ELectronics EXpress

IEICE Electronics Express, Vol.5, No.15, 574–580

A visual prosthesis with 100 electrodes featuring wireless signals and wireless power transmission

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Abstract: A visual prosthesis is an artificial sensory organ that transmits visual information to a blind person by electrically stimulating residual neurons in the visual nervous system. Such a system requires a large number of stimulating electrodes: It is technically difficult to connect a stimulator placed behind the ear to each of the stimulating electrodes over any significant distance with high reliability. We propose a visual prosthesis containing a multiplexer that is separately placed from the stimulator unit. The array of stimulating electrodes is connected to the stimulation unit through a multiplexer. The stimulating electrodes and multiplexer are placed onto the suprachoroidal space. The stimulation unit consists of a metal case and a coil and is implanted in the postauricular region of the cranium. The multiplexer and the stimulator unit are connected by a cable composed of six wires. Incorporating the multiplexer enables us to control of a large number of electrodes using a small number of conductors in the cable. We have developed a system with 100 electrodes which is powered and controlled wirelessly. Then we have confirmed that the proposed system functions successfully both in vitro and in vivo.

Keywords: visual prostheses, electrode, multiplexer
Classification: New functional devices and materials

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DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

IEICE Electronics Express, Vol.5, No.15, 574–580

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DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

1 Introduction

Recently, research both in Japan and overseas has accelerated in the field of artificial sight for patients with acquired sight disabilities; these efforts have concentrated on electrically stimulating the patient's remaining visual nervous system to transmit information to his visual center [1, 2, 3]. Our research group has been developing a system that uses suprachoroidal transretinal stimulation (STS) for this purpose [4]. Cochlear implants share many technical commonalities with visual prostheses, including signal transfer and wireless communication. One research group is actually pursuing development of an artificial vision system in collaboration with a cochlear implant manufacturer [1, 5, 6]. However, there is the technical challenge of establishing an electric connection over the considerable distance from the interiors of the eyeballs to the stimulator unit implanted behind the ears without any cable interruptions due to eye movement. The larger the number of electrodes, the more difficult this becomes. Simulations of artificial vision systems have suggested that over 100 electrodes are necessary to permit activities of daily living (ADL) such as face recognition and walking [7, 8]. One procedure that has been proposed to solve this problem involves combining the stimulating electrode and a miniaturized electronic circuit into a single unit [9]. Another method is to use a multiplexer; this would allow a low number of wires to be used until just before connecting to the stimulating electrodes.

This report proposes an artificial sight system that includes the best features of the cochlear implant, but incorporates a multiplexer that is separate from the hermetically sealed stimulation unit, thus permitting a large number of stimulating electrodes to be used. An implantable wireless power supply and transmitting device were also constructed. Validation tests results and

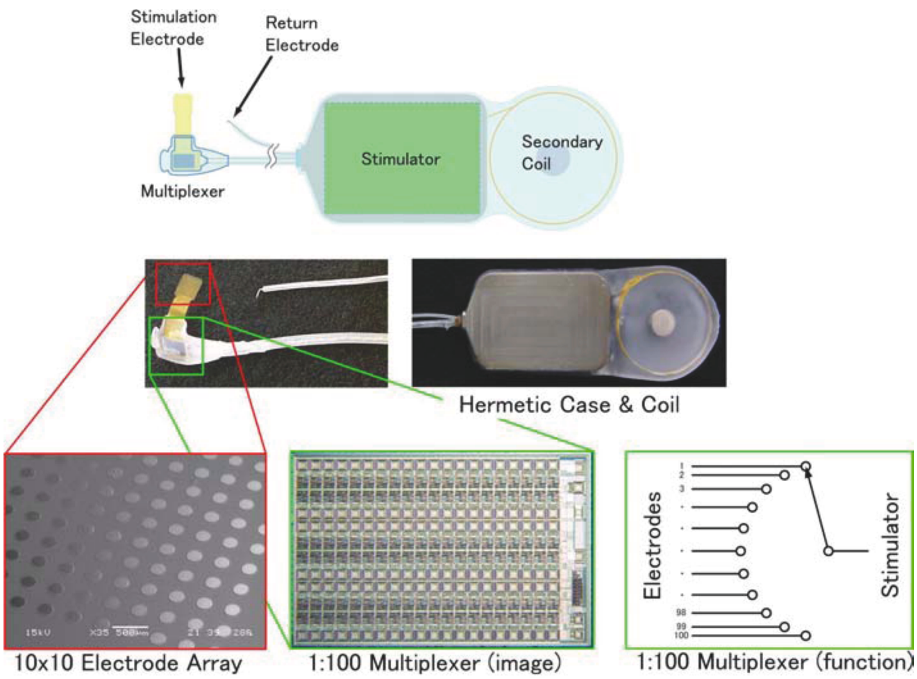

Fig. 1. overview of retina prosthesis.

DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

IEICE Electronics Express, Vol.5, No.15, 574–580

directions for future research efforts are discussed.

2 Design of a retinal prosthesis with 100 stimulation electrodes

An artificial vision system consists of both implanted and external components. Figure 1 shows a diagram of the implanted device; it consists of a secondary coil, a stimulator in a hermetically sealed case, a multiplexer, and stimulating and return electrodes. Just as in a cochlear implant, the stimulation unit is implanted behind the ear. The stimulating electrodes and multiplexer are placed on the sclera. The stimulator and multiplexer are connected via a cable composed of six wires which provide power for the multiplexer, the selection signal for the electrode, and the stimulator pulses. Each of the conductors is a stainless steel seven-stranded wire covered with a Teflon insulator. The six conductors and each stimulating electrode are connected with the input/output pads of the multiplexer. A custom integrated circuit (IC) was designed as a multiplexer and is mounted in a flip chip format directly on the board for the stimulating electrodes, with gold bump connections. This chip has dimensions of $4.9 \times 3.2 \times 0.57$ mm (thickness) and was manufactured in a 2 poly-2 metal high-voltage complementary metal oxide semiconductor (CMOS) process. Except for the stimulating electrodes and cables, the entire device is double-coated with 1 μm of parylene N and 5 μm of parylene C. The multiplexer is also then coated with silicone molded into a curve that fits the eyeball.

The stimulating electrodes consist of one layer each of gold and platinum on a polyimide base in the form of a 10×10 array of bumps, 200 μm in diameter, and 30 μm high. The outermost face of the array is coated with parylene C with just the tips of bumps exposed. More complete details about the electrodes are presented in a previous report [10]. The stimulation unit case is made of titanium hermetically sealed by electron beam welding.

3 Operation of the retinal prosthesis

The image data detected by the camera and transmitted to the external device is transferred along with power to the implanted device. Wireless transmission is on an amplitude-modulated carrier frequency of 16.64 MHz. The internal voltage of the implant is monitored regularly by back-telemetry of the load modulation. Stimulating current pulses are generated using the signals detected by the implanted device and transmitted via the multiplexer to the electrodes. The source circuit can apply a maximum of 10 V to the load. On the basis of instructions from the implanted device, the multiplexer selects one of the 100 electrodes and connects it to the current source in the stimulation unit.

4 Experimental results and discussion

First, in order to verify that the current required by the external device was being output from the designated electrode, a probe was directly attached

DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

to each stimulating electrode. The probing was performed automatically by controlling the position of the XYZ stage. Normal operation and wire connection of the implant such as electrode selection and controlling of the pulse parameters were confirmed with the use of the probing system. Cracks appeared on the surfaces of some electrodes where the probes came into contact with them. Future research is required to determine whether this can be solved by using a softer material for the probes, or by incorporating a liquid conductor.

An operation test was performed under phosphate-buffered saline (PBS). Figure 2 shows a photograph of the experimental setup. Three devices were submerged in 23°C PBS and supplied with a pulsed current for 72 hours. The pulse parameters were cathodic-first, 100 μs-duration, symmetric biphasic, 600 μA-amplitude at 100 Hz. The changes in the output current in response to changes in the image captured by a camera were monitored using an oscilloscope and a current probe (Fig. 2). Two of the three devices tested showed the expected response within the time tolerance. The other did not appear to be functioning properly, since some stimuli were delivered properly, while others were not delivered at all. It is quite likely that there were faulty connections at the multiplexer. Improving the reliability of these connections needs to be addressed in future research.

Finally, the functioning of implanted devices in vivo was checked. The left side of Fig. 3 shows a photograph of the experimental system. The internal device was implanted inside the subcutaneous pocket in the rabbit's back. Wireless power transmission was regularly conducted from the external device to the internal device starting before the procedure and continuing 7 days after the procedure. The internal voltage in the device was then verified by back telemetry. Figure 3 shows the time-dependent changes in the internal voltage of the implanted device. The voltage remained at the specified level until the 10th day after implantation, implying that the device was operating normally. All of the records for this in vivo experiment were maintained in compliance with the ARVO statement.

In this study, we employed a multiplexer to connect the many electrodes.

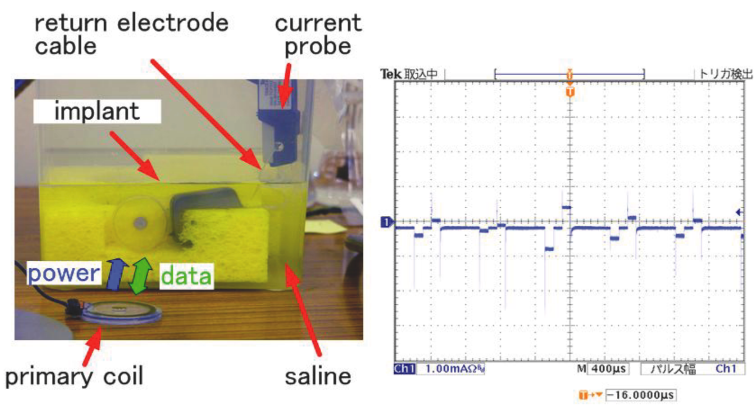

Fig. 2. Experimental setup (left) and current waveforms (right).

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Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

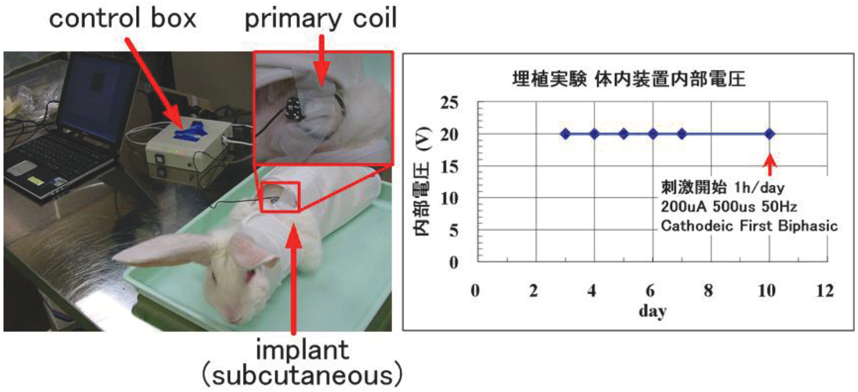

Fig. 3. Experimental setup (left) and current waveforms (right).

If the micro wiring that has been developed along with other dramatic advances in semiconductor manufacturing technologies is used for these connections, it will no longer be very difficult to provide large numbers of conductors in small spaces. Steiglitz et al. succeeded in placing 25 platinum conductors on a 1.2-mm-wide polyimide strap [11], and further miniaturization of conductors is possible. It has been shown to be possible to place small conductors on a parylene substrate [12, 13]. However, these schemes rely on thin films of noble metals, and would have high resistance due to the small conductor area. For example, a platinum film conductor that is 20 μm wide, 0.1-μm thick and 200 mm long, would have an estimated resistance of 10.6 kΩ. This impedance is approximately equal to that of typical biological tissue. The wiring resistance would require high source voltages in order to drive the circuit and would increase the power consumption. The volume resistivity of thin film conductors is known to be higher than that of bulk conductors, and the actual resistance would be even higher than the estimate given above. Wires of larger cross-sectional area could be used to avoid this. If they were used, however, a bundle of 100 such wires would be stiff, heavy, and thick, and so would be problematic for actual implants. Therefore, in order to create systems resembling the cochlear implant with many electrodes, we believe that the most practical approach is the multiplexer-based system proposed here.

Except for the multiplexer, the circuits for the device manufactured for this study were placed inside a hermetically sealed package. The multiplexer was covered with parylene and silicone, but it would be preferable to also install the multiplexer in a hermetically sealed container in order to ensure long-term reliability. However, it is technically difficult to create small sealed packaging for something as small as this component which is to fit against the client's eye. This advance is left to future research.

5 Conclusions

We have proposed architecture for an artificial vision system containing 100 electrodes for stimulating the optic nerve. We have succeeded in creating a

DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008

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wireless system for transmission of power and communications. The devices continued to function normally while submerged in a normal saline solution and while implanted for extended periods of time. Future research will address increasing the number of electrodes and developing a hermetically sealed version of the multiplexer.

DOI: 10.1587/elex.5.574
Received June 23, 2008
Accepted July 10, 2008
Published August 10, 2008