13th GOLDEN SILICON AWARDS

# D13-104

## A Hydrogel-Based Implantable Wireless CMOS Glucose Sensor SoC

## 以水凝膠為基礎的植入式無線 CMOS 血糖感測 SoC


**隊伍名稱**

糖尿病殺手 / Diabetes Killer

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## 作品摘要


糖尿病為目前全球最重要的慢性疾病，截至目前為止,全球糖尿病人口已經超過3億人，隨著血糖控制不良所導致的許多健康問題已經成為人類所必須急速解決的重要課題，由於糖尿病患之血糖需長期監控，因此精確方便的家用血糖量測機器能長時間有效的控制病患之血糖狀況。目前普遍的血糖檢測方式為invasive or semi-invasive，採用直接侵入取血或真空吸取取血等方式配合electro-enzymatic approach 或electro-catalytic approach 等電化學方式檢測，雖然此類技術已成熟商品化並應用在家用血糖監測上，但仍存在著許多缺點。侵入式血糖檢測需反覆利用針扎採血，依病患情況不同每天需要平均4~6次的採血，造成不便性與病患的痛楚。此外，對於血糖值經常在200mg/dl以上之病患，傷口愈合更加困難。對於極度害怕傷口感染的糖尿病患者來説侵入式血糖檢測法有此缺點。此外，電化學方式的試紙校正與保存方式皆會影響到血糖檢測的準確性。

本創作透過CMOS-MEMS製程，將高分子Glucose Sensitized Hydrogel材料，CMOS MEMS Sensor結構，微小信號感測電路與無限信號傳輸電路整合至一微小SoC晶片，讓醫生在一次微創手術下植入糖尿病患，進行24小時持續非侵入及時血糖監測，可以完全省去刺針採血之反覆性不便與痛楚，並且增加安全與準確性。準確量測出的血糖資料能透過無線電路傳輸至體外，能輕易的使用手機電腦或任何3C行動裝置讀取而出。並且由於植入式的電源考量，可額外整合電感天線與充電式電池進行體外無線電源充電，讓病患不用反覆開刀更換電池。

此創作預期能進一步整合醫院之遠距醫療系統，讓醫師能及時對病人之狀態進行長時間週期之觀察，有利醫療成效。


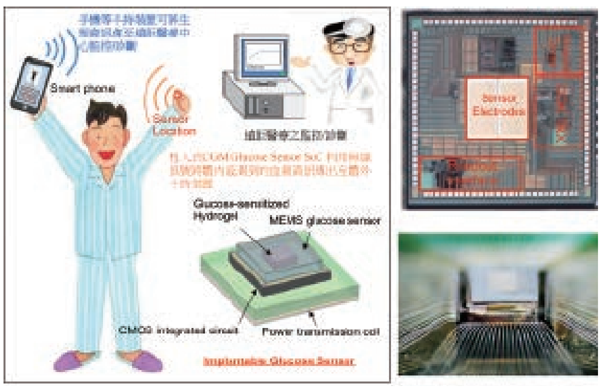


圖1 > 植入式CMOS連續血糖監測 System on Chip

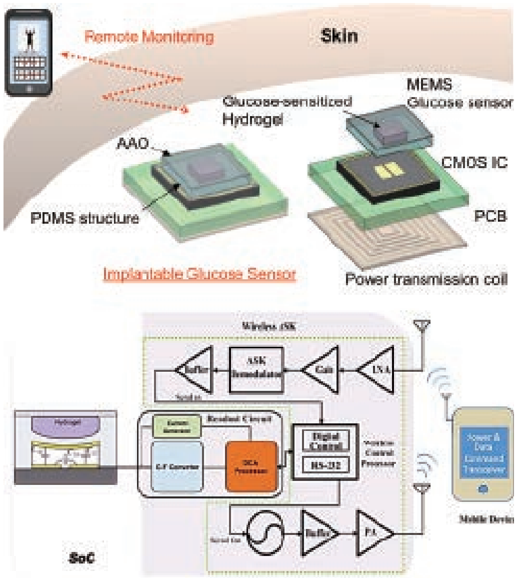


圖2 > A Hydrogel-Based Implantable Wireless CMOS Glucose Sensor SoC. Implantable Scenario (top) Circuit Blocks (down)

**呂學士 / 臺灣大學電子工程研究所**

於 1985 年取得臺大電機系學士學位；1988 年取得美國 Cornell University 碩士學位；1991 年取得美國 University of Minnesota 博士學位。曾任臺灣大學電子所所長，現任職於臺灣大學系統晶片中心副主任，臺灣大學奈米機電系統研究中心副主任，臺灣大學電機系教授和臺灣大學電子所教授。目前致力於生醫方面跨領域系統整合之前瞻性研究。

**研究領域**

LNA、MIXER、VCO、PLL 等 CMOS 射頻積體電路的設計以及 ADC、PGIA、FILTER 等類比積體電路設計。

**指導教授**

**楊燿州 / 臺灣大學機械工程研究所**

於 1997 年及 1999 年於麻省理工學院（MIT）電機暨資訊系（EECS）分別取得電機碩士及電機博士學位。之前，他於 1995 年取得加州大學洛杉磯分校機械碩士學位，於 1990 年取得臺灣大學機械學士學位（NTU-ME）。自 2000 年迄今，任教於臺灣大學機械工程學系，目前擔任教授職位，自 2011 年起亦兼任系主任暨所長。

**研究領域**

微機電系統及設計與製作、奈米技術、智慧節能光機電系統、可撓式感測陣列、無線感測器網路及平行運算等。

## Abstract


Being one of the most serious chronic diseases, diabetes has causes 0.3 billion patients troubled by the glucose monitoring routines. Today, glucose test is usually performed by electrochemical methods, such as electro enzymatic and electro catalytic approaches. These invasive test procedures are periodical and can result in four to six blood test per day. To the patients whose glucose concentration is larger than 200mg/dl, wounds from these blood tests are difficult to heal and inflammatory. To solve this problem, a reusable hydrogel-based glucose sensor SoC is proposed. Hydrogel is a cross-linked polymer that can absorb H2O molecular and swell. After glucose sensitization treatment, hydrogel becomes absorptive to glucose molecules and its volume can also vary according to the glucose concentration. The difference in volume resulting from the varying glucose concentration can be increased by H2O molecules, since the absorbed glucose molecules help to loose the crosslink and hence more H2O molecules can be filled with and enlarge the volume expansion. The absorbed molecules are able to diffuse among the crosslinks, which exhibits a reversible detection mechanism and makes the hydrogel able to recover from the deformation for reuse.

By using micromachining techniques, the hydrogel-based sensor can be fabricated on top of the chip and integrated with active circuits. Through the minimally invasive surgery, this sensor SoC can be implanted subcutaneously, and start transmitting the testing results. In this way, the glucose monitoring can be more humane to patients, and its ability in continuous data tracking can benefit the personalized medicine readily.

The figure shows the glucose monitoring SoC and its packaging strategy. A capacitive sensing structure is formed by a glucose-sensitized hydrogel that has a AAO (Anodic Aluminum Oxide) membrane on-top and a MEMS capacitor plate on the bottom. The volume of hydrogel varies with the glucose concentration and makes compression force difference on the MEMS capacitor, which leads to the changes in the air gap of this capacitor and a signal of the capacitance variation for further readout. The glucose-induced capacitance changes can be read accurately by readout circuits. The readout circuits consist of a current generator, a capacitance-to-frequency (C-F) converter, and a DCA processor. A feedback loop is formed from DCA to current generator to minimize the detection resolution. C-F converter, which embraces a sensing clock loop (SCL) and utilizes dynamic comparator, uses digital counting approach to reduce the power consumed by converting bio-signal from analog to digital domain. The wireless ASK transceiver will be waked up only by an external activation signal for saving energy. Wireless circuits include LNA, Pre-Amplifier, Demodulator, Buffer, Ring-Oscillator, and Power Amplifier.

In summary, An implantable wireless glucose monitoring SoC with hydrogel-based glucose sensor is proposed in CMOS 0.35 um technology. Owing to the reusable nature of the hydrogel glucose sensor and the wireless readout ability of the circuitry, this SoC is suitable for long-term and continuous monitoring. In-Vitro test shows a resolution of 40 mMole in glucose detection. The total power consumption of the SoC is 285 nW in standby mode and 11.9 mW in data transmission mode.