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.

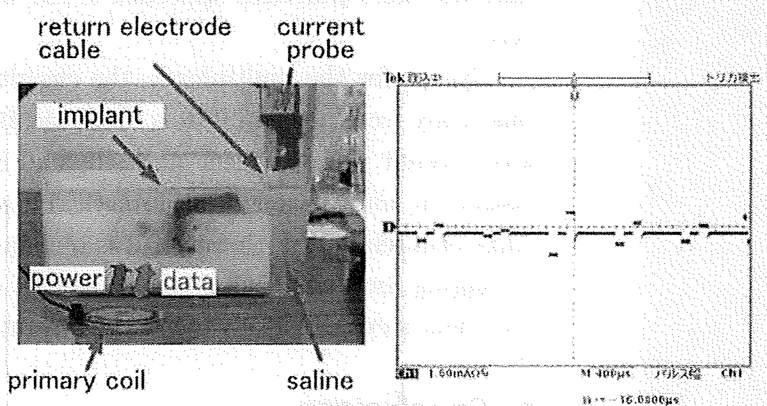

Fig. 2. Experimental setup (left) and current waveforms (right).

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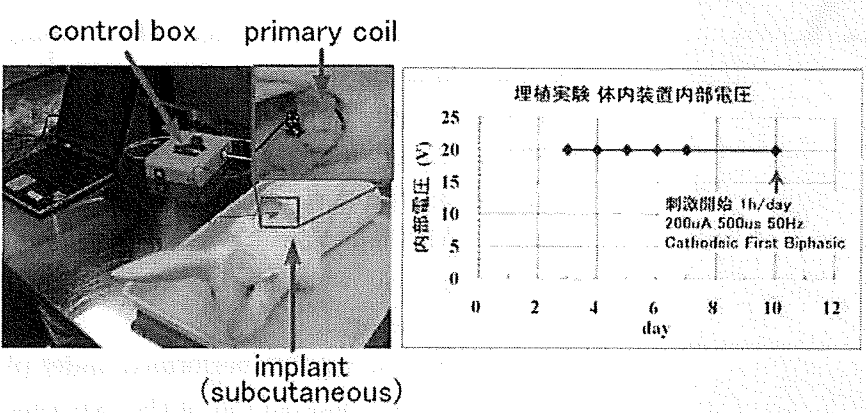

Fig. 3. Experimental setup (left) and current waveforms (right).

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 $20\,\mu$m wide, 0.1-μm thick and 200 mm long, would have an estimated resistance of $10.6\,\mathrm{k}\Omega$. 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

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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.

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