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Medical Electronics --- A Challenge and Opportunity for Semiconductor Technologies and Biomedical Sciences

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Abstract

The major design trends in medical electronic devices/systems are portability, miniaturization, connectivity, humanization, security, and reliability. Leading semiconductor technologies are enabling technologies for medical devices/systems to meet these trends. The general architecture of advanced implantable medical devices/systems consists of microchips, bio-compatible materials, package/integration, and biotic-abiotic interfaces. The needed enabling technologies are described. Two biomedical electronic systems are presented as demonstrative examples. One is the closed-loop SOC for real-time epileptic seizure control and the other is the self-powered sub-retinal implantation system for visual prostheses. Finally, research challenges and semiconductor engineering hope with medical electronics are addressed.

1. Introduction

Recently, increasing effort has been devoted to the research of medical electronics because of the strong demand from increasing global aging populations and rising healthcare needs in both emerging/remote regions and homes. Medical devices/systems, instruments, and appliances that treat intractable neurological disorders, restore health, and enable biotechnology development, are driving forces for future growth of the electronics industry. It is an technical area that bridge semiconductor engineering, biology, and medicine, and has great opportunities and challenges.

The major future trends in medical electronic devices/systems are portability, miniaturization, connectivity, humanization, security, and reliability. Portability requires accurate bio-signal sensors/actuators, efficient system power management, ultra-low power electronics, and energy harvesters. Miniaturization requires advanced integration technologies like CMOS integrated circuits or heterogeneous 3D integration of CMOS, MEMS, and/or flexible technologies. Connectivity requires low power RF wireless communication technologies. Humanization of medical devices requires design considerations from patients and clinical experiences as well as flexible or wearable electronics. Data security requires more hardware and software tools to support medical data security in RF transmission and storage. Reliability requires enforcement of regulations and standards.

The general architecture of advanced implantable medical electronic system consists of microchips/SOCs, bio-compatible materials, hermetic packaging and interconnect, and biotic-abiotic interfaces. A SOC may consist of sensors/actuators/stimulators, bio-signal processing units, power harvesting and management unit, and/or RF communication units, that involves many cutting-edge research topics. The research of bio-compatible materials is related to biocompatibility, biophysics, bio-adhesives and organics. Hermetic packaging and interconnect requires technologies in high-density interconnect, flexible substrates, inert coating, and thin-film polymers. Biotic-abiotic interface requires research on tissue response, neuroscience, electrophysiology, cell growth, and biomarkers. The applications of medical electronic systems are in the treatment of intractable neurological disorders and chronic diseases, healthcare, telemedicine, preventive medicine, etc.

2. Demonstrative Examples

As demonstrative examples, two biomedical electronic systems will be presented. One is the closed-loop SOC for real-time epileptic seizure control and the other is the self-powered sub-retinal implantation system for visual prostheses. In the CMOS 8-channel closed-loop neural prosthetic SoC implemented in 0.18um technology, real-time seizure-triggered neuro-modulation is performed [1]. The chip photography is shown in Fig. 1 where the chip size is 2.76mm x 4.88mm. Entropy-and-spectrum-aided seizure detection and adaptive neural stimulation are also presented. The SoC integrates 8 AFEAs, a DMSAR ADC, a bio-signal processor, and an electrical stimulator. The AFEA is designed with configurable gain and bandwidth. The DMSAR ADC operates at 500k Samples/s with the ENOB of 9.57b. The BSP implements an efficient seizure detection algorithm and achieves 92% detection accuracy in 0.8s. The stimulator delivers a constant 30μA stimulus current. In addition, the wireless power-and-data transmission system, including a MedRadio-band transceiver and an inductive link power supply system, is embedded for signal monitoring and wireless power transmission. It is demonstrated that the proposed SoC is able to successfully suppress epileptic seizures of Long-Evans rats. From the preliminary results, the developed closed-loop seizure control SoC is a promising solution for treating epilepsy.

Future research on hermetic packages with multiple interconnect for sensing electrodes up to 16 or 32 and stimulation electrodes up to 8 is needed. 3D electrodes with

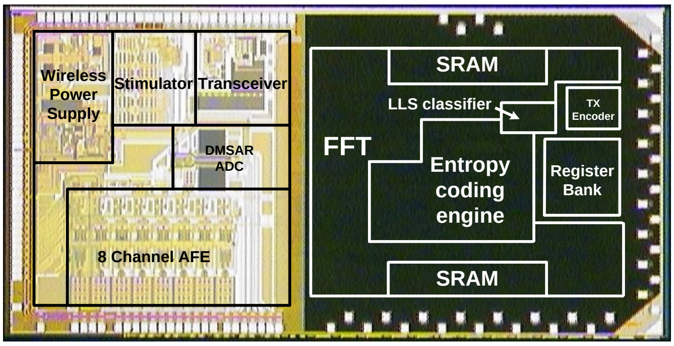

Fig. 1 Chip photograph of the SoC for closed-loop epileptic seizure control

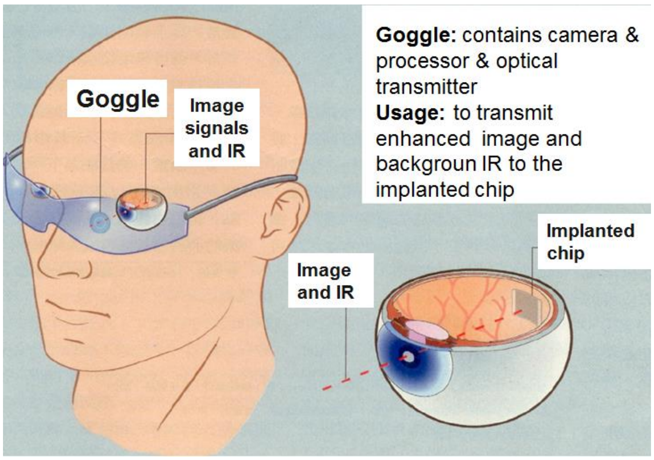

Fig. 2 Conceptual architecture of the self-powered sub-retinal implant system.

bio-compatible material coating for deep brain stimulation as well as flexible coils and antenna is also needed in the system integration.

The sub-retinal implantation system includes intraocular and extraocular units as shown in Fig. 2. In the intraocular unit, a CMOS self-power chip with photo-sensors, stimulator, solar cells, and electrodes is required for optical sensing and neural stimulation. In the extraocular unit, a goggle system is equipped with processor and optical transmitter. Successful ERG signal recorded after the implantation in the in-vitro test [2] has indicated that the method is promising.

Future research challenges are on the on-chip electrodes with bumps and bio-compatible material coating, high-efficiency on-chip solar cells, and increasing number of pixels to 1000 and beyond while keeping the chip size, power dissipation, and stimulation current the same. This might need advanced nanoelectronics technologies.

3. Conclusions

As CMOS technology is moving toward sub-10nm nodes future medical devices/systems will have great benefits from this technology advancement. Million-channel non-contact bio-signal sensing, real-time processing and neural stimulations with wireless transmission and control are feasible. Handling the cells and understanding human neural function are possible.

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