HORIZON 2020

Towards Indium free TCOs

Reporting

Project Information

INREP

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Project closed

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Periodic Reporting for period 2 - INREP (Towards Indium free TCOs)

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Summary of the context and overall objectives of the project

High-tech products, including electric and electronic equipment, green energy technologies or extreme applications, contain substantial amounts of certain Critical Raw Materials (CRM). Although the amount of CRM per product in
general is very low, the huge number of products manufactured makes the total amounts very

impressive. The prices and availability of CRM alternative solutions to replace certain CRM in concrete applications, or to diversify the supply
of raw materials sources. Substitution of CRMs can also increase the recyclability of waste products, allowing for more efficient processes and reduce environmental impacts.

Indium-based materials are technologically entrenched in the commercial manufacture of components. However, the decreasing availability and increasing cost of Indium poses a threat to the European electronics industry which uses this material in abundance. In terms of volume, one of its main uses is in making transparent electrodes for components that interact with light. These include flat panel displays, flexible electronics, high efficiency photovoltaic cells and light emitting diodes (LEDs), both inorganic and organic, all devices in which Europe has societal and economic interests. As such, the possibility of shortages in the supply of Indium poses an evident challenge to the future development of the high added value electronic industry in Europe.

The goal of the INREP project was to develop and deploy valid and robust alternatives to indium (In) based transparent conductive electrode materials as electrodes.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

High efficiency PV cells
For this specific application, the goal of INREP was to replace the indium-based layer of high efficiency photovoltaic cell device by an indium-free TCO while keeping as high as possible the efficiency.
Indium Tin Oxide is state of the art TCO material for this technology, and all indium based TCO have always surpassed other materials in terms of efficiency. The challenge was therefore to minimize the impact on the device performance and to lower the Cost of Ownership (CoO).
It was shown that AZO can make very efficient back reflectors, better than ITO ones, both for front and rear emitter solar cells. This result was demonstrated on sputtering tools. It was shown that for rear emitter solar cells, AZO offers a viable alternative to ITO front contact, with similar current, fill factor, and VOC. It was therefore demonstrated at the lab scale that it is possible to make an indium free solar cell using sputtered AZO without compromising the efficiency.

Inorganic LEDs
For this specific application, the goal of INREP was to explore new LED architectures and device manufacturing through the use of indium-free TCO materials and deposition techniques developed within the project.
The adoption of transparent conductive AZO layers deposited by sputtering and ALD in organic and GaN-based LED devices involved the challenging task to synthesize TCOs on nitrogen polar n-type GaN and explore new LED architectures. The partners successfully developed methods for creating low resistance contacts on nitrogen polar n-type GaN for both Aluminium Zinc Oxide (AZO) and Zinc Oxide(ZnO) TCO materials. Following on from the successful Ohmic contacts, a new LED process was constructed which was compatible with the standard manufacturing LED line, in conjunction with

various LED electrode designs and suite of test structures. The new LED process flow contained approximately 40% less processing steps than an equivalent non-TCO LED.

Organic LEDs

For this specific application, the goal of INREP was to develop In-free TCOs for use as anode in OLEDs with the same performance as devices with an ITO anode.
Candidate electrode materials developed by the project partners were tested by using these as anodes in OLEDs on glass substrate with a small pixel size of 1.5 cm x 1.5 cm. The test showed that OLED device with sputtered and ALD AZO anodes yielded the highest efficacy (luminance per power) in the tested set of TCO coatings, similar to that of reference devices with ITO anodes (which were not annealed due to the temperature restriction and had hence a relative high sheet resistance).

Touch screen monitor

For this specific application, the challenge of INREP was to investigate alternative, screen printable materials for the replacement of ITO as electrode material for transparent touch sensors.
The quest for valid replacement to ITO has witnessed the development and testing of transparent conductors deposited by wet chemistry approaches, instead of the previously addressed gas-phase deposition methods. The challenge was to synthesize printing pastes based on silver nanowires with rheological characteristics compatible with transparent touch sensors. A turning point was definitely represented by the switch from PEDOT- to cellulose based formulation, delivering colourless coatings. Different cellulose-based formulations were then applied in pre-production for touch screen displays applications and compared to corresponding ITO materials performances.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

The INREP partners have been working to produce a complete assessment of the relevant properties of the proposed TCOs, including the impact of deposition technique, to devise optimum processes for their application in selected, high value application areas. The selected application areas were organic and inorganic LEDs, solar cells and touch-screens. The physical properties of interest were transparency, electrical conductivity, work function, texture, and chemical and thermal stability. The approach included life cycle assessments of the environmental impact of the developed TCO materials and cost of ownership analyses of their formation technologies over the entire period from application in manufacturing, through component operation into waste management. This analysis enabled a profound and objective assessment of sustainability of TCO materials. As a result, the environmental impact of TCO will be considered in the design of the final product, allowing to achieve the highest environmental quality of the TCO being developed to a manufacturing standard.
Moreover, INREP brought innovative deposition equipment closer to an industrial level in order to accelerate the deployment of indium-free TCOs and achieve cost reduction for large area applications.
By relying on the new TCO material simulation and close integration of the developed solutions via its end-user partners, INREP have been creating a strong, competitive industrial base and a new

knowledge in the field of sustainable transparent conductor material. The applications-led approach has been conceived to maximise the opportunities of economic deployment of the research outcomes of the project and reduce the time to their deployment. The technical and commercial potential of the proposed Indium-free TCO solutions have been comprehensively demonstrated. The planned early take-up of the developed materials and processes will contribute to expand the partners' market shares. For example, Plessey Semiconductor and Meyer Burger plan to incorporate Indium-free TCOs into respectively their growing LED production and high efficiency photovoltaic cells manufacturing lines. In this sense, the project has allowed to secure technology jobs and, in case of several partners, to increase their workforce.

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