

## Semiconductor Nanostructures for Antireflection Coatings, Transparent Contacts, Junctionless Thermoelectrics and Li-ion Batteries

C. Glynn<sup>1,2</sup>, M. Osiak<sup>1</sup>, W. McSweeney<sup>3,4</sup>, O. Lotty<sup>5</sup>, K. Jones<sup>3</sup>, E. Quiroga-González<sup>6</sup>, H. Föll<sup>6</sup>, J. D. Holmes<sup>2,5,7</sup>, and C. O'Dwyer<sup>1,2</sup>

<sup>1</sup> Applied Nanoscience Group, Department of Chemistry, University College Cork, Cork, Ireland

<sup>2</sup> Micro- and Nanoelectronics Centre, Tyndall National Institute, Lee Maltings, Cork, Ireland

<sup>3</sup> Department of Physics & Energy, University of Limerick, Limerick, Ireland

<sup>4</sup> Materials and Surface Science Institute, University of Limerick, Limerick, Ireland

<sup>5</sup> Materials Chemistry and Analysis Group, Department of Chemistry University College Cork, Cork, Ireland

<sup>6</sup> Christian-Albrechts Universität, Kiel, Germany

<sup>7</sup> Centre for Research on Adaptive Nanostructures and Nanodevices (CRANN), Trinity College Dublin, Dublin 2, Ireland

A nanostructured three-dimensional electrode using transparent conducting oxide (TCO) is an effective approach for increasing the efficiency of optoelectronic devices used in daily life. We summarise MBE grown tin doped indium oxide (ITO) with high conductivity and high work function for application as solar cell back contacts with excellent antireflection and plasmon polariton-assisted transmissivity<sup>1</sup>. The growth of highly porous, large area ITO nanowire layers with superior optical and electrical properties is correlated to the graded porosity nanostructured layers.

For energy storage considerations such a Li-ion batteries, ITO has a theoretical reversible charge capacity of 883 mAh g<sup>-1</sup>, making it ideal transparent and conductive Li-ion battery anode. We present detailed structural and electrochemical investigations of unprecedented defect-free indium-tin oxide and tin oxide nanostructures grown by molecular beam epitaxy completely without any heterogeneous seed of growth-facilitating phase. By controlling the growth conditions, a variety of high quality nanostructures are possible and their electrochemical response is correlated with specific structural changes during insertion, alloying and removal of lithium. We detail the correlation between electrochemical lithium insertion and removal processes during charging and discharging for these transparent battery anodes.

By using silicon, comparable optical, electrical and charge storage paradigms can also be examined and developed. We show here, that by controlling the topology and surface crystallinity of metal-assisted chemically etched Si nanowire layers and electrochemically formed 3D hetero-photonic and phononic crystal membranes, thermoelectric materials are realised by exploiting the variable thermal conductivity of silicon due to thermalized phonon processes<sup>2</sup>, determined using *in-situ* temperature-dependent Raman scattering spectroscopy. This approach allows a range of processable thermoelectric silicon-based materials from quantum-confined nanostructure and topology variation, without necessitating a p-n junction.

Finally, as Si is receiving significant renewed interest for Li-ion batteries and emerging alternatives, we show recent work on the electrochemical response of Si and electrolessly etched Si nanowire layers to lithium insertion and removal<sup>3-6</sup>. Silicon has the highest theoretical specific charge capacity which has been realized with nanostructured silicon with limited cycle life. The specific details on nanostructured<sup>7</sup> versus bulk Si to charging will also be summarized and correlated to cyclic voltammetric analysis of lithium insertion processes in n- and p-doped silicon. Overall, both Si and ITO exhibit a range of potentially exploitable properties for energy storage and generation.

### References

- (1) C. O'Dwyer, M. Szachowicz, G. Visimberga, V. Lavayen, S. B. Newcomb, and C. M. Sotomayor Torres, *Nat. Nanotechnol.* **4**, 239 (2009).
- (2) A. I. Hochbaum, R. K. Chen, R. D. Delgado, W. J. Liang, E. C. Garnett, M. Najarian, A. Majumdar and P. D. Yang, *Nature* **451**, 163 (2008).
- (3) W. McSweeney, O. Lotty, J. D. Holmes, C. O'Dwyer, *ECS Trans.* **35**, 25 (2011).
- (4) K. Kang *et al.*, *Appl. Phys. Lett.* **96**, (2010).
- (5) C. K. Chan *et al.*, *Nat. Nanotechnology* **3**, 31 (2008).
- (6) Z. P. Huang, N. Geyer, P. Werner, J. de Boor and U. Gosele, *Adv. Mater.* **23**, 285 (2011).
- (7) O. Lotty, N. Petkov, Y. M. Georgiev, J. D. Holmes, *Jpn. J. Appl. Phys.* **51**, 11, (2012)