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Oral

SENSING SWEAT IN REAL-TIME USING WEARABLE MICROFLUIDICS

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We present how a simple, autonomous, wearable, robust, flexible and disposable microfluidic chemical barcode device based on ionogels can be used for monitoring the pH of sweat generated during an exercise period in real-time. pH values can be obtained by simply observing the barcode colour variation in comparison to a standard colour chart or through more sophisticated methods such as video analysis of the colour changes. A significant advantage of these approaches is that the on-body sensor consumes no power, does not require any electronics for signal acquisition or communication, and therefore does not need a battery [1]. The sensing function is provided by pH indicator dyes immobilized within an ionogel polymer matrix (see figure 1). Due to ion-pair interactions between the various pH indicators and the ionic liquid that forms the ionogel structure, there is no leaching of pH dyes during the experiments.[2]
The microfluidic system is fabricated using very thin PMMA and PSA layers (Figure 2) ensuring that the whole device is flexible and can easily adapt to the body contours. Moreover, it is comfortable to wear providing an unobtrusive and non-invasive method for the analysis of sweat during exercise. The chemical sensor barcode can be encapsulated into an adhesive plaster (Figure 3) or integrated in sports clothing. Particularly simple to implement is integration into a sweat band worn on the head or the wrist from which information about the sweat chemistry can be obtained directly during exercise.
The design of the microfluidic structure ensures that fresh sweat is continuously sampled from the skin and flows past the ionogel-sensors throughout the entire training period. In Figure 4, sweat is absorbed by the fabric of the clothes and comes in contact with the barcode sensor. The dyes react with the sweat and change colour according to their respective pKa's. Sweat is drawn continuously through the microfluidic device by the super-adsorbent material, which acts as a passive pump, in effect sucking the liquid through the microfluidic channel. The microfluidic system is easily calibrated in a conventional manner using standard buffer solutions. Each of the dyes exhibits a characteristic colour depending on the pH of the buffer which can be plotted against the pH value as shown in figure 5 for the indicator bromothymol blue (BTB).
Figure 6 presents the results of a real experiment obtained with the sensors during an exercise event. It was observed that the colour of each of the pH indicators in the ionogel matrix varies with the pH of the sweat over time except methyl red (MR) indicator probably due to interference by the ionic liquid anion $[dca]^-$, which is known to behave like a Lewis base [3]. However, the bromocresol green ionogel sensor correlates reasonably well with the commercial pH probe reference measurements. Moreover, the barcode pH sensor array acts as a self-referencing system giving rapid response to users with an accuracy of ca. 0.5 pH units.

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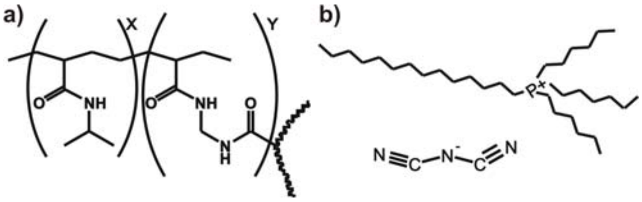

Figure 1: The molecular structure of the two components that make up the ionogel material. a) poly(N-isopropyl-acrylamide) and N,N-methylene-bis(acrylamide) cross-linked polymer in the ratio 100 (x):5 (y), and b) the ionic liquid trihexyltetradecyl- phosphonium dicyano-amide [$P_{6,6,6,14}$][dca].

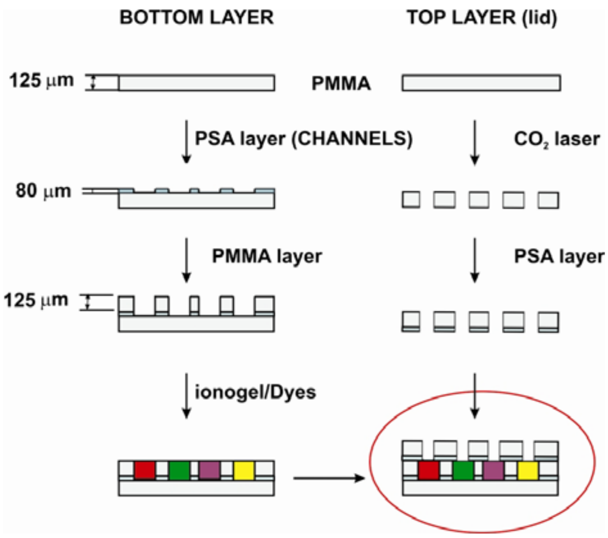

Figure 2. Microfluidic chip fabrication process.

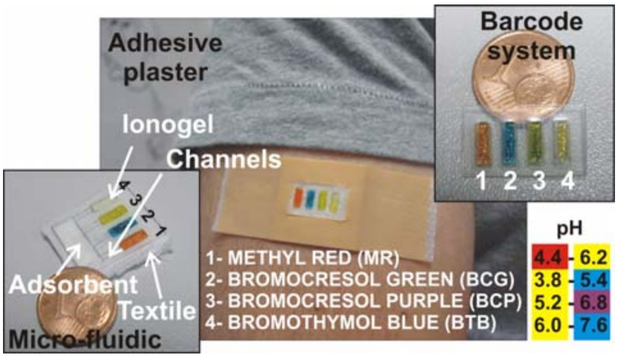

Figure 3: Digital images of the barcode (up right side), the microfluidic platform (down left side) and the incorporation of the platform into a commercially available adhesive plaster (centre); pH dye names and active pH range.

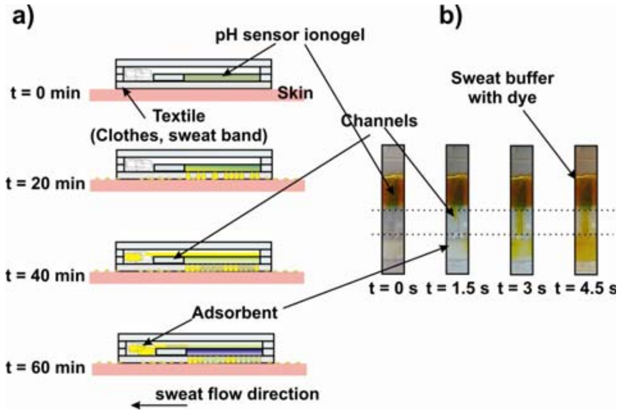

Figure 4: a) Schematic representation of the microfluidic system performance. b) Series of pictures showing the channel performance in the microfluidic system.

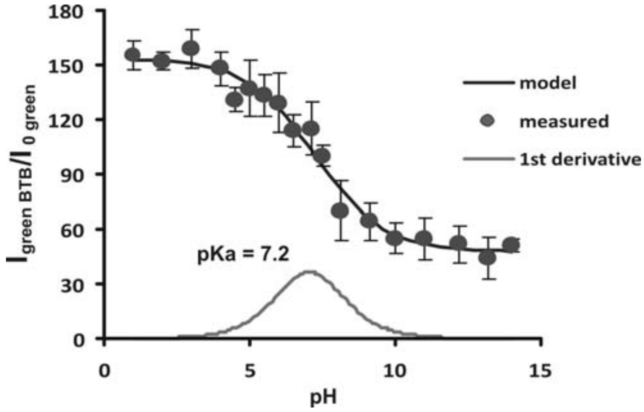

Figure 5: Calibration curve showing pH vs. green intensity of bromothymol blue (n= 3) from the microfluidic system pictures taken at each pH.

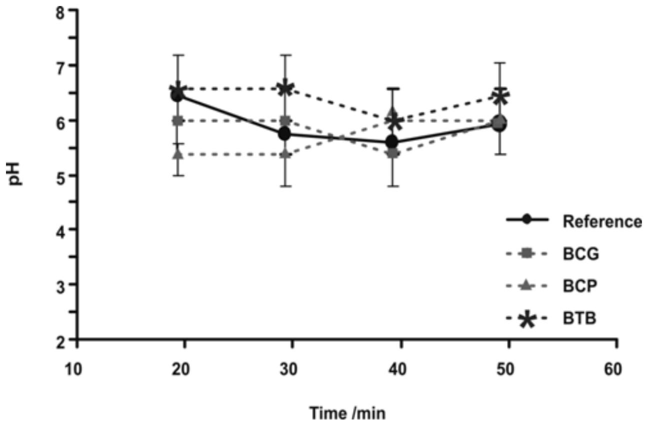

Figure 6. Sweat pH determination using the microfluidic device in an individual during a 50 minutes training period.