SIXTH FRAMEWORK PROGRAMME

http://www.uninova.pt/~multiflexioxides/

Project acronym: MULTIFLEXIOXIDES

Project full title: MULTICOMPONENT OXIDES FOR FLEXIBLE AND TRANSPARENT ELECTRONICS

Proposal/Contract number: NMP3-CT-2006-032231

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

PRIORITY: 3 NMP [FP6-2004-NMP-TI-4]

PRIORITY TITLE: Nanotechnologies and nano-sciences, knowledge-based multifunctional and new production processes and devices [new multifunctional ceramic thin films]

Publishable Final Summary

Revision 1

Coordinator: Prof. Rodrigo Martins

Coordinator Institution: UNINOVA/CEMOP

This consortium aimed the development of new ceramic thin films containing multi-component oxides (amorphous or nanostructured) to be used as transparent materials as conducting, semiconducting, or insulating components in rigid and flexible electronic devices. The inorganic nature of these metal oxide materials will result in environmentally stable and long lifetime devices using existing and novel room temperature deposition techniques and non-fab based patterning. The central focus of this project was the design, synthesis, and processing of novel multicomponent oxide materials in terms of electronic, mechanical, and optical properties.

Due to the large number of materials combinations that are available for these oxides, truly optimum properties were identified through simulation study coupled with experimental feedback into the model. Precursors suitable for novel deposition routes, including low temperature chemical vapour deposition, chemical solution deposition and inkjet were also developed and the deposition parameters for producing homogeneous films defined. The project delivers for the first time multicomponent oxides as active semiconductors processed at low substrate temperatures as an alternative to silicon and emerging organic semiconductors.

MULTIFLEXIOXIDES project addressed the need for Europe to develop novel materials and processing techniques which will facilitate the sustainable and competitive manufacture of new displays with low cost non-fab continuous-write technology. The successful development of this project opens up significant opportunities for numerous potential long-term applications due to both the availability of transparent materials with high electrical performances for flexible applications and the use of multicomponent oxides, reducing manufacturing costs. The envisaged applications could therefore range from the use of the multicomponent oxides as a true semiconductor to substitute silicon in a wide range of electronic applications such as switching, memories, sensors, on body health monitoring systems, smart cards, lightweight and flexible displays for signage, entertainment industrial and military applications, flexible electronic paper and radio frequency ID (RFID) tags, UV sensors, and novel blue light emitting diodes.

The project achieved the main goals that were:

- Sintering of new target materials
- Development of new semiconductor materials with improved electron mobility and optical transparency which are stable under mechanical stress and strain.
- Development of deposition techniques at temperatures $<150^{o}C$ compatible with flexible substrates.
- Non-fab based patterning of the oxide semiconductor films, both rigid and flexible.
- Production of multicomponent oxide films for thin film transistors (TFTs) and data drivers.

- Production of test vehicles such as TFT and passive and active matrices based on the set of materials developed.

1.1 Participant List

The MULTIFLEXIOXIDES consortium represents a world class interdisciplinary research team with leading experts in several fields. In particular, in the area of multicomponent oxide materials, the coordinator, CEMOP/UNINOVA has produced multicomponent oxide semiconducting materials with the highest published electrical mobility to-date. Within the consortium there are also leading experts in low temperature UV assisted chemical vapour deposition, sputter deposition, novel precursor design and synthesis, bulk target formation, materials simulation, sol-gel deposition, embossing, inkjet printing, materials characterization and device fabrication. The consortium is vertically integrated with two basic research universities (CENIMAT and UB), three national research institutes (TNI, JSI and CEMOP) and, two Tier 1 multinational end-users involved in display technology and automotive industrial sectors, namely HP (Europe) one of the world's leading suppliers of displays and CRF, who develop and integrate displays for/into automotive applications. The consortium therefore represents a good balance between industry and research organizations and provides a unique platform from which to achieve the ambitious project goals.

Table 1 – MULTIFLEXIOXIDES participant list

Participant Role	Participant Name	Participant short name	Country
CO	Instituto de Desenvolvimento de Novas Tecnologias / Centro de Excelência em Microelectrónica e Optoelectrónica de Processos	UNINOVA/CEMOP	Portugal
CR	Hewlett Packard	HP	Ireland
CR	Tyndall National Institute	TNI	Ireland
CR	Centro Ricerche Fiat	CRF	Italy
CR	Jožef Stefan Institute, Electronic Ceramics Department	JSI	Slovenia
CR	Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa / Centro de Investigação em Materiais	FCT-UNL/CENIMAT	Portugal
CR	University of Barcelona, Electronic Materials and Engineering Department	EME-UB	Spain

1.2 Activities

As a general remark we can inform that the project exceed some of the expected goals, being in some points well ahead of the actual state of art. The consortium did a complete development concerning novel oxides with exceptional properties for device production. This included the study of new compositions, for both chemical and physical routes, new methods for sputtering targets (the outstanding result here was to get homogeneous phase composition over large areas) and chemical precursors processing and new deposition procedures.

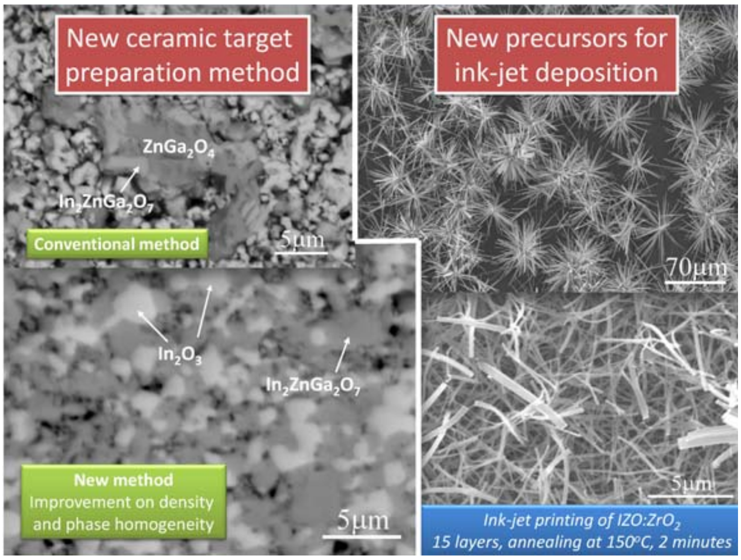

Figure 1 – New synthesis methods for sputtering targets and chemical precursors.

Concerning the physical route (sputtering deposition) the new target processing and deposition methods allowed the consortium to achieve electrical performance on films and devices ahead of the state of the art for low temperature processing. For instance, resistivity close to $1x10^{-4}$ Ω.cm and field effect mobility higher than 50 $cm^2V^{-1}s^{-}1$ were achieved on amorphous transparent conductive oxides (TCOs) and TFTs, respectively. As far as dielectrics are concerned, novel multicomponent dielectrics based in the combination of high band gap and high k-dielectrics were developed and the results patented. This resulted in amorphous dielectrics with very smooth surface, important factors aiming the application on TFTs. Also important is the fact these materials are deposited at room temperature and then annealed at a maximum temperature of 150ºC, being possible to use them on flexible substrates. These are state-of-the-art results for low temperature processing (<150ºC). In Figure 2 is presented an image of the pixel area of an active matrix (background) and the transfer curve on a TFT integrating amorphous semiconductor oxides, TCOs and dielectrics developed during the project.

Doing so, the first passive demonstrator involving the LEDchip display was presented having a similar performance to those obtained using conventional materials processed at higher temperature. An important development achieved during this project was the production of an active matrix display that was entirely processed within the consortium, from the mask design to the final integration (Figure 3). This represent a major breakthrough as it represents, at least to our knowledge, the first oxide based active matrix display produced in Europe. Also import is to keep in mind that the maximum processing temperature was kept below 150ºC.

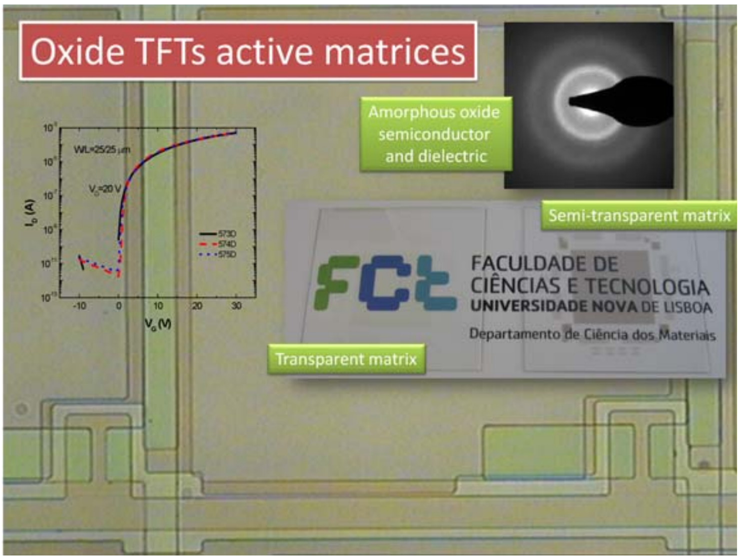

Figure 2 – Transparent TFTs and active matrix based on amorphous oxides.

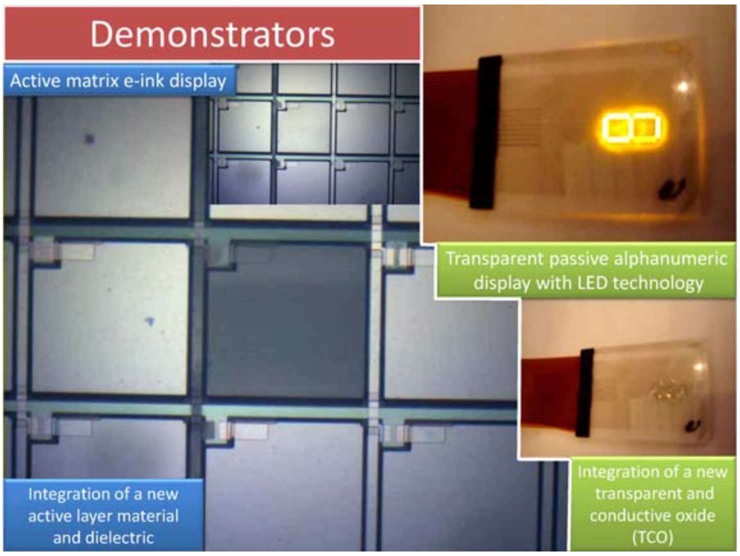

Figure 3 – Active and passive backplanes developed during the project.

Further progresses were made in the last year of the project. Concerning passive applications, the materials developed within the consortium were used to build a fully functional chipLED flexible test vehicle. Further improvements were at the same time achieved on the oxide based active matrix display with fully functional and fully transparent 128 x 128 pixel array on glass substrates (Figure 4).

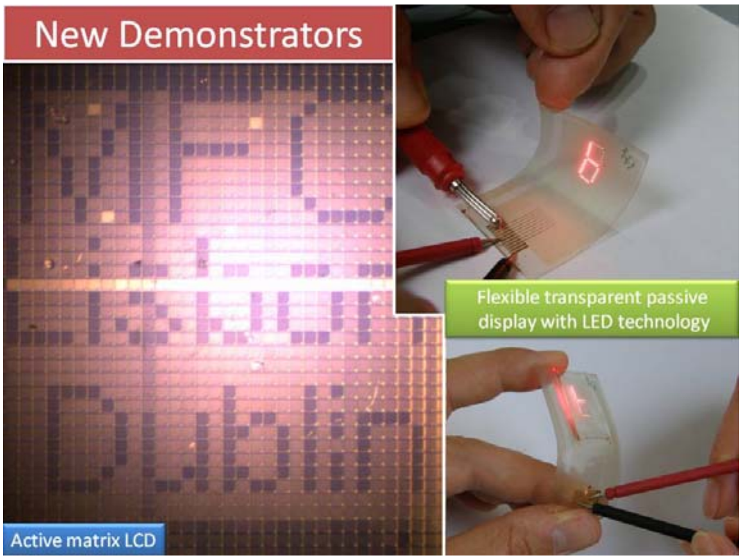

Figure 4 – Lastest fully integrated demonstrators.

The final step aimed to achieve active devices on flexible substrates. Fully functional oxide TFTs were produced making possible to get what we can call flexible and transparent electronics. Again the maximum processing temperature was kept below 150ºC to make the process compatible with the substrates used. These devices were then integrated in a 128x128 flexible oxide based active matrix backplane (Figure 5).

Concerning the chemical route, huge progresses were also made, namely on the deposition procedures, where the processing temperature was decreased down to 150ºC. However, the electrical resistivity has been the biggest issue so far, because these films cannot equal the electrical performance of the sputtered ones, at last for application as conductive tracks. However, these films deposited by sol-gel or printed by inkjet were successfully used as active layer in TFTs, were encouraging performance was obtained as field effect mobility above 2 $cm^{-2}V^{-1}s^{-1}$ (Figure 6). This translates the strong efforts done by the partners involved in this task in order to improve the electrical properties of chemical deposited oxides.

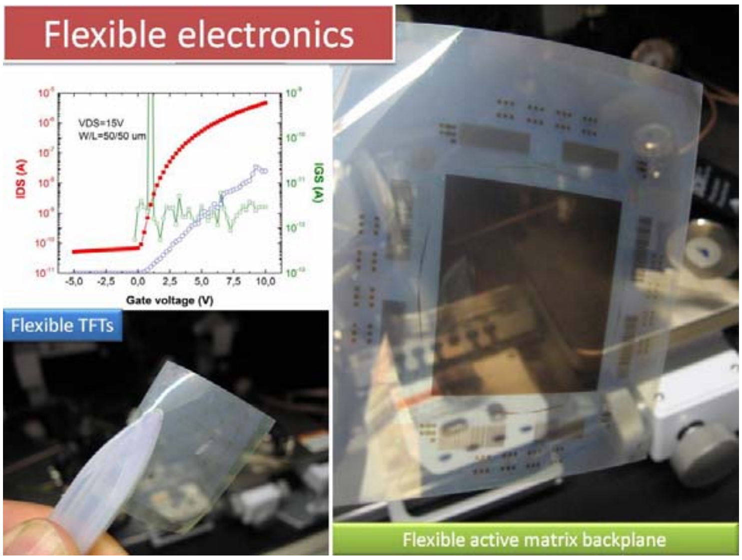

Figure 5 – Flexible active devices and its integration on a active matrix backplane.

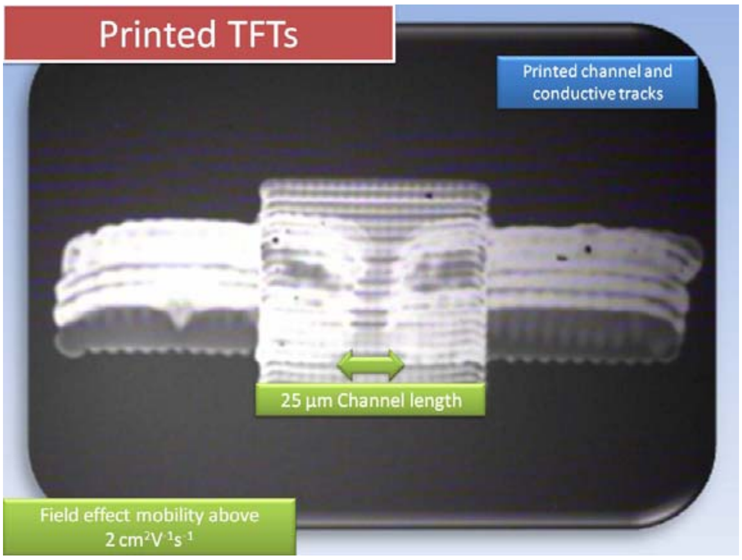

Figure 6 – Printed TFT (active layer and conductive tracks).