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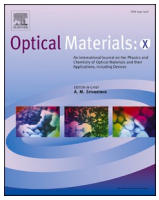

Transparent conducting metal oxides nanoparticles for solution-processed thin films optoelectronics

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ABSTRACT

Semiconductor nanomaterials, and in particular, metal oxides offer great functionality and versatility for many applications at the forefront of material science research. One of the most significant advantage of these compounds at the nanoscale, both for the technological and commercial implications, is the solution synthesis and the consequent exploitation of solution processing. In this work, we present a detailed analysis of ITO nanoparticles solution deposition via the spin coating technique, considering its most common use in optoelectronics as thin films. The results and discussion can provide a list of guidelines for the optimization in the use of these class of materials.

1. Introduction

Transparent Conducting Oxides (TCO) are a prominent family of materials in optoelectronics by virtue of the concurrence of ideal transmittance in the visible range and metal-like electron mobility [1,2]. TCOs are mostly used in the form of thin films for different cutting-edge technologies ranging from lighting and display devices to energy harvesting and conductive glass applications (smart windows, touch screens, detectors, etc.) [3,4]. They typically consist of a wide-gap semiconductor including metals and oxygen atoms with the possible presence of a dopant [5]. Indium tin oxide (ITO) has been the dominant TCO material to date. However, there have been several attempts to find more cost-effective alternatives. Examples of such alternatives include fluorine tin oxide (FTO) and aluminum zinc oxide (AZO) [6–9]. Nevertheless, the fabrication of thin films of such materials require peculiar conditions which strongly depend on the substrate or on the application field, resulting in expensive and not versatile processes [10,11]. Therefore, there is a need for innovative and economically viable processing techniques to replace the current deposition methods for oxides in general, and TCOs in particular. These techniques should be capable of producing films with comparable optical and electrical performance to those achieved with the well-established industrial deposition techniques. In this context, solution processing of thin TCO films can offer an intriguing solution [12]. It is based on the use of TCO nanoparticles (NPs) colloids with a number of different techniques, ranging from the spin coating, to the drop casting, dip coating or doctor blading. These techniques can be very versatile as they allow controlling several different parameters that will ultimately influence the thin film's physical properties. From a manufacturing point of view, the development of solution-based processes offers indisputable economic benefits (mild working conditions, low-cost, scalability, versatility) [13]. However, the continuous improvement and sharpening of deposition via liquid techniques in terms of precision and repeatability, even at the nanoscale, has greatly rebalanced the competition compared to other techniques (such as evaporation/sputtering, vapor- or electro-deposition or top-down approaches). Solution processing easily enables to build up complex architectures and hybrid structures also employed in photonic or plasmonic applications [14,15]. Alongside the advancements in deposition techniques, significant progress has been made in the synthesis of nanoparticles, particularly colloidal systems. This development has had a profound impact across a wide range of scientific research fields [16,17]. The manipulation of inorganic compounds, such as metal oxides, at the nanoscale has brought to light new intrinsic optical and electronic properties, as well as mechanical and morphological characteristics, often deserving a completely separate analysis from the bulk counterparts. Regarding TCOs, for example, the optical properties are becoming more and more important. In particular, the near- and mid-infrared wavelength range is becoming increasingly

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important for wireless communication, biophotonics, sensing, or heat shielding [18–20]. The use of transparent conductive oxides in the form of nanoparticles and consequently the possible exploiting solution processes for their deposition and therefore the preparation of thin films open, new interesting prospects for the application of these materials. Within this work, we will give an overview over TCO NPs films preparation by means of simple and reproducible deposition method that is the spin coating, with particular focus on the standard case of ITO.

2. Experimental

2.1. Materials

ITO Nanocrystals synthesis: Indium tin oxide (ITO) nanocrystals (NCs) were synthesized with a slow injection approach. Indium(III) acetate (CAS: 25,114-58-3), tin(IV) acetate (CAS: 2800-96-6), oleyl alcohol (technical grade, 85% purity, CAS: 143-28-2) and oleic acid (technical grade, 90% purity, CAS: 112-80-1) were purchased from Sigma-Aldrich, and used without further purification. As first step, a 500 mL three neck round flask was filled with 208 mL of oleyl alcohol and left at 150 °C to degas for 3 h under a nitrogen flux. In total 16 mmol of indium and tin precursors were loaded, along with 32 mL of oleic acid, to a 100 mL three neck round-bottom flask. Doping of the final material will follow molar ratio between In/Sn precursors. Under magnetic stirring, the flask content was degassed for 3 h under a nitrogen flux, allowing tin and indium oleates to form. After degassing, the flask with oleyl alcohol, which will act as the reaction vessel, was kept under a flux of 0.130 L/min of nitrogen and heated to 290 °C. Indium and tin precursors were transferred in syringes and injected in the hot oleyl alcohol using a syringe pump with an injection rate of 4.8 mL/min. After the end of injection, crystals are left growing for 15 min. The solution was then cooled to room temperature and centrifuged at 5540 G for 10 min, using ethanol as antisolvent. The supernatant was discarded, the material was redispersed in hexane, ethanol was added, and the solution was centrifuged again using the same parameters. Finally, the NCs were stored in octane. Ligand exchange: ITO nanocrystals were transferred to polar phases (water, ethanol, methanol) via a ligand exchange procedure at environmental conditions. Briefly, a 20 mM Tetrabutylammonium hydroxide 30-hydrate (TBAOH) (CAS: 147,741-30-8) was prepared in MilliQ water. A 20 mg/mL hexane dispersion of ITO NCs was added with a volume ratio of 1:2 to the TBAOH solution, then shaken for 10 min. It was followed by centrifuging twice for 8 min at 8500 rpm, using toluene as antisolvent. The precipitate was then stored in the polar solvent of choice.

2.2. Optical measurements

The absorption spectra were recorder by means of an Agilent Cary 5000 UV–Vis-NIR spectrophotometer both for the case of ITO NPs solutions and films.

2.3. Structural characterization

Transmission electron microscopy analysis was carried out using a JEOL JEM-1400Plus – 120 kV TEM/STEM while the thin films characterization was performed with a Dual Beam Helios Nanolab 650 (FEI Company).

3. Results and discussion

3.1. TCO NPs

The most widespread techniques for the fabrication of TCO nanoparticles rely mainly on wet-chemical synthesis, that is, processes in liquid phase [2,21]. This typical bottom-up approach for the preparation of nanomaterials allows an optimal control on the synthesis parameters and conditions and, consequently, on the intrinsic characteristics of the output products. The synthesis starting point consists of a mixture containing the precursor compounds and the surfactants dissolved in a highly boiling solvent [17]. The use of this procedure allows controlling thermodynamic and kinetic regime of the nucleation and growth of the nanocrystals by setting different conditions for the temperature or the injection of the components [16]. Through solution preparation, it is possible to tune concentrations and determine different proportions a priori, especially in the case of multicomponent systems like doped materials or core@shell structures [22–24]. This allows for precise control over the composition of the solution during the synthesis process. Finally, the addition of surfactant molecules allows guiding the formation of nanoparticles and acting on their size and shape [25]. Moreover, the coating of metal oxide nanocrystals with ligands also affects their properties of solubility and stability, as well as their functionality and reactivity towards other compounds or different dielectric environments [26,27]. Furthermore, engineering the process with potential ligand-exchange provides a valuable tool to tailor the particles according to specific requirements. Targeting a direct integration in solid devices, as transparent electrodes, the TCO NPs characteristics that it would be more useful to strategically define upstream of the preparation are shape and size, on the one hand, and chemical composition on the other. Together, these features can define not only the optical and electrical response, but also the quality of the thin film (thickness, degree of packing), hence, the viability of the implementation. Considering the subsequent liquid deposition, the shape of the nanocrystals should be as regular as possible (for example nano-spheres or nano-cubes) in order to guarantee good layer uniformity, as well as optimal inter-particle connection [28]. Fibrous structures, such as nanowires, can be interesting networks from the point of view of conduction properties, as preferential charge-carrier's pathways, but a random distribution can also imply some problems of adhesion to the substrate while, on the other hand, precise alignment or controlled growth require much more sophisticated and expensive techniques [29]. Regarding the choice of material for electrode fabrication, as previously mentioned, the majority of works on TCO thin films predominantly focus on ITO. However, the developments in colloidal synthesis and the enormous versatility represented by the doping process have greatly expanded the chemical palette from which to draw fully [30]. In any case, in the selection of a starting material for the fabrication of a device and in the perspective of commercialization, several aspects not directly related to optoelectronic properties, such as cost, abundance, availability and toxicity, are also fundamental [9]. In this context, the oxide nanoparticles doped with tin and zinc emerge alongside with the oxides based on indium. As for the doping of these compounds, compositional permutations become innumerable, especially in the case of multinary nanomaterials. Naturally, the increased complexity of the product requires a sophisticated preparation process and meticulous attention to numerous details. However, it is crucial to maintain a focus on the liquid deposition strategy, which is suitable for these materials and necessary for electrode preparation.The elements used to form the TCO NPs must fulfill specific optoelectronic requirements related to three spectral regions: the bandgap (UV), the transparency window (Vis), and the plasmon resonance (IR) [31–35]. For the study we analyzed ITO NPs synthesized using a slow injection method already described in previous works [36]. This method enables the possibility of ligand exchange that opens up the possibility to have the ITO NPs both in polar (hexane) and non-polar (ethanol) solvents without affecting the nanocrystals shape, as demonstrated in Fig. 1a and b, and their typical optical response (Fig. 1c).

3.2. Thin films

Once we obtained reproducible TCO NCs colloids solution with desired concentration, we can focus on the corollary of parameters involved for a successful liquid phase deposition for the preparation of a

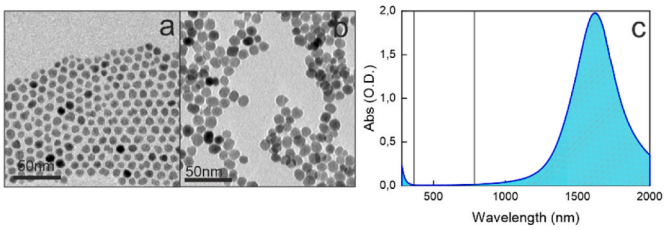

Fig. 1. TEM micrographs of the ITO NPs in a) hexane and b) ethanol; c) Absorption spectra recorded from ITO NPs solution with the typical features in the three different regions (UV–Vis–NIR).

film. Taking spherical particles as the archetype, among the most stable, most reproducible and therefore most common forms, the first intrinsic aspect that can have secondary repercussions, beyond electronic properties, is the size. The dimensions of the nanoparticles are in fact directly responsible for the interaction with light in more macroscopic properties, such as reflectance and transmittance of the film as illustrated in the scheme in Fig. 2a. The same reasoning applies in the case of particles with dimensions below those of the wavelength of visible light. However, these particles tend to form macro-agglomerates once they are no longer in the colloidal dispersion, such as in a thin film. The latter aspect is also closely linked to concentration. Apart from the critical concentration above which a solution begins to lose its colloidal stability, the change in thermodynamic conditions after the deposition of the nanomaterials on a substrate must be considered. The occurrence of such post-synthetic phenomenon can basically results in thin film scattering as evident form the absorption spectra reported in Fig. 2b. This effect turns the aspect of the transparent film to more opaque (see Fig. 2c and d). The stability of the colloidal solution is also reflected in the possibility of obtaining a significant film thickness (of the order of microns). The tendency to self-aggregation can in fact also mean an easy loss of adhesion in the subsequent deposition of a multilayer system and therefore mechanical instability and breaking or cracking of the film [37]. As for the dimensions, even the size dispersion of the sample is a

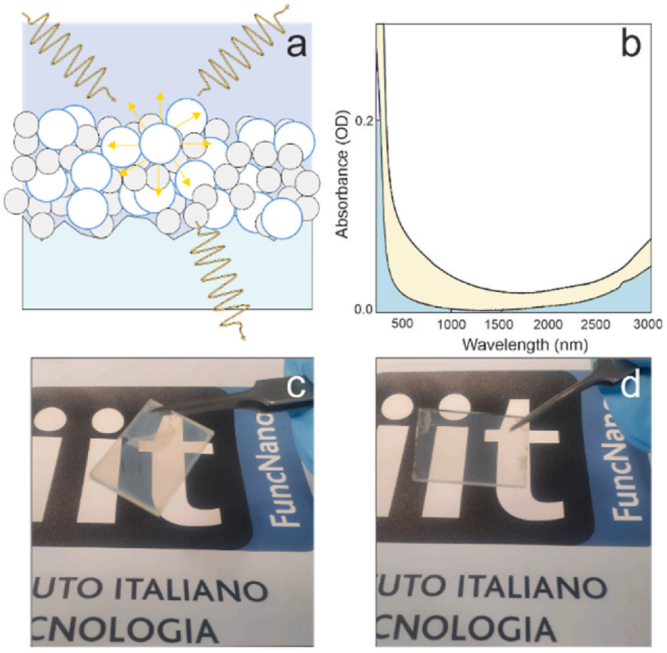

Fig. 2. a) Schematic picture of the light interactions with a nanoparticles-based thin films; b) Absorption spectra recorded from ITO NPs films with (yellow shade) and without (blue shade) scattering; c) and d) photographs of ITO NPs film with different optical quality. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

rather influential parameter not only on the optical response but also on the structure of the nanoparticle-based film. The deposition of spheres of different diameters would result in a packing and therefore a different material density. Depending on the final purpose or use, the result can be advantageous (e.g. for the charge conductivity). In some other cases, it can be a disadvantage as for the preparation of composite systems undermining their structural stability.

Here, it is noteworthy that the preceding discussion hinges upon the premise that the use of deposition techniques for NP liquid solutions enables the control over the stratification process involved in the formation of the thin film. First, it is possible to ascertain the number of layers, followed by precise determination of the thickness. In the case of films based on photoactive materials, this aspect can be regarded as a crucial determinant of performance, since a thinner electrode (like a monolayer) certainly confers the best transparency, and still, on the other hand, the thickness becomes directly proportional to the absorption [38]. In the same way, it is possible to build up some more complex (composite) architectures. It is possible to stratify nanoparticles that are different in terms of shape, size or type. A very enlightened example, in this sense, is the periodic stratification of materials with a different refractive index that can make up a Bragg mirror [39,40]. Creating a composite film can also be referred to the integration of a completely different material, organic or inorganic, within the porous structure formed by the inter-particle gaps of the NPs layer. A film made up of nanoparticles can in fact be considered as a porous matrix, which can host other elements (molecules, ions, other crystals or polymers) or can even act as a template for the formation of other nanocrystals [41,42]. In this context, the film is also characterized by a specific porosity (volume and size of the pores) which will again depend on the shape and size of the nanoparticles and the total thickness of the film [43]. However, the behavior as a simple host structure or not, also depends on the possible instauration of new interactions considering the charge at the surface, the ligands and their functional groups, the hydrophilic or hydrophobic character or even the affinity towards a certain type of charges and solvents. The control over the nanoparticle layers, made possible by the deposition of a colloidal solution and by the control on their surface reactivity and the types of solvents, allows a very attractive morphological versatility compared to a bulk film prepared from the same metal oxides.

3.3. ITO nanoparticles deposition

Spin-coating is one of the most widely used deposition techniques for the preparation of films using colloidal nanoparticles both in fundamental analysis labs and facilities for the fabrication of devices and prototypes. Hence, in this section we want to focus attention on the use of this methodology and in the experimental conditions to be taken into consideration for the fabrication of thin films based on metal oxide nanoparticles. As previously mentioned, a monodisperse starting solution can ensure a homogeneous film, but for the latter it is equally important to obtain a uniform deposition. In general, it would be ideal to avoid the formation of defects that can perturb the optical and electronic response of the material. The centrifugal force assisted deposition of a certain volume of solution dropped in the center of a sample can allow a uniform dispersion of material across the entire substrate area available. In the case of nanoscale particles, the subsequent deposition of further material can easily ensure coverage of the entire surface of a substrate. However, in order to obtain exactly a single layer of particles, it is necessary to refine several parameters. First, we need to consider the substrate. The choice of substrate is by no means trivial because it is not simply a support material for the actual sample. Beyond the use of specific substrates for the development of a device, the choice of support material for the sample depends also on the type of analysis. For example, more commonly transparent substrates are used for optical characterizations and conductive substrates are needed for microscopic analysis (like scanning electron microscopy). A different substrate

implies a completely different surface that the particle solution must adapt to in order to form a uniform layer. The determining factors in this case are the roughness and the chemical composition at the interface. A jagged surface can improve the wettability of a substrate but can also be uncomfortable despite the deposition being uniform. The dispersion of nanometric-size particles can reproduce the asperities of the substrate, which, especially in the case of optical studies, can turn into scattering points. For the same reasons, a substrate washing cycle is equally necessary in any case to remove impurities that can accumulate on the surface exposed to the environment and cause subsequent holes and irregularities in the NPs deposition. For an efficient cleaning of the substrate, detergents (such as Hellmanex) and polar organic solvents such as ethanol, acetone and isopropanol can be used, in successive sonication cycles. A further step in preparing the substrate, on the other hand, concerns the application of plasma cleaning step. For this treatment, different gaseous species can be used, among which oxygen is one of the most commonly employed for cost reasons. The action of the plasma on the surface of the substrate serves above all for its activation, promoting the formation of specific functionalities containing the element present in the gas. Oxygen plasma, for example, can be used in order to turn the surface of a polymeric material hydrophilic by producing hydroxyl (OH) groups [44]. In general, also depending on the power, the exposure time and the type of plasma, the latter can increase the roughness of the surface or smooth it by modifying, as already mentioned, the wettability of the substrate or the ability to retain the sample ink.

In what follows, we analyze the case of ITO nanocrystals colloidal solution, in hexane, with regular particles of ~10 nm diameter size capped by a long-chain organic ligands shell (oleic acid) [36]. In order to monitor the deposition of a uniform film composed of a single layer of these particles we used the scanning electron microscopy technique by coating a SiO_2 (285 nm)-on-Si substrate. Once the substrate has been cleaned (acetone/ethanol/isopropanol), it is necessary to tune and balance different parameters both relating to the instrument and to the colloidal solution to optimize the deposition conditions. In general, the thickness of the film depends above all on the acceleration and rotational speed (inversely proportional) and on the concentration (directly proportional). First, the acceleration and rotation speed must ensure total coverage of the substrate. Further increase of these two parameters allows pushing out the excess material by thinning the nanoparticles film. At this point, by setting a rotation time sufficient to dry the solvent (at least 30 s), in Fig. 3 we can observe how acceleration also plays a fundamental role in controlling the deposition. Using a final rotational speed of 6000 rpm it is possible to obtain a film consisting of a double layer of particles (Fig. 3a), while by increasing the acceleration, or the centrifugal force, the excess layer is drastically reduced to a few islands above the monolayer (Fig. 3b).

As regards, instead, the colloidal solution of nanoparticles, the concentration heavily influences the deposition, under the same spin-coating conditions as schematized in Fig. 3c. The Fig. 3d–3f show how by reducing the concentration from 10 mg/mL (3d) to 5 mg/mL (3e) and up to 2 mg/mL (3f), one passes from a double layer to a monolayer condition with sporadic islands of superimposed nanocrystals up to a single layer of particles interrupted by micrometric empty areas. This effect is a direct consequence of the evaporation of the solvent.

The reduction of the thickness through dilution of the nanoparticle solution is an effective strategy but in order to maintain a nanometer control it is necessary to consider the consequent weight increase of the effects linked to the solvent. A sufficient volume of solution has to be used (in our case 30 μL) in order to ensure a distribution of material over the entire substrate and, depending on the area to be poured, the amount of nanocrystals contained. However, the characteristic volatility of the solvent can become a crucial factor in the success of the deposition. Working in the same ambient temperature and humidity conditions, the rapid evaporation of the solvent, as in the case of hexane, in fact, compromises the uniform dispersion of the materials both at a microscopic and macroscopic level. In addition to the effect due to the easy formation of air bubbles, illustrated previously, the volatility of the solvent prevents adequate coverage of the substrate surface even with short deposition times, amplifying the sensitivity especially in non-automated procedures and affecting negatively the reproducibility of the samples. Using a low-boiling solvent, such as octane (with a vapor pressure about 250 times higher than that of hexane), the uniformity of the layer of particles can be greatly improved, also reducing the formation of bubbling defects, as can be seen in Fig. 4a. A co-solvent or surfactants can also be used to change the vapor pressure of the sample solution [45]. These measures could also improve wettability and reduce equally harmful phenomena such as the coffee ring effect [46]. In these cases, however, it is necessary to avoid compromising the colloidal stability of the nanoparticle solution before deposition.

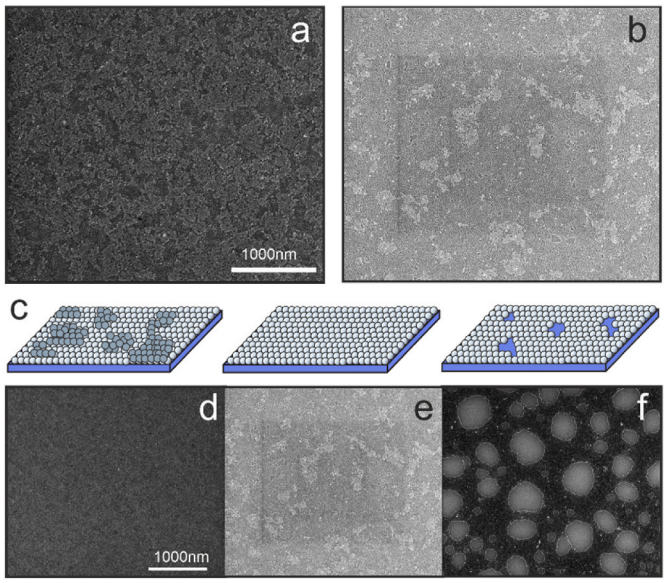

Fig. 3. S.E.M images of the ITO NPs spin coated using different acceleration conditions without any heating treatment. a) 600 rpm/s and b) 3000 rpm/s; c) Representation of the effect of concentration on the NPs deposition; S.E.M images of the ITO NPs spin coated using different solutions. d) 10 mg/mL, e) 5 mg/mL and f) 2 mg/mL.

The nanoparticle layer optimized up to now must finally also meet the requirements of technological applicability. For these reasons, a further high temperature treatment is often necessary, which gives better mechanical stability by increasing adhesion to the substrate and permanently eliminating all unwanted volatile components. However, this step also requires careful control of the temperature rise ramp and the maximum value to avoid the formation of cracks or even the degradation of the material. Cracking of the particle layers can be dangerous especially for thicker and multilayer architectures. On the other hand, from the point of view of optical and electronic properties, calcination can be crucial. The main effects concern the removal of the organic parts (that is the ligands of the nanoparticles) and the shrinkage of the film, or the convergence of closed particles following the withdrawal of the solvent. The first effect basically involves the removal of the dielectric barrier constituted by the insulating organic shell, while the further reduction of the distances between the particles can induce a possible coupling of the optoelectronic response of the materials. Fig. 4b shows the modification induced by the temperature increase (up to 300 °C) of the same monolayer of ITO nanoparticles analyzed so far. It can be seen that the monoloyer of nanocrystals appears more arid as a result of the shrinkage caused by the thermal treatment. On the one hand, the film is crossed by nanometric cracks, while, at the same time, the nanocrystals can almost touch each other, creating a denser packaging.

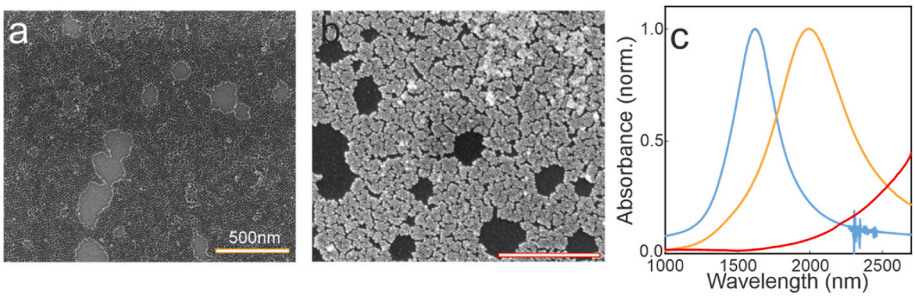

Fig. 4. S.E.M. images of ITO NPs monolayer before a) and after b) thermal treatment; c) Absorption spectra recorded for the ITO NPs in solution (blue curve), freshly deposited (yellow curve) and calcined (red curve) on fused-silica substrates. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

By examining the spectroscopic behavior of such samples, it is possible to deduce the optoelectronic implications of this type of preparation for thin films based on nanoparticles of TCOs. Fig. 4c shows the typical spectral shape of the absorption of the ITO sample in solution (blue curve), of the monolayer film at room temperature (yellow curve) and of the same film after calcination for 1 h at 300 °C. The figure focuses on the spectral range around the localised surface plasmon resonance (LSPR) peak, in the infrared, characteristic for this type of material. The position of this peak can reveal changes in the electronic environment of the ITO nanocrystals and in this case, a clear red shift can be observed starting from the colloidal system. The transition from the liquid to the solid state is certainly characterized by a change in the dielectric conditions in which the nanocrystals are found [47]. In the first case, they can be considered as isolated systems, while in the second one they are fundamentally separated by the mere presence of the ligands. The latter, however, can still constitute a good insulating barrier. In fact, after the removal of the ligands, the displacement of the peak is much stronger also conditioned by the fact that in the inter-particle distances are extremely reduced. In this case the plasmonic resonances are affected by a much stronger near-field coupling and we can only observe the ascending tail of the peak (red curve) [48].

From the point of view of the fabrication of electrodes based on conductive metal oxide nanoparticles, the heat treatment is evidently equally important and beneficial considering the possibility of percolation of the electric charges and facilitating the mobility of the charges after the ligand stripping and film shrinking [49]. The presence of bulky ligands, in fact, can hinder the electric conductance of the film acting as an insulating barrier [50]. Furthermore, in this case, as already mentioned above, the deposition in the liquid phase allows the construction of more complex structures constituted, for example, by the superposition of different layers of nanocrystals. For this type of architecture, heat treatment becomes necessary in order to eliminate the interference of any residue that could compromise compatibility with the subsequent deposition of another colloidal solution and in any case improve adhesion so as not to risk removing the layers below after each subsequent solution casting. This is also true if it is necessary to build a rather thick film of nanoparticles. In fact, considering the limits for a single deposition of particles, it is possible to form thicker layers without drastically increasing or reducing, respectively, the concentration and the rotational speed. It is possible to deposit the same nanoparticle solution in several steps, interspersing the different depositions with a light heat treatment without reaching the calcination temperature but maintaining a temperature sufficient to dry most of the solvent. In Fig. 5 it can be seen how starting from the same material used up to now for the realization of a monolayer, it is possible to get to the preparation of an electrode with a typical thickness of the order of micrometers.

Finally, the affinity between a sample and its substrate is a key parameter even if the goal is to transfer the sample to another surface or the preparation of a self-supported sample. On the other hand, a collection of nanoparticles poured in the liquid phase can also easily adapt to any type of substrate in terms of configuration and adapt to curved surfaces, once the right chemical-physical affinity has been ensured with the substrate. This allows broadening the spectrum of applications in which it is possible to integrate a film of a certain metal oxide when it is prepared in the form of nanoparticles. Furthermore, an alternative solution for the same type of scope becomes accessible as well. As a porous scaffold, the nanoparticle film, as previously suggested, can be permeated by a polymer matrix. The latter can be preformed or it is also possible to infiltrate a solution of monomers in the network of interconnected pores, which can then polymerize and give shape to a flexible film that incorporates the TCO NPs [42].

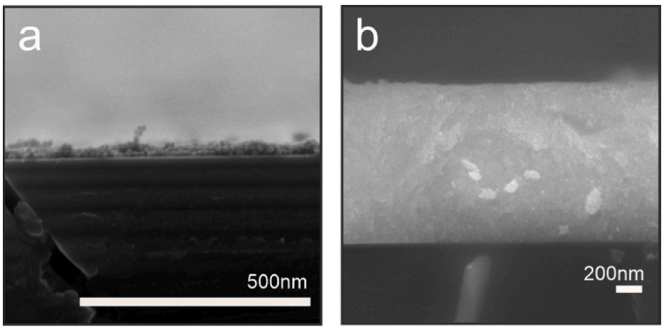

Fig. 5. S.E.M. cross section images of ITO NPs film with different thicknesses from a) few layers deposited without thermal treatment to b) tens of layers deposited and finally calcined.

4. Conclusions

In this manuscript, we investigated the fabrication of thin films made of transparent and conductive ITO nanoparticles starting from a stable colloidal solution. We analyzed in particular the conditions for the preparation of layered architectures by means of the spin coating technique in order to optimize the control over the quality of the deposition. The solution processing of TCO NPs allows a powerful versatility nevertheless, it is crucial to establish a proper fabrication protocol in order to achieve the best results. The protocol will depend on the final goal and, in this work, we wanted to give a compendium of useful details about the deposition of TCO NPs for the application as electrodes in optoelectronics. We studied the most used coating method and examined the influence of various parameters on the film quality. With the results we showed, it could be possible to better tune, for example, uniformity and thickness and the NPs scaffold according to the starting materials. We also demonstrated the effect of the transition from the liquid phase to the solid phase on the on the optical response of the ITO nanocrystals. The case study and the discussion we reported can serve as a guidance in design and develop new TCO NPs thin films from simple and cost-effective solution process.

CRediT authorship contribution statement

Luca Rebecchi: Methodology, Investigation, Writing – review & editing. **Nicolò Petrini:** Methodology, Investigation, Data curation. **Ivet Maqueira Albo:** Investigation. **Nicola Curreli:** Writing – review & editing. **Andrea Rubino:** Conceptualization, Writing – original draft, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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