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An Implantable Sensing and Programmable Stimulation CMOS SoC for Trigeminal Neuralgia Alleviation on Demand

治療三叉神經痛之可植入式CMOS感測與可調參數電刺激系統晶片

隊伍名稱

最佳刺激機 / The Only Stimulator

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作品摘要

隨著現今社會的高齡化及對高生活品質的追求，對醫療電子產品的需求也日漸增加。我們的夢想是以CMOS標準製程來實現一個使用便利、高安全性及高療效的生醫微型單晶片，使植入式醫療產品的使用更為便利和普及，以期造福更多的病患及降低醫療的成本。因此，一個價格合理、即刻治療、安全且有效的設計就成為了我們本次作品的目標。此次鎖定的病症是三叉神經痛，這是一種極重度疼痛的病症，疼痛程度約等同於癌症末期，曾被稱為是自殺疾病。因此，三叉神經痛是一種非常需要即刻止痛的病症，是一個很適合本作品的應用。

本作品的重點特色有三：一、即刻治療。無論何時何地，都可以使用手持裝置無線供電來進行治療，無需到醫院去，也沒有電池更換的問題，極具便利性。二、結合前端感測器介面電路及可調參數波形產生器。感測器可提供體內溫度及阻抗的資訊，再依此來判斷是否進行電刺激治療或調整電刺激參數，使安全性和療效可以進一步地得到提升。波形產生器可依不同參數產生不同強弱、頻率及波形的電刺激輸出，使療效可以針對病患個人達到最佳化。三、多病症治療平台。本作品可針對三叉神經痛及癲癇分別進行治療，達到單一晶片可以治療多種疾病的目的。不但功能較單一功能晶片更佳，而且還可以進一步降低製造的成本。我們之後計畫以單晶片來完成更多病症治療的整合，使此創意可以真正地表現出它的價值。

實作上，本作品以台積電0.35um CMOS製程實現了一個可植入式感測及止痛系統單晶片（SoC），結合臨床上所使用的脈衝式射頻電刺激，以低電壓來刺激三叉神經節，可有效地治療三叉神經痛，同時也可以避免對神經組織造成熱破壞。此晶片不需電池，晶片的無線供電電路可將電磁波吸收後轉換成直流電壓，當使用者需要使用晶片進行治療時，只需將手持裝置靠近晶片即開始動作，其使用1MHz無線電波進行充電，就可供應整個系統的運作。使用者亦可利用手持裝置，以MICS頻段進行無線傳輸，更改晶片的電刺激參數，同時晶片也可以感測晶片溫度與組織增生情況供使用者參考，搭配體質及當下的需求，彈性調整所欲輸出電刺激訊號的強弱、頻率、波形等，形成一個回授路徑，以達到對使用者最安全有效、最為即時的電刺激治療。晶片同時也內建了癲癇的電刺激波形，可刺激迷走神經來抑制癲癇的發作，以單一系統晶片輸出不同電刺激波形來達成治療多種病症的目的。

在動物活體實驗中，我們將大鼠的三叉神經以羊腸線打結來壓迫以產生疼痛感，接著以電刺激模組連結植入電極進行治療，不同於傳統數十伏特的電刺激，本晶片採用5伏特電壓進行刺激5分鐘。實驗結果顯示，有進行電刺激的大鼠具有近乎正常大鼠的疼痛承受能力，且可以持續兩天以上。這不但驗證了此晶片使用的脈衝式電刺激確實具有止痛療效，同時也與藥物實驗對照，此止痛效果也遠超過臨床常用止痛藥物的療效。本作品並於今年獲得EE Times資深編輯R. Collin Johnson來臺採訪及肯定。

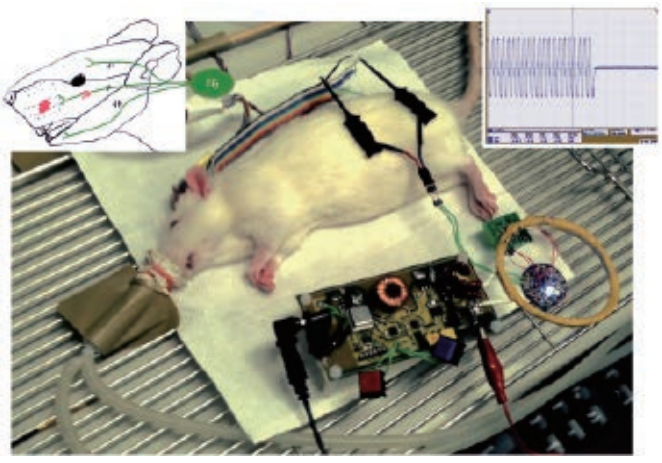

圖1 > 三叉神經痛動物實驗電刺激波形及設定

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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。

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臺灣大學電機研究所博士。曾任職於台積電設計服務部門從射頻類比之 IP 設計，目前擔任臺北科技大學電腦與通訊研究所副教授。

研究領域

無線電力傳輸、生醫電路之晶片與系統之相關研究。

Abstract

Due to the graying population and pursuit of high life quality, the demand for medical electronic products is growing day by day. Our dream is to realize a bio-medical micro-chip with high convenience, safety and curative effect by utilizing CMOS standard process and make implantable medical electronics be used more conveniently and widely. Thus we can benefit more suffering patients and decrease the medical cost. As a result, the goal of our work is to implement a design with reasonable price, immediate treatment, high safety and curative effect. Trigeminal neuralgia is the most painful disease as well as terminal cancer, and it's dubbed "the suicide disease". Consequently, trigeminal neuralgia patients need immediate treatment much badly, and it is a quite suitable application for our work.

Our work has three key features. First, it can provide immediate treatment. Users are able to treat themselves anywhere anytime with a handheld device. They don't have to go to hospital for treatment, and no battery replacement issue bothers. Second, it integrates front-end sensor interface circuit and programmable pattern generator. Sensors can provide inside temperature and impedance information, and accordingly users are able to wirelessly program the pain-control chip for the best effectiveness. Last, it can be a platform for multi-disease treatment. This chip is designed for both trigeminal neuralgia and epilepsy treatment. It not only has the function of multi-disease treatment but also further lowers the fabrication cost. We are going to improve this work by the pain control of more disease and make our idea show its real value.

In this work, we implemented an implantable sensing and pain-control SoC, using a low voltage PRF stimulation which works well in trigeminal neuralgia alleviation and avoids causing thermal damage to tissues, with 0.35μm CMOS process. The RF power is inductively coupled to a coil antenna and converted to DC by a full-wave rectifier when putting handheld device close to the chip. This chip needs no battery and sustains normal operation with the RF power. Users also can specify a customized stimulation protocol in MCU wirelessly with a handheld device. Simultaneously temperature and impedance info can be sensed during system operation, and users can take it as a reference for parameter adjustment to achieve quiet safe and effective treatment. It's also effective in epilepsy treatment by applying PRF stimulation to the vagus nerve. This bio-chip generates specified stimulation pattern for each disease to achieve multi-disease pain control.

In the animal experiment, the trigeminal nerve was ligated by catgut to induce trigeminal neuralgia. We connected the module to inserted electrodes and provided PRF stimulation of 5V, in contrast to the conventional tens volts for a duration of 5 min. The experimental group with PRF stimulation consistently had much higher pain tolerance than the control group without PRF stimulation, and the curative effect can sustain more than 2 days. This result not only demonstrates the effectiveness of PRF treatment for pain alleviation of trigeminal neuralgia, but also shows the curative effect of PRF stimulation is much better than that of commonly used clinical drug according to medicine experimental results. This work is also interviewed and recognized by senor editor R. Collin Johnson from EE Times in Taiwan this year.

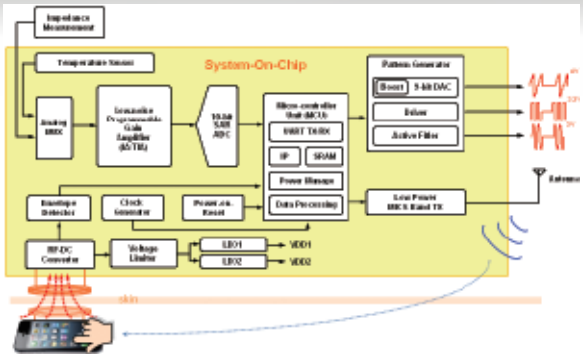

Fig.2 > System block diagram of implantable PRF stimulation SoC