future.

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