Nanowires of Yttrium Oxide-Stabilized Zirconium oxide (YSZ) as a Solid Electrolyte for Ion Transport

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I. INTRODUCTION

Yttrium Oxide-Stabilized Zirconium oxide (YSZ) is a solid-state electrolyte which allows the propagation of oxygen species (O^{2-}) through its lattice structure.[1] Fuel cells are one of the appealing applications where this electrolyte is proven as a functional technology. High surface area forms of this reactive material improve the efficiency of such devices by increasing the permeability through the structure.

The reduction and oxidation of oxygen species can only occur at the point where the Pt electrode is in contact with both the YSZ and gas phase. This is called the **three phase boundary (TPB)** To create a TPB, YSZ nanofibers are further coated with platinum nanoparticles by using hexachloroplatinic acid (H_2PtCl_6) as the platinum precursor.

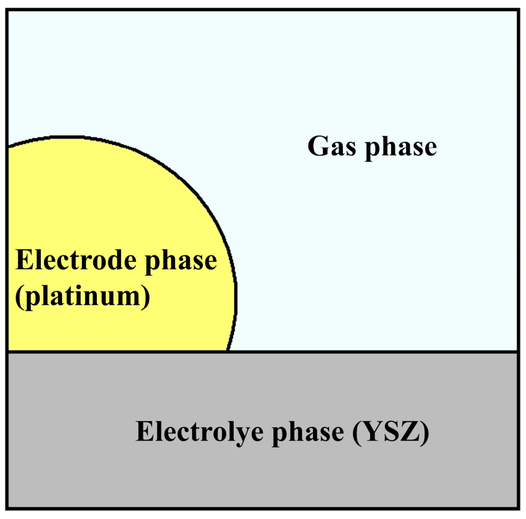


Figure. 1: Illustration of a three phase boundary (TPB)

II. MATERIALS & METHODS

In this research, polycrystalline YSZ nanowires are prepared by using suitable zirconium and yttrium precursors in a sol gel reaction in combination with an electrospinning technique. Electrospinning is a procedure which uses a high voltage electrical discharge to produce nano/microfibers from a solution containing desired precursors and a template polymer.

Polyvinylpyrrolidone (PVP) is used as the polymer template, zirconium (IV) tert-butoxide and yttrium (III) 2-ethylhexanoate are used as YSZ precursors. The PVP template is removed by calcinating it air in two stages, 220°C and 1000°C, respectively.

Flow chart showing the sol-gel procedure:

Yttrium (III) 2-ethylhexanoate + Ethanol (EtOH)

Zirconium (IV) tert-butoxide + EtOH

H_3O^+

PVP + EtOH

Electrospinning

2 stage annealing process

Flow chart showing the synthesis of platinum nano-domes on YSZ nanowires

- *5.88 mM H_2PtCl_6 in isopropanol was prepared*

1 drop of H_2PtCl_6 solution is placed on annealed YSZ nanowires and allowed to air dry

2^{nd} drop of H_2PtCl_6 solution is applied and allowed to air dry

Thermal reduction of H_2PtCl_6 to Pt(0) by annealing at 550°C under Helium atmosphere

Process repeated until desired Pt coating is achieved

Mechanism of Chloroplatinic Acid to Metallic Platinum[2]

(220°C) : $H_2PtCl_6 \rightarrow PtCl_4 + 2HCl$

(350°C-415°C): $PtCl_4 \rightarrow PtCl_2 + Cl_2$

(510°C): $PtCl_2 \rightarrow Pt + Cl_2$

III. RESULTS

The zirconium and yttrium precursors allow for production of nanowires in the 100 nm to 300 nm range. In addition, the nanowires made by this sol-gel method produces nanofibers that are less brittle (compared to other synthesis method like the suspended particle route).

Pt-coated YSZ nanowire characterization:

- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)
- Energy Dispersive X-Ray (EDX) spectroscopy
- X-Ray Diffraction (XRD)

(1) SEM analysis of YSZ nanowires:

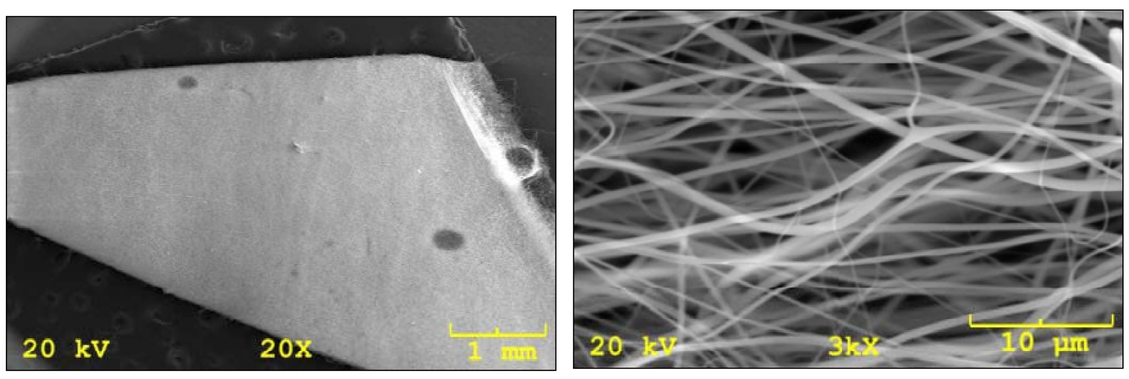


Figure. 2: Unannealed nanowires (SEM image)

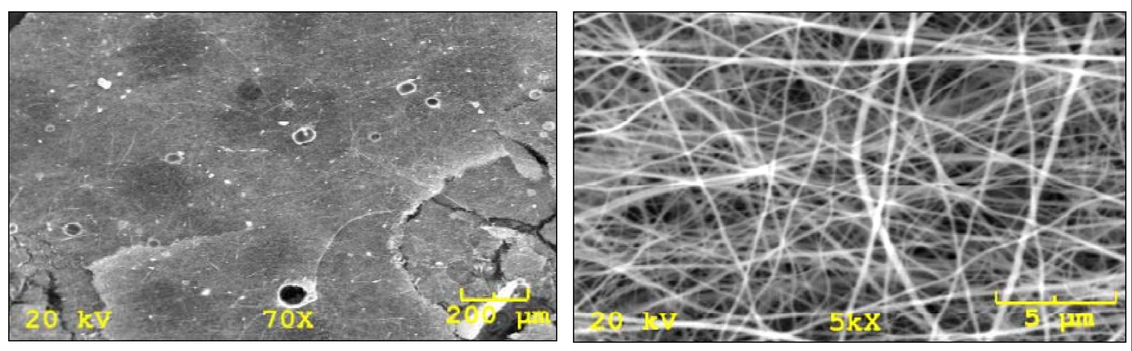


Figure. 3: Annealed nanowires at 1000°C (SEM image)

RESULTS (continued…)

(2) TEM analysis of YSZ nanowires:

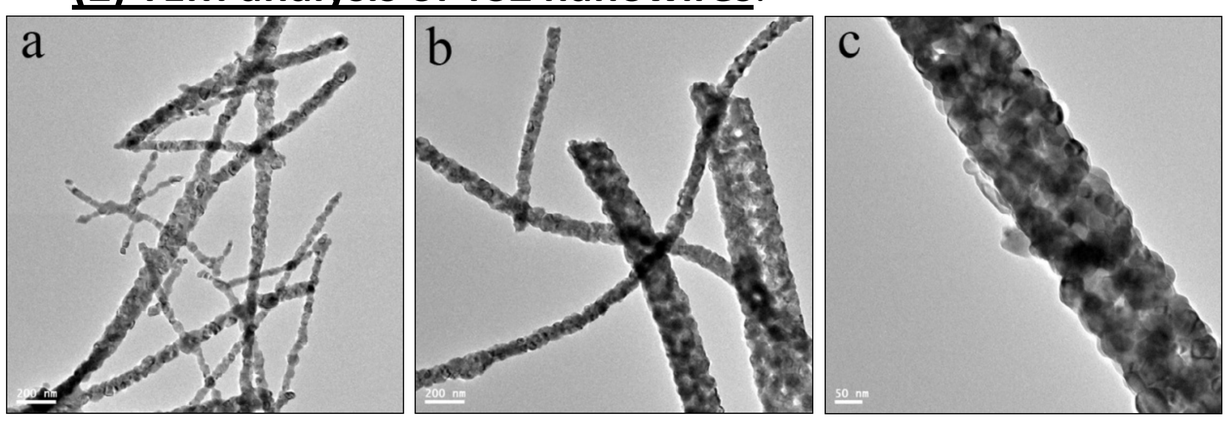


Figure. 4: TEM images of annealed YSZ nanofibers.

(3) HRTEM analysis of YSZ nanowires:

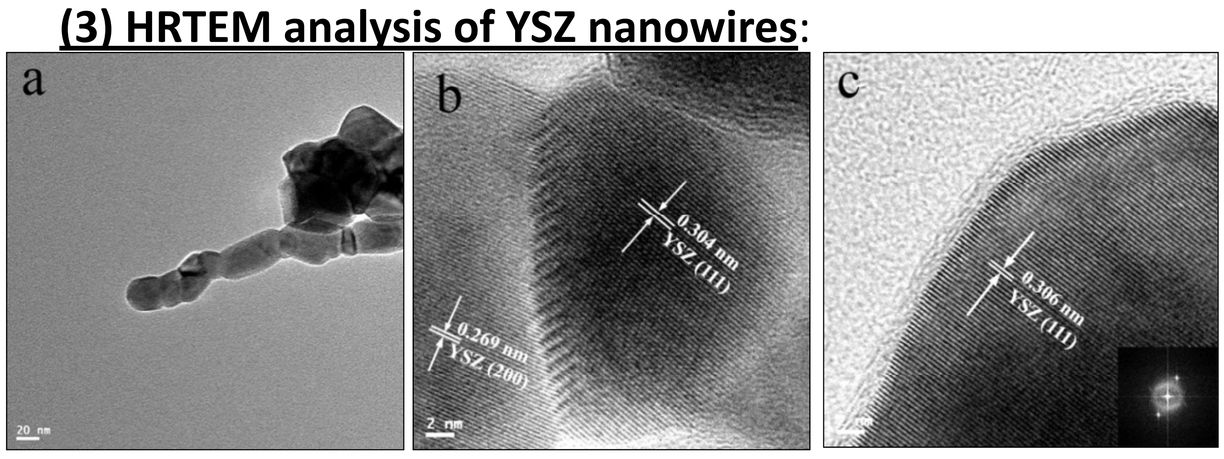


Figure. 5: Shows the HRTEM images of the annealed YSZ nanofibers formed by (a) fusion of the individual YSZ sol particles with distinct (b) phase boundaries between two particles and (c) lattice spacing corresponding to the cubic YSZ (111) plane.

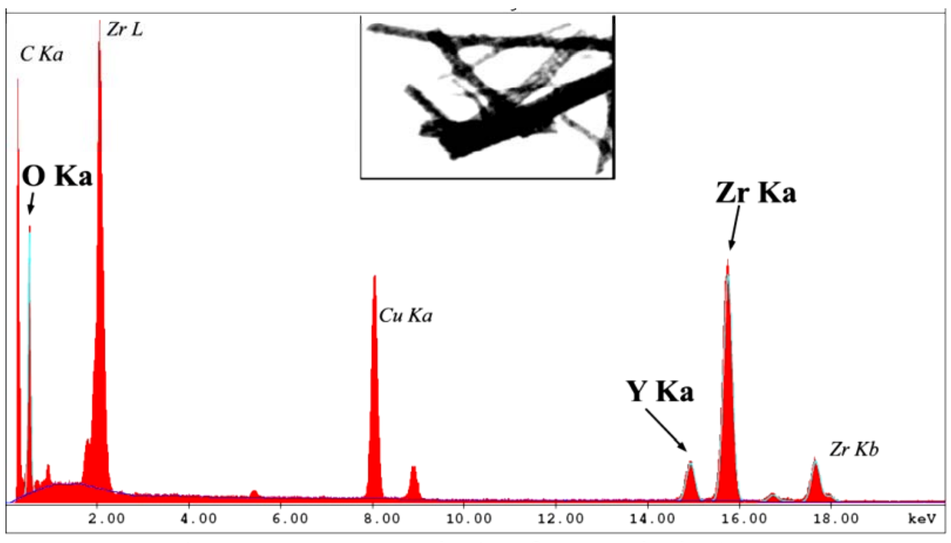


Figure. 6: EDX analysis of annealed YSZ

- EDX map showing uniform elemental distribution throughout the nanowire.

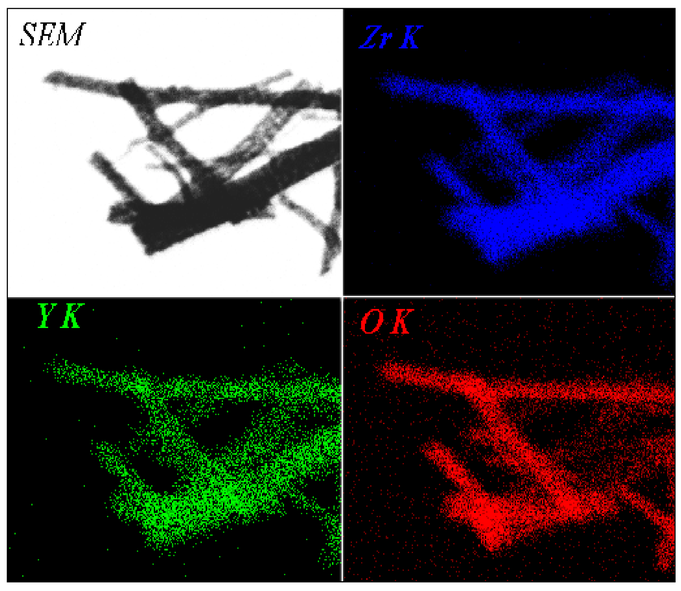
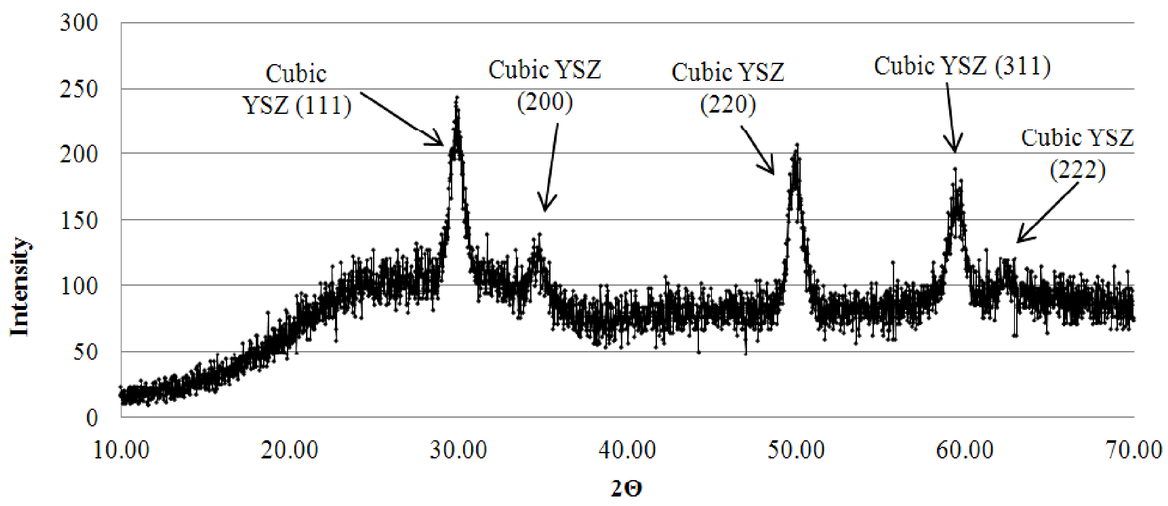
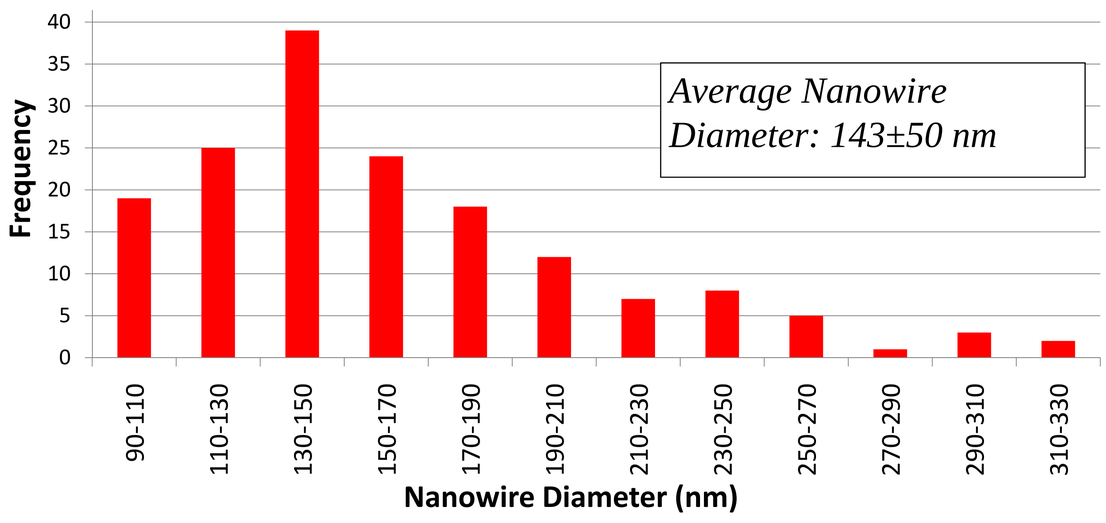


Figure. 7: EDX map of annealed YSZ showing the Zr, Y, and O atom distribution in the sample.

(4) XRD analysis of YSZ nanowires:



(5) Size distribution of annealed YSZ nanofibers



(6) Platinum nano-domes on YSZ nanowires:

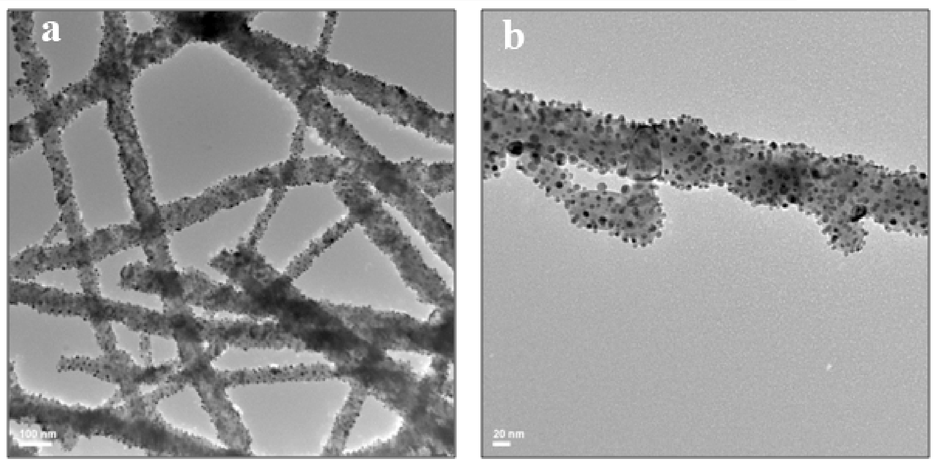


Figure. 8: TEM image showing the distribution (a) and morphology (b) of the Pt deposition on YSZ nanofiber.

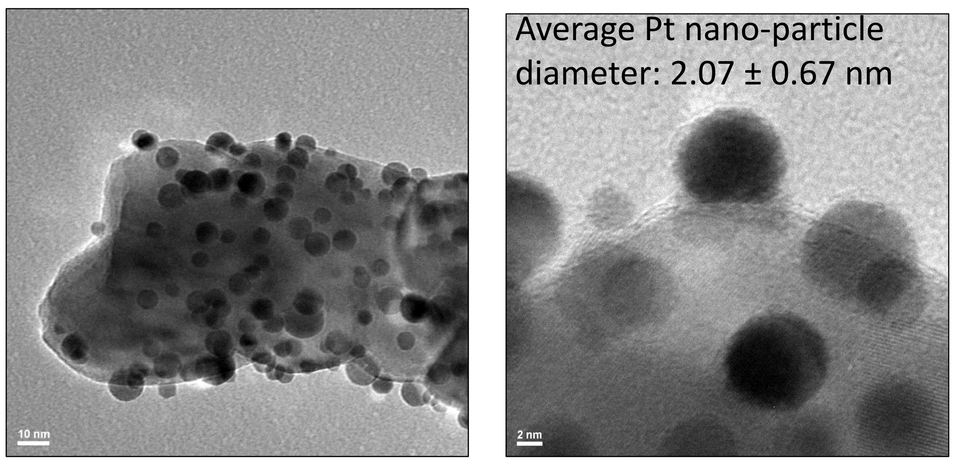


Figure. 9: (Left) TEM image showing Pt nanoparticles deposition on a YSZ nanofiber. (Right) Histogram showing distribution of Pt nanoparticles size deposited on YSZ nanofiber (unit in nm).

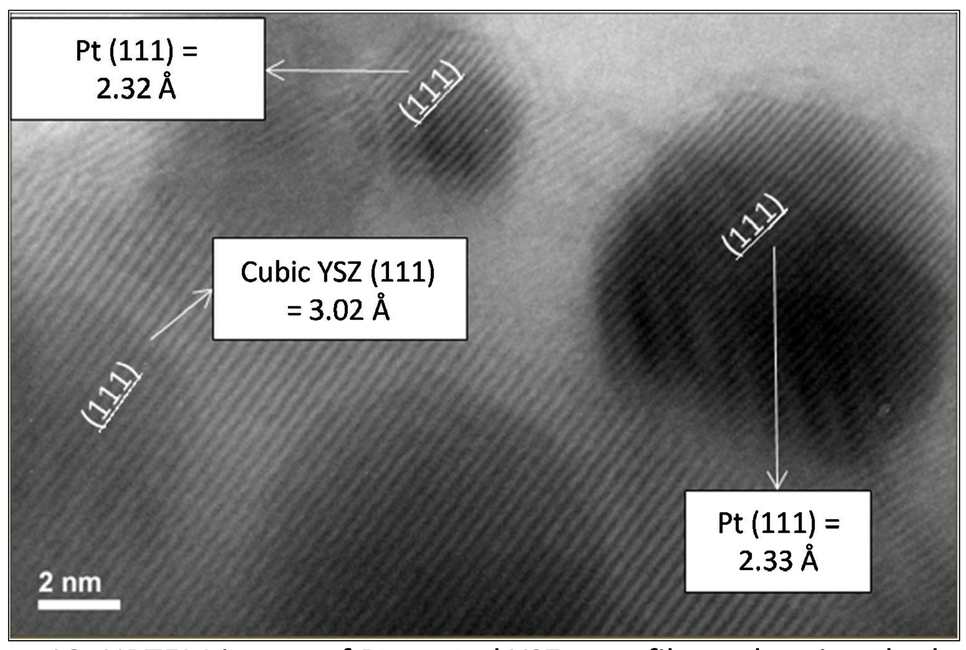
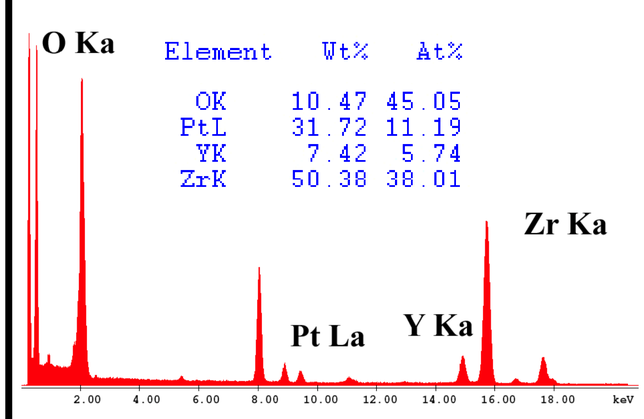


Figure. 10: HRTEM image of Pt coated YSZ nanofibers showing the lattice constant and corresponding planes of Pt nanoparticles on cubic YSZ



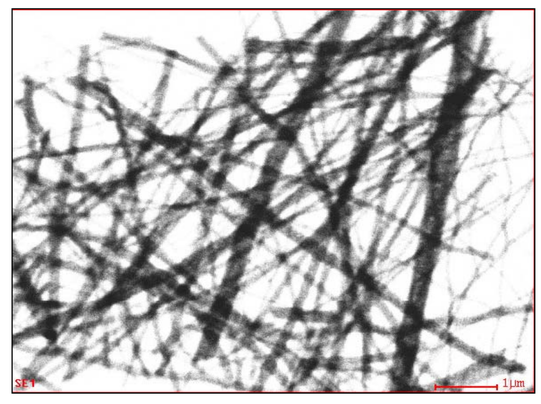


Figure. 11: EDX analysis (left) of the Pt coated YSZ nanofibers with the STEM image (right).

IV. CONCLUSIONS

- By carefully controlling the precursors and reaction conditions, the desired morphology of the platinum coated YSZ nanowires was achieved.

- Further study is being done to evaluate the ion conductivity (through YSZ electrolyte) by controlling the density of the TPB produced by platinum deposition on YSZ nanowires.

V. LITERATURE CITED

1. *E.L. Shoemaker et al. / Sensors and Actuators B 110 (2005) 89–100*
2. *A. E. Schweizer, G. T. Kerr; Inorganic Chemistry, Vol 17, No. 8, I978*