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(54) **ELECTRICALLY ACTIVE FILMS**

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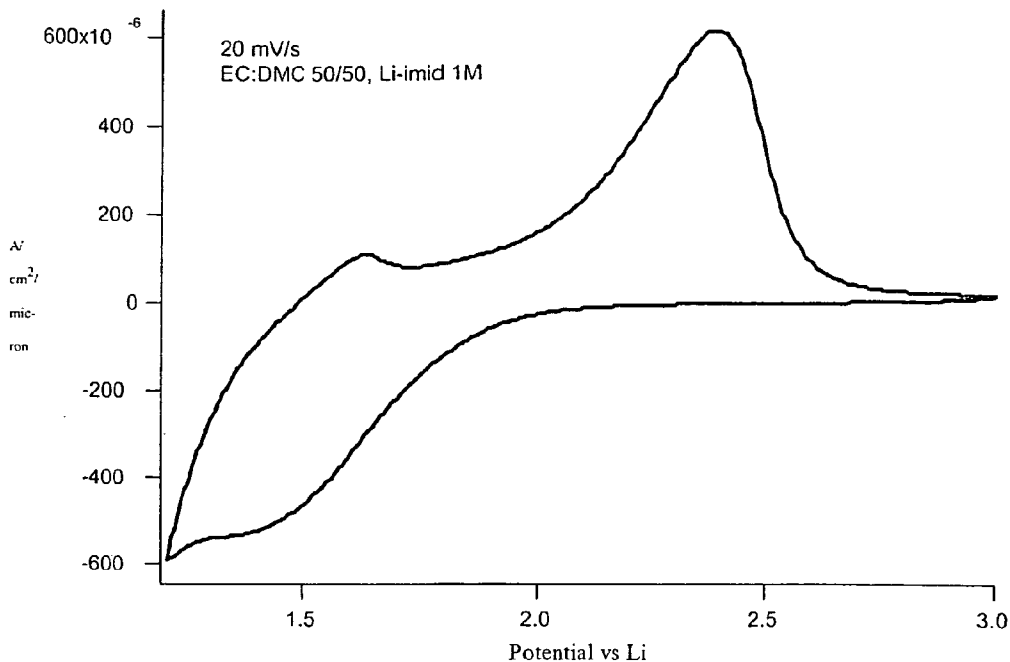
(57) **ABSTRACT**

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An electrically active film and a process for its preparation at low temperatures are described. The electrically active film consists of a support having coated thereon at least one electrically active layer which contains nanocrystalline, nanoporous transition metal oxides, transition metal chalcogenides or their lithium inclusion complexes and, optionally, auxiliary, electrically non-active layers, wherein the electrically active layers still contain a binder or a mixture of binders at the end of the preparation process.

**Prior Publication Data**

(15) Correction of US 2005/0075913 A1 Apr. 7, 2005  
See Abstract, Specification, Claims and Drawings.



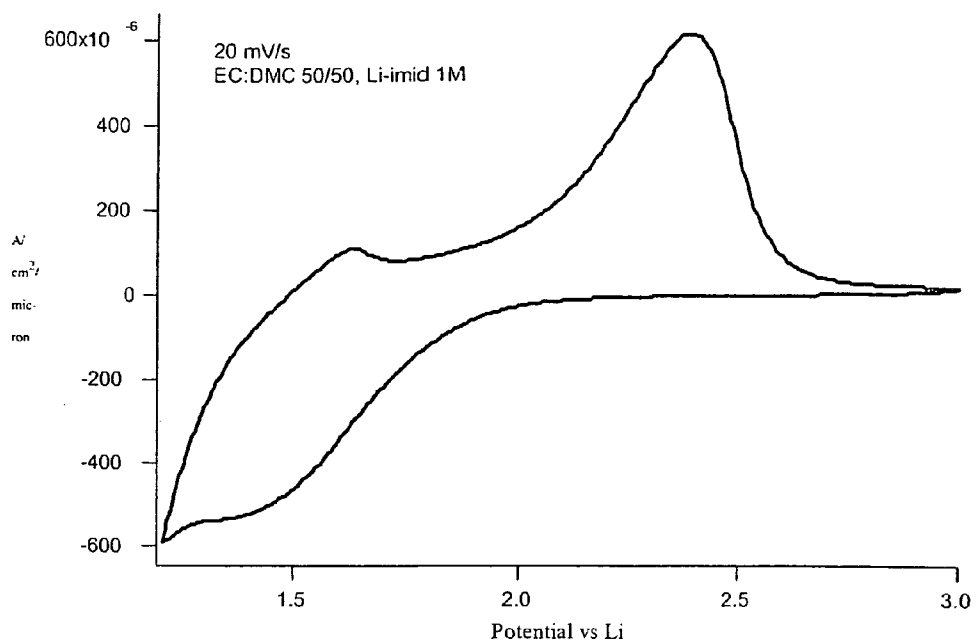


Figure 1

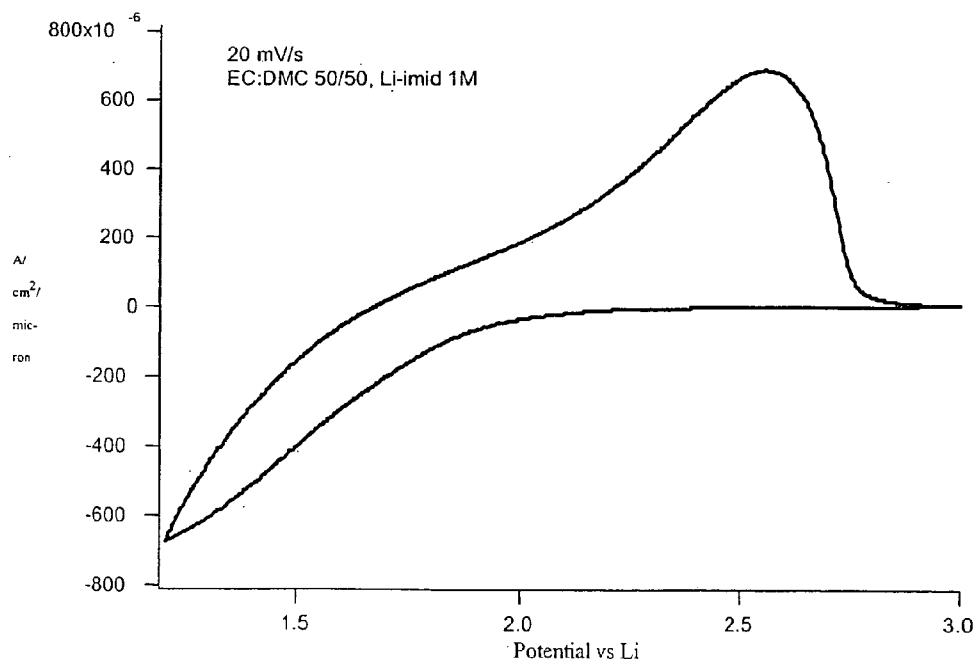


Figure 2

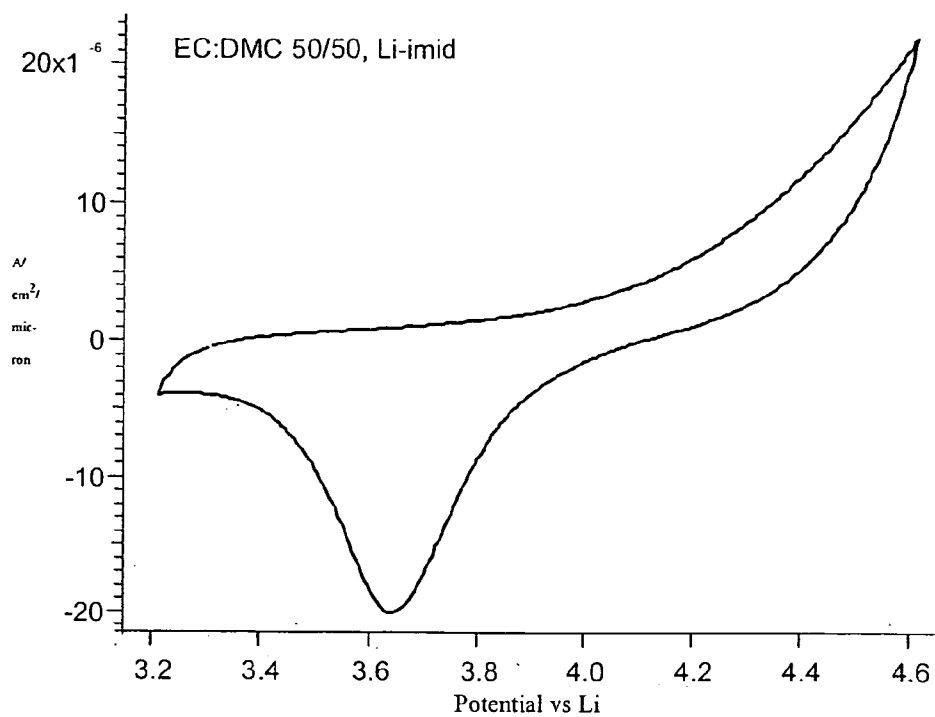


Figure 3

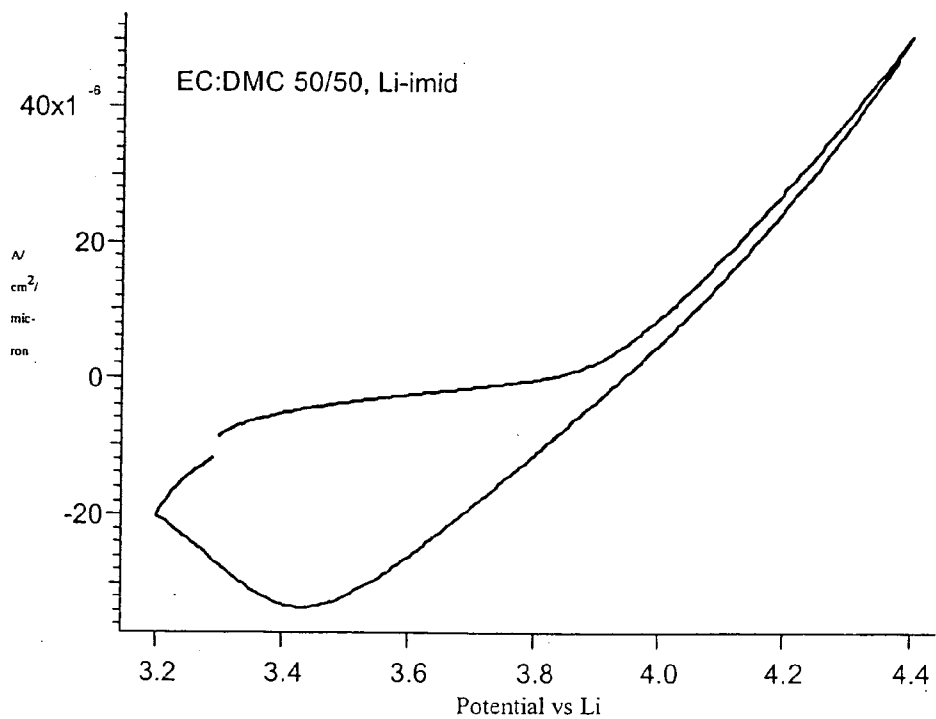


Figure 4

## ELECTRICALLY ACTIVE FILMS

### FIELD OF THE INVENTION

[0001] The present invention relates to electrically active films comprising a support having coated thereon a layer containing nanocrystalline, nanoporous transition metal oxides, transition metal chalcogenides or their lithium inclusion compounds together with a binder and a process for their preparation at low temperatures.

### BACKGROUND OF THE INVENTION

[0002] Electrically active films, which contain nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion compounds, are used as electrodes in primary or secondary electrochemical generators, as described for example in patent application WO 99/59,218. These electrically active films are further used in photovoltaic cells or in electrochromic displays.

[0003] In patent application EP 0,709,906 a positive electrode is described consisting of sintered particles of oxygen containing lithium compounds of a size of 33  $\mu\text{m}$ . These particles are heated under pressure at a temperature between 350° C. and 1000° C. in order to attain the required electrical activity.

[0004] In U.S. Pat. No. 5,604,057 a cathode is described consisting of amorphous, nanoporous particles of manganese oxide including lithium ions of sub micrometer size having an internal surface greater than 100  $\text{m}^2/\text{g}$ . These electrodes are prepared by coating the manganese oxide together with a preferentially conductive binder or a mixture of binders onto a conductive support (as for example an aluminium foil). Coating may be effected by spraying, spin coating, blade coating or painting. Subsequently the coated support has to be heated, but not to a temperature exceeding 400° C. in order to prevent crystallization of the manganese dioxide.

[0005] In U.S. Pat. Nos. 5,211,933 and 5,674,644 a preparation method for  $\text{LiMn}_2\text{O}_4$  with spinel structure and for  $\text{LiCoO}_2$  with a layer structure is described, wherein the compounds are prepared from acetate precursors. The powder of  $\text{LiMn}_2\text{O}_4$  prepared in this way consists of particles having a size from 0.3  $\mu\text{m}$  to 1.0  $\mu\text{m}$ . Pressed tablets of this powder, with the addition of 10% of small graphite particles, are used as positive electrode in lithium batteries. Conductivity between the individual tablets is caused by the graphite particles.  $\text{LiMn}_2\text{O}_4$  and  $\text{LiCoO}_2$  may also be coated onto a support together with a binder. Afterwards the coated support is heated to a temperature of 600° C. During this heating step, the organic binder is completely removed from the layer. The finally obtained electrically active film therefore no longer contains any organic binder.

[0006] In U.S. Pat. No. 5,700,442 inclusion compounds of manganese dioxide are described which are used as positive electrode in lithium batteries. These inclusion compounds are prepared by heating of a  $\beta\text{-MnO}_2$  powder with a lithium compound at a temperature between 150° C. and 500° C. for a sufficiently long period of time. The particles prepared in this way are relatively coarse and have a specific surface below 7  $\text{m}^2/\text{g}$  and are therefore not suitable as a material for active electrodes that may be discharged rapidly.

[0007] In patent application EP 0,814,524 lithium manganese oxides with spinel structure are described as active cathode material in secondary lithium ion batteries. The mean size of the particles is between 1  $\mu\text{m}$  and 5  $\mu\text{m}$  and the specific surface is between 2  $\text{m}^2/\text{g}$  and 10  $\text{m}^2/\text{g}$ . Due to the coarse particles and the low internal surface, these compounds are not suitable as a material for active electrodes that may be discharged rapidly.

[0008] In patent application WO 99/59,218 the preparation of electrodes consisting of  $\text{TiO}_2$  and  $\text{LiMn}_2\text{O}_4$  with the aid of a coating or printing process is described, wherein an aqueous suspension of a manganate precursor compound is deposited onto a substrate. This coating operation normally has to be repeated several times in order to obtain the required layer thickness. Subsequently the coated substrate has to be heated to a temperature between 400° C. and 750° C. in the presence of air for a few minutes in order to obtain the required conductivity. The sintering process at high temperatures leads to layers with higher electrical activity than a sintering process at lower temperatures.

[0009] The preparation of thin film electrodes at room temperature by coating aqueous suspensions of manganate powers containing 3% of polyvinyl alcohol and 10% of graphite onto conductive supports is mentioned in "Influence of the Particle Size of Electrode Materials on Intercalation Rate and Capacity of New Electrodes", Journal of Power Sources 81-82, 621-626 (1999). The layers are heated subsequently to a temperature of at least 200° C. during 15 minutes.

[0010] The known methods for the preparation of transparent conductors are listed in "Criteria for Choosing Transparent Conductors", MRS Bulletin 25, 52 (2000) (Table 1). Most of the preparation methods need high temperatures up to 1000° C.

[0011] All these preparation methods do not allow a cost effective production of electrically active films due to the required high temperatures and the long process times. In particular, it is not possible to use cheap, transparent, commercially available supports that are used for example in the photographic industry, because they would be destroyed at the high temperatures required. There is the further disadvantage of the required high temperatures that heat-sensitive compounds, in particular organic compounds such as spectral sensitizing dyes cannot be added to the electrically active films. Furthermore the mechanical stability of such electrically active films is not sufficient as well as the adhesion of the layers to the substrate.

### SUMMARY OF THE INVENTION

[0012] Accordingly, it is an object of the invention to provide electrically active films containing binders with excellent mechanical stability using cost-effective production methods, which show a high electrical activity without removal of the binder in a sintering step at high temperatures.

[0013] A further object of the invention is the provision of such electrically active films having excellent mechanical stability using cost-effective coating methods at low temperatures, wherein suspensions containing a binder are deposited onto cheap organic plastic supports which are subsequently dried. These electrically active films show a

high electrical activity even without removal of the binder in a sintering process at high temperature.

[0014] Such electrically active films comprise a support having coated thereon at least one electrically active layer containing binders and, optionally, one or more electrically inactive layers.

[0015] We have now found unexpectedly that such binder-containing films with high electrical activity may be prepared in a cost-effective way in large scale quantities by coating liquid suspensions or colloidal dispersions containing nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes together with a binder or a mixture of binders at temperatures between 5° C. and 95° C., optionally together with electrically inactive layers, onto commercially available plastic supports or paper supports and subsequent drying at temperatures below the boiling point (at standard pressure) of the suspension liquid. The temperature of the coated support or of the drying medium never exceeds the boiling point (at standard pressure) of the suspension liquid during the whole drying step and therefore all of the binder or the mixture of binders remains in the electrically active film together with the transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes.

[0016] In a preferred embodiment of the invention, aqueous colloidal dispersions containing such nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes together with one or more film-forming, nonconducting binders are coated at temperatures between 20° C. and 55° C., optionally together with electrically inactive layers, onto plastic supports or metallized plastic supports and subsequently dried with a gas mixture, preferably air, at temperatures below 100° C., preferably below 60° C.

[0017] Preferred nanocrystalline, nanoporous transition metal oxides are titanium dioxide, preferably with anatase structure, and  $\text{LiMn}_2\text{O}_4$  as lithium inclusion compound.

[0018] Other objects, features and advantages of the present invention will be apparent when the detailed description of the preferred embodiment of the invention are considered with reference to the drawings which should be construed in an illustrative and not limiting sense as follows:

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 illustrates the cyclic voltammogram of a support coated according to the present invention as described in Example 1;

[0020] FIG. 2 illustrates the cyclic voltammogram of Comparative example C-1;

[0021] FIG. 3 illustrates the cyclic voltammogram of a support coated according to the present invention as described in Example 2; and

[0022] FIG. 4 illustrates the cyclic voltammogram of Comparative example C-2.

#### DETAILED DESCRIPTION OF THE INVENTION

[0023] The invention describes a method for the large scale production of films containing binders with high

electrical activity, wherein liquid suspensions or colloidal dispersions containing nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes and a binder or a mixture of binders are coated at temperatures between 5° C. and 60° C., optionally together with electrically inactive layers, onto commercially available plastic supports or paper supports and subsequent drying at temperatures below the boiling point (at standard pressure) of the suspension liquid. The temperature of the coated support or of the drying medium never exceeds the boiling point (at standard pressure) of the suspension liquid during the whole drying step and therefore all of the binder or the mixture of binders remains in the electrically active layer of the electrically active film together with the transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes.

[0024] In a preferred embodiment of the invention, aqueous colloidal dispersions containing such nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes together with one or more film-forming, nonconducting binders are coated at temperatures between 20° C. and 55° C., optionally together with electrically inactive layers, onto plastic supports or metallized plastic supports and subsequently dried with a gas mixture, preferably air, at temperatures below 100° C., preferably below 60° C.

[0025] Drying may also be done using infrared radiation or in a combined drying step consisting of drying with a gas mixture and infrared drying.

[0026] Suitable nanocrystalline, nanoporous transition metal oxides and transition metal chalcogenides are oxides or chalcogenides of the transition metals such as  $\text{TiO}_2$ ,  $\text{Ti}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{WO}_3$ ,  $\text{V}_2\text{O}_5$ ,  $\text{MoO}_3$ ,  $\text{MnO}_2$ ,  $\text{HfO}_2$ ,  $\text{TiS}_2$ ,  $\text{WS}_2$ ,  $\text{TiSe}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ ,  $\text{RuO}_2$ ,  $\text{RuS}_2$ ,  $\text{MoS}_2$ ,  $\text{WS}_2$ ,  $\text{IrO}_2$ ,  $\text{CeO}_2$ ,  $\text{InO}_2$ ,  $\text{TaO}_2$ ,  $\text{ZnO}$ ,  $\text{SnO}_2$ ,  $\text{BaTiO}_3$ ,  $\text{SrTiO}_3$  or indium tin oxide having specific surfaces between 10  $\text{m}^2/\text{g}$  and 400  $\text{m}^2/\text{g}$ . Lithium inclusion compounds such as  $\text{LiMn}_2\text{O}_4$ ,  $\text{LiNiO}_2$ ,  $\text{LiCoO}_2$  or  $\text{Li}(\text{NiCo})\text{O}_2$  may also be used.

[0027] Nanocrystalline, nanoporous transition metal oxides and the lithium inclusion compounds of such nanocrystalline, nanoporous transition metal oxides are preferred.

[0028] Especially preferred are titanium dioxide with anatase structure and  $\text{LiMn}_2\text{O}_4$ .

[0029] The size of these nanocrystalline, nanoporous primary particles is preferably from 10 nm to 500 nm, especially preferred from 10 nm to 100 nm.

[0030] In the case of  $\text{TiO}_2$  the primary particles preferably have a size from 10 nm to 50 nm with a maximum of the size distribution at 25 nm.

[0031] In the case of  $\text{LiMn}_2\text{O}_4$  the primary particles preferably have a size below 100 nm.

[0032] The electrically active films contain these nanocrystalline, nanoporous transition metal oxides and transition metal chalcogenides or their lithium inclusion compounds in a quantity of 1  $\text{g}/\text{m}^2$  to 100  $\text{g}/\text{m}^2$ , preferably in a quantity of 3  $\text{g}/\text{m}^2$  to 50  $\text{g}/\text{m}^2$ . These quantities correspond to a film thickness between 1  $\mu\text{m}$  and 100  $\mu\text{m}$ , respectively between 3  $\mu\text{m}$  and 50  $\mu\text{m}$ .

[0033] Preferred are electrically active films having coated onto the support an electrically active layer and on top of this

layer an electrically inactive layer. Preferably the electrically inactive layer contains a film-forming binder and an electrically inactive pigment.

[0034] In an especially preferred embodiment of the invention the electrically inactive layer contains  $\gamma$ - $\text{Al}_2\text{O}_3$  as pigment and polyvinyl alcohol as binder, where the ratio between the binder and the pigment is from 1:5 und 1:40, particularly from 1:10 and 1:30, and where the thickness of the electrically inactive layer is from 2  $\mu\text{m}$  to 20  $\mu\text{m}$ , preferably from 4  $\mu\text{m}$  to 15  $\mu\text{m}$ .

[0035] The binders are in most cases water-soluble, non-conducting polymers. Film-forming, nonconducting polymers are preferred.

[0036] The water-soluble, nonconducting polymers include for example natural polymers or modified products thereof such as albumin, gelatine, casein, starch, gum arabicum, sodium or potassium alginate, hydroxyethylcellulose, carboxymethylcellulose,  $\alpha$ -,  $\beta$ - or  $\gamma$ -cyclodextrine and the like. In the case where one of the water-soluble polymers is gelatine, all known types of gelatine may be used as for example acid pigskin or limed bone gelatine, acid or base hydrolysed gelatine.

[0037] A preferred natural, nonconducting, film-forming, binder is gelatine.

[0038] Synthetic, nonconducting binders may also be used and include for example polyvinyl alcohol; polyvinyl pyrrolidone; completely or partially saponified products of copolymers of vinyl acetate and other monomers; homopolymers or copolymers with monomers of unsaturated carboxylic acids such as (meth)acrylic acid, maleic acid, crotonic acid and the like. Homopolymers or copolymers of vinyl monomers of (meth)acrylamide; homopolymers or copolymers of other monomers with ethylene oxide; polyurethanes; polyacrylamides; water soluble nylon type polymers; polyesters; polyvinyl lactams; acrylamide polymers; substituted polyvinyl alcohol; polyvinyl acetals; polymers of alkyl and sulfoalkyl acrylates and methacrylates; hydrolysed polyvinyl acetates; polyamides; polyvinyl pyridines; polyacrylic acid; polyacryl nitrile; copolymers with maleic anhydride; polyalkylene oxides; methacrylamide copolymers and maleic acid copolymers or fluoropolymers such as polyvinylidene fluoride may also be used. All these polymers may also be used as mixtures.

[0039] Preferred synthetic nonconducting, film-forming binders are polyvinyl alcohol, polyvinylidene fluoride, polyethylene oxides, polyethylene glycols and polyacryl nitrile or mixtures thereof.

[0040] Polythiophenes, polyanilines, polyacetylenes, poly(3,4-ethylene)dioxythiophene and polyphenylenevinylene may be used as conducting, film-forming polymers. Poly(3,4-ethylene)dioxythiophene is preferred.

[0041] Small graphite particles or nanosize carbon tubes may be added to the nonconducting polymers.

[0042] These polymers may be blended with water insoluble natural or synthetic high molecular weight compounds, particularly with acrylate latices or with styrene acrylate latices.

[0043] Although water-insoluble, conducting or nonconducting, film-forming polymers are not specifically claimed

in this invention, water-insoluble, conducting or nonconducting, film-forming polymers should nevertheless be considered to be part of the system.

[0044] The amount of the film-forming polymer should be as low as possible, but still sufficiently high in order to obtain coatings well adhering to the support. Suitable amounts are from 0.5% to 20% relative to the amount of the total quantity of all the nanocrystalline, nanoporous transition metal oxides, transition metal chalcogenides or lithium inclusion compounds. Preferred are quantities from 1% to 10%, in particular from 2% to 5%.

[0045] The polymers mentioned above having groups with the possibility to react with a cross-linking agent can be cross-linked or hardened to form essentially water insoluble layers. Such cross-linking bonds may be either covalent or ionic. Cross-linking or hardening of the layers allows for the modification of the physical properties of the layers, like for instance in water take-up of the layer or in resistance against layer damage.

[0046] The cross-linking agents or hardeners are selected depending on the water-soluble polymers used.

[0047] Organic cross-linking agents and hardeners include for example aldehydes (such as formaldehyde, glyoxal or glutaraldehyde), N-methylol compounds (such as dimethylol urea or methyloldimethylhydantoin), dioxanes (such as 2,3-dihydroxydioxane), reactive vinyl compounds (such as 1,3,5-trisacryloyl-hexahydro-s-triazine or bis-(vinylsulfonyl)methyl ether), reactive halogen compounds (such as 2,4-dichloro-6-hydroxy-s-triazine), epoxides, aziridines, carbamoyl pyridinium compounds, melamine resins or mixtures of two or more of these above mentioned cross-linking agents.

[0048] Inorganic cross-linking agents or hardeners include for example chromium alum, aluminium alum, boric acid, zirconium compounds or titanocenes.

[0049] The layers may also contain reactive substances that cross-link the layers under the influence of ultraviolet light, electron beams, X-rays or heat.

[0050] Electrically active films having coated on a support an electrically active layer and on top of this layer an electrically inactive layer are hardened additionally with a cross-linking agent adapted to the polymer in the electrically inactive layer in order to obtain an excellent mechanical stability. In the case where polyvinyl alcohol is used in the electrically inactive layer, boric acid or borates are suitable cross-linking agents.

[0051] A wide variety of supports are known and commonly used in the photographic industry. For the manufacture of electrically active films all those supports used in the manufacture of photographic materials may be used, such as transparent films made from cellulose esters such as cellulose triacetate, cellulose acetate, cellulose propionate or cellulose acetate/butyrate, polyesters such as polyethylene terephthalate or polyethylene naphthalate, polyamides, polycarbonates, polyimides, polyolefins, polyvinyl acetals, polyethers, polyvinyl chloride and polysulfonamides. Polyester film supports, and especially polyethylene terephthalate or polyethylene naphthalate are preferred because of their excellent dimensional stability characteristics. The usual opaque supports used in the manufacture of photographic

materials may be used including for example baryta paper, polyethylene coated papers, voided polyester as for instance manufactured by DuPont under the trade name of Melinex®. Especially preferred are polyolefin-coated papers or voided polyester. All of these supports may also have a conducting metallic layer on their surface.

[0052] Plain papers, comprising all different types of papers varying widely in their composition and in their properties, may also be used as supports. Pigmented papers and cast-coated papers may be used as well.

[0053] Metal foils, such as foils made from aluminium, may also be used as supports for electrically active films, as well as plastic supports having a highly conducting layer at their surface. Metallized plastic supports or plastic supports having a layer of indium tin oxide on their surface are preferred.

[0054] The electrically active layers are in general coated from aqueous solutions or dispersions containing all necessary ingredients. In many cases, surfactants are added to those coating solutions in order to improve the coating behavior and the evenness of the layers. Although not specifically claimed in this invention, surfactants nevertheless form an important part of the invention.

[0055] The coating solutions may be coated onto the support by any number of suitable procedures. The coating methods include for example extrusion coating, air knife coating, doctor blade coating, cascade coating and curtain coating. The coating solutions may also be applied using spray techniques, intaglio or offset printing. The electrically active may be coated in different coating passes. It is likewise possible to coat a support on both sides with electrically active layers. The selected coating procedure however is not to be considered limiting for the present invention.

[0056] The coating speed depends on the coating procedure used and may be varied within big limits. Curtain coating at speeds between 30 m/min and 300 m/min is the preferred coating procedure.

[0057] The support having coated thereon the electrically active layers, optionally together with electrically inactive layers, is dried immediately after coating. The temperature of the support or of the drying medium never exceeds during the whole production process the boiling point (at standard pressure) of the suspension liquid.

[0058] The temperature of the coating solution containing these nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion compounds and the binder or mixture of binders is between 20° C. and 60° C. and the temperature of the drying medium, in particular air, never exceeds 100° C., preferentially it never exceeds 60° C.

[0059] The present invention is illustrated in more detail by the following examples without limiting or restricting the scope of the invention in any way.

## EXAMPLES

### Example 1

Preparation of an Aqueous Dispersion of Titanium Dioxide

[0060] 24.6 g of nanocrystalline, nanoporous TiO<sub>2</sub> (P25 (anatase structure), available from Degussa-Hüls AG, Frankfurt am Main, Germany) were dispersed by exposure to ultrasound for a few minutes at a temperature of 40° C. in 170 g of deionized water. Afterwards the value of pH of the dispersion was adjusted to 4.50 by the addition of a solution of potassium hydroxide (1%). After a further exposure to ultrasound, the total weight was adjusted to 200 g with deionized water. The dispersion of P25 prepared in this way contained 12.3% by weight of TiO<sub>2</sub>.

Preparation of the Coating Solution

[0061] 65.04 g of this dispersion were mixed with 7.2 g of deionized water at a temperature of 40° C. Afterwards 4.27 g of a solution of polyethylene glycol (7.5%, molecular weight 100'000, available from Fluka Chemie AG, Buchs, Switzerland) were added, the total weight of the mixture was adjusted to 80 g with deionized water and the solution was exposed to ultrasound for a few minutes.

Coating

[0062] 100 g/m<sup>2</sup> of this coating solution were coated at a temperature of 40° C. with a bar coater onto a thin, transparent polyethylene terephthalate support having glued onto its surface a thin copper foil. Afterwards the coated support was dried for 60 minutes at a temperature of 30° C. 1 m<sup>2</sup> of the coated support contains 10 g of TiO<sub>2</sub> and 0.4 g of polyethylene glycol.

### Comparative Example C-1

[0063] A sintered layer of nanocrystalline, nanoporous, sintered TiO<sub>2</sub>, prepared by the method described in "Nanocrystalline Titanium Oxide Electrodes for Photovoltaic Applications", Journal of the American Ceramic Society 80, 3157-3171 (1997). TiO<sub>2</sub> is mixed with polyethylene glycol (molecular weight 25'000) and water. The resulting paste was deposited onto a glass plate coated with conducting tin oxide and heated for 20 minutes in the presence of air at a temperature of 400° C. The organic binder was destroyed and removed from the coated layer by this treatment.

### Example 2

Preparation of an Aqueous Dispersion of Lithium Manganate

[0064] 100.0 g of cathode powder SP 30 (available from Merck, Darmstadt, Germany) were dispersed in ethanol and subsequently milled in a ball mill for 3 hours. The milled powder was dried at a temperature of 40° C. 20.0 g of this nanocrystalline, nanoporous LiMn<sub>2</sub>O<sub>4</sub> were dispersed in 65.8 g of deionized water by exposure to ultrasound for a few minutes.

Preparation of the Coating Solution

[0065] 10.67 g of a solution of polyethylene glycol (7.5%, molecular weight 100'000) were added to 65.8 g of this dispersion at a temperature of 40° C., the total weight of the mixture was adjusted to 100 g with deionised water and the mixture was exposed for a few minutes to ultrasound.

## Coating

[0066] 24 g/m<sup>2</sup> of this coating solution were coated at a temperature of 40° C. with a bar coater onto a thin, transparent polyethylene terephthalate support having on its surface a thin evaporated layer of indium tin oxide. Afterwards the coated support was dried for 60 minutes at a temperature of 30° C. 1 m<sup>2</sup> of the coated support contains 4.8 g of LiMn<sub>2</sub>O<sub>4</sub> and 0.2 g of polyethylene glycol.

## Comparative Example C-2

[0067] A sintered layer of nanocrystalline, nanoporous, sintered LiMn<sub>2</sub>O<sub>4</sub>, prepared by the method described in "Journal of the American Ceramic Society" 80, 3157-3171 (1997), was used in this comparative example. LiMn<sub>2</sub>O<sub>4</sub> was mixed with polyethylene glycol (molecular weight 25'000) and water. The resulting paste was deposited onto a glass plate coated with conducting tin oxide and heated for 20 minutes in the presence of air at a temperature of 400° C. The organic binder was destroyed and removed from the coated layer by this treatment.

## Example 3

## Coating

[0068] 45 g/m<sup>2</sup> of the coating solution of Example 1 were coated at a temperature of 40° C. with a bar coater onto a thin, transparent polyethylene terephthalate support having glued onto its surface a thin copper foil. Afterwards the coated support was dried for 60 minutes at a temperature of 30° C. 1 m<sup>2</sup> of the coated support contains 4.5 g of TiO<sub>2</sub> and 0.18 g of polyethylene glycol.

## Example 4

## Double Layer System

## Preparation of the Coating Solution for the Upper Layer

[0069] 14.5 g of aluminium oxide C (Content 96.6% of Al<sub>2</sub>O<sub>3</sub>, available from Degussa-Hüls AG, Frankfurt am Main, Germany) were dispersed under efficient mechanical stirring at a temperature of 25° C. in 62.9 g of deionized water and 0.2 g of aqueous lactic acid (90%). After 60 minutes of stirring 15.47 g of an aqueous solution of polyvinyl alcohol (7.5%, hydrolysis degree 98%-99%, molecular weight 85'000 to 146'000, available from ALDRICH Chemie, Buchs, Switzerland) were added, the coating solution was exposed to ultrasound and the total weight was adjusted to 100 g with deionized water.

## Coating (Upper Layer)

[0070] 40 g/m<sup>2</sup> of this coating solution, after the addition of boric acid as cross-linking agent, were coated at a temperature of 40° C. with a bar coater onto the coated support of Example 3. Afterwards the support coated with the two layers was dried for 60 minutes at a temperature of 30° C. 1 m<sup>2</sup> of the coated support contains 4.5 g of TiO<sub>2</sub>, 0.18 g of polyethylene glycol, 6.04 g of Al<sub>2</sub>O<sub>3</sub> and 0.76 g of polyvinyl alcohol.

[0071] Cyclic voltammetry was used to determine the electric activity of the electrically active films described herein.

[0072] The cyclic voltammogram of the support coated with TiO<sub>2</sub> according to our invention (Example 1) is

recorded in FIG. 1; the cyclic voltammogram of an electrically active film containing sintered TiO<sub>2</sub>, prepared according to the state of the art (Comparative example C-1) is recorded in FIG. 2. These two figures immediately show that the electrical activity of the electrically active film according to our invention (Example 1, without high temperature treatment) is as high as that of an electrically active film prepared according to the state of the art (Comparative example C-1, with high temperature treatment).

[0073] The cyclic voltammogram of the support coated with LiMn<sub>2</sub>O<sub>4</sub> according to our invention (Example 2) is recorded in FIG. 3; the cyclic voltammogram of an electrically active film containing sintered LiMn<sub>2</sub>O<sub>4</sub>, prepared according to the state of the art (Comparative example C-2) is recorded in FIG. 4. These two figures immediately show that the electrical activity of the electrically active film according to our invention (Example 2, without high temperature treatment) is as high as that of an electrically active film prepared according to the state of the art (Comparative example C-2, with high temperature treatment).

[0074] The normalised (thickness) maximum current density of the electrically active film of Example 3 according to our invention (determined by cyclic voltammetry in the tension range between 1.2 V and 3 V against lithium) was 0.6 mA/cm<sup>2</sup>/μm at a scanning speed of 20 mV/sec.

[0075] The normalised (thickness) maximum current density of the electrically active film of Example 4 according to our invention was, under the same experimental conditions, 1.1 mA/cm<sup>2</sup>/μm at a scanning speed of 20 mV/sec.

[0076] The electrically active film having on top of the electrically active layer an electrically inactive layer (Example 4) has a higher electrical activity than the corresponding electrically active film (Example 3) with only the electrically active layer. Furthermore, the mechanical stability of the electrically active film of Example 4 is excellent.

[0077] Finally, variations from the examples given herein are possible in view of the above disclosure. Therefore, although the invention has been described with reference to certain preferred embodiments, it will be appreciated that other coating solutions may be devised and used in the method described herein, which are nevertheless within the scope and spirit of the invention as defined in the claims appended hereto.

[0078] The foregoing description of various and preferred embodiments of the present invention has been provided for purposes of illustration only, and it is understood that numerous modifications, variations and alterations may be made without departing from the scope and spirit of the invention as set forth in the following claims.

1. Electrically active films, comprising a support and having coated thereon at least one electrically active layer containing nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes and optionally supplementary, electrically inactive layers, wherein the electrically active layers still contain a binder or a mixture of binders after the end of the production process.

2. Electrically active films according to claim 1, wherein at least one of the binders is film-forming.

3. Electrically active films according to claim 1, wherein the electrically active layers contain the binder or the mixture of binders in an amount of 0.5% to 20% relative to the total amount of the nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes.

4. Electrically active films according to claim 1, wherein the electrically active layers contain the binder or the mixture of binders in an amount of 1% to 10% relative to the total amount of the nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes.

5. Electrically active films according to claim 1, wherein the electrically active layers contain the binder or the mixture of binders in an amount of 2% to 5% relative to the total amount of the nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes.

6. Electrically active films according to claim 1, wherein the binder or the mixture of binders contains at least one compound selected from the group consisting of polyvinyl alcohol, polyvinylidene fluoride, polyethylene oxide, polyethylene glycol and polyacryl nitrile.

7. Electrically active films according to claim 1, wherein the binder or the mixture of binders is cross-linked.

8. Electrically active films according to claim 1, wherein the nanocrystalline, nanoporous transition metal oxide or transition metal chalcogenide or lithium inclusion complex is titanium dioxide in its anatase modification or  $\text{LiMn}_2\text{O}_4$ .

9. Electrically active films according to claim 1, wherein the support is selected from the group consisting of polyethylene terephthalate, polyethylene naphthalate, polyethylene terephthalate coated with indium tin oxide or metals or

polyethylene naphthalate coated with indium tin oxide or metals.

10. Electrically active films according to claim 1, wherein the electrically active film comprises, on top of the electrically active layers, an electrically non-active layer consisting of polyvinyl alcohol and  $\gamma\text{-Al}_2\text{O}_3$ .

11. Electrically active films according to claim 10, wherein the electrically non active layer is cross-linked with boric acid or borates.

12. Process for the preparation of electrically active films according to claim 1, wherein a liquid suspension or colloidal dispersion of the nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes is coated onto the support together with a binder or a mixture of binders at a temperature between 5° C. and 60° C. and that the coated support is subsequently dried at a temperature below the boiling point (at standard pressure) of the suspension liquid, wherein the electrically active film is never exposed to higher temperatures during the whole production process.

13. Process for the preparation of electrically active films according to claim 1, wherein an aqueous colloidal dispersion of the nanocrystalline, nanoporous transition metal oxides or transition metal chalcogenides or their lithium inclusion complexes is coated onto the support together with a binder or a mixture of binders at a temperature between 20° C. and 55° C. and that the coated support is subsequently dried with air at a temperature below 60° C., wherein the electrically active film is never exposed to higher temperatures during the whole production process.

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