Using an Atmospheric Pressure Chemical Vapor Deposition Process for the Development of “Smart Windows”

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Aims and Objectives

Geneva, 27 April 2009 - New modeling by the World Business Council for Sustainable Development (WBCSD) shows how energy use in buildings can be cut by 60 percent by 2050 to meet global climate change targets.

Building Performance → Design a facade that could change its physical characteristics according to the time of day, time of year and weather conditions. → **Chromogenic Technology**

Chromogenic Technology

Chromogenic windows possess the ability to alter their optical properties, taking on a lighter or darker tint with a change in light intensity, temperature, electrical field or charge.

Passive chromogenic windows

a. Photochromic: vary their light transmission characteristics according to changes in sunlight.
b. Thermochromic: change from clear to opaque when the temperature reaches a certain set point.

Active chromogenic windows

Electrochromic: manually or automatically operated using a small electric current to alter their solar heat and light transmission properties.

Advantages

- Reduce energy usage in buildings

  => lower energy costs for cooling a home.

- Eliminate the need for window coverings such as shades or blinds

  => homeowners can enjoy the outside view on cloudy as well as sunny days without wasting energy.

- Protect a home's interiors from damaging UV rays

  => carpets, furniture, and artwork don't experience fading from the sun.

- Self-powered windows can be possible, requiring no electrical connections to operate the windows.

  => the EC technology would then be positioned for the residential and commercial retrofit market, as well as new construction markets.

Disadvantages

- Low durability,
- Practical sizes,
- High cost.

A bright future

Buildings

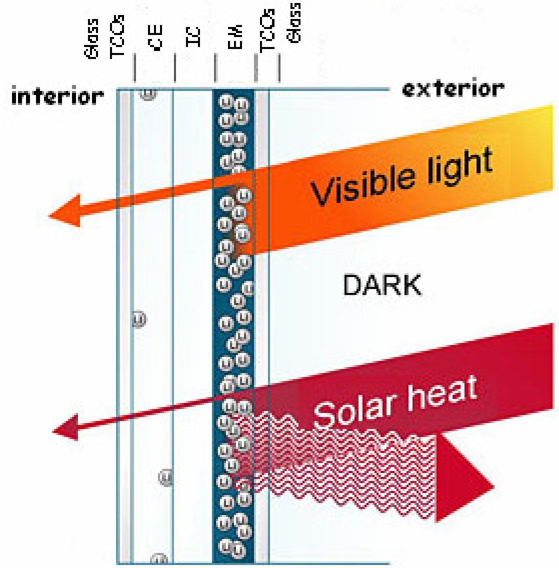
- Lighten a window when direct light is available, but darken it for privacy at other times,
- In a building with ample solar heating, one could use electrochromic windows as a thermostatic control.

Cars-Trains

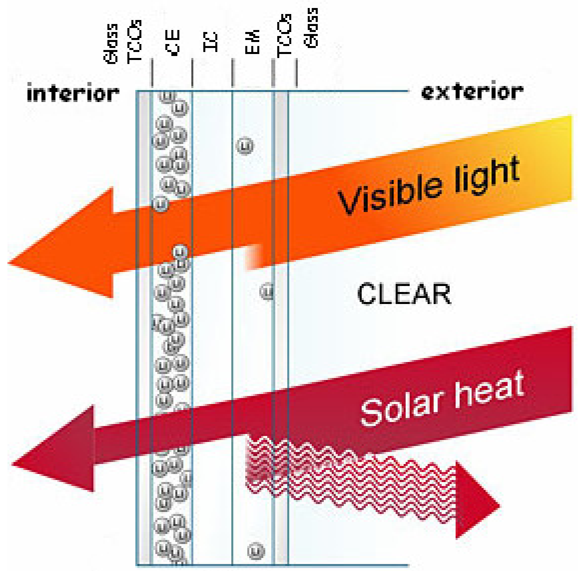
- An electrochromic sunroof could darken in the direct sunlight, but lighten at other times, providing functions while keeping the car cool,
- Electrochromic rear or side windows in a car or a train could darken while the car is parked, keeping the car cool, and then lighten again once the car is started.

How do Electrochromic Windows work?

To darken (or "color") the windows, a voltage is applied across the two transparent conducting oxide layers. This voltage drives the ions from the ion storage layer, through the ion conducting layer and into the electrochromic layer.



To reverse the process, the voltage is reversed, driving the ions in the opposite direction, out of the electrochromic layer, through the ion conducting layer, and into the ion storage layer. As the ions migrate out of the electrochromic layer, it lightens (or "bleaches"), and the window becomes transparent again.



Challenges

LOW COST

PRACTICAL SIZES

↓

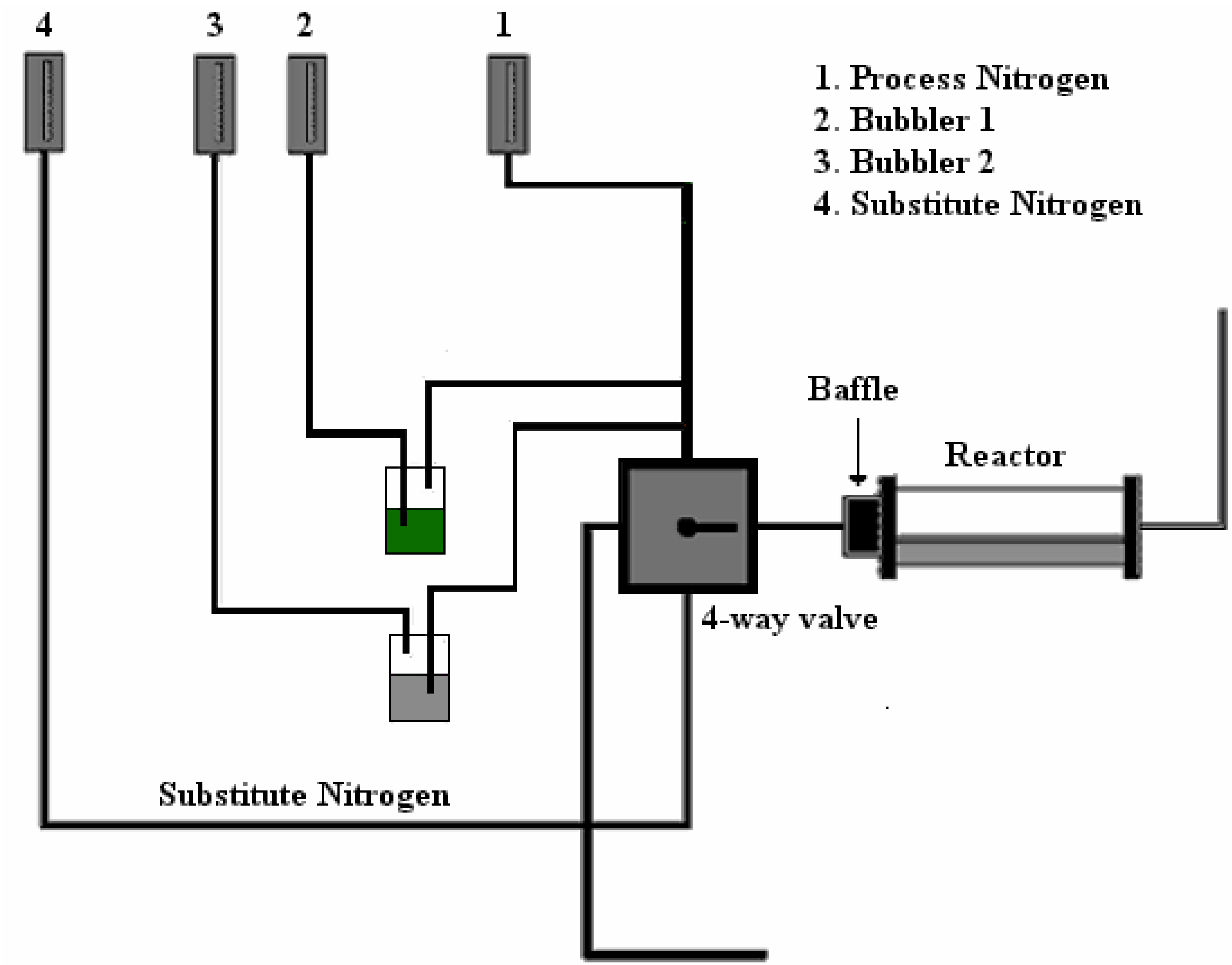
Growth of EC layers by Atmospheric Pressure Chemical Vapor Deposition

Why an APCVD process?

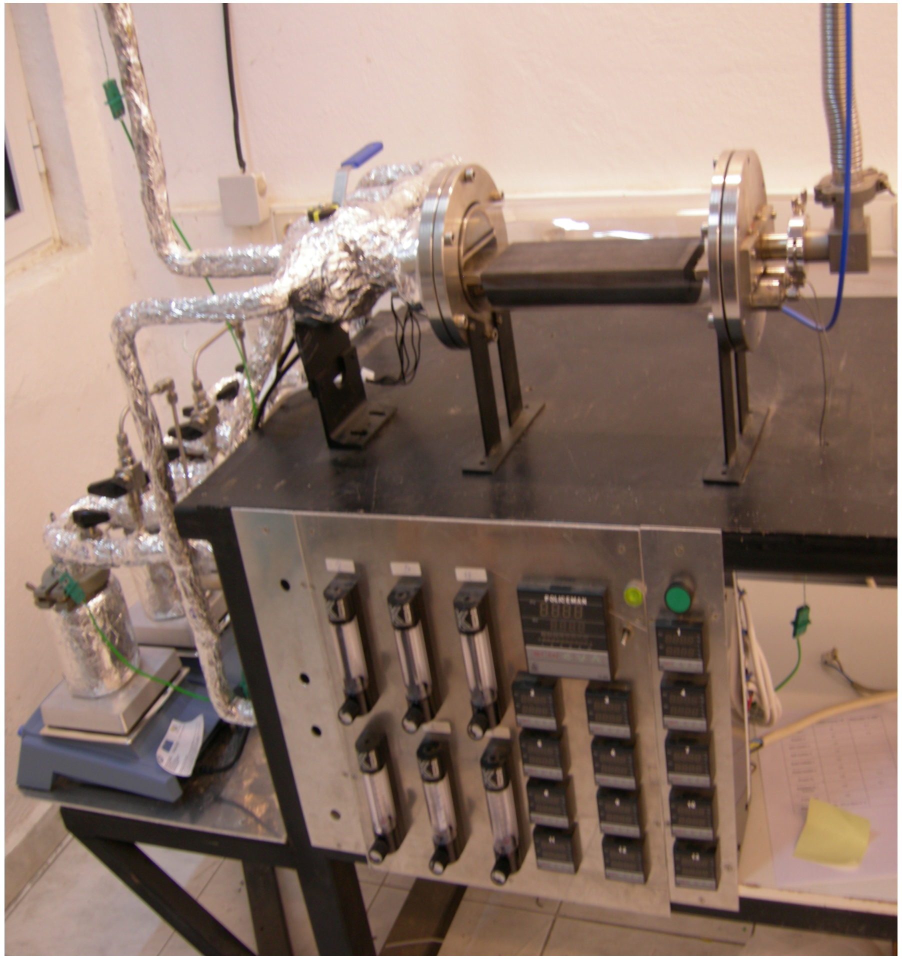
APCVD

- Easily integrated to float glass plants.
- No expensive vacuum systems are required.
- Suitable for coated float glass.

Schematic presentation of the reactor



Atmospheric Pressure CVD reactor



Experimental approach

Substrate SiO_2 – precoated glass (Pilkington, UK) of 22 cm x 8.5 cm x 0.3 cm
Deposition time 2 min

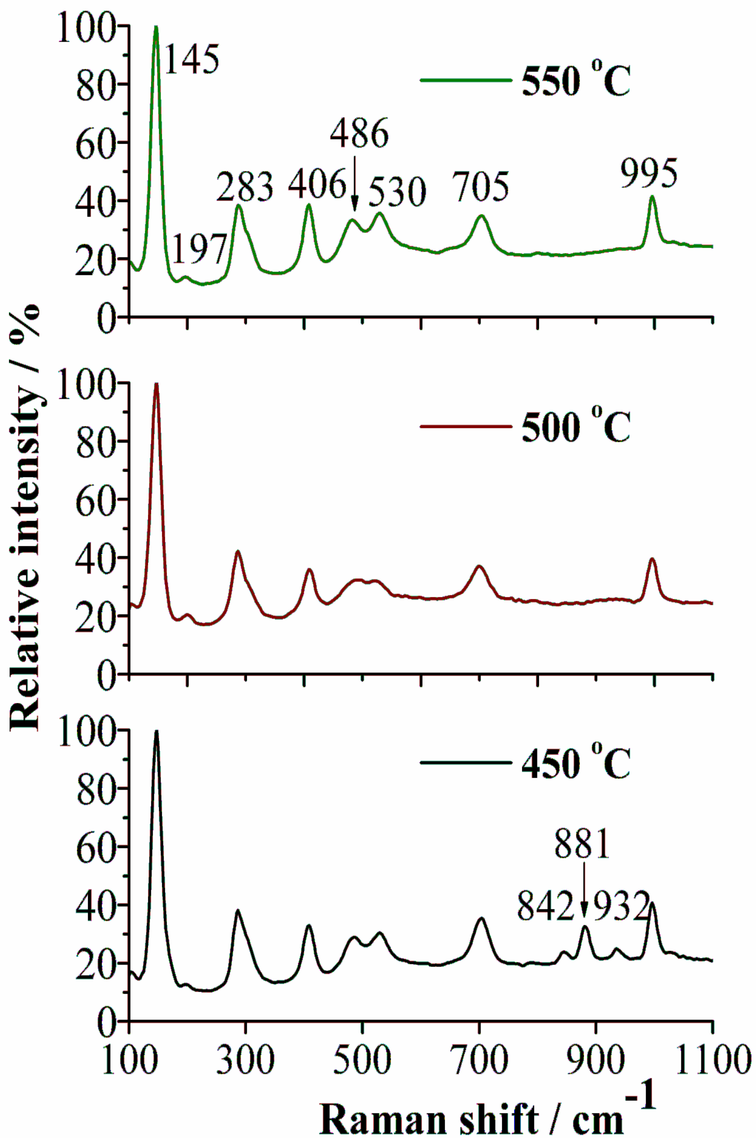
Series A

- **Deposition temperature** 450 ^{o}C
- **Ratio of VCl_4:H_2O** 1:1, 1:2, 1:3, 1:5, 1:7

Series B

- **Deposition temperature** 450, 500, 550 ^{o}C
- **Ratio of VCl_4:H_2O** 1:7

Raman Spectroscopy



✓ Only a single phase of V_2O_5 was detected apart from the samples grown at 450 °C,

✓ For gas precursor ratio of VCl_4:H_2O < 1:7 at 450 °C, the vanadium oxide films presented only the peaks at 842 cm^{-1}, 881 cm^{-1} and 932 cm^{-1},

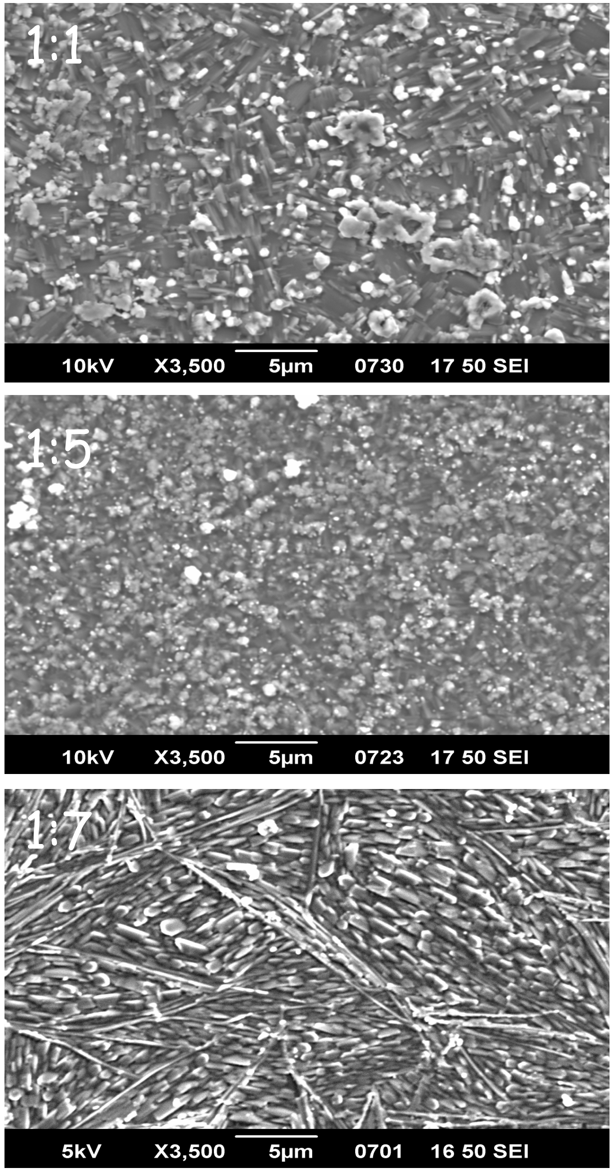
✓ It is possible to define a window of operating conditions wherein single-phase V_2O_5 may be reliably expected to form

=> precursor ratio equal to 1:7, with a substrate temperature of > 500 ° C.

Growth conditions

Deposition time, 2 min and ratio of VCl_4:H_2O, 1:7 at 450 °C, 500 °C, 550 °C.

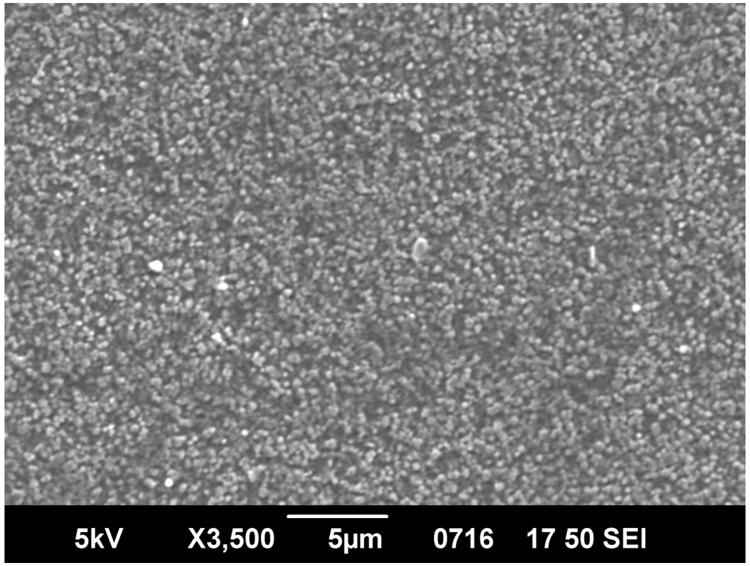
Scanning Electron Microscopy (Series A)



Growth conditions

Deposition time, 2 min and ratio of VCl_4:H_2O, 1:1, 1:5, 1:7 at 450 °C.

Scanning Electron Microscopy (Series B)

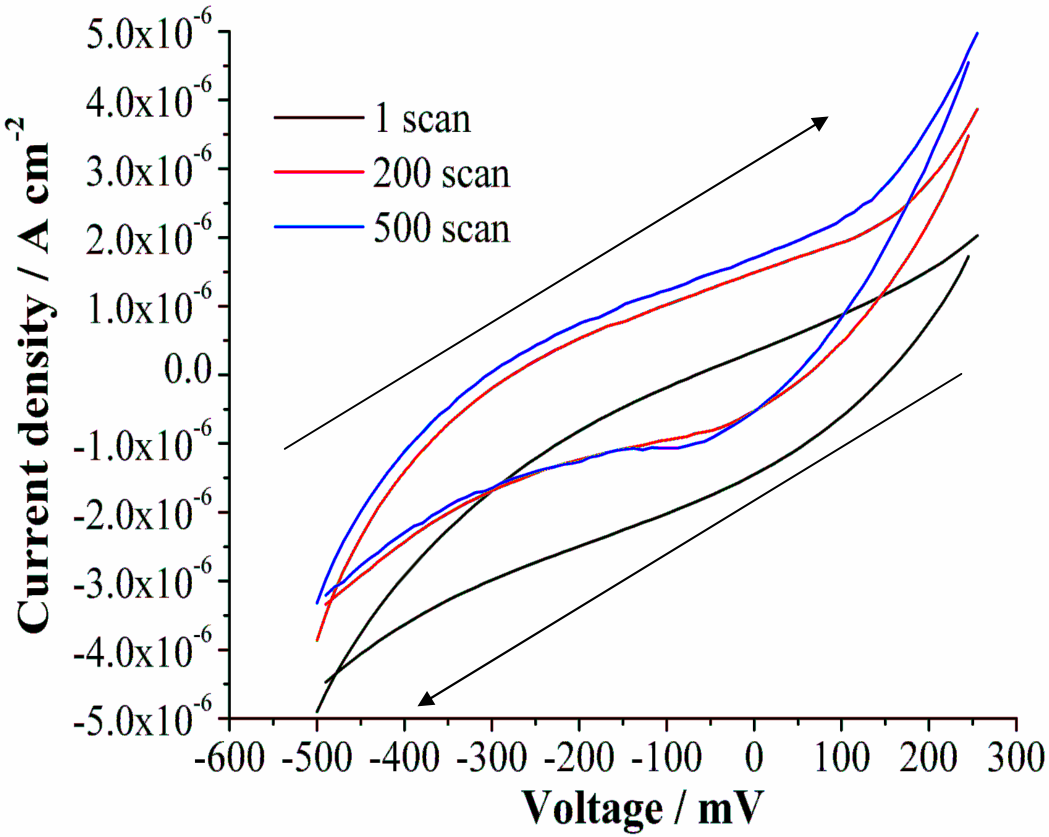


As the growth temperature increases to 550 ° C, surface diffusion is activated, the surface morphology becomes flattened, and columnar grains of uniform size and shape are formed.

Growth conditions

Deposition time, 2 min and ratio of VCl_4:H_2O, 1:7 at 550 °C.

I - V measurements



- The current density increases from 1st to 200th cycle and shows no appearance of degradation after 200 cycles,
- A decrease by two degrees of magnitude of current density is evident after a smaller number of runs for samples prepared under different deposition parameters,
- The vanadium oxide prepared under the particular conditions, exhibits greater channels allowing improved ion intercalation in comparison with the other films.

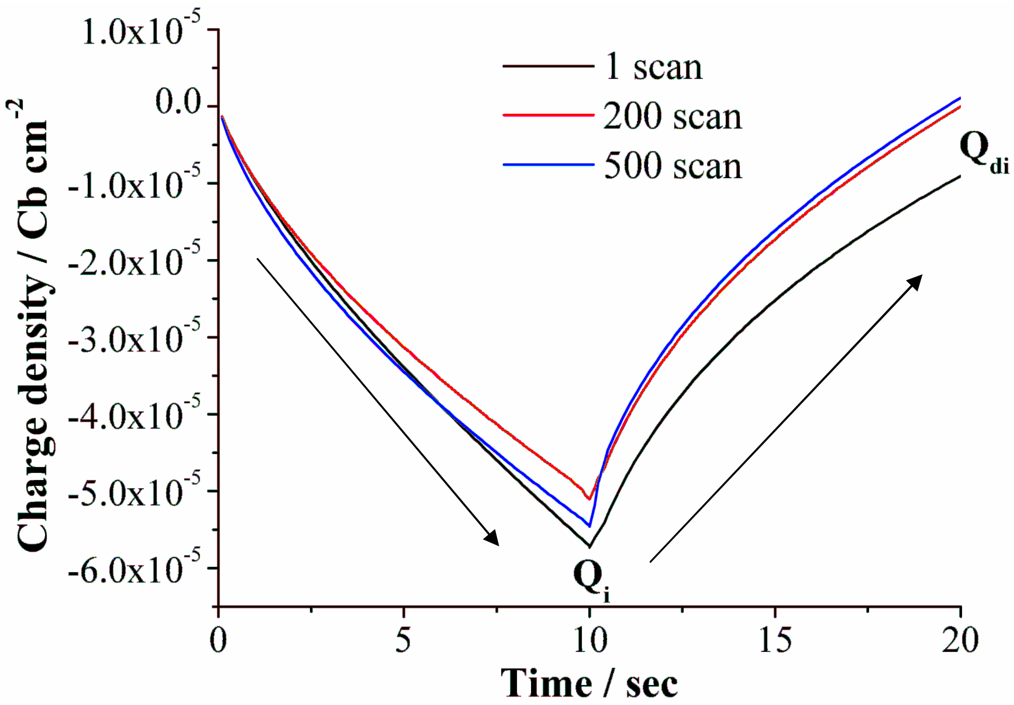
Growth conditions

Deposition time, 2 min and ratio of $VCl_4:H_2O$, 1:7 at 550 °C.

Parameters

Number of scans 1, 200, 500, scan rate 10 mV sec^{-1}, electrode active area, 1 cm^2, electrolyte 1 M $LiClO_4$ / polypropylene carbonate.

Chronocoulometry



For long term measurement, the intercalated charge density was

<u>1st scan</u>, 5.1 x 10^{-5} C cm^{-2}
<u>200th scan</u>, 5.44 x 10^{-5} C cm^{-2}
<u>500th scan</u>, 5.68 x 10^{-5} C cm^{-2}

The intercalated/deintercalated charge ratio was
1st scan, 1.0
200th scan, 1.0
500th scan, 0.8.

Parameters

<u>Number of scans</u> 1, 200, 500, el<u>ectrode active area</u>, 1 cm^2, <u>potential step</u> -0.5 V and +0.25 V, time step 10 s, electrolyte 1 M $LiClO_4$ / polypropylene carbonate.

Growth conditions

<u>Deposition time</u>, 2 min and <u>ratio of VCl_4:H_2O</u>, 1:7 at 550 °C.

Conclusions

- ✓ Vanadium oxide thin films were grown using an APCVD reactor varying the substrate temperature and the gas precursor ratio.
- ✓ Substrate temperatures of 550 °C presented enhanced electrochemical response, which is repeatable after 200 cycles.
- ✓ This is related to the columnar structure of the film, which favours the intercalation, deintercalation of small ions such as Li.
- ✓ The capability to control the oxidation phase and properties of the films by altering the growth parameters may be significant for the production of "smart windows" and related applications.

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