✦ D24-098 ✦

應用於汗液監測之印刷式分枝狀電極感測器與電阻抗頻譜分析晶片

An Electrical Impedance Spectroscopy IC with a Printable, Fractal Root Textile Sensor for Perspiration Analysis

隊伍名稱｜掉到水裡的銀斧頭
Silver Axe Dropped in the Water

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美國西雅圖華盛頓大學電機工程博士，現為陽明交通大學電機工程學系教授。曾獲臺灣積體電路學會傑出年輕學者獎、中國電機工程師學會優秀青年電機工程師獎、IEEE ISSCC Silkroad Award、美國Cade Prize、科技部未來科技獎、科技部哥倫布計畫、國科會2030國際年輕學者研究計畫等獎項。

研究領域

低功耗類比 / 射頻積體電路設計、生醫感測晶片、高效率能量管理晶片與感測器介面電路設計

✦ 作品摘要 ✦

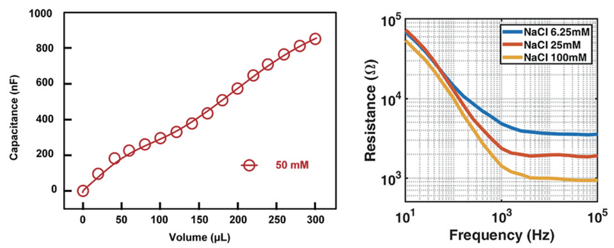
在現今社會，隨著人們對健康和運動的認識日益提升，可穿戴裝置市場正逐漸擴大。這些裝置能夠在日常生活或運動中實時監測身體狀態和健康數據，讓使用者更加了解自身身體狀況，並做出適當調整，但卻忽略了運動或日常生活中可能出現的脫水或低血鈉等問題。因此，本設計旨在開發一種能夠監測汗液中電解質（如鈉離子）的穿戴式裝置。

根據研究顯示，正常情況下人體的出汗速率與汗液中的電解質濃度有高度的關聯性，若僅直接透過導電度量測離子的濃度，將無法有效地獲得真正的離子濃度。因此必須同時獲得離子濃度與汗液流速的資訊。

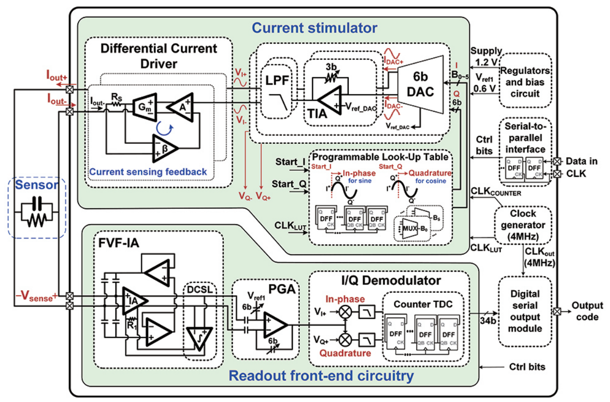
我們的設計核心在於開發一種利用電化學阻抗頻譜（Electrical Impedance Spectroscopy，EIS）進行非侵入性、實時阻抗量測的裝置。透過EIS的技術可以進行頻率掃描,使電解質顯現出不同的特性,並獲取汗液中鈉離子的濃度以及汗液的流速等關鍵信息。圖一左為50mM的NaCl水溶液在不同的容量下所呈現出的電容大小，其電容值會隨著出汗量的增加而上升，可以用來測量出汗速率；圖一右為對不同濃度的NaCl水溶液進行掃頻得到的阻抗，在高頻時，不同濃度的阻抗差異大且穩定，適合用於分辨濃度。以EIS進行監測的方式不僅能夠提供即時數據,還比傳統的汗液分析方法（如實驗室化學反應）更為便利。

圖二為EIS系統晶片架構圖。在EIS的電路設計上，我們開發並優化了一種低失真、高輸出阻抗的電流刺激電路。其中，電流驅動電路採用了電流回饋結構，使得在1MHz頻寬下能夠實現1.25mA/V的固定轉導增益，同時總諧波失真僅為0.4%。此外，透過在回饋回路中添加感測電阻，提高了輸出阻抗，在100kHz頻率下達到了1MΩ以上，從而將可量測的阻抗範圍擴展到14kΩ，並且保持了小於1%的總諧波失真。此外，在讀取電路上，我們則採用了低功耗且低雜訊的前端放大電路與正交解調變電路技術。此EIS讀取晶片採用了0.18μm CMOS製程，操作於1.2V電源電壓下，其功耗僅為228μW。最終的實驗結果證實了該系統能夠達到實時監測汗液中鈉離子濃度（6.25-100mM）以及透過電容值的低頻變化進行流速分析的需求。

綜上所述，本設計開發出了一款新型的穿戴式裝置，不僅能夠實時監測和分析汗液中的電解質濃度和流速，還具有便攜性、實時性和高精準度等優點。這款裝置將為運動健康監測領域帶來新的可能性和機會。



圖一 NaCl水溶液的電容與阻抗特性。



圖二 此作品之架構圖。

✦ Abstract ✦

These days, as people become increasingly focused on health and exercise, the market for wearable devices is expanding. These devices can track the body's condition and health data in real time during daily activities or exercise, helping users better understand their physical state. However, they often neglect issues like dehydration or hyponatremia that can occur during exercise or daily life. To address this, our goal is to develop a wearable device that can monitor electrolytes, such as sodium ions, in sweat.

Research has shown that the concentration of electrolytes in sweat is highly correlated with the sweat rate. Therefore, it is crucial to be able to obtain both pieces of information simultaneously to interpret physiological conditions accurately.

Our design focuses on developing a device that uses Electrical Impedance Spectroscopy (EIS) for non-invasive, real-time impedance measurement. Through this technology, we can scan frequencies to reveal different characteristics of electrolytes, including the concentration of sodium ions in sweat and the flow rate of sweat. The left side of Fig. 1 shows the capacitance of a 50mM NaCl aqueous solution at different volumes. The capacitance value increases with the amount of perspiration, which can be used to measure the perspiration rate. The right side of Fig. 1 shows the impedance obtained by frequency sweeping of NaCl aqueous solutions at different concentrations. At high frequencies, the impedance differences between different concentrations are large and stable, making it suitable for distinguishing concentrations. This approach provides real-time data and is more convenient than traditional sweat analysis methods such as laboratory chemical reactions.

To achieve our goal, we have developed and optimized a low-distortion, high-output impedance current stimulation circuit, as shown in Fig. 2. This circuit employs a current feedback structure and a sensing resistor in the feedback loop, enabling us to reach over 1MΩ of output impedance at a frequency of 100kHz and keep total harmonic distortion below 1%. Furthermore, for the readout circuit, we have adopted low-power and low-noise front-end amplifiers and quadrature demodulation circuits. The chip, shown in Fig. 3, was implemented using a 0.18μm CMOS process, with a power consumption of just 228μW at a supply voltage of 1.2V. Our experimental results have confirmed that this system can achieve the real-time monitoring of sodium ion concentrations in sweat (6.25-100mM) and flow rate analysis through low-frequency variations in capacitance.

In summary, our design has created a novel wearable device that can monitor and analyze the concentration and flow rate of electrolytes in sweat in real time. This device offers advantages such as portability, real-time performance, and high accuracy, bringing new possibilities and opportunities to the field of sports health monitoring.

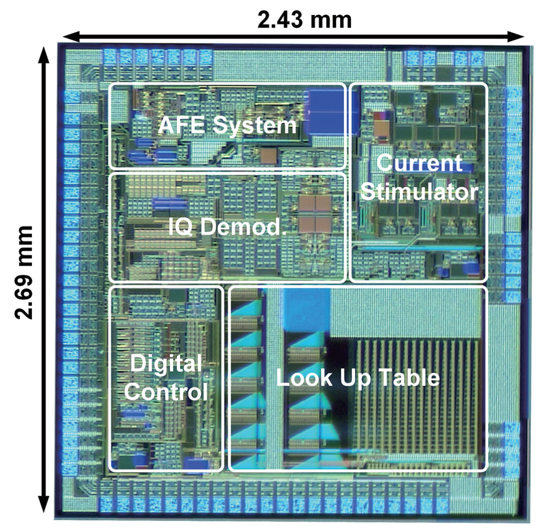


Fig. 3 Chip micrograph.