A THIN FILM FLEXIBLE ANTENNA WITH CMOS RECTIFIER CHIP FOR RF-POWERED IMPLANTABLE NEURAL INTERFACES

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ABSTRACT

This paper reports a parylene film antenna integrating a CMOS rectifier chip for wireless neural recording devices. An implanted antenna requires the flexibility to fit the shape of brain surface. In addition, an integrating technology with solid-state and flexible substrate is needed because a silicon chip can provide high-performance and multi-functionality. The fabricated device that packages antenna, transformer, and rectifier generates more than 1.5V and achieves a power transmission efficiency of 0.086 %.

KEYWORDS

Antenna, Parylene, Rectenna, Flexible, Implantable, Wireless Power Transmission

INTRODUCTION

Neural interfaces have been studied in order to monitor neural activity for several applications such as the brain machine interface (BMI) and scientific researches [1]. Recent reports, the operation of the robot arm has been achieved by analyzing the data of neural signals from the brain by using wired BMI [2]. However, these wired neural interfaces have problems that restrain the BMI user by their wires and increase the risk of infection. The wireless systems have been considered for data communication from implantable device to outside the body [3]. Therefore, the implantable neural interface requires a small antenna and wireless module for noninvasive implantation. In addition, the wireless power transfer (WPT) technology is necessary for long-term implantation on the brain because the battery must require replacement.

Although the method using electromagnetic induction by the two coils has been demonstrated for WPT, it is difficult to align these two coils and it is short range of communication distance [4], resulting in inconvenience to patients. Therefore, WPT by using radio frequency (RF) wave has been discussed to solve these problems [5]. The embedded antenna is required high-gain and low frequency because the radio wave emitted to the antenna embedded on the human brain is absorbed in the human bio tissues [6]. In order to produce high efficiency antenna, we proposed on-chip antenna using a sapphire substrate [7]. However, although the sapphire chip antenna is realized very small size of 5mm×5mm and high antenna gain, it is difficult to integrate the antenna, high-performance circuits and sensor devices. Therefore, we proposed the ultra-thin flexible devices such as neural electrodes and antenna by using the parylene film which has a good biocompatibility [8, 9].

We propose a flexible WPT device in order to implant on brain surface for an RF-powered neural interface as shown in Fig.1. This device has the neural electrode and the antenna realized by a flexible film, and high-performance CMOS circuits realized by the silicon chip [10-17]. For integrating these different substrates which have several functions, we used a flip-chip bonding technology. In this study, we fabricate a WPT device by using package technology of a flexible antenna and a CMOS rectifier chip. The purpose is to realize WPT by using this device immersed in saline tank that assumes the brain model.

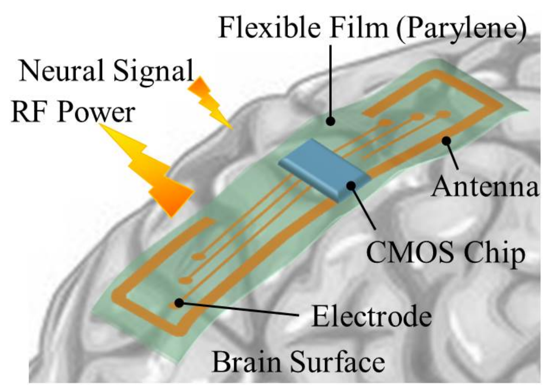

Figure 1: Concept of fully-implantable flexible neural interface device with Si CMOS LSI chip

DESIGN OF A FLEXIBLE DEVICE

The small size or flexible antennas have been studied for implantable and wearable devices [18]. In design of an antenna embedded on brain, the structure which has the dielectric layer between antenna electrode and GND is undesirable because it have a thickness of several hundred μm In order to fit the shape of the brain surface, flexible substrate is necessary to realize ultra-thin film about several tens of μm. Therefore, the antenna model was used the dipole antenna to realize in a thin film. A parylene film was selected as a flexible substrate because of a good biocompatibility. Figure 2 shows a designed flexible antenna. The antenna metal line is patterned width of 1 mm and thickness of 120 nm by Au. The Au line is coated by parylene film which has total thickness of 10 μm in order to insulate from bio tissue. The designed antenna was analyzed by electromagnetic field analysis using high frequency structure simulator (HFSS). The saline is used for analysis instead of the biological tissue because modeling of brain tissue in simulation and measurement system is difficult.

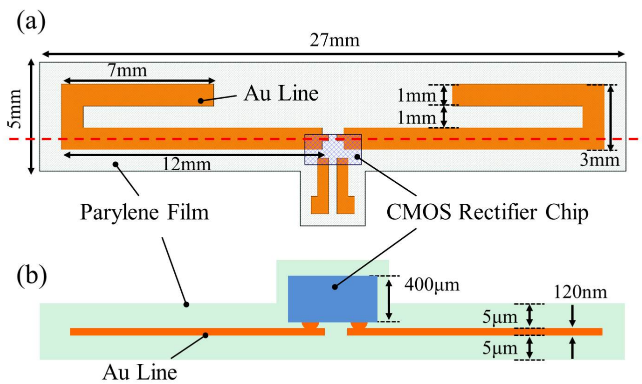

Figure 2: Design of flexible antenna, (a) Top view, (b) Cross section

Figure 3 shows a circuit schematic of the proposed WPT device. An RF-DC conversion is based on CMOS full-wave rectifier [19], which has a function of charge pump and it is fabricated in an 180nm CMOS process. The input impedance of the CMOS rectifier is expressed as a series of high resistance and capacitance. Therefore the CMOS chip contains an on-chip transformer with a turn ratio of 1: 3 for impedance matching. Additionally, In order to cancel the capacitance component of a CMOS rectifier, the flexible antenna is designed to have inductance.

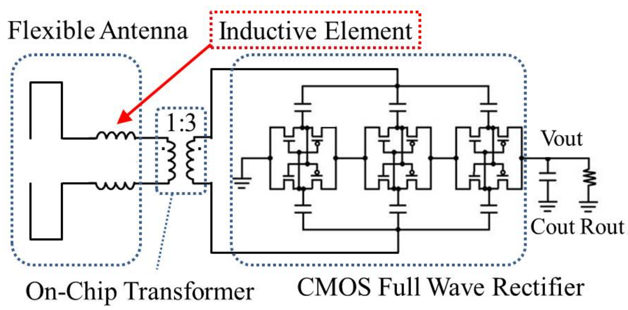

Figure 3: Circuit schematic of the proposed WPT device: the antenna with inductance can removes on-chip inductor, saving die area of CMOS rectifier chip.

FABRICATION PROCESS

The flexible antenna was fabricated by using silicon wafer. The fabrication process of parylene film antenna is illustrated in Fig.4. First, titanium was sputtered on a silicon wafer as a sacrificial layer. A parylene was deposited by thickness of 5 µm on Ti layer, and Au layer was sputtered by thickness of 120nm on parylene layer. Au line was patterned by using photolithography and a wet etching. The CMOS rectifier chip was bonded to an antenna pad by using a flip chip bonder and the anisotropic conductive paste. After bonding a CMOS rectifier chip, a parylene was deposited by thickness of 5 µm again. The output pads were opened using metal mask of Ti by plasma etching and then parylene film was patterned. Finally, by etching the sacrificial layer of Ti, the parylene film was released from silicon wafer.

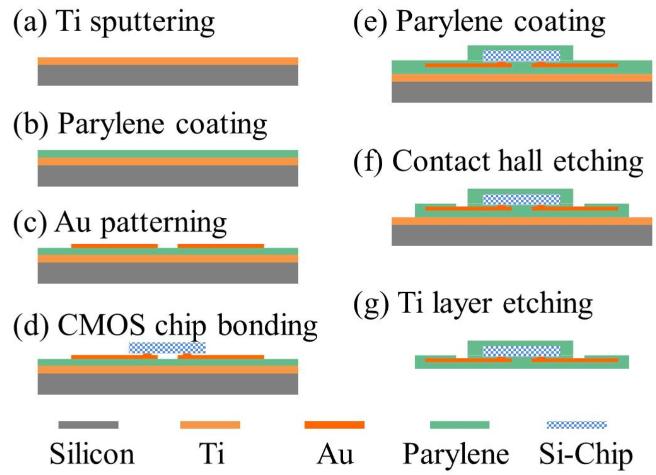

Figure 4: Fabrication process of flexible antenna integrating CMOS rectifier chip

Figure 5 shows the fabricated parylene film device and the bonded full wave rectifier chip photo. The flexible device has size of 27 mm × 5 mm and has a good flexibility. The CMOS rectifier chip has a size of 1100 µm × 840µm and a total of four pads of the rectified output voltage, GND and the RF signal input.

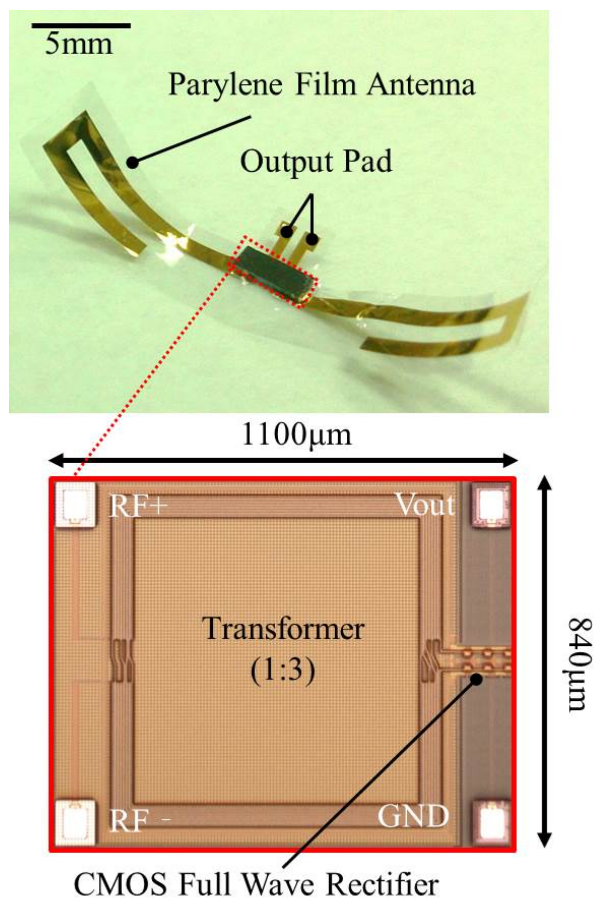

Figure 5: Fabricated device photo and CMOS rectifier chip

MEASUREMENT OF FLEXIBLE ANTENNA

The antenna characteristics were assessed by measuring the fabricated antenna immersed in saline for assuming the embedded to brain. The saline is composed by water mixed with 0.9 wt% of NaCl. Figure 6 shows the return loss characteristics in simulated and measured. In measurement result, the resonance frequency was observed at 825 MHz, then the input impedance was 29.3 + j49.4 Ω and return loss was -4.83 dB. Ad designed, the fabricated flexible antenna has inductive input impedance immersed in saline. Since the measured return loss characteristic is slightly different compared with the simulated result, it is considered that caused by the Influence of the parasitic capacitance of the wiring for the measurement setup, and the slightly difference in model of simulation and the measurement.

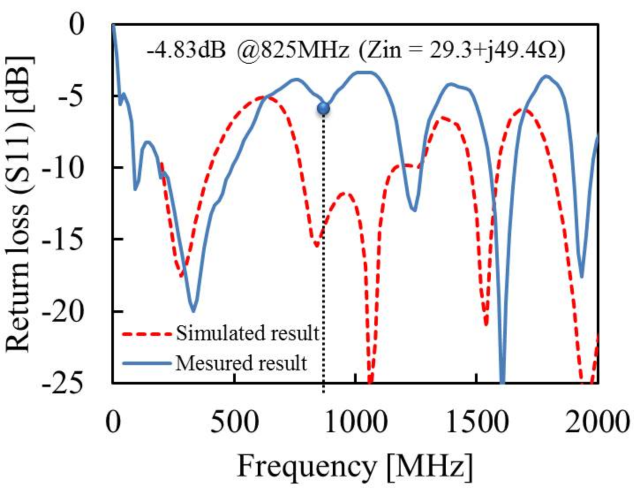

Figure 6: Simulated and measured return loss characteristics of antenna in saline (S_{11})

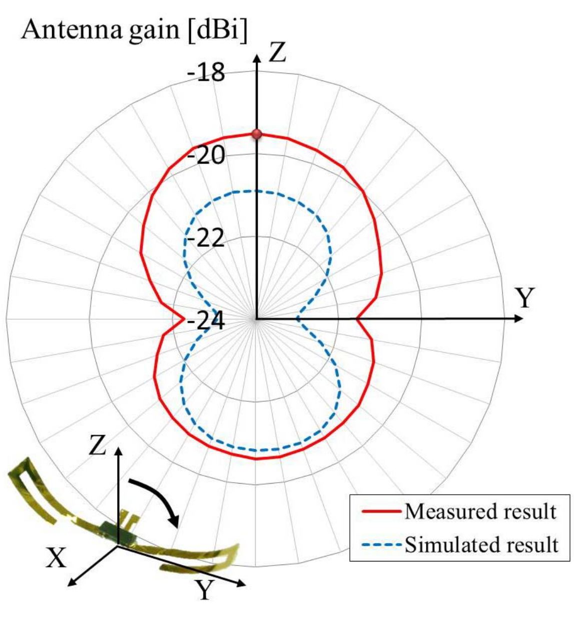

Figure 7: Radiation characteristics immersed in saline

The radiation characteristics of the antenna were measured in a state immersed in saline tank. The antenna gain and directional characteristics were measured at a distance of 1 m between the fabricated antenna and the standard dipole antenna. The assessed frequency region is 825 MHz which is the resonance frequency of the flexible antenna. The fabricated antenna has the antenna gain of -19.04 dBi in direction of Z axis. Figure 7 shows the directional characteristics of the fabricated antenna, which is measured by rotating 10 degree each. The radiation pattern in ZY plane is like to standard dipole antenna's one. The measured radiation characteristics were nearly identical to calculated characteristics by simulation.

WIRELESS POWER TRANSFER

We demonstrated WPT using fabricated flexible device. The RF signal of frequency of 825 MHz was transmitted using dipole antenna at a distance of 10 cm from saline tank as shown in Fig.8. The load resistance of 100 kΩ and the capacitance of 100 μF were connected to the output port of the rectifier. The efficiency of RF to DC conversion was calculated by measuring the power of rectifier output port. Figure 9 shows the relationship of the total efficiency versus the input RF power.

The input power was increase 0.5 dBm each to 15 dBm. The RF power was hardly converted to DC power, when the input power was 10dBm or less. The input impedance of the CMOS rectifier becomes high impedance when the power of the RF signal input to the MOS transistor gate is lower than threshold voltage of gate. The maximum efficiency in this WPT device was 0.086 % at the input power of 14.5 dBm In addition, the RF-DC conversion efficiency is varied depending on the load resistance connected to the output terminal of rectifier. Therefore in order to maintain maximum conversion efficiency with respect to any input power, the circuits to monitor the conversion efficiency and control the load resistance are required.

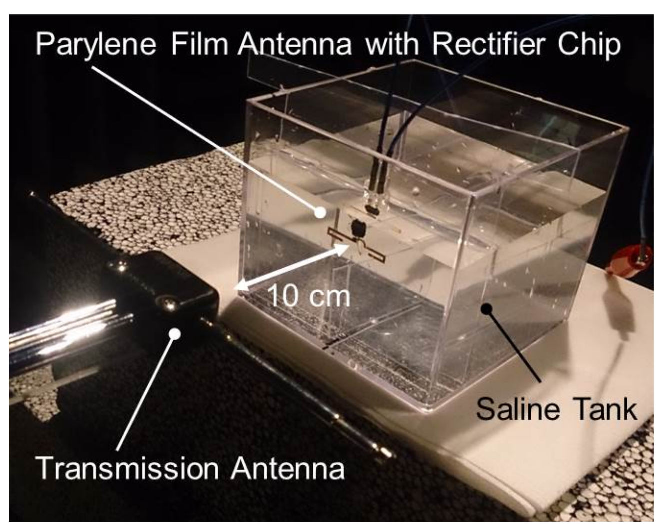

Figure 8: Measurement setup of WPT demonstration

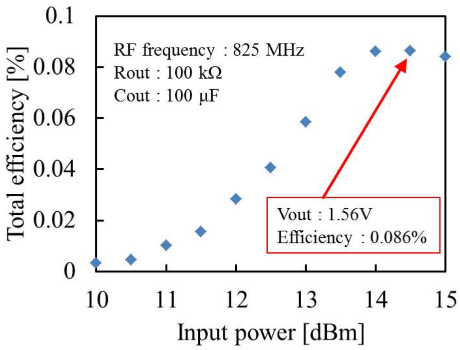

Figure 9: Total efficiency of wireless power transmission

CONCLUSION

In this study, we proposed a WPT device using a technique to integrate the flexible substrate and CMOS chip for RF-powered implantable neural interfaces. Flexible antenna can be designed by electromagnetic field simulation using a saline model. In WPT demonstration, we achieved RF-DC conversion efficiency of 0.086% when the RF power was transmitted from 10cm distance. Therefore, the proposed parylene film antenna with a CMOS rectifier is expected to supply power to implantable devices.

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