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(71) Applicant *(for all designated States except US):* WOLLONGONG UNIADVICE LIMITED [AU/AU]; 49 Northfields Avenue, Wollongong, NSW 2500 (AU).

(72) Inventor; and
(75) Inventor/Applicant *(for US only) :* WALLACE, Gordon, George [AU/AU]; Department of Chemistry, University of Wollongong, P.O. Box 1144, Wollongong, NSW 2500 (AU).

(74) Agent: SHELSTON WATERS; 55 Clarence Street, Sydney, NSW 2000 (AU).

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(54) Title: ELECTROPOLYMER COATED MICROELECTRODES

(57) Abstract

The manufacture of microelectrodes, layer coated with polymers by electropolymerisation is disclosed. The electropolymerisation may be effected by galvanostatic, potentiostatic or potentiodynamic oxidation of the monomer and thus embraces both electrolytic and electrophoretic techniques. The microelectrode susbtrate may be a noble metal such as Au, Pt or C and the polymeric layers are preferably derived from pyrrole, thiophene, furan or 3-methylthiophene monomers. Additional preferred monomers include N-ethyltyramine, phenol and 2,2'-bithiophene. Selection of monomers is based on whether conducting/non-conducting polymer coatings are required and which are amenable to electrosynthesis by oxidative or reductive mechanisms. An extension of the invention allows for the production at low potential of polymers with low counter ion content, (i.e., less conductive ions), or with low affinity ions, both of which may be readily exchanged by ion-exchange techniques for more useful agents such as proteins, antibodies, antigens and drugs in one or more layers. These incorporated materials are subsequently control released into the body by applying a cathodic potential to the microelectrode. The microelectrode in its finished form is typically < 50 μm in diameter and has an additional important application as a component in voltammetric sensors with an improved signal/noise ratio and the ability to operate in resistive media and/or at higher scan rates, by comparison with the prior art microelectrode.

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ELECTROPOLYMER COATED MICROELECTRODES.

Technical Field

The present invention pertains to new polymer coated microelectrodes, particularly microelectrodes having polymers as polymeric layers applied by electropolymerization.

Background Art

Microelectrodes, typically <50μm diameter, are an important tool and are of particular interest in the development of new voltammetric sensors due to the improved signal to noise ratio, compared with conventional macroelectrodes, as well as the ability to operate in resistive media and/or at high scan rates.

A major limitation of electrodes is the lack of chemical activity on the electrode surface and whilst decreasing the size of the electrode surface of macroelectrodes is known to improve the limitations referred to above, such modification does not assist chemical activity. It is known in art to chemically

modify the electrode surface of macroelectrodes and such methods have been known to increase chemical activity on the electrode surface of a macroelectrode.

In general, the chemical activity on the surface of a macroelectrode has been improved by coating with a material which prevents interferents migrating to the sensor surface, or by increasing sensitivity by providing a rapid preconcentration of an analyte onto the electrode surface of a macroelectrode. An alternative approach has been the use of an electrocatalyst on the electrode surface to improve sensitivity. Such processes increase sensitivity to specific analytes and thereby selectivity on the electrode surface.

All the above described processes have only been applied to macroelectrodes.

Disclosure of the Invention

Electropolymerization, in general, occurs more readily on microelectrodes and it is therefore desirable and advantageous to polymer coat microelectrodes resulting in advantages during analysis preferably sensitivity is increased on the electrode surface. Such methods also offer advantages during synthesis of the polymer coated microelectrode wherein electroactive agents such as antibodies and the like may be incorporated.

One of the advantages of the present invention is

that polymerisation may be initiated at lower potentials whereby the polymer and the counterion may remain intact. This embodiment of the invention assists in the incorporation of the agents, such as proteins.

The polymerization may also be carried out in shorter stages or lower volumes in order that smaller amounts of expensive agents such as antibodies may be incorporated at their preferred volume.

The polymeric coating of microelectrodes also offers the capability of electrochemical synthesis on less conductive substrates such as SnO_2, with the result that electropolymerisation is improved on these electrodes.

The present invention provides polymer coated microelectrodes particularly, for use as sensors.

Such microelectrodes enable the preparation of polymeric layers of polymer coating, which are inherently less conductive, to be grown electrochemically by electropolymerization on the microelectrodes, thereby increasing the range of polymers appropriate for use. Some polymeric coatings such as phenolic-type polymers are relatively non-conductive and consequently only thin coatings can be grown electrochemically by electropolymerization on macroelectrodes. However, when microelectrodes are employed, the ohmic potential (iR) drop problems which previously hindered growth on macroelectrodes are

alleviated because only small currents flow between the polymer coating and the microelectrode.

More conductive polymers such as polypyrrole become less conductive if certain agents, such as large metal complexing agents or antibodies, are incorporated during electrochemical growth. The electrochemical growth of such polymers is limited on macroelectrodes but the use of microelectrodes enables such synthesis to be easily facilitated.

A further advantage of the present invention is that during electropolymerization, side products of the polymerization reaction, e.g., H^+ion formation, quickly diffuse away from the electrode at a rate faster than at macroelectrodes, thereby causing less interference.

In a further aspect of the invention, the use of microelectrodes enables the more efficient preparation of agent-containing polymers produced using a subsequent ion exchange step, since polymeric coatings of microelectrodes may be electropolymerized from low ionic strength media enabling conducting polymers with low counter ion content, i.e., less conductive, or containing anions with low affinity for the polymer, to be electrochemically grown. The use of ion exchange processes induced either chemically or electrochemically to firstly remove the counter ion and secondly incorporate a different, more useful agent, typically, a chemical reagent, is therefore more readily implemented.

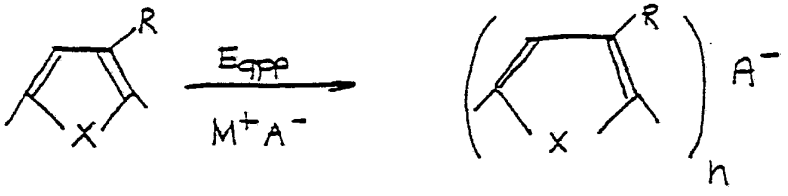
This is also important in producing conducting polymers capable of molecular recognition. Different counter ions are more readily incorporated via the ion exchange step due to the rapid movement of agents in the coating layers since the agents diffuse away more quickly. The agents may be control released by application of a cathodic potential and may even be released into non-conductive media.

The use of microelectrodes allows these processes to be carried out in smaller volumes. This aspect of the invention is particularly useful and important for application to biosensors. Microelectrodes may be also be used at very fast scan rates to enhance the signal to noise ratio which is particularly important for use in sensors. Furthermore, microelectrodes may be used in more resistive media without the addition of an external supporting electrolyte.

The term "microelectrode" in this specification includes microelectrode arrays including ring disk microelectrodes and any other microelectrode geometry.

Polymerisation of the monomer onto the microelectrode may be applied to any suitable microelectrode substrate such as Au, Pt or C, and is preferably achieved by galvanostatic, potentiostatic or potentiodynamic oxidation of a solution containing the monomer and an appropriate supporting electrolyte.

Polymerisation preferably proceeds according to the following type of reaction:



Wherein X is preferably NH, S or O and R is preferably hydrogen or an alkyl group of 1 to 6 carbon atoms and E app is the applied electrical potential. The E app value varies according to the polymer applied but preferably varies between 0 to 2 volts. M^+ is a cation, preferably Na^+, K^+ or Cu^{2+} and A^- is an ion, preferably NO_{3-}, Cl^- or EDTA. M^+A^- is an electrolyte appropriate for use with highly conductive polymers but is not required when low or non conductive polymers are used in the method of the present invention. This aspect is evidenced in Example 3.

Rapid movement of the analyte to and through the polymeric layers maximizes the interaction with the analyte and maximizes the analytical signal which may be faradaic (oxidation/reduction) or due to movement of the agent.

The most preferred monomers for use in the coatings of the present invention are pyrrole, thiophene, furan and 3-methylthiophene.

Other monomers may also be used to produce either conducting or non-conducting polymer coatings on appropriate substrate.

Other preferred monomers that may be used include N-ethyltyramine, phenol, 2,2'-bithiophene and any other monomer that is amenable to electrosynthesis either by oxidative or reductive mechanism.

Modes for Carrying out the Invention

Preferred embodiments of the invention will now be described in more detail in the following examples with reference to the accompanying drawings, in which:

Fig. 1 Chronopotentiograms for polypyrole-chloride (PP/Cl)-synthesis on micro and macro Pt electrodes
a) 0.5 mA/cm^2 b) 1.0 mA/cm^2 c) 2.0 mA/cm^2 d) 5.0 mA/cm^2

Fig. 2 Cyclic voltammograms of PP/Cl electrodes in 0.1 M $NaNO_3$
a) macro PP/Cl b) micro PP/Cl. Scan rate 50mV/sec.

Fig. 3 a) Response obtained for 10^{-3} M ferrocyanide in 0.1 M $NaNO_3$ on bare Pt micro and macro electrodes
b) Response for 10^{-3} M ferrocyanide at PP/Cl macro and micro electrodes.
Scan rate 50mV/sec.

Fig. 4 Illustrates the increase in surface area when PP/Cl is deposited onto a Pt microdisk electrode. Note: Not drawn to scale.

Fig. 5 Responses obtained after uptake of 1ppm Ag^+ for ten minutes on micro and macro PP/Cl electrodes a) grown galvanostatically b) grown potentiodynamically. Scan rate 50mV/sec.

Fig. 6 Cyclic voltammograms showing the fall in silver uptake ability over six consecutive determinations at the 50 ppb level. Scan rate 50mV/sec.

Fig. 7 Comparison between chronopotentiograms for the growth of PP/EDTA on micro and macro electrodes. Current density = 1 mA/cm^2.

Fig. 8 Cyclic voltammograms of micro and macro PP/EDTA electrodes in a) 0.1 M $NaNO_3$ b) 10^{-3} M ferrocyanide in 0.1 M $NaNO_3$. Scan rate 50mV/sec.

Fig. 9 a) Cyclic voltammogram after uptake of 0.5 ppm Ag^+ for 10 min on a micro PP/EDTA electrode b) Cyclic voltammogram after uptake of 1.0 ppm Ag^+ for 10 min on a macro PP/EDTA electrode. Scan rate 50mV/sec.

Fig. 10 Chronopotentiogram for polypyrrole growth on a micro electrode in the absence of supporting electrolyte. Current density 1.0 mA/cm^2.

Fig. 11 Cyclic voltammogram of a polypyrrole electrode grown in the absence of deliberately added supporting electrolyte. Scanned in 0.1 M $NaNO_3$. Scan rate 50mV/sec.

Fig. 12 a) Cyclic voltammogram of a PP/Cl micro electrode scanned in triple distilled water (no added electrolyte) before silver uptake

b) After silver uptake

Scan rate 50mV/sec.

EXAMPLE 1

Polypyrrole-Chloride (PP/Cl)

(i) Synthesis and Characterisation:

Polypyrrole electrodes, incorporating chloride (Cl^-) as the counterion, were grown galvanostatically using various current densities. The chronopotentiograms which give an indication of polymer growth characteristics during synthesis, for both the micro-PP/Cl and macro PP/Cl electrodes are shown in Fig.1. The general shape of the chronopotentiograms for both cases are similar. There is an initial potential rise (corresponding to the application of the constant current) which has been associated with nucleation. This potential decreases with time, indicating good conducting polymer growth. There are however a couple of subtle differences. On microelectrodes no spike is observed indicating that polymer growth occurs more readily. Also the polymerisation potential of a microelectrode is slightly less than that required for the corresponding current density of a macroelectrode. This is another indication that polypyrrole grows more readily on microelectrodes and that any resistance

problems due to the growing polymer is less of a problem on microelectrodes than for macroelectrodes.

The increased sensitivity of the polypyrrole-chloride microelectrode is demonstrated by results obtained for ferrocyanide responses on both macro and micro PP/Cl^- electrodes. Fig. 3a shows the response obtained for $10^{-3}M$ ferrocyanide on bare Pt macro and microelectrodes respectively. As expected, The signal to noise ratio is greater on the micro electrode. Fig 3b shows the ferrocyanide ($10^{-3}M$) responses on macro and micro PP/Cl^- electrodes. As we understand, the size of the response for the modified macroelectrode is the same as for the bare Pt - the latter being superimposed onto the background of the former. The size of the response on the PP/Cl^- microelectrode however, is bigger than the bare Pt micro. The relative increase in response size is 1.8 times that of the bare Pt response. We understand this feature to be due to a relatively large increase in the effective surface area of the micro-working electrode when the polymer is on the surface (see Fig. 4). This is also supported by the fact that a PP/Cl^- microelectrode gives a similar increase for a ferrocene response in acetone. Such a phenomenon would be difficult to notice on a macroelectrode since the increase in surface area (between modified and unmodified electrodes) due to the polymer would be relatively small. It is important to note that

the increase in signal to noise ratio evident on bare micro Pt electrodes is also noticed (and even exemplified) on polypyrrole modified micro electrodes.

(ii) Performance-Ag determination

The determination of silver ions in solution by precipitation onto polypyrrole chloride electrodes is a well defined system that utilizes the selectivity and preconcentration effects of a chemical reaction i.e. $Ag^+ + Cl^- \rightarrow AgCl$. The latter is analogous to anodic stripping voltammetry (A.S.V.) except that preconcentration occurs chemically rather than electrochemically. Silver ions are concentrated onto the electrode surface for a given time (10 min in this example) and are subsequently determined voltammetrically. A direct comparison of the analytical performance of micro PP/Cl^- and macro PP/Cl^- electrode is made using this system.

For a deposition time of ten minutes the limit of detection for a galvanostatically grown PP/Cl^- macro electrode is 1ppm Ag^+. For a PP/Cl^- microelectrode grown under the same conditions the limit of detection is 50 ppb with a 20 fold improvement. Detection limits of < 10 ppb have been obtained on PP/Cl^- microelectrodes grown potentiodynamically, but electrodes grown by this method are much less reproducible than those grown galvanostatically. Even so, Fig 6 shows the comparison between the responses

obtained on micro PP/Cl^- and macro PP/Cl^- at the detection limit of the macroelectrodes.

Silver determinations below 100 ppb are only obtainable on the micro PP/Cl^-. As a result the greater sensitivity of the microelectrodes has not only led to detection at the ppb level but also leads to the possibility of reusability - which is not possible on the macroelectrodes.

EXAMPLE 2

Polypyrrole-ethylenediaminetetraacetic acid (PP/EDTA)

(i) Synthesis and Characterisation

The comparisons between macro and micro polypyrrole electrodes in the previous example were made with a well defined conducting polymer system - ie PP/Cl^-.

Although there were noticable differences in the analytical performance and electrochemical characteristics of these electrodes, the synthetic or growth characteristics were similar. This is to be expected with polymers such as PP/Cl^-, however, polypyrrole electrodes of lower conductivity are not so well defined.

The incorporation of the ethylenediaminetetraacetic acid (EDTA) anion into a polypyrrole film is not as straight forward as simple anions such as Cl^-, NO_3^- etc. Problems, particularly with synthesis, of PP/EDTA electrodes have been noted previously. It has been shown that the potential required to synthesize PP/EDTA

from a 50:50 water-acetonitrile mixture, rose quite sharply with time, typical of resistance problems during polymer growth. Chronopotentiograms showing galvanostatic growth characteristic of PP/EDTA (from 100% aqueous solution) of various current densities on both micro and macro Pt electrodes are shown in Fig. 8. A noticable difference is observed between micro and macroelectrodes. The potential required for polymerization of macroelectrodes rises slowly with time in all cases, except the lowest current density shown where it remains constant. The polymerisation potential of microelectrodes however, decreases with time in a similar manner to the PP/Cl^- examples. This indicates that the resistance problems observed on the macroelectrodes are not a problem on the microelectrodes. Although PP/EDTA still grows well and produces a relatively good conducting film on macroelectrodes, the lack of resistance problems on the microelectrodes suggest that polymers which suffer much greater resistance problems and are unable to be grown on macroelectrodes, may be possible to grow on microelectrodes. This is certainly an advantage of microelectrodes for synthesis.

The electrochemical characteristics of PP/EDTA electrodes are similar to those observed on PP/Cl^- electrodes. For instance, Fig. 9 shows cyclic voltammograms of micro and macro PP/EDTA in a) 0.1M

$NaNO_3$ and b) 10^{-3}M Ferrocyanide solutions. The ion-exchange response is more pronounced on the microelectrode (as was the case with PP/Cl^-) and ferrocyanide responses are similar in size to the PP/Cl^- examples. The only major difference appears to be that the oxidation of the polymer occurs at a lower potential for PP/EDTA (by about 100 mV).

ii) Analytical Performance

Silver determinations with PP/EDTA electrodes is very similar to determinations with PP/Cl electrodes except that the pre-concentration mechanism is complexation rather than precipitation. Figure 10 shows the relative difference in sensitivity between micro and macro PP/EDTA for silver. The detection limit for the PP/EDTA macroelectrode after 10 min deposition is 0.5 ppm (Ag) while the corresponding micro electrode can detect silver below 50 ppb. The sensitivity and preconcentration efficiency of PP/EDTA microelectrodes are undoubtably superior to the macro electrode.

EXAMPLE 3

Synthesis and Analysis without added supporting electrolyte

The greatly reduced ohmic potential (iR) drop characteristic of microelectrodes suggests the possibility of performing electrochemistry without deliberately added supporting electrolyte. Polypyrrole electrodes have been synthesised and used for silver

analysis in the absence of added supporting electrolyte, both of which are not possible on macroelectrodes due to resistance problems.

Figure 11 shows the chronopotentiogram obtained for the growth of a polypyrrole film on a Pt microelectrode from a solution containing only 0.5M Py. The shape of the chronopotentiogram is very similar to the one obtained for PP/Cl^- at the same current density (ie 1mA/cm^2).

This indicates that the polymer formed has good conductivity since the potential falls off with time. For polypyrrole to be so conductive it must incorporate (negative) counter ions to maintain electrical neutrality. Therefore it is suggested that the concentration of ions in triple distilled water (CO_3^{2-},HCO_3^-, trace Cl^-) is sufficient to allow the polymer to grow on a microelectrode - remembering only a very small amount of polymer is grown, therefore only a very small amount of counter ion need be present.

The only difference in the chronopotentiograms for PP/Cl^- and polypyrrole grown without supporting electrolyte is that the latter has a polymerisation potential 300 mV higher than the former. This could be due to the lower conductivity of the media having an effect on the potential required for polymerisation or it could be due to ohmic potential (iR) losses due to

the resistivity of the media.

Attempts to grow polypyrrole without added supporting electrolyte on macroelectrodes have been unsuccessful resulting in polymers which tend to be very thin and patchy with very poor electrochemical characteristics. Microelectrodes however give rise to polymers with quite good electrochemical characteristics, as indicated by the cyclic voltammogram in Fig. 12. Analysis without supporting electrolyte after preconcentration of the analyte is also possible on modified microelectrodes. Fig. 13(a) shows the cyclic voltammogram obtained when a PP/Cl^- electrode is scanned in triple distilled water with no added electrolyte before silver uptake. This is very different from cyclic voltammograms using a supporting electrolyte where definite transitions between conducting and non-conducting regions occurs. Here, no such transitions are observed. The ion-exchange processes that take place in "normal" conducting solutions seem to be inhibited when little or no electrolyte is present. After cycling in triple distilled water the PP/Cl^- micro electrode can then be cycled in 0.1M $NaNO_3$ to give a cyclic voltammograms similar to that in Fig 2.

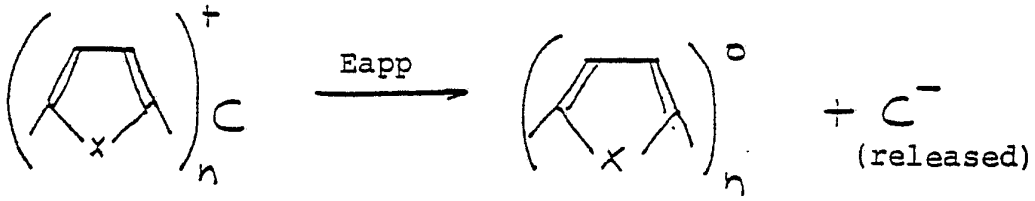
Fig 13(b) shows the response obtained on a PP/Cl^- microelectrode in triple distilled water after silver uptake.

EXAMPLE 4

Incorporation of Ferrocyanide

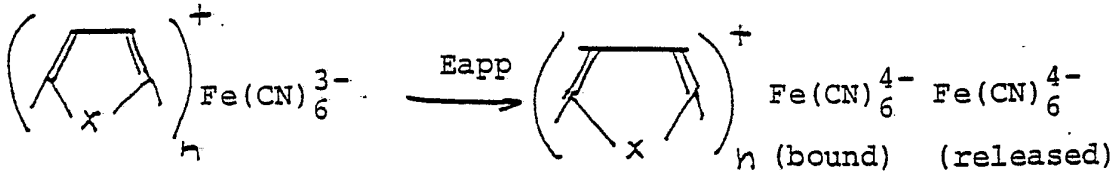
Conducting polymers containing ferrocyanide can be grown on both macro and microelectrodes.

Experiments with these polymer coated electrodes highlight some important advantages to be gained from the use of microelectrodes. After growth, cycling of the potential can be used to release the counter ion, C^-, (ferrocyanide) according to:-



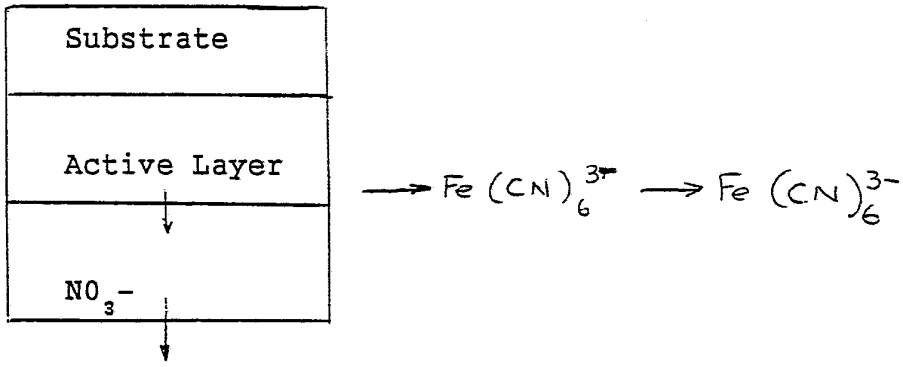
With microelectrodes after only one cycle from +0.80V ⟷ -0.80V at 50mv/sec all of the ferrocyanide is removed. This is not so with the macroelectrode counterparts. This indicates that diffusion occurs more readily through the micropolymeric coating.

It was also found that release could be initiated on the microelectrodes by simply reducing the ferrocyanide according to:-



It was further found that the release was substantially faster on a microelectrode compared to the corresponding macroelectrode.

Preparation of sandwich polymers using both micro and macro was investigated. Again, it was shown that on the microelectrode, release was more readily achieved since again all of the ferrocyanide could be released, as shown below:-



This behaviour, enhanced movement of counter ions on microelectrodes, is important for controlled release devices as well as for sensors where the signal is generated by ion movement. In the latter case, a greater rate of movement will result in larger signals.

EXAMPLE 5

Incorporation of a Protein - HsH or AHsA

Protein can be incorporated into conducting polymers using galvanostatic or potentiodynamic means of growth.

Using microelectrodes, growth can be initiated at less anodic potentials.

The microelectrode sensors can then react with the corresponding antibody or antigen in solution to produce non-faradaic responses. As these responses are usually due to ion movement within the polymer, they are more sensitive than those obtained on more conventionally sized electrodes.

Our experiments indicate that PP/Cl^- microelectrodes have superior sensitivity to corresponding macroelectrodes and we understand that one of the factors of superiority is the ratio of surface area to volume of polypyrrole is greater on a microelectrode than a macroelectrode.

Both the faradaic and capacitative charging currents due to the polymer decrease linearly with the surface area of the electrode. Therefore, polymers grown under the same conditions on macro and micro substrates should result in the same relative amount of background current. This is seen in Fig. 2 where the surface areas of the electrodes and the current scales differ by a factor of 200,000, giving cyclic voltammograms of approximately the same size. The analytical current in this case is not only determined by the concentration of silver, but also on the ability to uptake silver, which is determined by the number of available chemically reactive sites exposed to solution. For polymers grown under the same conditions the surface area of PP/Cl^- exposed to solution

(responsible for analytical current) per unit volume of PP/Cl^- on the substrate (responsible for background current) is greater for micro PP/Cl^- electrodes than for macro PP/Cl^- electrodes - resulting in a higher signal to noise ratio for the microelectrode.

Therefore polymer coated microelectrodes (where the modifier contributes to background currents) that involve concentrating the analayte species of chemically reactive sites on the electrode surface are inherently more sensitive than the corresponding macroelectrode because the ratio of surface area to volume of modifier is greater for the microelectrode.

It has been shown that polypyrrole modified microelectrodes can be used for the detection of silver ions and that the sensitivity of the modified microelectrode is 20-50 times greater than the corresponding macroelectrode depending on the counterion and growing conditions. Very few differences were observed in the synthetic characteristics of PP/Cl^- on the micro and macro substrates. This was to be expected for such a highly conducting polymer.

The synthetic characteristics of PP/EDTA however were very different. Problems with synthesis on a macroelectrode were not evident when using microelectrodes.

The ability of microelectrodes to be used without supporting electrolyte was used to advantage in the

synthesis of, and analysis with polypyrrole electrodes.

It will be envisaged that various modifications and departures may be made to the invention without departing from the scope thereof.

CLAIMS

1. A microelectrode, of less than or equal to 50μm diameter, said microelectrode having one or more polymers as polymeric layers applied by electropolymerization.

2. A microelectrode in accordance with Claim 1 wherein an agent is incorporated into one or more of said polymeric layers.

3. A microelectrode in accordance with Claim 2 wherein the agent is electroactive.

4. A microelectrode in accordance with any one of the foregoing claims wherein the agent is one or more of the group comprising antigens, antibodies, proteins, drugs or the like.

5. A microelectrode in accordance with any one of the foregoing claims wherein the microelectrode is used as a sensor.

6. A microelectrode in accordance with any one of Claims 2, 3, 4, or 5 wherein the agent is control-released.

7. A method of preparation of agent-containing polymers on a microelectrode, said method including the steps of:

electropolymerization of one or more polymers as polymer layers on the microelectrode

wherein said electropolymerization is derived from low ionic strength media by ion-exchange, thereby

allowing a polymer of low counter ion content or non-polar agent to be electrochemically grown.

8. A method according to Claim 7 wherein by a subsequent ion-exchange step a counter ion is removed and exchanged for an agent.

9. A method according to Claim 8 wherein said agent is one of the group comprising antigens, antibodies, proteins, drugs or the like.

10. A method according to any one of Claims 7, 8 or 9 wherein the agent is control-released.

11. A method according to any one of Claims 7 to 10 wherein electropolymerization is achieved by galvanostatic, potentiostatic or potentiodynamic oxidation of a solution comprising a monomer and an electrolyte.

12. A method according to Claim 11 wherein the monomer is one or more of the group comprising pyrrole, thiophene, furan, 3-methylthiophene, N-ethyltyramine, phenol, 2,2'-bithiophene or any other suitable monomer amenable to electropolymerization.

13. A microelectrode in accordance with any one of Claims 1 to 6 wherein electropolymerization is achieved by galvanostatic potentiostatic or potentiodynamic oxidation of a solution containing a monomer and an electrolyte.

14. A microelectrode in accordance with Claim 13 wherein the monomer is one or more of the group

comprising pyrrole, thiophene, furan, 3-methylthiophene, N-ethyltyramine, phenol, 2,2'-bithiophene or any other suitable monomer amenable to electropolymerization.

15. A microelectrode substantially as hereinbefore described with reference to the examples.

16. A method substantially as hereinbefore described with reference to the examples.

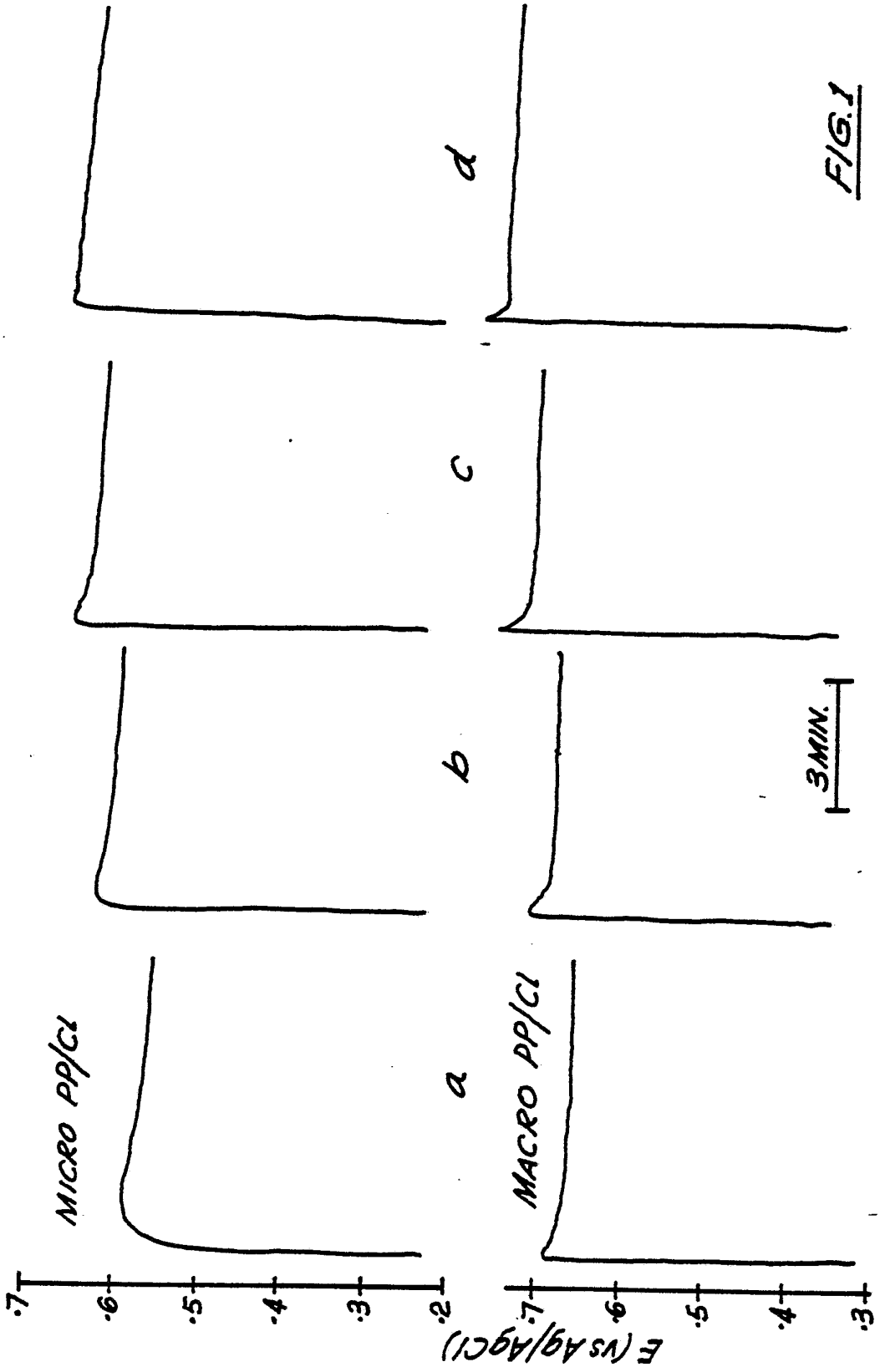


FIG.1

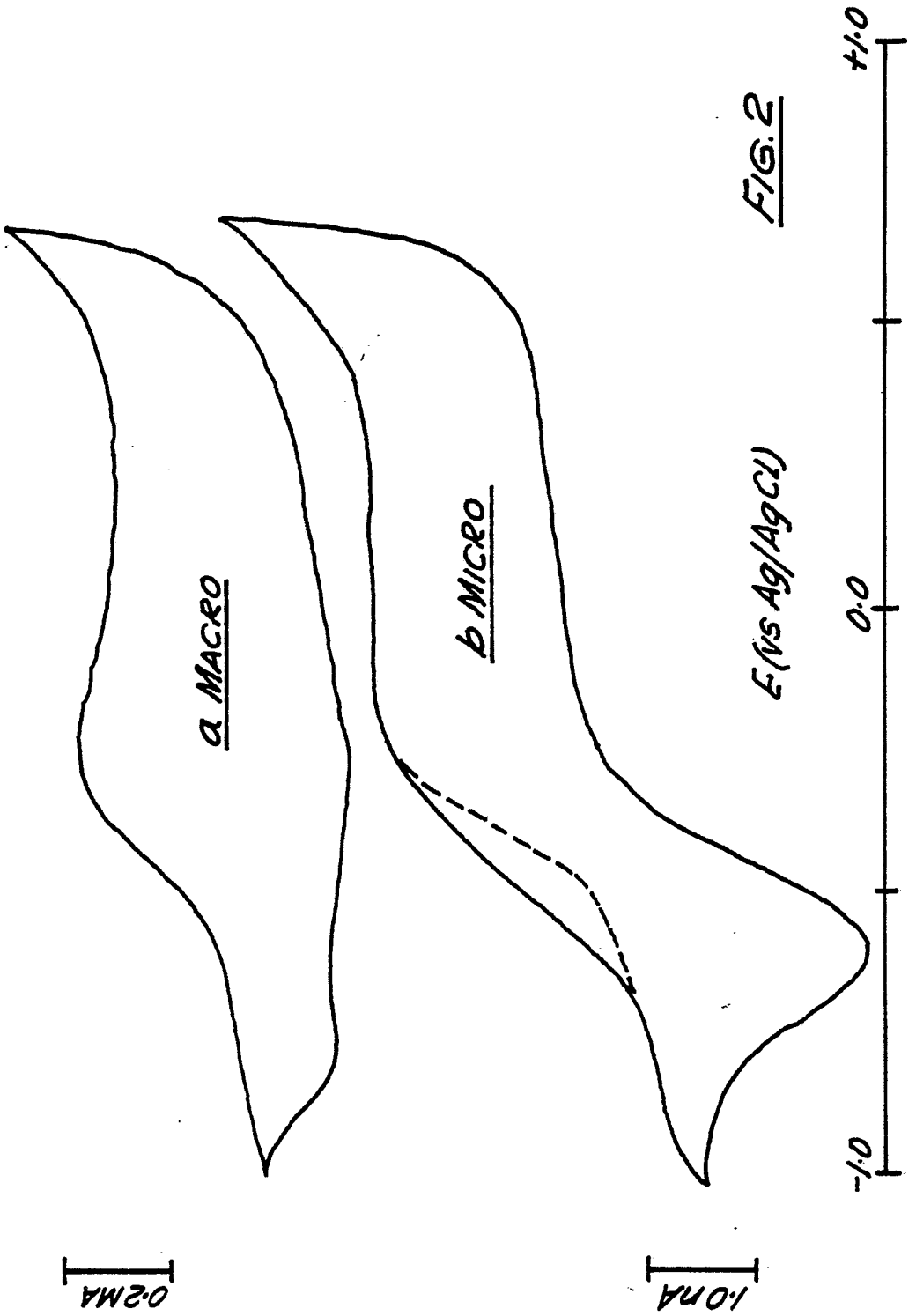


FIG. 2

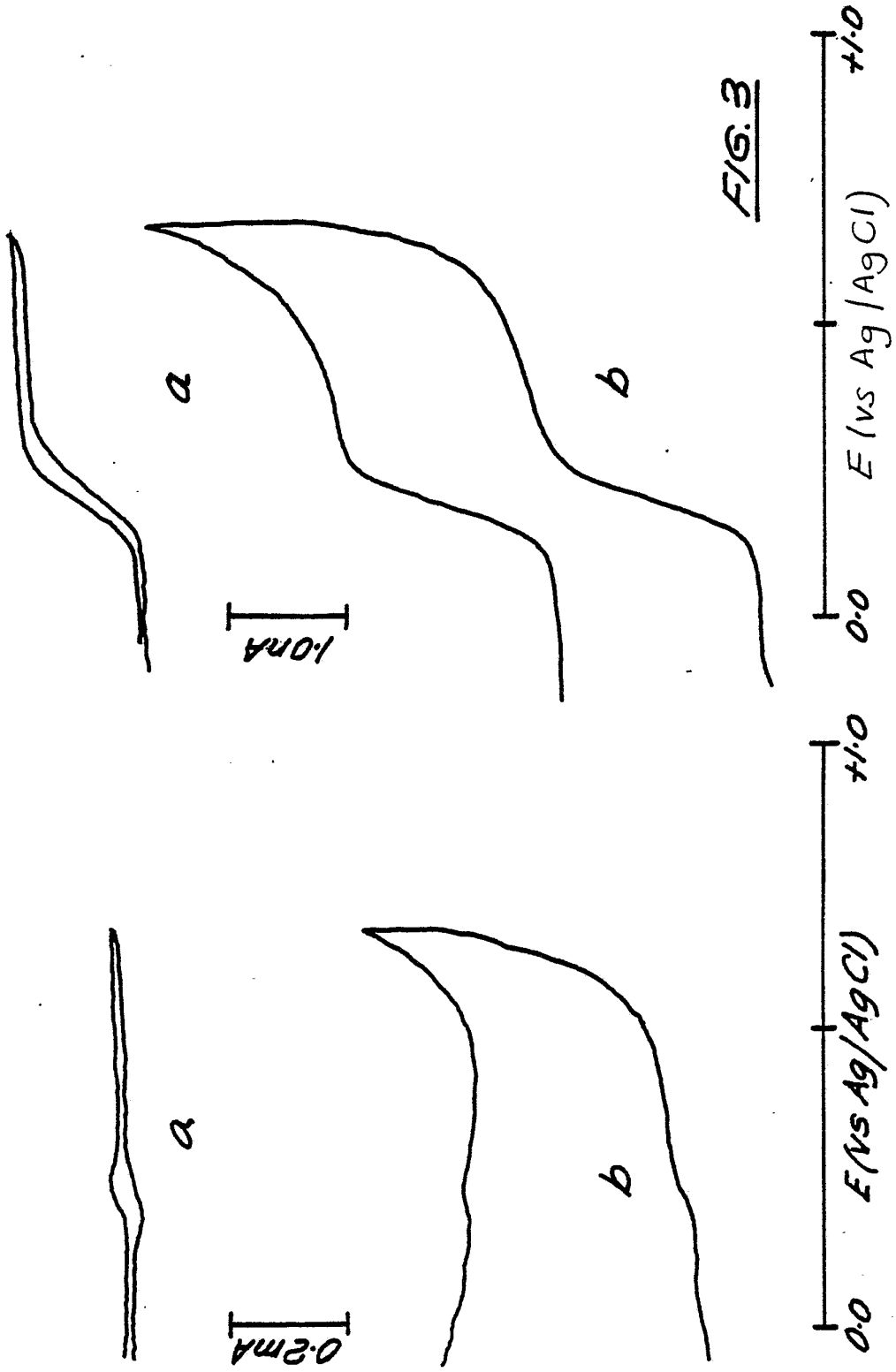


FIG. 3

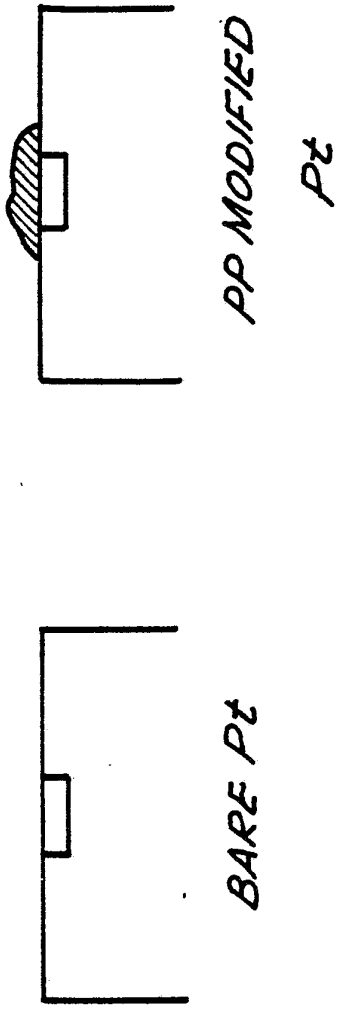


FIG. 4

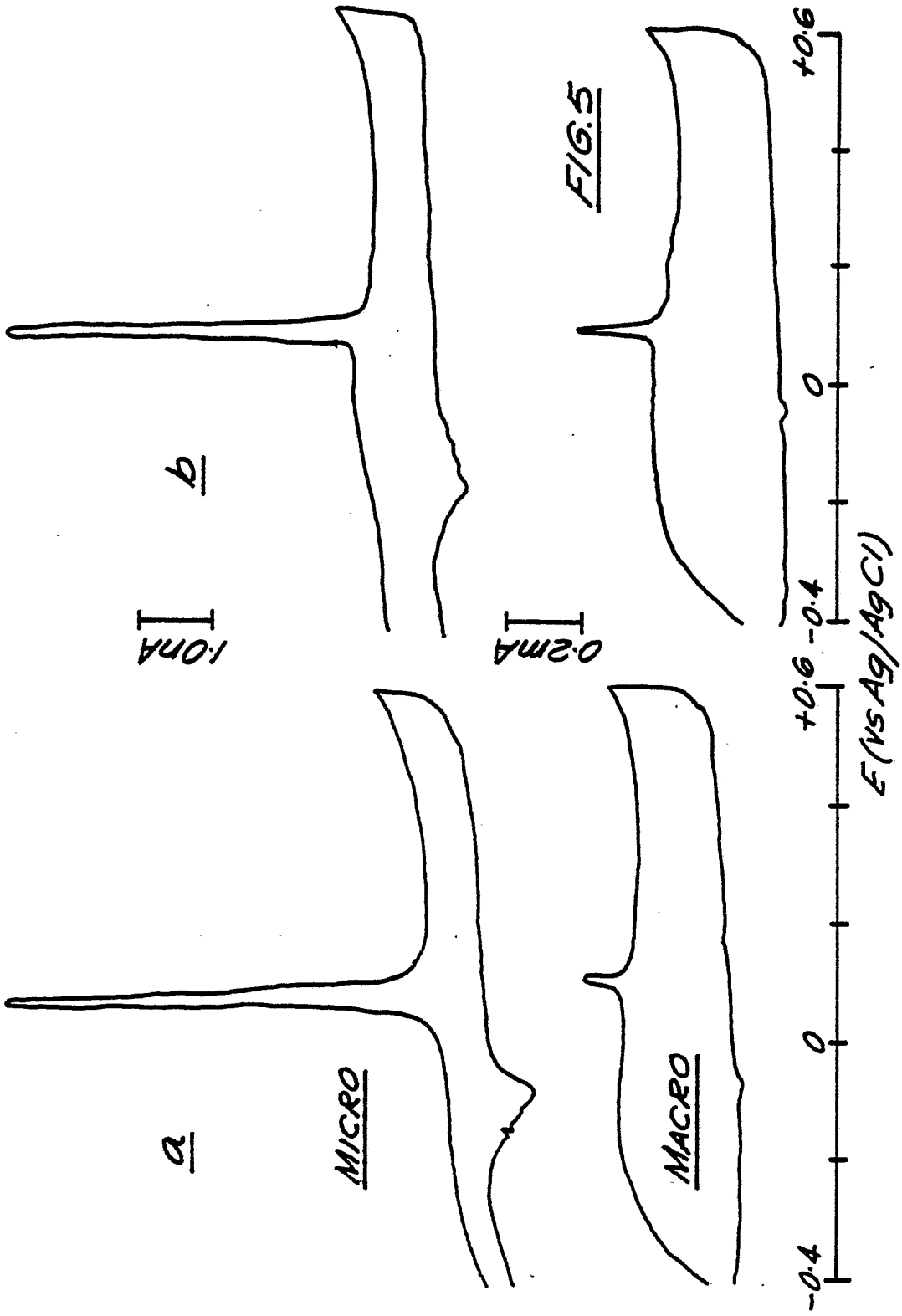


FIG.5

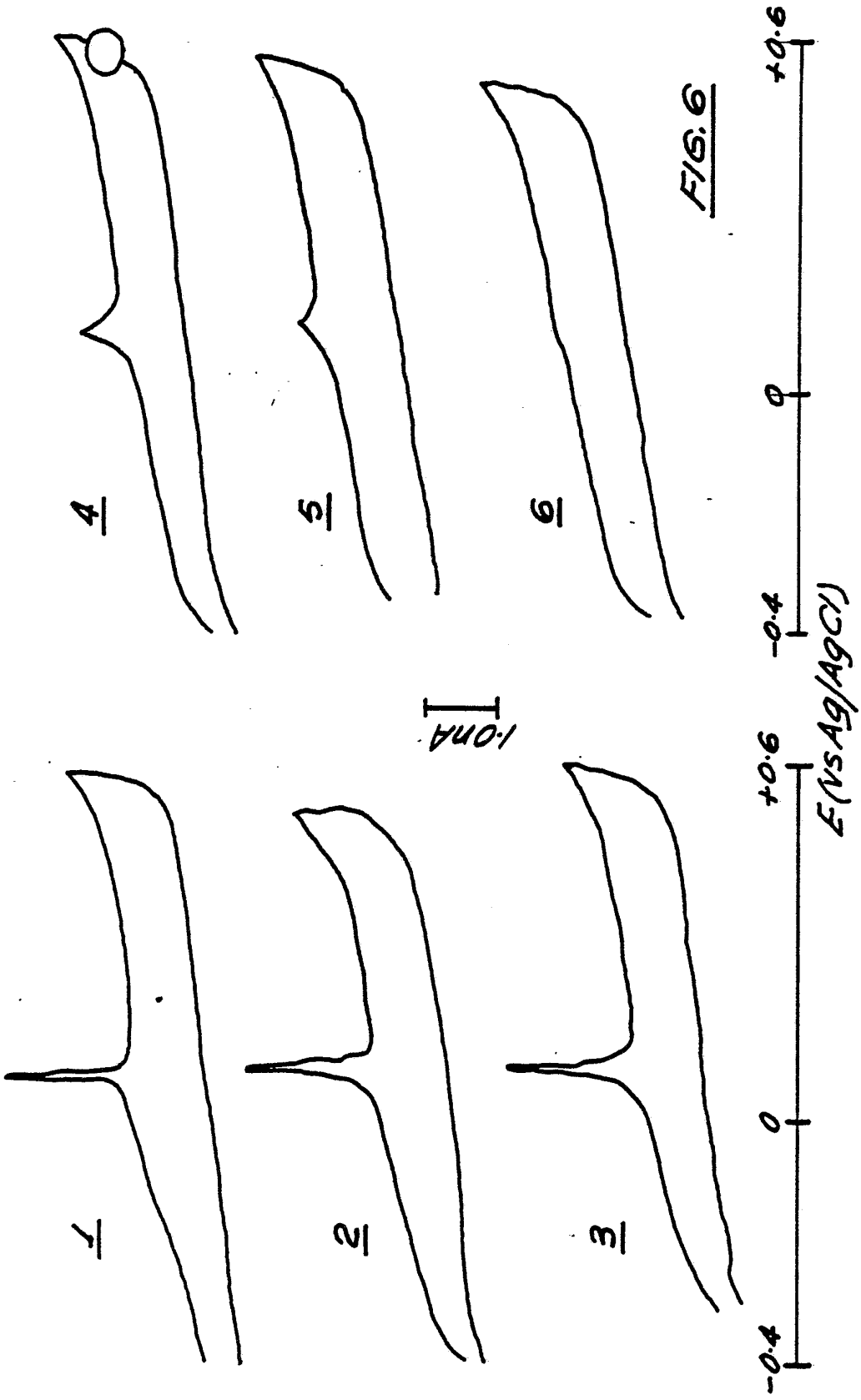


FIG. 6

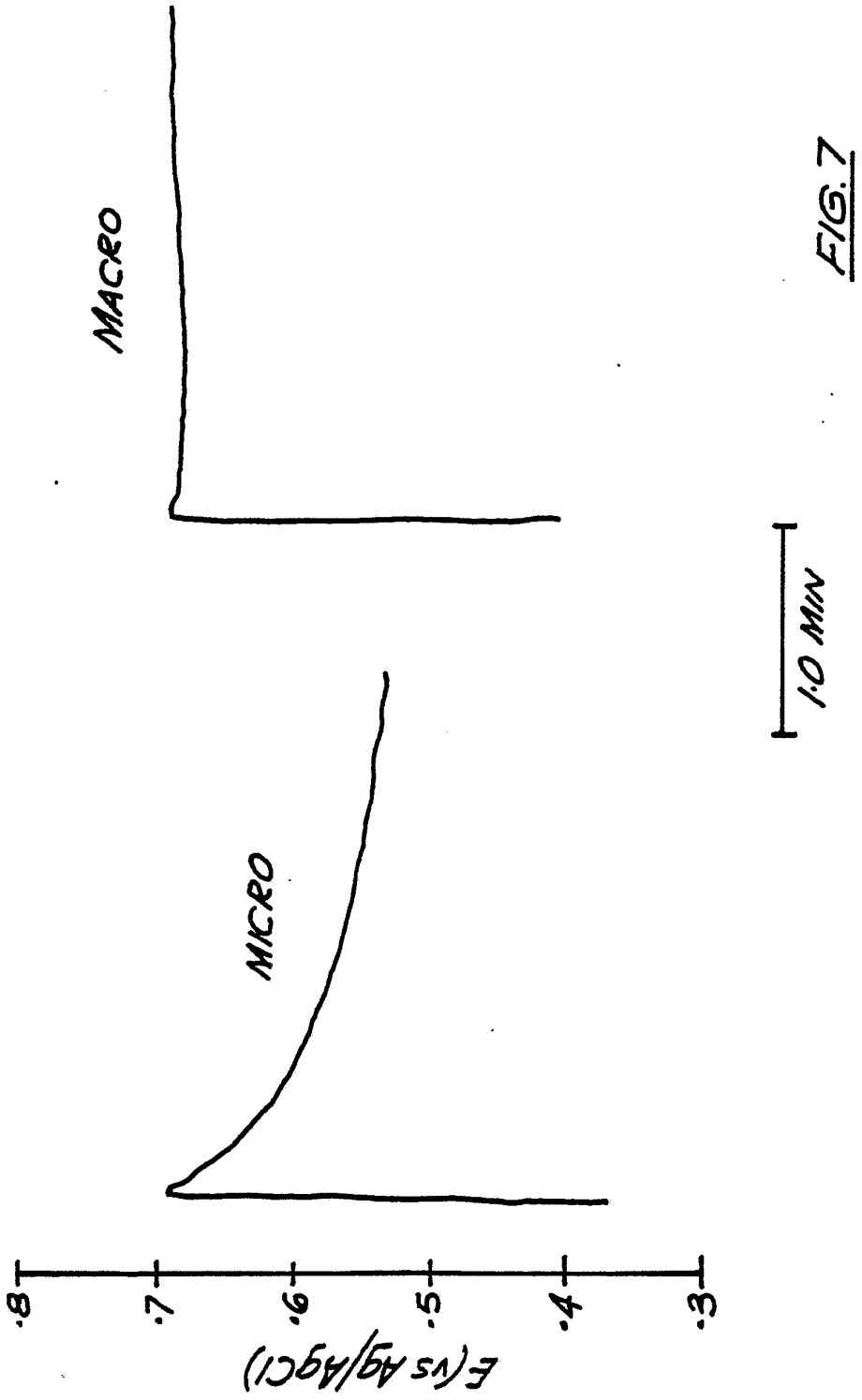


FIG. 7

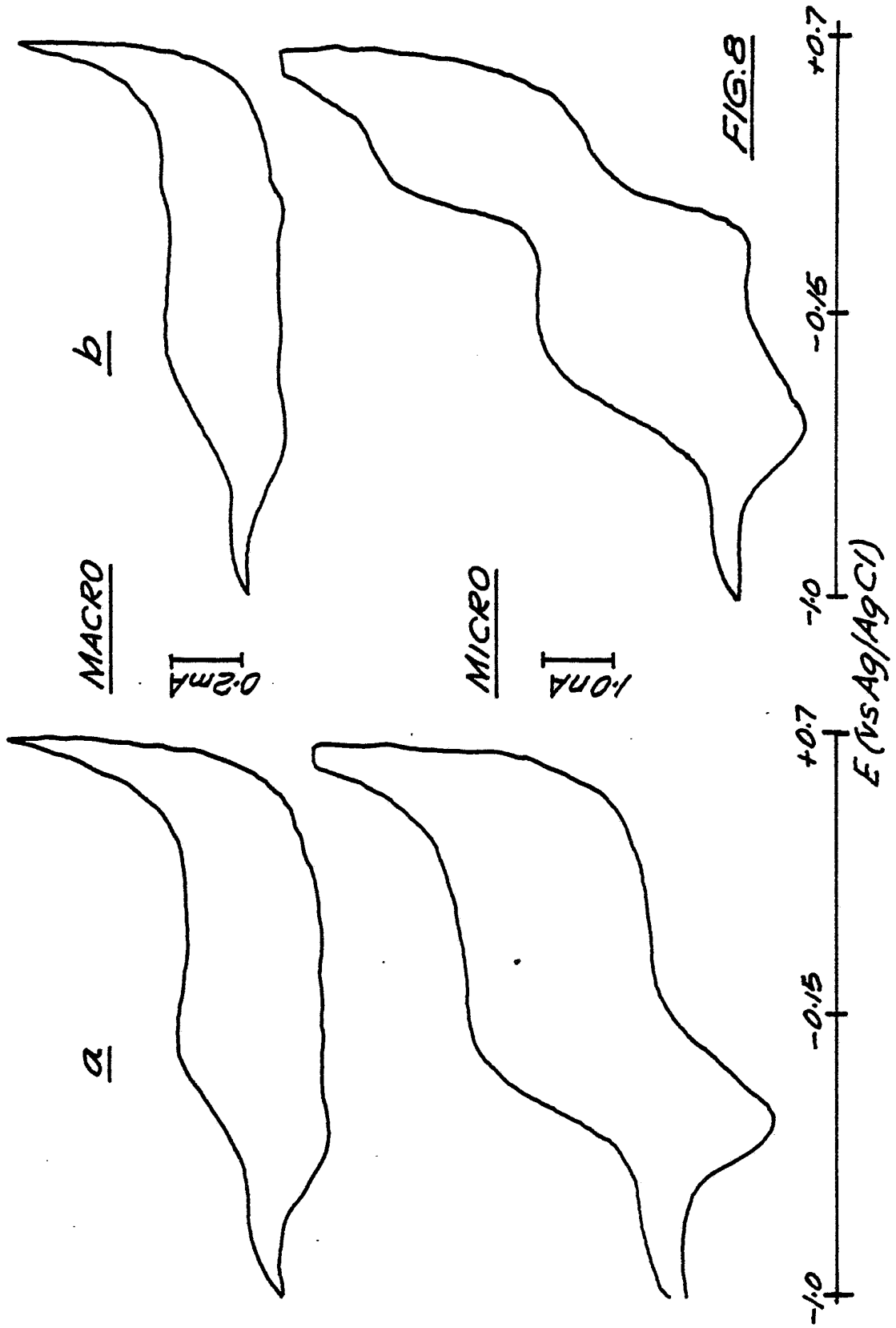


FIG.8

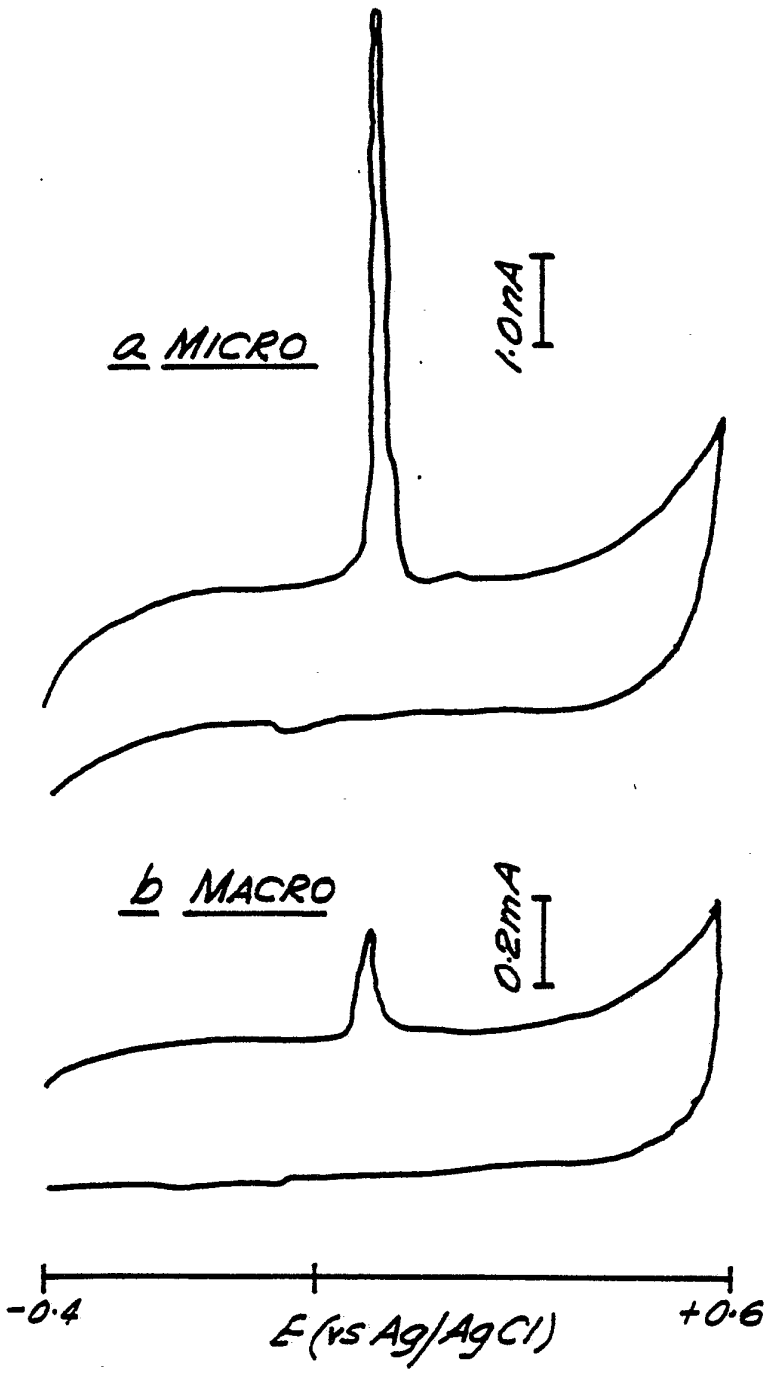


FIG. 9

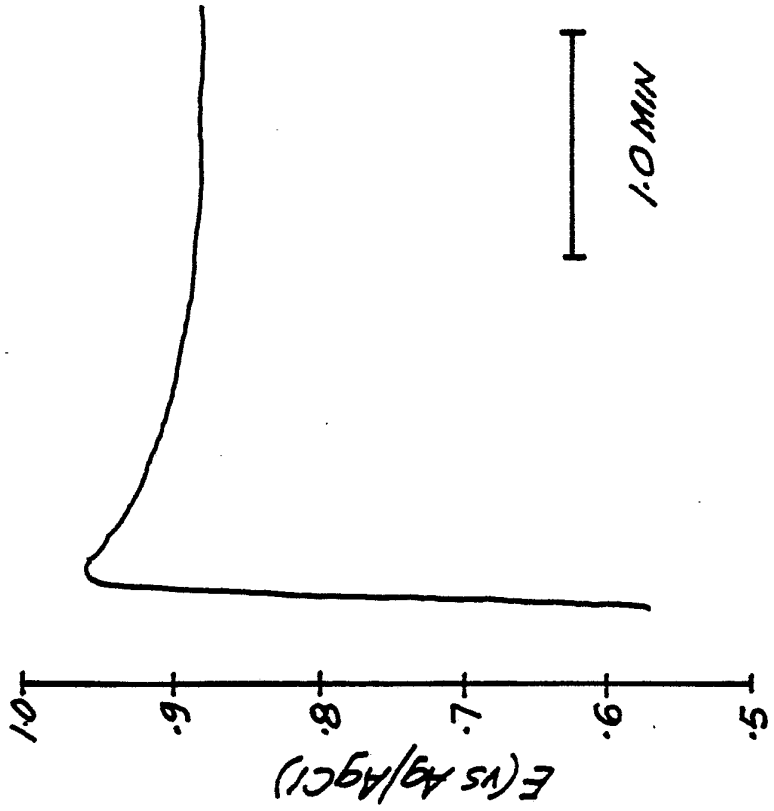


FIG.10

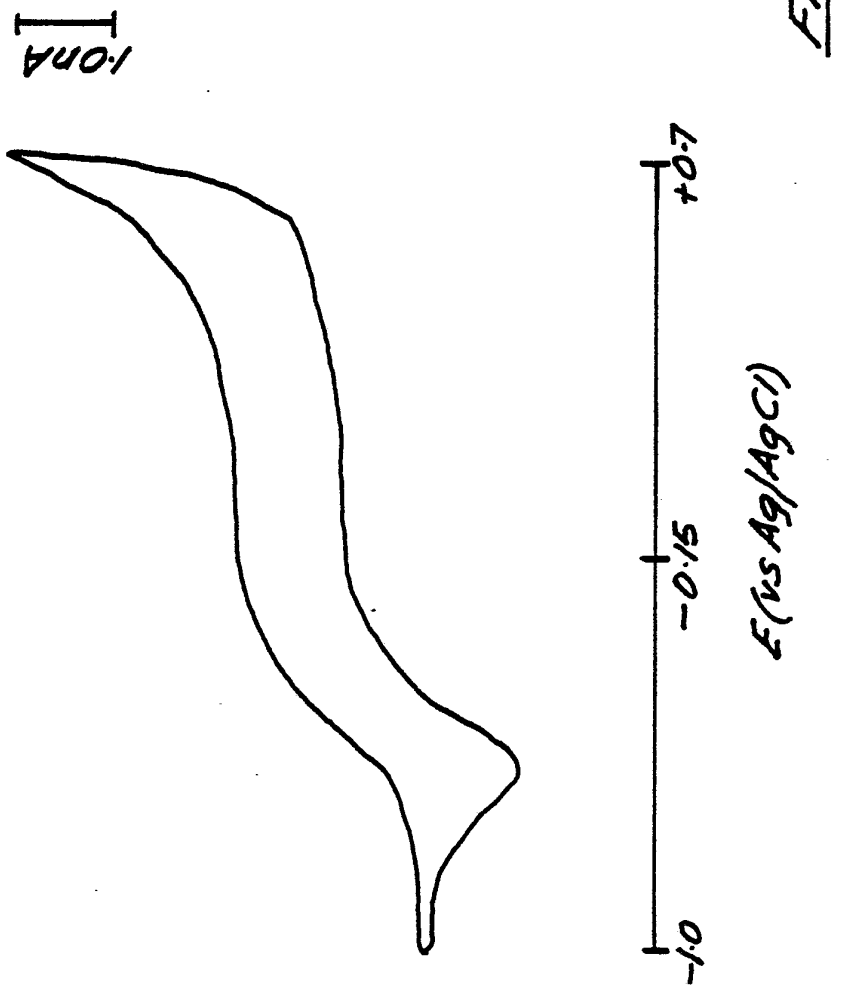


FIG. 11

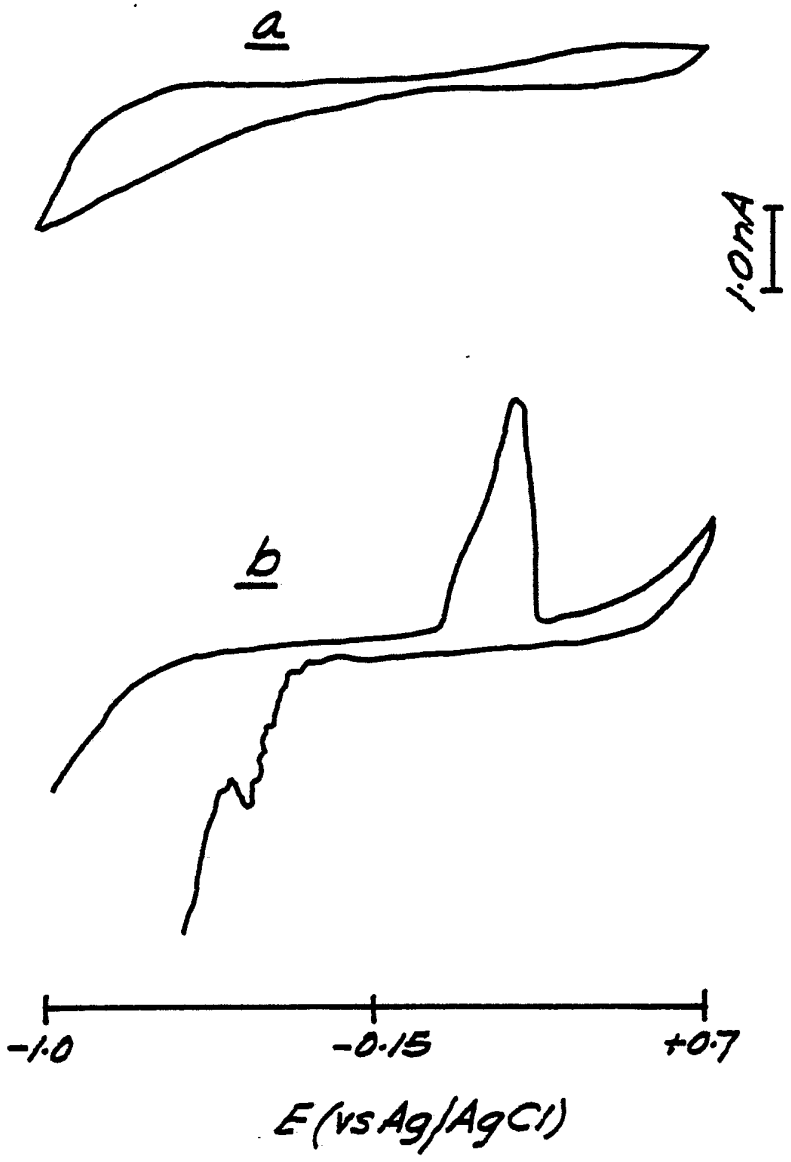


FIG. 12

INTERNATIONAL SEARCH REPORT

International Application No PCT/AU89/00381

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl.[4] C25D 9/02, 13/08, 15/00, 17/12 // A61B 5/04, A61M 5/14, A61N 1/05, 1/30, G01N 27/30

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	C25D 9/02, 13/00, 13/06, 13/08, 15/00, 17/12.

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [10]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	DE A1 3508266, (BASF AG), 11 September 1986, (11.09.86), (see the claims and the examples).	(1-14)
A	EP A2 145843, (W. R. GRACE & CO.), 26 June 1985 (26.06.85), (see the claims and the examples).	(1-14)
A	EP A1 193978, (STAMICARBON B.V.), 10 September 1986 (10.09.86), (see the claims and the examples).	(1-14)
A	GB A 655763, (SPRAGUE ELECTRIC COMPANY), 1 August 1951 (01.08.51), (see the claims, page 5 line 49 to page 8 line 31 and the drawings).	(1-14)
A	GB A 1305743, (FORD MOTOR COMPANY LIMITED), 7 February 1973 (07.02.73), (see the claims and the examples).	(1-14)

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
19 December 1989 (19.12.89)	22/12/89
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office.	(R.G.HOWE)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	DERWENT XRPX FILM, Abstract No. N86-057322, JP A2 61/026799, (NITTO ELECTRIC INDUSTRY K.K.), 6 February 1986 (06.02.86), (see the whole abstract).	(1-14)
A	DERWENT XRPX FILM, Abstract No. N88-182144, JP A2 63/174223, (JAPAN CARLIT K.K.), 18 July 1988 (18.07.88), (see the whole abstract).	(1-14)
A	US A 4013531, (K.NAKAMURA, H.KAKUTANI), 22 March 1977 (22.03.77), (see the claims, the examples and the drawings).	(1-14)
A	US A 4468291, (H.NAARMANN,G.KÜHLER,J.SCHLAG), 28 August 1984 (28.08.84), (see the claims, page 7 line 1 to page 8 line 68, the examples and the drawings).	(1-14)
A	US A 4559112, (T.TAMAMURA, O.NIWA), 17 December 1985 (17.12.85), (see the claims, page 3 line 22 to page 10 line 43, the examples and the drawings).	(1-14)
A	US A 4569734, (H.NAARMANN,J.NICKL,G.KÜHLER), 11 February 1986 (11.02.86), (see the claims and the examples).	(1-14)
A	US A 4724062, (H.NAARMANN,F.HAAF,G.FAHRBACH), 9 February 1988 (09.02.88), (see the claims and the examples).	(1-14)
A	US A 4728399, (H.MOEHWALD), 1 March 1988 (01.03.88), (see the claims and the example).	(1-14)
A	US A 4749451, (H.NAARMANN), 7 June 1988 (07.06.88), (see the claims, the examples and the drawings).	(1-14)

ANNEX TO THE INTERNATIONAL SEARCH REPORT OF INTERNATIONAL PATENT APPLICATION NO. PCT/AU89/00381.

This annex lists the patent family members relating to the patent documents cited in the above-mentioned International Search Report. The Australian Patent Office is in no way liable for these particulars, which are provided merely for the purpose of information.

EP A2 145843 --- ES A1 538554 ES A1 8604746	EP A1 193978 --- ES A1 551705 ES A5 551705 ES A1 8702521 JP A2 61/183498 NL A 8500335	GB A 1305743 --- CA A1 955881 DE A 2023406
US A 4013531 --- DE A1 2613093 GB A 1510253 JP A2 51/111337 NL A 7603123	US A 4559112 --- CA A1 1231670 EP A1 144127 EP A1 247366 JP A2 60/079609 JP A2 60/105532 JP A2 60/107209 JP A2 60/107214 JP A2 60/177506 JP A2 60/228547 JP A2 60/257235 JP A2 61/002204 JP A2 61/012887 JP A2 61/024103	US A 4468291 --- DE A1 3226278 EP A1 95055 JP A2 59/023889
US A 4724062 --- DE A1 3531019 EP A2 217099		US A 4569734 --- DE A1 3318857 EP A2 129698 JP A2 59/226020
US A 4749451 --- DE A1 3603373 JP A2 62/185894		US A 4728399 --- DE A1 3507419 EP A1 193894