Optoelectronic CMOS Power Supply Unit for Interventional MRI Devices

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Introduction

The most challenging task in development of active interventional devices for MRI environment is realizing a safe transmission system where conductor line usage is avoided due to strong RF field related heating effects [1][2]. Therefore, optical transmission systems are becoming more popular in active interventional MRI devices [3]. In such transmission systems, the optical powering is usually realized with specially built photovoltaic solar cell based optical components. Although photovoltaic solar cells have been frequently used as the optical-to-electrical converters for macro-scale applications [4][5], they are not convenient for micro-scale biomedical implants [3][6] which demand compact, miniaturized optical-to-electrical converters. CMOS compatibility of the optoelectronic device becomes an important issue when there is a need of high-level integration of various functionalities in a small area using a single substrate [7]. A solution to the challenge of realizing a compact device is to use CMOS photodiodes as solar cells and hence realize a monolithic integration of solar cells and electronic circuits.

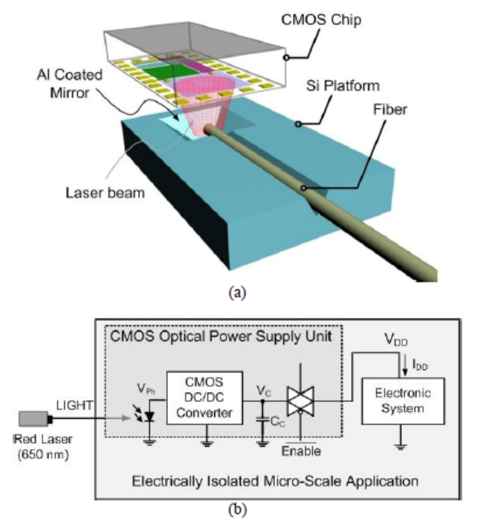

Fig. 1 (a) Sketch of the physical realization of the integrated system. (b) The architecture of the proposed CMOS power supply unit.

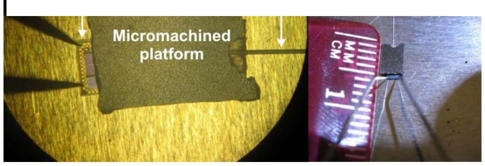

Fig. 2 Integration of CMOS Photodiodes with fiber lines.

Methods

Physical realization of the optical power supply presented in this paper is shown in Fig. 1(a). There are two main blocks for this system, namely CMOS Application Specific Integrated Circuit (ASIC) chip where optical power is translated into electrical counterpart and a micromachined silicon based platform which serves both as a path for the fiber line and a mirror that reflects the light coming out of the fiber to the photodiodes on the CMOS chip. Front side of the CMOS chip is facing to the mirror of the fiber-platform for optimum coupling of the light to the CMOS photodiode. The mirror consists of a V-shaped groove for placement of the fiber cable and a mirror with an angle of 54.7 degrees specified by the micromachining process. In order to increase the reflectivity of the mirror, the platform is coated with 25 nm thick aluminum layer. Integration of the CMOS chip and the fiber-platform is accomplished by injecting epoxy in between the mirror opening and the electronics chip. Fig. 1(b) shows the architecture of the proposed CMOS power supply unit utilized in an electrically isolated micro-scale application. The working principle of the proposed unit can be described as follows; the very low voltage on the photodiode (V_{Ph}) generated by the light from an external laser source serves as the input voltage for the DC/DC voltage converter, where two cascaded stages of voltage doublers driven by two clock signals step up the input voltage to a higher level (V_C) and accumulate the charge on a storage capacitor (C_C). The accumulated charge can be transferred directly to any electronic system in order to function as a power supply. Besides, transferring the charge through a transmission gate activated by an appropriate control signal enables supplying more current (I_{DD}) at a voltage level (V_{DD}) for applications powered intermittently.

Results

Designed integrated circuits (ICs) are implemented with UMC 0.18µm triple-well CMOS technology using a foundry service. The die area is 1.5 mm × 1.5 mm. The DC/DC converter circuit consumes an area of 340 µm × 340 µm. The photodiodes has an area of 300 µm × 300 µm. Silicon mirror platforms are fabricated in house using basic bulk micromachining processes. Coating the silicon mirrors with a reflective material such as aluminum is necessary in order to increase their reflection performances. The reflectivity of the silicon mirrors are measured by inserting a fiber optic cable inside the silicon V-grooves and measuring the incident laser power inside the fiber and the reflected laser power from the silicon mirror using an optical power meter. A multimode fiber optic cable with a diameter of 125 µm and a core diameter of 62.5 µm is used in the experiments.

The pictures of the packaged system are shown in Fig. 2. The packaged system is characterized by monitoring the output current and voltage of the DC/DC converter circuit while a laser beam is applied to the photodiode on the same die at different power levels through fiber optic cable. The results are presented in Fig. 3. The experimental results show that the proposed power supply unit is able to deliver 50 µA of bias current with a 1.2 V of supply voltage to an electronic system continuously, when an external optical power of 160 mW is given as the input. It is projected that the same electrical power can be achieved with an optical power of 24 mW if metal patterns above the photodiode are removed.

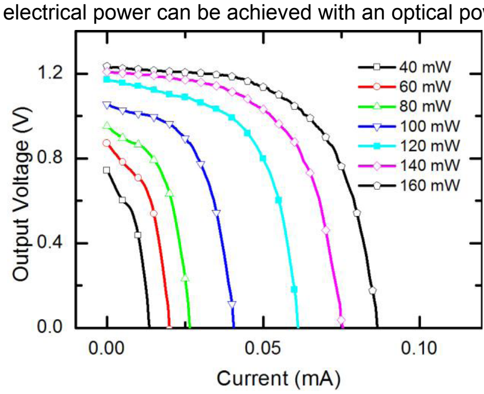

Fig. 3 The current-voltage characteristics of the DC/DC converter with a triple-well photodiode illuminated at different optical power levels by using micromachined mirror platform.

Conclusion

Our results confirm that the proposed miniaturized optical power supply unit could be used at the tip of the interventional devices consuming powers in the mW range.

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