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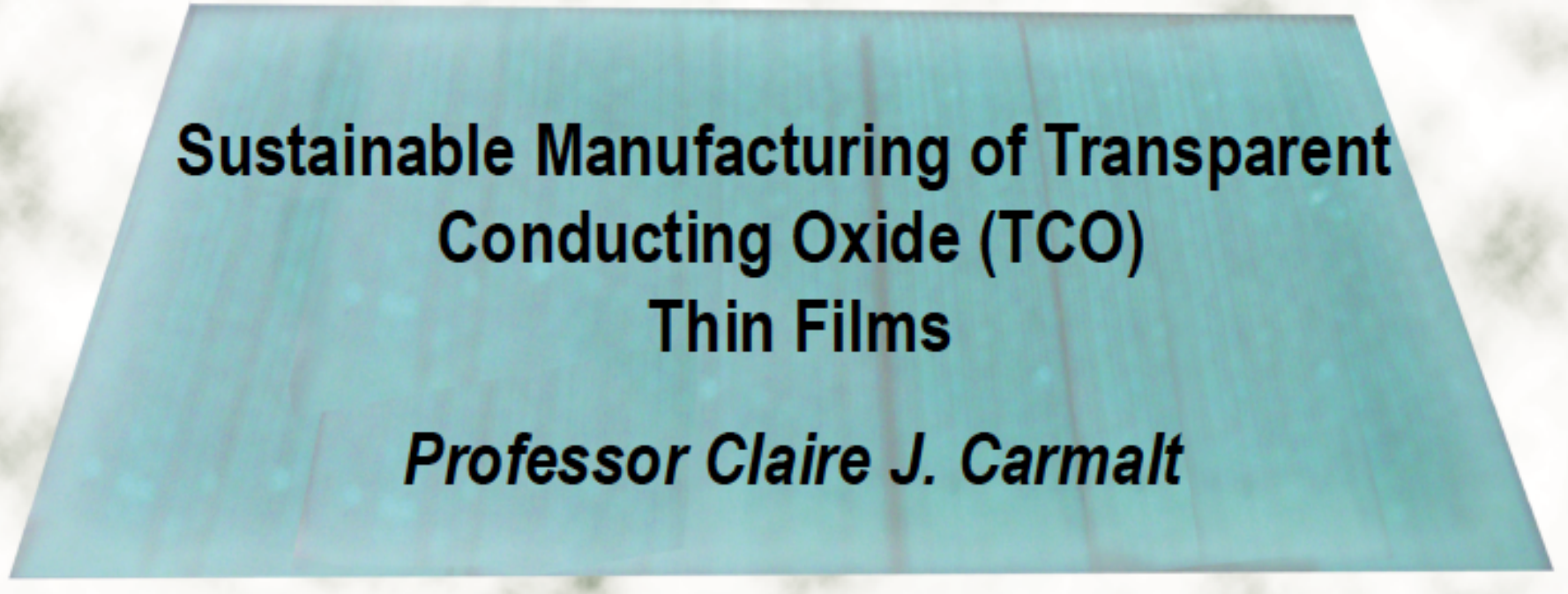

Sustainable Manufacturing of Transparent Conducting Oxide (TCO) Thin Films

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NSG GROUP

AkzoNobel

XAAR

Miba

SunChemical

Malvern

EPSRC

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TCO Thin Films

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This project is developing new manufacturing routes towards sustainable and inexpensive high quality TCO films and printed tracks on float glass and plastics.

TCOs exhibit high transparency and electrical conductivity simultaneously:

- Transparency > 80%
- Resistivity < 10^{-4} Ωcm
- Ease of formation and deposition
- Good chemical and thermal stability

Widely used in optoelectronic devices, low-e window coatings, displays, photovoltaics, touch screen modules, and solar cell devices etc.

TCOs are used where electrical conductivity and transparency are required. Different applications use different aspects of the TCO properties:

- Glazing applications make use of the high reflectance at long wavelengths.
- Thin film solar cells make use of the electrical conductivity to collect electrons generated by the photoactive materials.

What is a TCO?

TCOs are based on simple oxides – In_2O_3, SnO_2, Ga_2O_3 and ZnO – which are doped with other elements to provide electrical properties similar to metals, whilst also maintaining transparency.

The TCO Market is predicted to reach ~$9.4 billion by 2018

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Current TCOs

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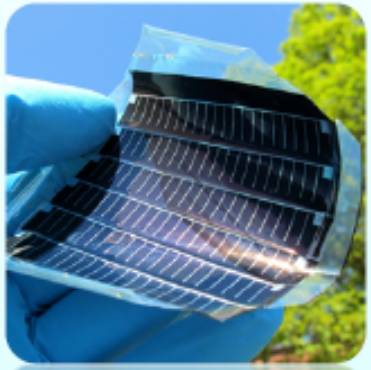
Materials used commercially for TCOs are Indium tin oxide (ITO) and fluorine-doped tin oxide (FTO).



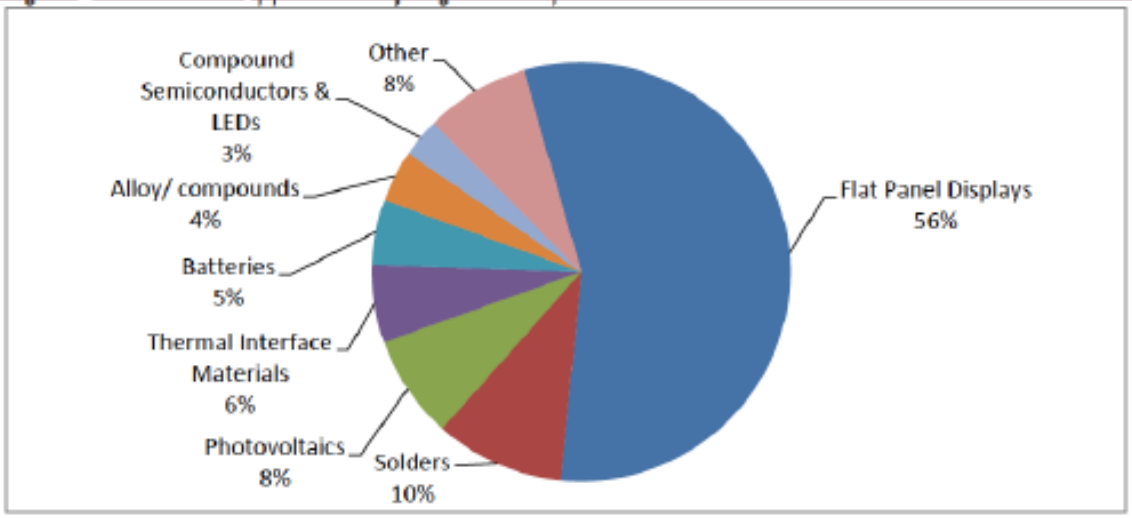
- Supply of indium
- High and variable cost of these elements

  Tin $7.03/lb Zinc $0.82/lb
- Instability of supply
- Real need to develop efficient routes for ITO and FTO alternatives.
- Ensure that the EU maintains a world-leading capability in the manufacturing of sustainable TCOs.

Research driven by the increasing demand for TCO films and the need to replace the use of indium and tin.

May 2014. REPORT ON CRITICAL RAW MATERIALS FOR THE EU

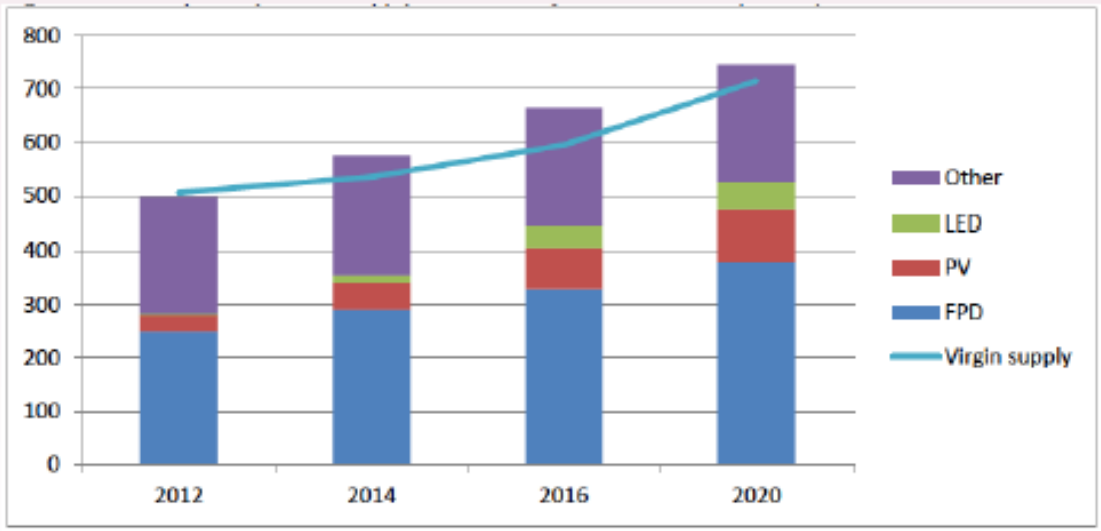
Indium



Source: Indium Corporation (2011), The Indium Market

Worldwide applications of indium – the major use is in the form of ITO which is used in flat panel devices

World primary indium supply and end-use forecasts to 2020



Source: Indium Corporation Presentation (2013)

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Significant opportunity for materials substitution, to replace the widely used indium and tin based TCOs.

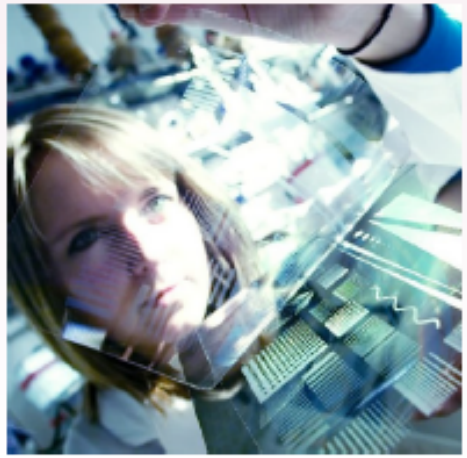
- $F:TiO_2$
- $Nb:TiO_2$
- F:ZnO
- Al:ZnO

Key Opportunities

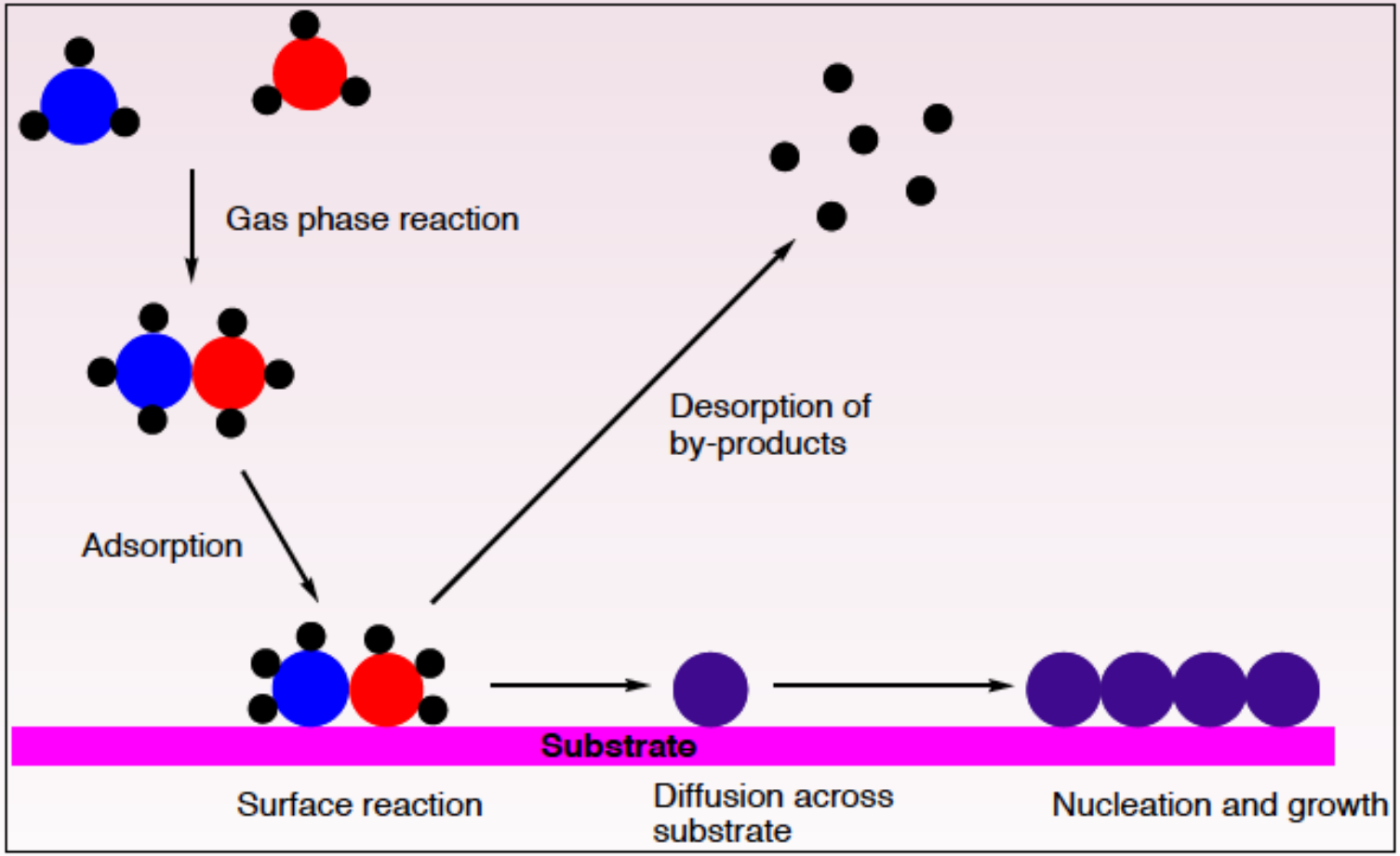
ITO alternatives expected to be worth ~ $1.3 billion by 2018

Development of non-ITO TCO films and printed tracks.

Market for earth abundant elements.

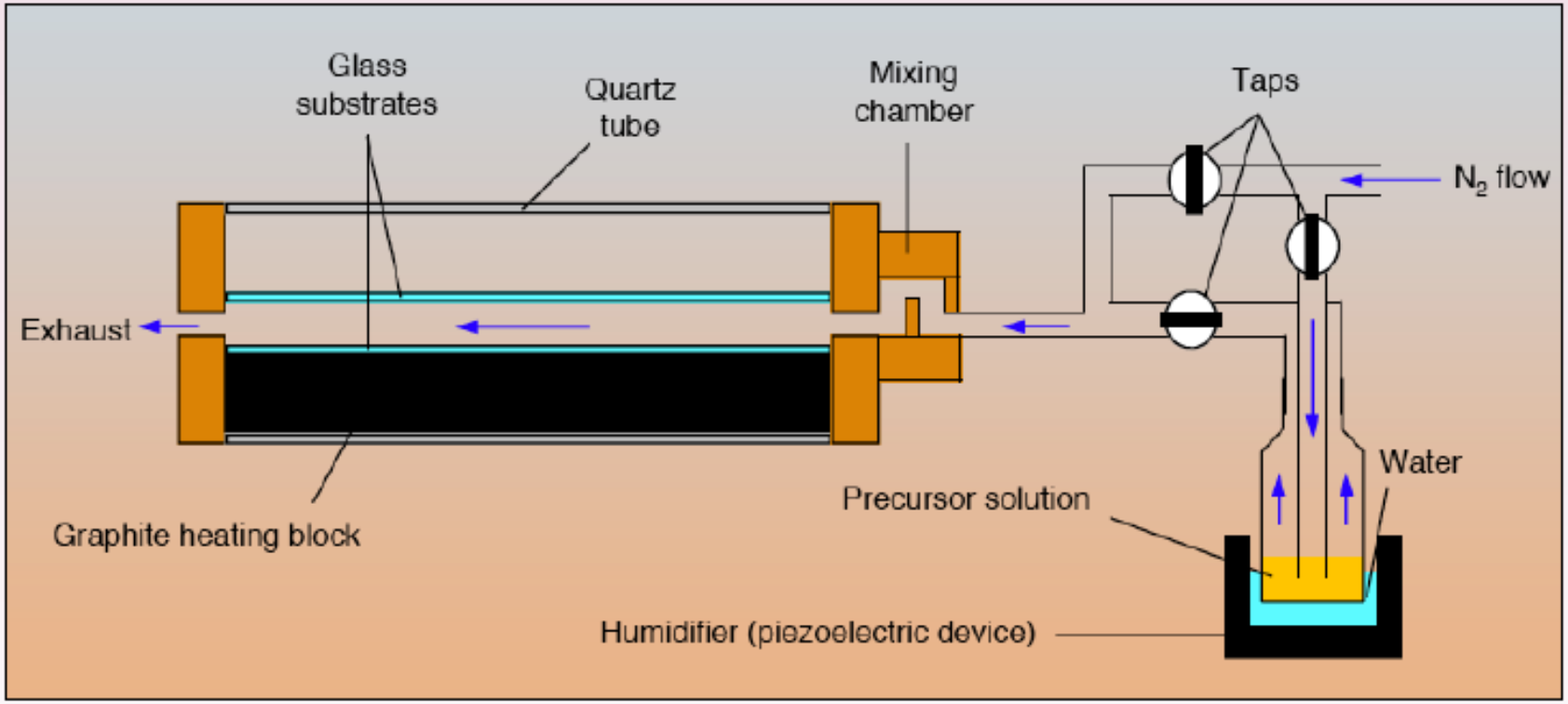


Chemical Vapour Deposition (CVD)



D.S. Bhachu, D.O. Scanlon, G. Sankar, T.D. Veal, R.G. Egdell, G. Cibin, A.J. Dent, C.E. Knapp, C.J. Carmalt, I.P. Parkin, *Chem. Mater.*, **2015**, *27* (8), pp 2788–2796.

Aerosol Assisted CVD Process



Aerosol-assisted delivery of precursors for chemical vapour deposition: expanding the scope of CVD for materials fabrication. P. Marchand, I.A. Hassan, I.P. Parkin, C.J. Carmalt, *Dalton Trans*, 2013, **42**, 9406-9422.

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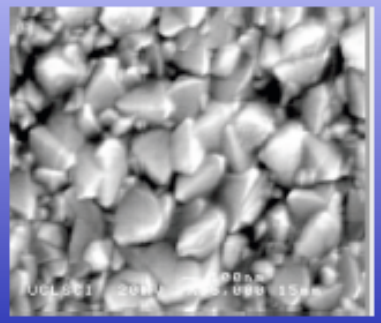
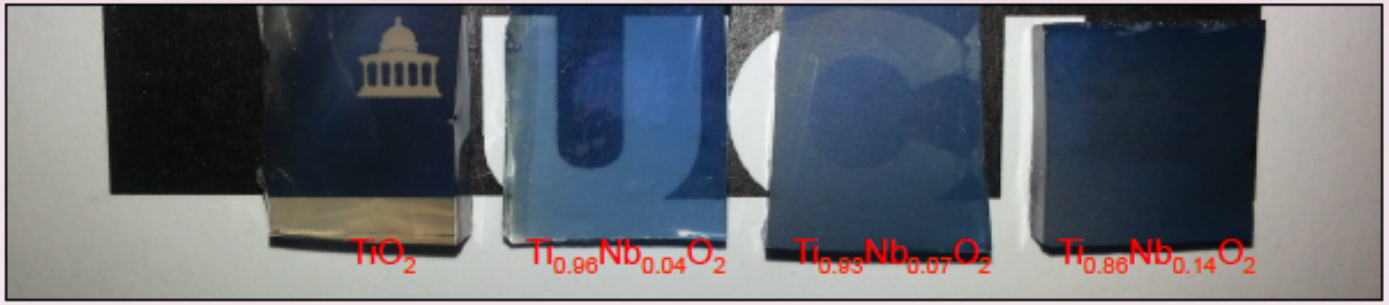
- Produces **highly functional** thin films with no need for further batch post-deposition treatment.
- Greater availability of precursor chemicals – reduces cost.
- Ideal technique for achieving a **textured surface** – different and unique morphologies with controllable roughness of films can be obtained.

Taking an aerosol-assisted chemical vapour deposition (AACVD) process from **small lab-scale** to **large pilot-scale** reactor

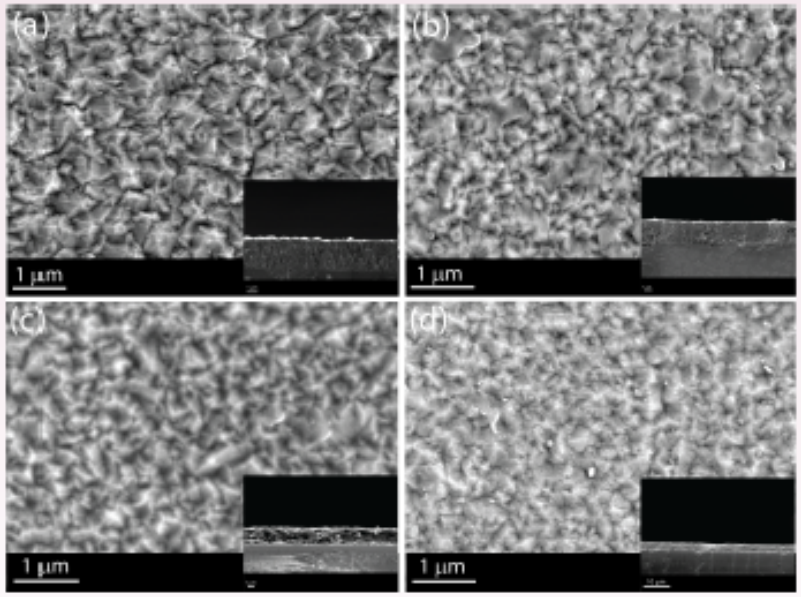


Encompassed within an overall life-cycle and cost-benefit based analysis

Electrically conductive Nb:TiO_2



One-pot, one-step method, without post-deposition annealing and expensive vacuum systems by using aerosol-assisted CVD



Rs = 13 Ω/sq; ρ = 2.4x10^{-3} Ω.cm

Films deposited at 500 °C

$Ti(OEt)_4$ dissolved in toluene

Dopant quantities of $Nb(OEt)_5$ from 5, 10, 20 mol.% in starting solution

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AACVD of Nb-doped TiO_2

- Simple and effective method for the deposition of TCO Nb:TiO_2 films.
- Scalable method using commercially available precursors.
- Films could be used as electrodes in photovoltaics or architectural glazing due to the surface morphology and opto-electrical properties.
- Can control the conductivity via control of the amount of dopant introduced.
- Also shown to be an effective photocatalyst.
- The doped films are also blue in colour, with the intensity dependent on the Nb concentration in the films.

D.S. Bhachu, S. Sathasivam, G. Sankar, D.O. Scanlon, G. Cibin, C. J. Carmalt, I.P. Parkin, G.W. Watson, S.M. Bawaked, A.Y. Obaid, S. Al-Tabaiti, S.N. Basahel, *Advanced Functional Materials* 2014, **24**, 5075.

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