A multiple-electrode array for a cochlear implant

By Graeme M. Clark and Richard J. Hallworth
(Melbourne)

Introduction

It is becoming increasingly evident from experimental work on animals and humans that if cochlear implants are going to help patients understand speech, they must be designed to stimulate a number of different groups of auditory nerve fibres.

Recently it has been shown (Clark *et al.*, 1975) that an electrode array can be inserted into the scala tympani and passed around the turns of the cochlea so that a number of different auditory nerve fibres can be stimulated electrically. To do this it is necessary to first insert the electrode array through an opening in the apical turn of the cochlea, and ensure that it has the appropriate stiffness and extensibility.

One way of making an array of sixteen electrodes small enough to pass comfortably around the scala tympani is to strand teflon coated platinum wire with an outside diameter of approximately 0·15 mm. (Clark *et al.*, 1975). This electrode array is satisfactory, and smaller versions have been used in animal experimentation in our laboratory. It is, however, difficult to obtain a sufficiently large electrode surface area that will permit a satisfactory current density for electrical stimulation.

For this reason it has been considered necessary to further develop the thin film technology first used by Sonn, Jako and Feist (1971) for a flexible microelectrode array, and to carry out studies to ensure that the ribbon-like multiple-electrode array can be passed around the cochlear turns. A detailed account of the technology involved is described elsewhere (Hallworth, 1976).

In manufacturing this multiple-electrode ribbon-array, a thin layer of platinum at a thickness of 0·1 μm. is deposited on specially-cleaned fluorinated ethylene-propylene (FEP Teflon) using a radio-frequency sputtering technique. The sputtering process is illustrated in Figure 1. A platinum target and the teflon sheet substrate are placed in a sputtering chamber, which is evacuated to a very low pressure and then backfilled to a pressure of approximately 1 mtorr., or about one millionth of an atmosphere. A radio frequency electrical field is then induced between

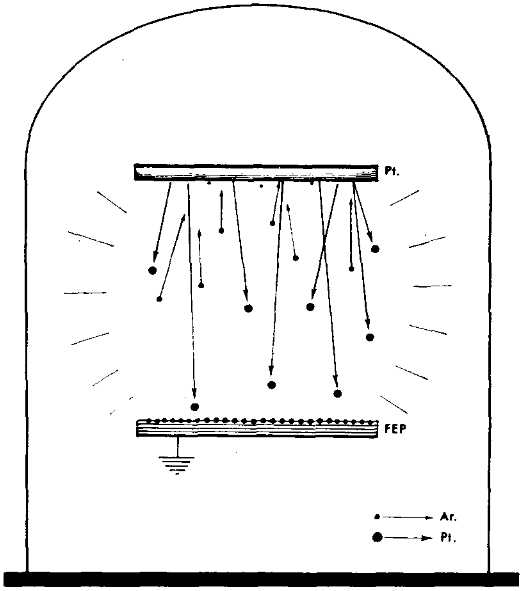

FIG. 1.
A diagram of the technique used for the radio frequency sputtering of platinum onto teflon sheeting.
Ar—argon atom; Pt—platinum target and atom;
FEP—fluorinated ethylene-propylene teflon sheet.

target and substrate, and this results in the formation of argon ions. These are accelerated towards the target and have sufficient energy to eject platinum ions from the target at high velocities. Sufficient ejected atoms reach the teflon substrate and adhere to form a thin uniform layer of platinum.

The platinum layer is then dip-coated in a photoresist material. This is then exposed to ultraviolet light through a photographic mask having the design of the electrodes, and then developed. The result is a pattern of etch resistant material defined on the platinum film. The unexposed areas are then etched using a sputter-etch technique as described before, using the substrate and film as the target.

Insulation of the array and exposure of the electrode tips and connection pads can be accomplished using a negative relief mask technique. A resist mask is formed over the areas to be exposed (the electrode tips and connections pads) and then the insulator (PTFE Teflon) sputtered over in a thickness of $0 \cdot 3$ μm. or greater. When the device is dipped into the resist stripping solution, the resist swells and breaks free, clearing away the teflon overlying it. The desired areas are thus exposed, and the remainder is insulated. Electrical measurements indicate that track to track impedance will be high and the breakdown strength of the insulator is more than adequate.

Results

The technological developments outlined indicate that it is possible to produce a satisfactory multiple-electrode array for cochlear implantations. An array of platinum can be made to adhere to a teflon substrate, it can be insulated with teflon, and the electrode stimulating areas exposed. Bending tests on the array indicate that it is both flexible and strong.

A number of designs have been considered and we have found the one shown in Figure 2 to be satisfactory. There are seventeen electrodes and their feed lines have widths of 80 μm. outside the cochlea (Fig. 3), tapering (Fig. 4) to a width of 6 μm. in the intracochlear section (Fig. 5).

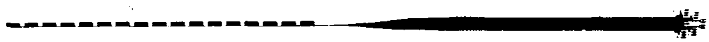

FIG. 2.
A photograph of the multiple-electrode array. Magnification—2·45.

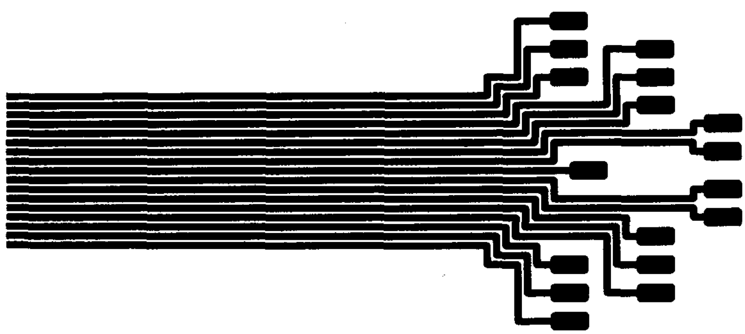

FIG. 3.
A photomicrograph of the extra-cochlear portion of the multiple-electrode array showing the terminals. Magnification—20·0.

FIG. 4.
A photomicrograph of the junction between the extra-cochlear and intra-cochlear portions of the multiple-electrode array. Magnification—18·3.

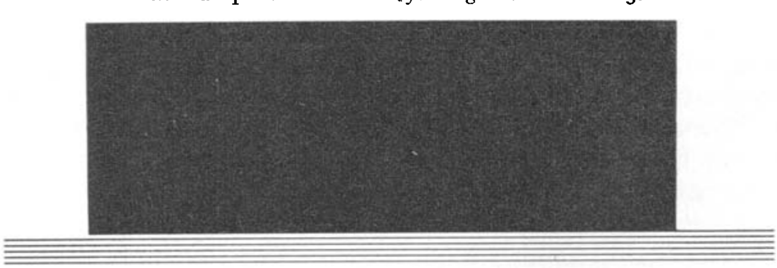

FIG. 5.
A photomicrograph of the intra-cochlear portion of the multiple-electrode array. Magnification—105.

This reduction in size enables large electrode stimulating areas of approximately 0·5 mm.[2] (Fig. 5) to be used so that the current density can be kept to a minimum.

The experimental studies to insert a ribbon of teflon around the turns of the cochlea have shown that this can be done, as illustrated in Figure 6.

FIG. 6.
A diagram of the cochlea showing the multiple-electrode array passing through an opening in the apical turn and around to the basal turn.

When using FEP Teflon, measurements indicate that it should have a width from 0·5–0·7 mm. and a thickness of 0·12 mm. Furthermore, to facilitate the passage of the electrode around the cochlear turns, the tip should be rounded.

Discussion

The development of this multiple-electrode ribbon-array should enable different groups of auditory nerve fibres to be stimulated separately, and so enable patients to understand speech.

When electrodes are implanted in the scala tympani, the stimulating current will tend to flow along the scala because it has a low resistance, and this will reduce the effectiveness of each electrode in stimulating a localized group of auditory nerve fibres. However, studies by Békésy (1951), Misrahy *et al.* (1958), and Johnstone and Johnstone (1966), show that in the basal turn of the cochlea the voltage is reduced by half over a distance of 1–2 mm., and in the apical turn over only 0·2 mm. Consequently, there is sufficient reduction in electrical voltage with distance to permit optimism about stimulating a localized group of nerve fibres. This of course requires experimental confirmation which is now being undertaken.

Although platinum is said to be inert, it can pass into solution at certain current densities and pH's. For this reason long term electrical stimulation at current densities similar to those used in patients will also be needed in experimental animals prior to its insertion into the cochleas of patients.

Summary

A satisfactory multiple-electrode array for a cochlear implant has been developed. This can be passed around the turns of the cochlea if it is first introduced into the scala. tympani through an opening in the apical turn.

Acknowledgements

We would like to thank the Weapons Research Establishment, Salisbury, South Australia, for providing facilities and technical assistance, in particular T. Dowling, D. Neale and L. Pearce.

We acknowledge the financial assistance provided by the Channel O Nerve Deafness Appeal and the National Health and Medical Research Council of Australia.

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Professor Graeme M. Clark,
Department of Otolaryngology,
32 Gisborne Street,
East Melbourne, 3002,
Victoria, Australia.