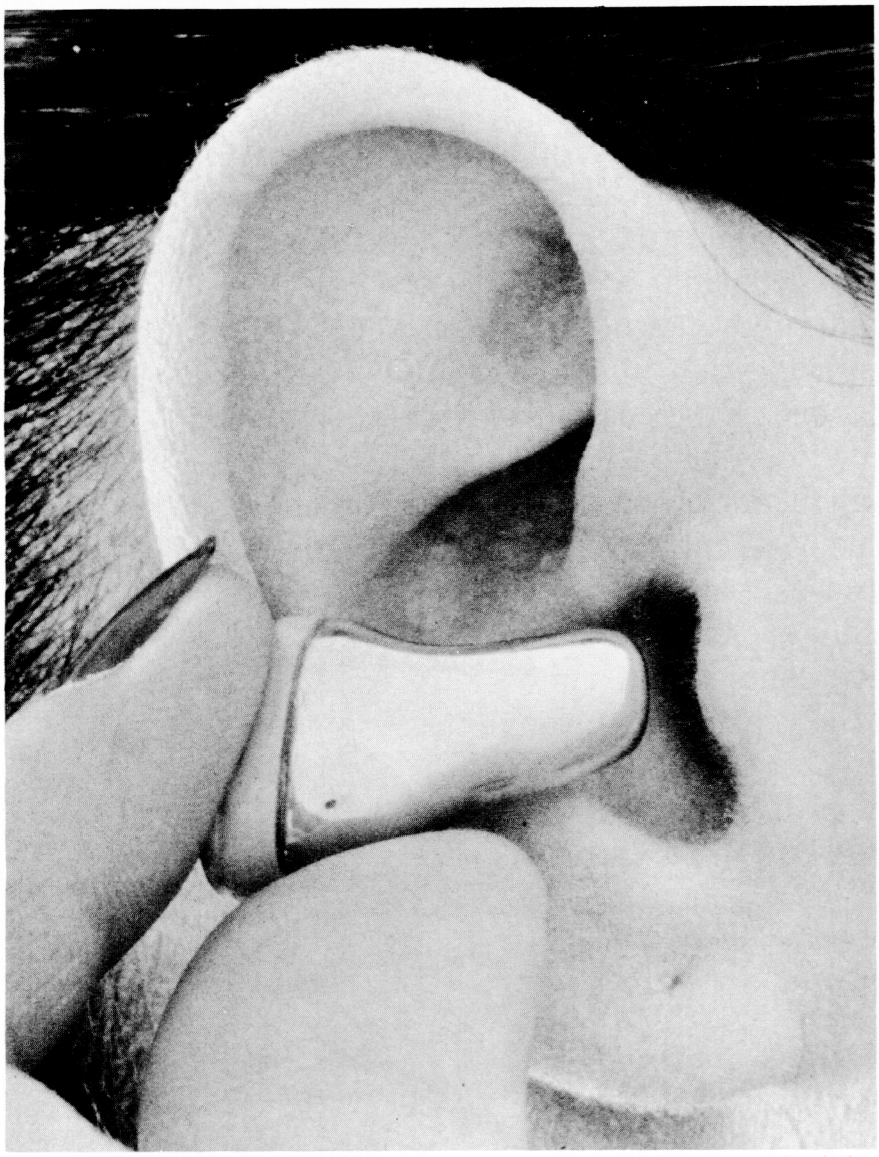
Clinical Applications of Electroformed Gold Alloy

High-purity sulfite gold supplies requisite properties for dental crowns, bridges, even shells for hearing aids.



Inside electroformed gold shell are microphone, amplifier, receiver, and other electronics devices covered with faceplate.

Gold alloys have been used in electroforming for many years. For example, 14- and 18-karat gold shells are electroformed with the aid of computer control in the manufacture of jewelry.[1] Dental crowns and bridges can also be produced by this technology and the electroforms modified to accept composite resin veneers. Shells for hearing aids can be gold electroformed, too, using similar equipment.

The development of electroforming for such clinical applications is the focus of this report.

Dental Restorations

There is a great deal of interest in improving productivity in the practice of dentistry. The cost of alloys for casting the metallic parts of crowns and bridges has drawn much attention recently.[2] During the past 15 years, a variety of alloys containing a base metal and a small percentage of gold have been introduced. The choice of alloy affects the cost of dental treatment but is by no means the most important factor. The dentist and the dental technician are responsible for those. Figure 1 shows the relative cost to the patient of a particular metal/ceramic crown made from different cast alloys.[3,4]

There seems to be little prospect of reducing laboratory costs with the traditional casting technique, which is exacting and time consuming. Many steps are involved in making a crown or bridge. After casting, extensive

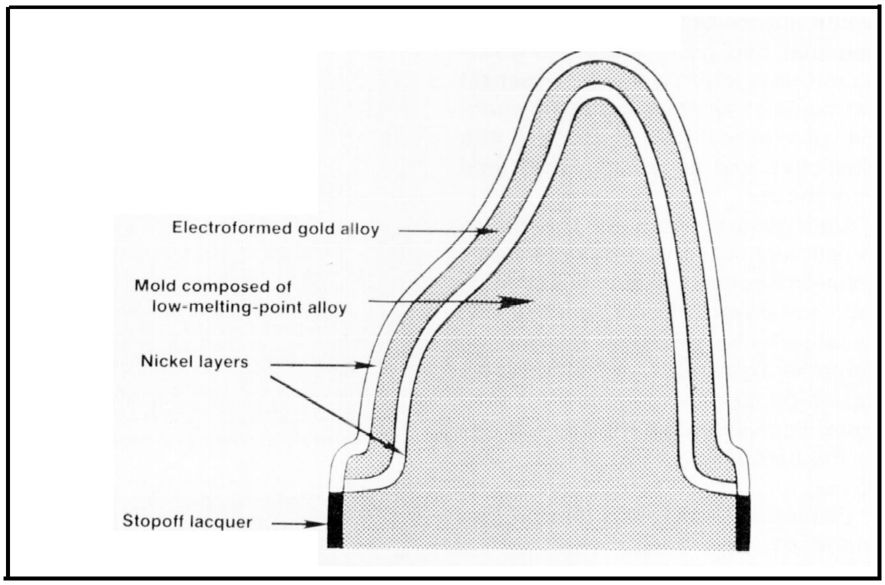


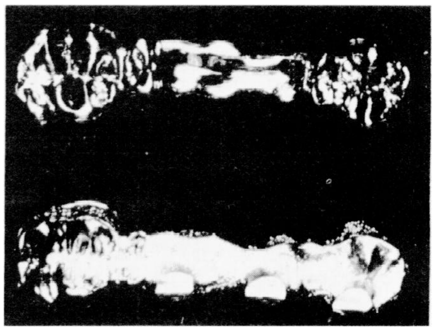
Fig. 2—Schematic drawing of electroformed layers on mold composed of alloy with low melting point.

grinding and polishing contribute significantly to high labor costs. Electroforming has considerable potential as an alternative.

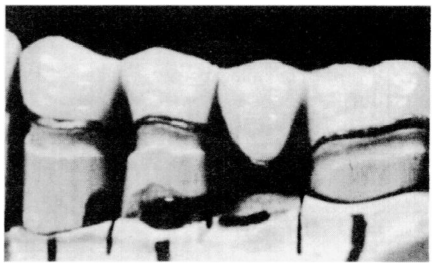
An exact surface reproduction can be obtained by electroforming, and this is not always true with casting. For example, problems can arise when the liquid does not completely fill recesses in the mold. A second advantage is that electroforming provides a more uniform thickness. The casting technique often produces 10-fold thickness variations (e.g., from 0.1 to 1 mm). With electroforming, the average thickness can be controlled more accurately and can result in substantial material savings. A four-unit cast alloy bridge weighing 8 g can be reduced to 3 g by electroforming. A 50 percent reduction in labor costs due to a substantial decrease in grinding and polishing is another advantage of electroforming. Unlike casting, electroforming can be used to produce several articles simultaneously.

Table 1 lists the steps used in the electroforming process. Taking an accurate impression of the teeth to be restored is the first step performed by the dentist. A low-melting-point alloy mold is cast from this impression. The mold is a negative of the impression and an exact replica of the teeth to be restored. A typical low-melting-point alloy for the mold is 60/40 bismuth-tin.

After the mold is covered with a stopoff lacquer up to the margin of the preparation or design (Fig. 2), approximately 10 μm of a bright, low-leveling nickel is deposited on the exposed surface. The nickel provides the area needed for the bonding cement to bind the crown or bridge onto the residual tooth or teeth. In addition, the nickel prevents the low-melting-point alloy from contaminating the gold electroforming bath and prevents formation of the detrimental alloy phases between the alloy and the electroformed gold.



The gold alloy is then electrodeposited on the nickel to a thickness of about 200 μm for crowns and 300 μm for bridges. A second nickel layer is applied to protect the gold during removal of the alloy, which is melted at 180° C. The nickel is removed by chemical dissolution in a nitric acid solution. A textured surface is created on the electroformed gold piece in areas where a composite resin veneer is used. The outer surfaces and, in the case of bridges, the hollow inside parts, are covered with the resin veneer. Figure 3 compares cast and electroformed bridges. Figure 4 is a side view of an electroformed bridge.



Process Considerations

The goal of this study was to obtain a non-toxic electroformed structure that

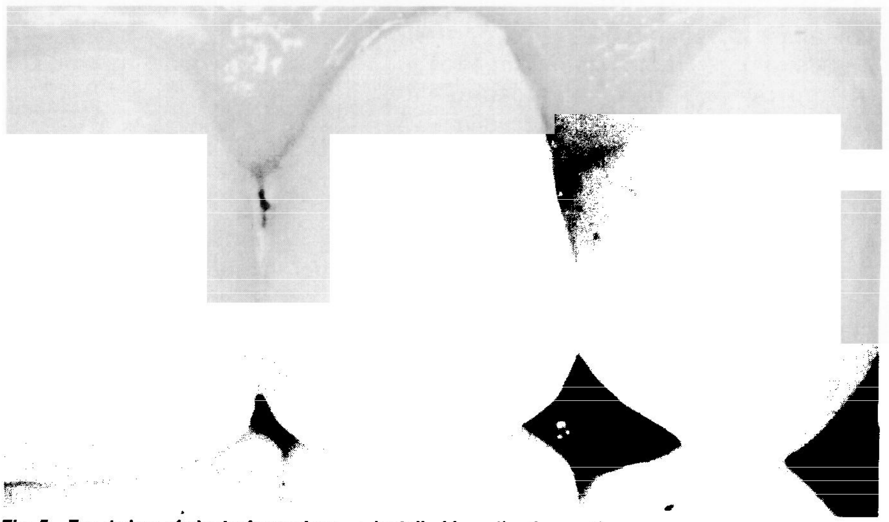


Fig. 5—Front view of electroformed crown installed in patient's mouth.

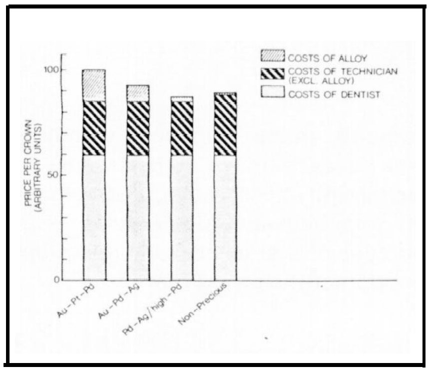


Fig. 1—Relative cost of alloy, dental technical and dentist as reflected on price of metal/ceram crowns made from various commercial alloys.

would not cause biological reactions and that had good thickness distribution, low internal stress, excellent corrosion resistance, good mechanical properties (e.g., hardness and elasticity), and acceptable color and brightness.

Gold was chosen as the major constituent. A high-purity gold sulfite solution was used instead of a cyanide bath for environmental reasons and because better thickness distribution could be expected. Most importantly, based on prior experience in electronic and decorative applications, the sulfite bath is known to result in less stress.

Electroformed crowns and bridges made of high-purity gold with a composite veneer were installed in the mouths of several patients (Figs. 5 and 6). The results described previously[1] were impressive. The crowns and bridges fit well. Biological reactions, sensitivity to pressure or galvanic or thermal shocks, and adverse tastes did not result. The patients receiving the restorations were initially satisfied. However, problems were encountered in some cases with bridges after about three months. The veneer started to fracture and even separated from the metal substrate (Fig. 7). Such problems were observed on bridges where chewing forces were highest and were attributed to poor mechanical adhesion of the resin to the metal and limited stiffness of the metal structure.

The veneer separation was subsequently entirely eliminated by increasing the roughness of the gold surface (initially 1 to 2 µm) by blasting with fine alumina particles. Figures 8 and 9 illustrate the original and increased surface roughness, respectively. The surface shown in Fig. 9 has a roughness of 8 to 12 µm.

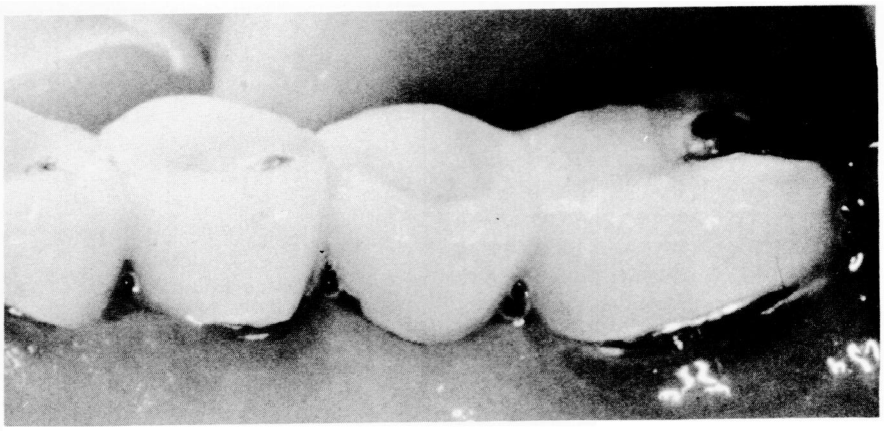


Fig. 6—Electroformed bridge in patient's mouth.

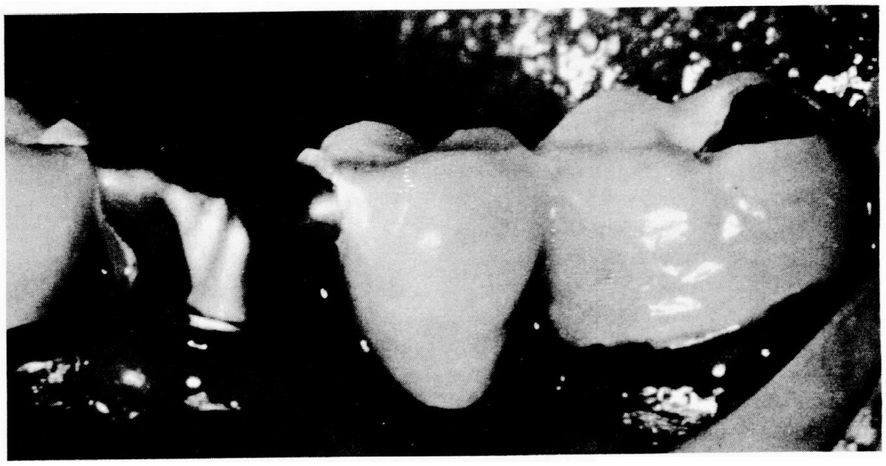
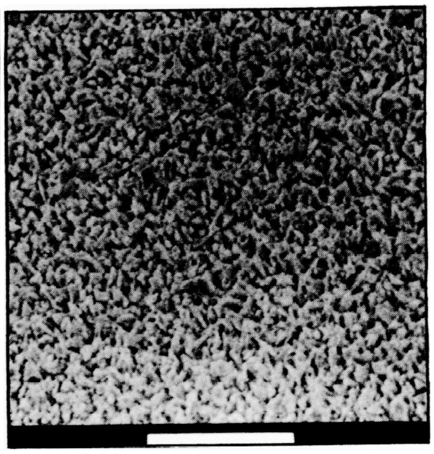


Fig. 7—Electroformed bridge in patient's mouth after separation of composite veneer.

Table 1
Sequence for Making Electroformed Dental Restorations with Composite Resin Veneer

1. Take impression of teeth.
2. Cast model (negative of impression).
3. Apply stopoff lacquer.
4. Watts nickel plate.
5. Electroform gold alloy.
6. Watts nickel plate.
7. Melt out cast model.
8. Chemically remove nickel.
9. Apply textured surface.
10. Apply composite resin veneer.



Overall Improvements

An electroforming bath was developed to improve stiffness and other mechanical properties summarized in Table 2. The bath* contains 10 g/L gold, has a pH of 7.2, and is operated at 0.5 A/dm^2 and 65° C. Gold is deposited at the rate of 118 mg/A-min. A special completing agent[6] provides excellent stability. The influence of operating conditions on efficiency is shown in Fig. 10.

The alloy deposit contains 99 percent gold with the balance chiefly copper. It has a modulus of elasticity above the minimum provided by proprietary cast alloys and therefore is rigid enough for restorations. Because the deposit is hard, it is possible to use metal rather than a composite veneer for the chewing area (i.e., occlusive surface). The elongation of the deposit is within the limits of the base alloys used in dentistry.

Figure 11 shows the laminar structure of the deposit, which is compressively stressed at 5 kg/mm^2 according to a method** developed by Dvorak and Vrobel.[7] On bridges with a complex shape, thickness variations can be as high as 100 percent. On nickel with microcracks, the thickness of gold halfway up the track is 95 percent of that at the top, illustrating good microthrowing power.

*Ultraclad Y 840, Sel-Rex/OMI International, Nutley, NJ.
**Employs an IS meter, Sel-Rex.

Porcelain can be applied on the gold alloy in place of the composite resin veneer, but, in this case, the porcelain must be fused on the electroformed framework by heating at 980°C at low pressure. Adhesion is excellent and the electroformed shell maintains its shape. However, the alloy is recrystallized (Fig. 12) and its properties changed. Further development in this area is ongoing.

Heating Aids

Electroforming is also used successfully in the manufacture of hearing-aid shells. The process reproduces the surface exactly, controlling the thickness for material savings. All electronic devices can be mounted inside the shell, thereby reducing the total size of the hearing aid.

The process cycle for fabricating hearing-aid shells is very similar to that for electroforming dental restorations. From an impression of the patient's auditory canal, a low-melting-point. alloy casting is made and stopped off at the required length. After nickel plating, gold plating, and the final nickel plating step, the alloy is removed by heating and the nickel by chemical dissolution. The microphone, amplifier, receiver, and other electronic devices are mounted in the gold shell and finally covered with a faceplate. Figure 13 shows a cross section of a hearing aid in the auditory canal.

In clinical tests, the acoustic properties of the hearing aid have been excellent, making stereophonic sound possible. High-frequency background noise due to close proximity of microphone and receiver has not been reported. Due to the good mechanical properties of the alloy (Table 2), the hearing-aid shells are normally only 100 μm thick. Corrosion and tarnish resistance were evaluated in the environments listed in Table 3. A 10-day test in sweat at 40° C gave excellent results. The electroformed hearing aid has created considerable interest.[8]

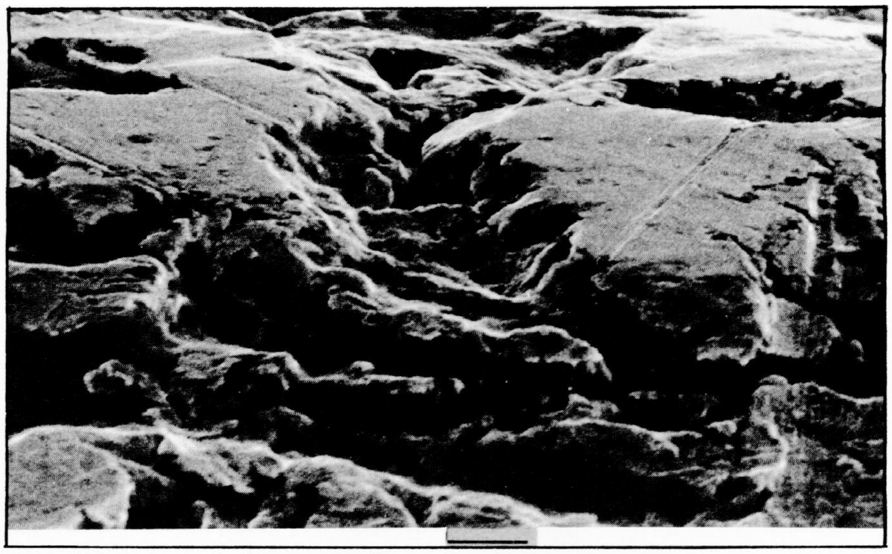


Fig. 9—SEM photo showing increased roughness of metallic substructure. Black bar represents 10 μm.

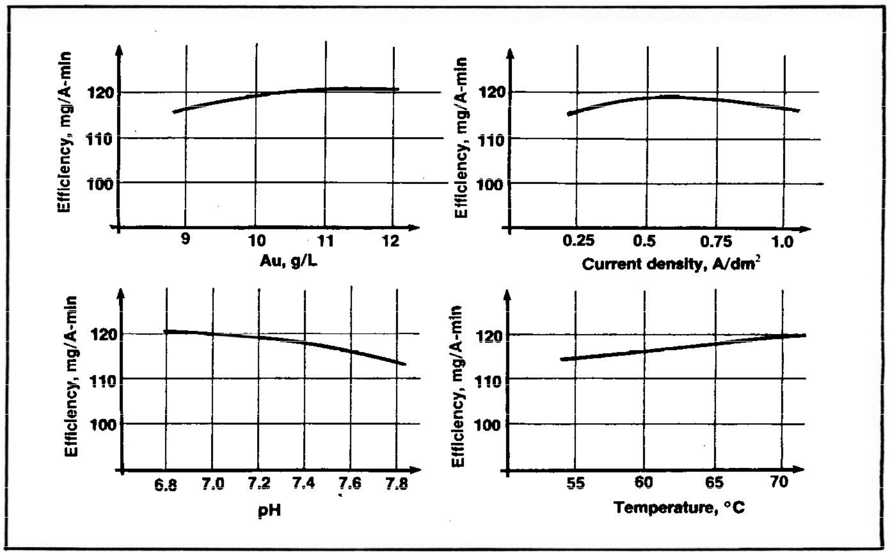


Fig. 10—Influence of operating conditions on cathode efficiency.

Table 2
Mechanical Properties of Electroformed Deposit

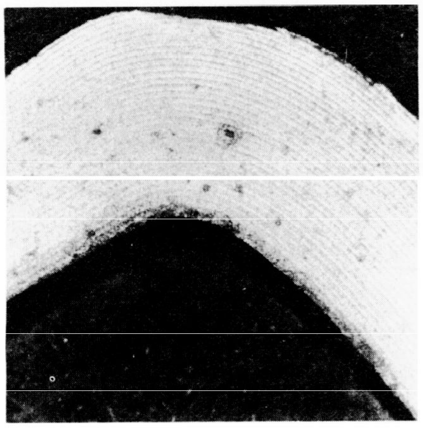
Property	Initial process	Improved process
Modulus of elasticity, GN/m^2	60	77
Yield strength, MN/m^2	310	460
Tensile strength, MN/m^2	420	460
Elongation, %	13.4	<1
Vickers hardness	145	250

Table 3
Corrosion and Tarnish Resistance

Tests	One day	Two days	Three days	Six days	10 days
NH_3	Excellent	Excellent	Excellent	—	—
HNO_3	Excellent	Excellent	Excellent	—	—
CH_3COOH	Excellent	Excellent	Excellent	Excellent	Excellent
Thiocetamide	Excellent	Excellent	Excellent	Very good	Very good
Sweat at 40° C	Excellent	Excellent	Excellent	Excellent	Excellent

Conclusion

Precise control of gold alloy properties has demonstrated that electroforming can be used for dental restorations and hearing aids. Compared with classical methods, electroforming offers significant advantages to the producer and the patient.



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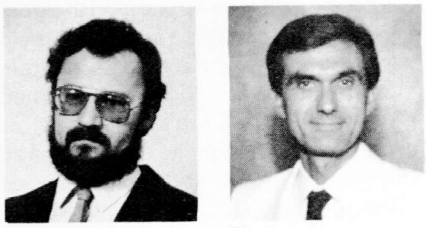

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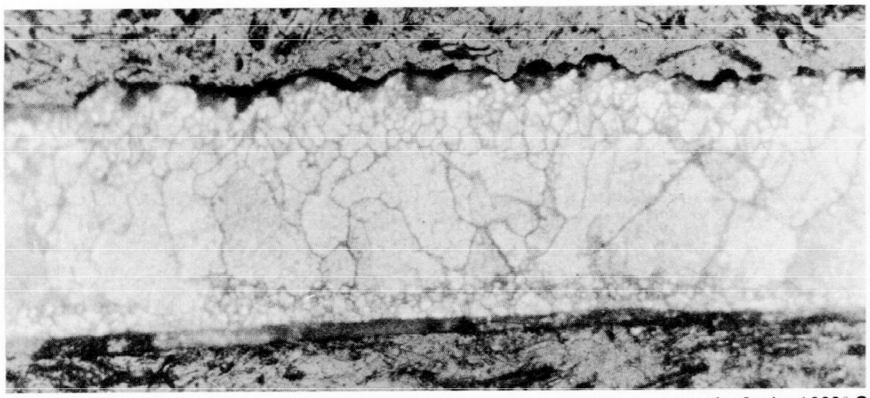

Fig. 12—Etched microsection of alloy showing recrystallization after heat treatment for 2 min at 980° C (60° C/min).

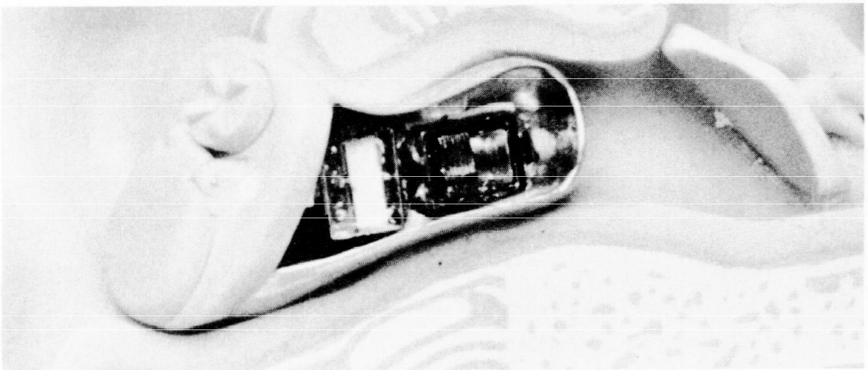

Fig. 13—Cross section of hearing aid placed in auditory canal.