



# NiO<sub>x</sub> via Flame Assisted CVD as a route to Stable, low cost, large Area, Hole Transport layers for Perovskite Solar Cells

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## Introduction

The advancement of perovskite photovoltaics continues to provide improved power conversion efficiencies, and steps have been made towards large scale production, though typically by wet chemical or vacuum based processing. However the widespread application of this promising technology is, to date, still limited by the hygroscopic nature of the organic hole transport layer (HTL) which severely impacts long term stability. Additionally, the commonly reported materials, such as Spiro-MeOTAD and PTAA, carry a major cost providing further motivation for an alternative material. Recent reports in the literature have demonstrated the use of nickel oxide to provide an effective hole transporting layer with significant benefit in terms of both air and thermal stability.

In this work we describe the use of a flame assisted CVD process for the production of NiO<sub>x</sub> from aq nickel nitrate hexahydrate. This approach may be readily implemented on-line, combining continuous large area coating with a relatively low cost of installation and operation. It is envisaged that maximum benefit could be achieved when used sequentially alongside an on-line APCVD process depositing the FTO to provide a substrate for a cell stack.



Figure 1: Photograph showing a production flame treatment system



Figure 2: Photograph showing the Salford FACVD demonstrator

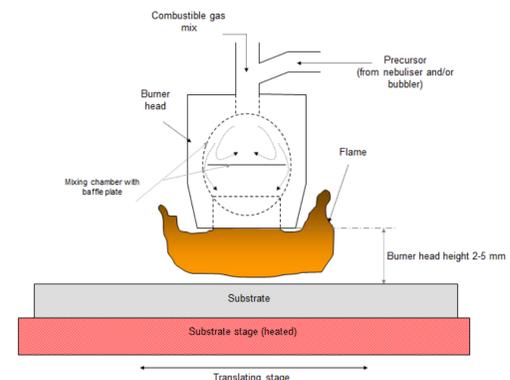


Figure 3: Schematic depicting the lab system [1]

## Technical Approach

- Flame treatment and CVD process used industrially for on and off line coatings
- Line width up to 4 metres typical (glass)
- Relatively low cost / small footprint
- Can be configured for sequential multichemistry deposition
- laboratory demonstrators utilising shorter burners (10cm - 20 cm line width)

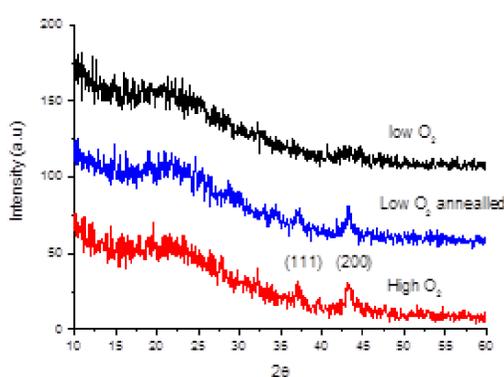


Figure 5: X-Ray diffraction patterns showing maxima at 37.2° and 43.3° indicative of the (111) and (200) planes of NiO (JCPDS-47-1049).

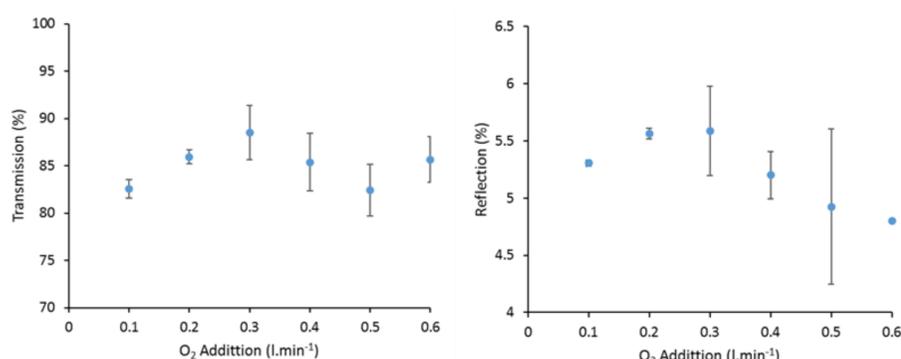


Figure 6: The influence of oxygen addition on visible region transmission & reflection (400-800 nm).

## Experimental

The films were deposited using an in-house FACVD system depicted schematically in figure 3. Additional extraction ducts were positioned at each side of the linear burner head to extract any particulates that may be produced in the flame. A 0.05M nickel nitrate solution was delivered as an aerosol via an ultrasonic nebuliser with a carrier gas flow of 2 l.min<sup>-1</sup>. The precursor was added to the combustion gases (1 l.min<sup>-1</sup> propane / 20 l.min<sup>-1</sup> air) upstream of the burner head. Incremental additions of oxygen were made ranging from 0.1 to 0.6 l.min<sup>-1</sup>. In order to simulate the envisaged online process, the substrate was heated to 400°C and translated under the flame for 50 passes.

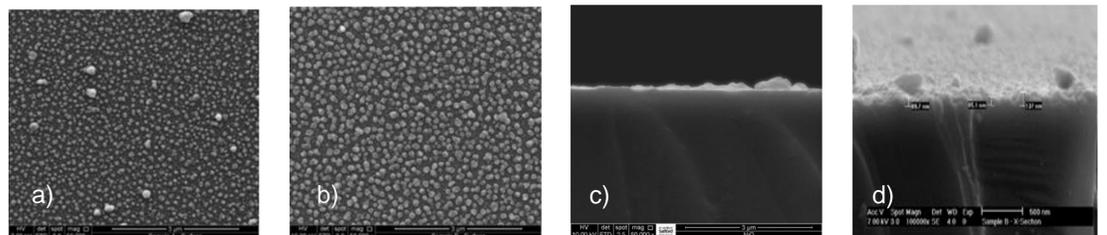


Figure 4: SEM image of the NiO surface a) 0.1 l.min<sup>-1</sup> O<sub>2</sub> b) 0.6 l.min<sup>-1</sup> O<sub>2</sub> and cross section c) 0.1 l.min<sup>-1</sup> d) 0.6 l.min<sup>-1</sup> O<sub>2</sub>.

## Summary

We have demonstrated the production of nickel oxide films via a relatively low cost and highly scalable FACVD process.

The process conditions have a strong bearing on film properties such as morphology with the addition of O<sub>2</sub> resulting in crystalline films showing similar XRD to films reported to give strong cell performance [2].

SEM images indicated an increasing mean particle size (3.3 x 10<sup>-3</sup> μm<sup>2</sup> to 5.4 x 10<sup>-3</sup> μm<sup>2</sup>) with O<sub>2</sub> addition, and whilst the films are particulate, EDAX measurements confirmed the presence of Ni both on and between the surface particles, suggesting complete coverage. SEM cross sections showed improved uniformity with oxygen addition with film thicknesses in the order of ~90 nm.

The changing nature of the film is reflected in the visible region with the average (400 – 800 nm) transmission measurements initially increasing to a maximum for 0.3 l.min<sup>-1</sup> O<sub>2</sub> additions, perhaps due to an increasing proportion of stoichiometric oxide. Further addition of O<sub>2</sub> resulted in reduced and variable transmission possibly resulting from the increasing particle size and reduction in voids within the semi-particulate films. The reflection values show a similar trend to that of the transmission, and are in agreement with the measured haze which gave a maximum of 2% (450 nm) for the lowest oxygen addition corresponding to the greatest roughness (RMS 15 nm), and a minimum of 1% for the 0.3 l.min<sup>-1</sup> O<sub>2</sub> sample which also presented the smoothest surface (RMS 8 nm).

Future work aims to improve film density and evaluate hole transport performance in planar cell structures.