國立交通大學

電子研究所

碩 士 論 文

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The Design of 180-nm CMOS Auto-Adaptive 256-pixel Sensing and Biphasic Current Stimulation Chips with Bidirectional-Sharing Electrodes and Closed Loop Charge Pump for Subretinal Prosthesis

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中華民國一〇九年十月

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摘要

本論文提出及分析應用於下視網膜植入具自動適應光源像素電路提升影像光動態範圍之互補式金氧半太陽能供電256像素晶片，晶片以台積電0.18微米互補式金氧半影像感測器(CIS)製程設計並製作。在此晶片中，重要創新有自動適應光源之像素電路、雙向共用電極(BDSEs)配合最佳化刺激安排使串擾電荷最低、使用脈波省略調變與脈波頻率調變之閉迴路電荷泵、改良式定電流刺激器和恆定電流產生器。

在自動適應光源像素電路中，可模仿人眼對影像光反應之Michaelis-Menten方程式(MME)特性，並產生MME電流。而後主動像素感測器(APS)可將MME電流轉換為電壓，進而產生刺激電流。根據上述操作，環境中的背景光可被消去，而增加晶片之影像光動態範圍。

此晶片採用雙向共用電極和分區供電，以增加電極面積與刺激電荷，並降低

功耗，最佳化刺激安排可降低因串擾所造成的漏電荷，最大總漏電荷可降至1.07nC，可降低誤刺激的可能性。電荷泵中加入脈波省略調變與脈波頻率調變，組成閉迴路電荷泵，可得到較穩定之刺激電壓。改良式定電流刺激器可避免在動態回復階段時誤開啟之電晶體所產生的漏電路徑，也減少了刺激器會產生的暫態峰值電流，因此可降低細胞受損之風險。另外，改良式定電流刺激器使用N型金氧半電晶體作為電流源，可降低因電荷泵產生之暫態漣波對刺激器的影響。所設計的恆定電流產生器，可以產生不受製程飄移影響之偏壓電流給環式震盪器，以降低晶片與晶片之間的頻率飄移。

所研製之晶片其面積為3.2 x 3.2平方毫米。閉迴路電荷泵之輸出電壓經量測確認在輕載時刺激電壓並不會超過水窗限制。量測晶片之最小感測光強為39Lux而最大為21267lux，量測之動態範圍提升至54.7dB。量測之最大刺激電流為7.09uA，最大刺激電荷為8.89nC。透過模擬與量測均已驗證刺激電流與輸入光強可產生類MME之轉移函數。晶片與晶片間之頻率飄移，經過量測可知在23.5Hz到28.6Hz之間。與上一版晶片[21]相比，動態範圍增加為1.79倍，暫態峰值電流可降低至接近0uA，刺激頻率變化為23.5Hz～28.6Hz(-94%～114%)，其飄移遠低於[19]-[21]的值。所研製晶片已進行rd1小鼠之視網膜體外膜片鉗技術實驗，驗證該下視網膜晶片之功能。晶片之電流刺激可成功誘發rd1小鼠之視網膜神經節細胞，並且成功驗證背景光消除之功能。

透過電性量測與體外實驗，已成功驗證所設計具自動適應光源像素電路提升寬動態範圍之下視網膜晶片的功能。結果印證本論文提出之下視網膜晶片適用於視網膜植入。

THE DESIGN OF 180-NM CMOS AUTO-ADAPTIVE 256-PIXEL SENSING AND BIPHASIC CURRENT STIMULATION CHIPS WITH BIDIRECTIONAL-SHARING ELECTORES AND CLOSED LOOP CHARGE PUMP FOR SUBRETINAL PROSTHESIS

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ABSTRACT

A CMOS photovoltaic-powered 256-pixel subretinal prosthetic chip with auto-adaptive pixel circuit for wide image dynamic range is proposed and fabricated by TSMC 0.18um CIS (CMOS Image Sensor) technology. In the proposed chip, the key innovations are auto-adaptive pixel circuit, bi-directional sharing electrodes (BDSEs) with optimized stimulation pattern to minimize crosstalk charges, closed-loop charge pump with pulse-skip modulation (PSM) and pulse-frequency modulation (PFM), improved constant current stimulator and improved constant current generator.

In the auto-adaptive pixel circuit, the characteristic of Michaelis-Menten equation (MME) in human eyes can be mimicked by auto-adaptive pixel circuit to generate the MME current. Then the APS (active pixel sensor) circuit is used to transfer

the MME current into a voltage which generates the corresponding MME-like stimulation current. Thus the background light cancellation can be performed to increase the image dynamic range.

Bi-directional sharing electrodes (BDSEs) and divisional power supply scheme (DPSS) are adopted to increase electrode size and stimulation charges while reducing power consumption. The optimized stimulation pattern is designed to reduce the charge leakage of crosstalk. The maximum total charge leakage is decreased to 1.07nC to reduce the risks of error stimulations. Pulse-skip modulation (PSM) and pulse-frequency modulation (PFM) are added to the charge pump to form the closed-loop charge pump and obtain a stable stimulation voltage. The improved constant current stimulator is designed to avoid the undesired turn-on of MOS devices in the active recovery phase and decrease the transient peaks of the stimulation current so that the risk of tissue damage can be reduced. The improved constant current stimulator also take the advantage of NMOS current source to avoid the transient ripples from the supply voltage generated by the charge pump. A process independent constant current generator is designed to generate a stable bias current for the ring oscillator so that the stimulation frequency is stabilized with low die-to-die frequency variations.

The chip area is 3.2mm x 3.2mm. The output voltage of closed-loop charge pump has been measured to confirm that the stimulation voltage does not become higher under the light loading to exceed the water-window limit. The measured minimum illumination of signal light 39Lux. The maximum stimulation current can be measured under illumination of 21267Lux signal light. The measured dynamic range of the input light is increased to 54.7dB. Moreover, the maximum stimulation current is 7.09nA and the corresponding maximum stimulation charge is 8.89nC. The MME-like shape of stimulation current versus light intensity has been verified by simulation and measurement. Furthermore, the measured die-to-die variations of stimulation frequency reduces to 23.5Hz to 28.6Hz. As compared with the previous work, the image dynamic range is 1.79 times larger than [21]. The transient peak of improved constant current stimulator is ~0uA and the stimulation frequency variations of the work is 23.5~28.6Hz (-94%~114%), which are much lower than those in [19]-[21]. The *ex vivo* patch clamp experiments with the retinas of *rd1* mice have been performed to validate the functions of fabricated subretinal chip. The retinal ganglion cells (RGCs) of retinas have been successfully evoked by the stimulation current pulses from the chip and the function of background cancellation has also been verified.

Through both electrical measurement and *ex vivo* experiments, the functions of designed subretinal chip with auto-adaptive pixel circuit for wide image dynamic range have been validated. It is shown that the proposed subretinal chip is suitable for retinal implant.