Title	Creating paper-based sensors using inkjet printer : development of handy sensing chips for medical and environmental uses
Sub Title	
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Publisher	Faculty of Science and Technology, Keio University
Publication year	2010
Jtitle	New Kyurizukai No.5 (2010. 10) ,p.2- 3
JaLC DOI	
Abstract	
Notes	Introducing researchers
Genre	Article
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO50001003-00000005-0002

Introducing Researchers

Featured in this issue is Associate Professor Citterio, Daniel, who focuses on the development and practical implementation of a handy sensing chip fabricated by the inkjet printing technology.

Creating Paper-based Sensors Using Inkjet Printer

Development of handy sensing chips for medical and environmental uses

The condition of one's health can be judged by simply putting a drop of saliva or urine on a piece of paper and observing a color variation. Or the degree of river pollution can be determined from a small quantity of river water . . . The development of such handy sensing chips is now in progress. All that is required to create the sensing chip is paper and an inkjet printer. We listened to Dr. Citterio who addresses the development of innovative, highly useful sensors by combining existing technologies with new "chemical sensing inks" specifically designed for this purpose.

Fantastic paper-based sensors . . . No special equipment, not even a power supply, is required to use them!

"What I'm focusing on are chemical sensors and biosensors that can be carried and handled by anyone and anywhere, making measurement quite easy," remarks Associate Professor Citterio.

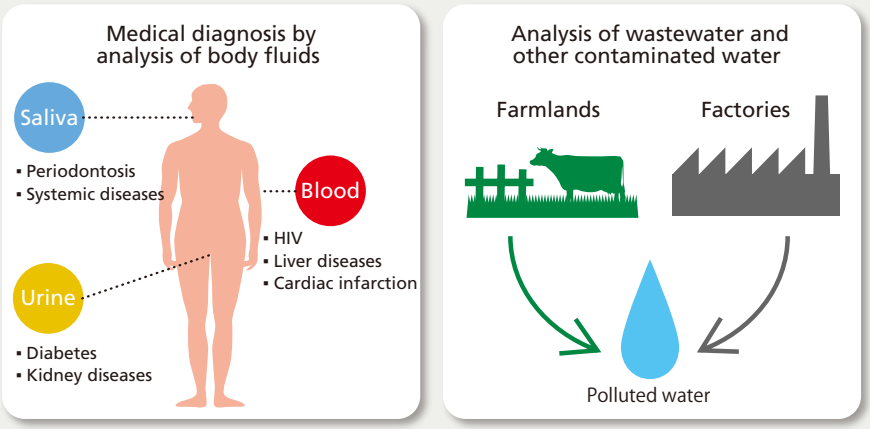
Among familiar examples of chemical sensors are litmus paper for pH measurement and gas leak detectors. Furthermore, biosensors make use of biomolecules such as enzymes and antibodies to selectively recognize target substances. One well-known example are pregnancy test kits. What Dr. Citterio aims to develop are handy sensing systems that will allow instantaneous visual recognition, like that of a color variation on litmus paper.

"In particular, I'd like to create handy sensing systems for medical and environmental applications. When it comes to health management and medical diagnosis, the sensing system will allow you, while at home, to check urine, saliva or blood for protein, blood sugar and hemoglobin conditions, for example. Regarding environmental applications, the system will make it possible to easily check drinking or lake water for pH value or for the existence of contaminants such as lead, cadmium and other heavy metals as well as nitrite, arsenic, herbicides and pesticides. Effective combination of already established sensing technologies and their adaptation towards new inkjet printable materials is my approach to the development of easy-to-use and highly practical systems."

With this approach in mind, Dr. Citterio decided to employ "paper" as the sensor substrate – filter paper made of cellulose fibers. He thought paper would be ideal as it is available anywhere easily and for a low price, lightweight and handy to carry, mailable, easily storable, and can be burned or discarded after use. Presently available systems for medical and environmental analysis are of a large scale, their use requiring an air-conditioned laboratory and cooling equipment like a refrigerator. But a paper-based system would eliminate the need for such equipment or even a power source. This means great advantages when used at home and at fieldwork sites and in developing countries where medical facilities are poor or insufficient. What's more, it can be used easily even under emergencies.

"In the world of chemistry, paper has been used since ancient times. Chemicals can be fixed to it and it's capable of wicking a solution by means of the capillary action phenomenon. One fine example is the established technology known as paper chromatography used to separate chemical substances by virtue of these filter paper characteristics.

The amount of reagent consumption would be minimized if various kinds of tests can be conducted by dropping only one drop of sample on to a small piece of paper. Given some reagents for example based on antigen-antibody reactions are costly, it is very important to reduce reagent consumption by reducing the chip size itself.

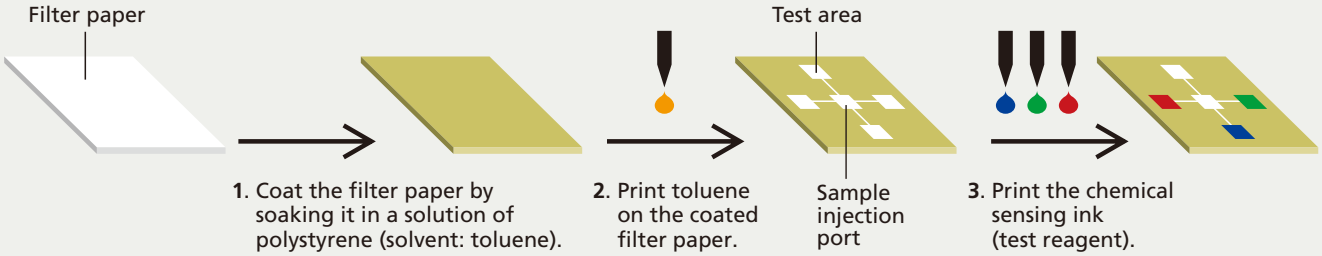


Handy medical/environmental sensing chip
The use of this chip allows anyone to conduct medical tests with only a small amount of body fluid (saliva, blood, or urine) and to check wastewater or river/lake water quality – at low costs, promptly and easily.

Making chips with one single inkjet printer

In reality, several research groups recently began pursuing the method of using paper as sensor material. However, the originality of Dr. Citterio's team lies in the use of an inkjet printer based on the piezo method (a method of jetting out ink by means of a piezoelectric element when voltage is applied to the print head).

"Since more than ten years ago, research efforts have been increasingly made on Micro-TAS (Micro-Total Analysis Systems) – devices for the analysis of chemicals by combining microscopic



How to make a medical/environmental sensing chip

The sensing chip is made using the following processes ; (1) Soak the filter paper in a solution of polymer (polystyrene) for coating, making it hydrophobic ; (2) Use an inkjet printer to discharge an organic solvent (toluene) and make a channel. Polymer on the part to which toluene was applied is dissolved, thereby creating a hydrophilic channel ; (3) Then use the inkjet printer to print the sensing ink (test reagent) on the test area at the end of the channel.

flow-channels, reaction chambers and mixing chambers on a minute chip. Glass and plastic chips have been used until recently. In 2007 Professor Whitesides of Harvard University proposed paper chips as a cheaper and easier solution.

In association with paper, Dr. Citterio's team set their eyes on an inkjet printer capable of jetting any desired controlled amount of ink. Today, inkjet printing has grown into a highly generalized technology, finding wide applications not only for paper printing, but also for large-size color display films through to the production of microscopic items such as semiconductor substrates. This advantage makes the inkjet printer very attractive, Dr. Citterio says.

"To make a chip, you basically put the required reagents in the ink cartridge and print onto paper. Then, simply use a pipette to apply a sample like blood or urine. Soon a reaction occurs. Besides, we are not only able to print chemical reagents, but we also create microfluidic channels on the chip using the inkjet printer. It will be highly cost-saving if we can perform the entire chip-making process with a single printer, you know."

The keys: the sensing ink and chip's microfluidic channel design

The greatest challenge involved in the chip-making process is the development of multiple functional chemical and biochemical sensing inks. For this purpose, the creation of chemically functional materials in nanoparticulate form is essential.

"With ordinary printer nozzles, there are limitations to the liquid viscosity and particle size that can be discharged. Also, you must ensure that the normally water soluble reagents are not washed away by the flowing sample, but stay firmly on the test area so that color change occurs uniformly, in a repeatable manner. So it becomes important to exert ingenuity such as the use of small polymeric particles in the ink to prompt the reagent adsorption onto the paper.

Although we still have a number of chemical and physical problems to be solved, it would be fantastic if in the future we could develop a sensing system with which we can perform everything with an ordinary printer we're using at home."

Another challenge Dr. Citterio is intent on is the design of the microfluidic channels to be patterned on the paper substrate – only 500μm in width.

"We are making the flow-channels and sensing areas by printing a pattern on a piece of filter paper that has been dried after being soaked in a solution of a highly hydrophobic polymer known as polystyrene. Here we use toluene as the ink, an organic solvent that dissolves polystyrene. In other words, only the flow-channel and sensing area parts become hydrophilic. Chemical and biochemical sensing inks are printed onto those sensing areas to make the final chip.

If we succeed in making a good pattern, it will be possible to have one single piece of paper accommodate multiple test items."

Currently Dr. Citterio is also studying a method of drawing a pattern using a material that is more environment-friendly than toluene, accelerating the research work aiming for completion and launch within a few years' time.

(Reporter & text writer: Madoka Tainaka)

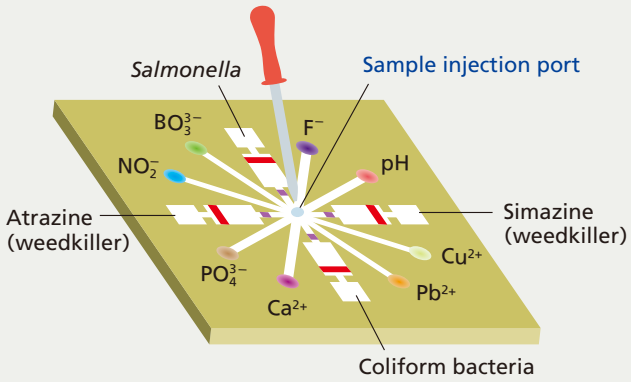


Fig. A: Water-quality testing chip

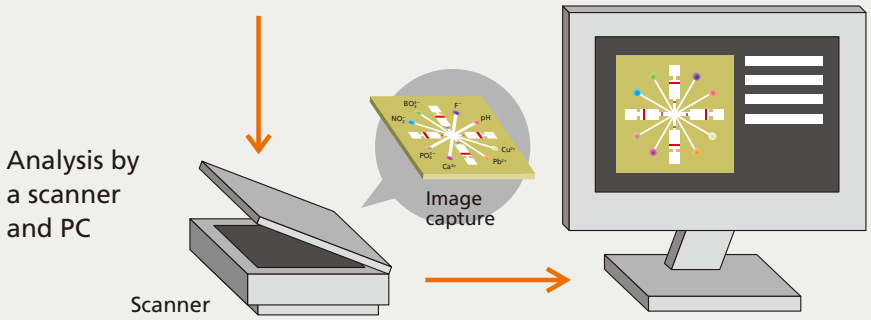


Fig. B: PC and color analysis software package

A handy system anyone can use anywhere

When making a sensing chip, you print the sensing inks (test reagents) for your targeted test items such as *Salmonella* and ingredients of weedkillers (Simazine and Atrazine) on the chip. Then, by simply placing one drop of the sample into the sample injection port, reactions will occur in the respective areas, making it possible to measure multiple test items simultaneously (Fig. A). This sensing chip is not only suitable for visual judgment, but it is also capable of quantitative analysis if used together with a scanner. Systemizing it by combining with a PC, you can create an easily portable, epoch-making sensing system (Fig. B).