

# Investigation of several Carbon Allotropes as Electrode Materials for Vanadium Redox Flow Batteries

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## Introduction

The performance of the all-vanadium redox flow batteries can be improved by an enhancement of the electrocatalytic reactions. The activity of several carbon materials in vanadyl sulfate solution (Figure 1) are very different. Therefore we have analysed the structure of these materials in order to determine the critical parameters. We think this knowledge will help in further the development of electrodes.

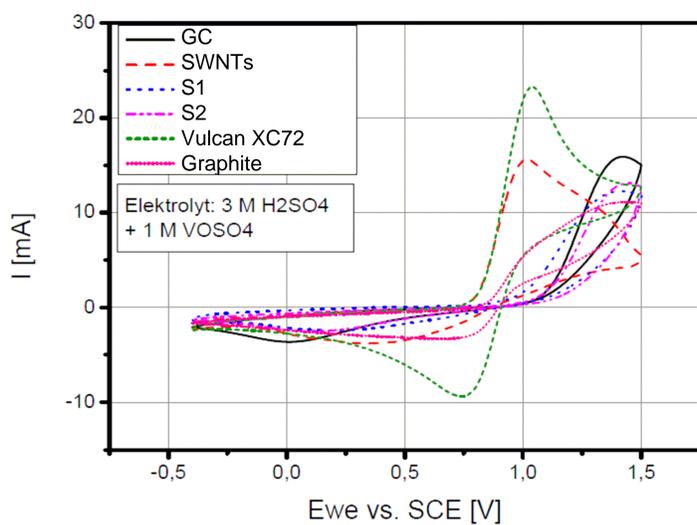


Figure 1. Cyclic voltammetry of nanoparticle Graphite, Vulcan XC72, Single-Walled-Carbon-Nanotubes (SWNTs), Glassy Carbon Nanospheres (GC) and two carbon blacks with a special pore geometry (S1, S2).

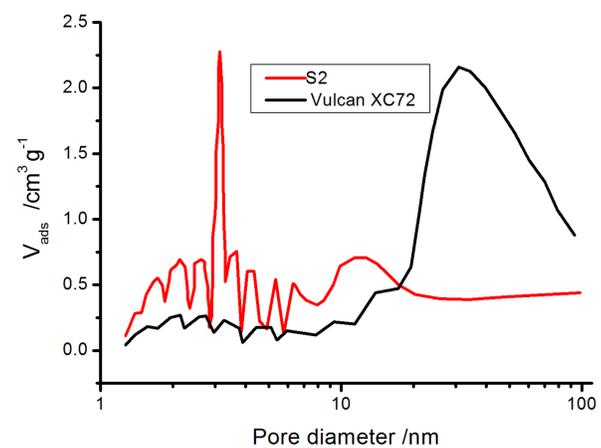


Figure 3. The Pore size distribution obtained by BET analysis shows a larger amount of pores >30nm for Vulcan in comparison with sample S2.

## Disorder obtained by Raman spectroscopy

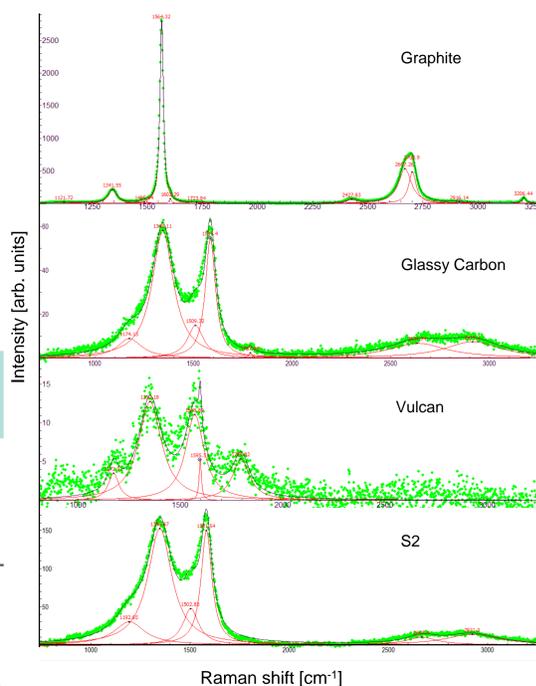


Figure 4. The Raman spectra of graphite shows the typical G-band [1580  $\text{cm}^{-1}$ ] and the disorder induced D-band [1350  $\text{cm}^{-1}$ ]. These bands are also observed for the other materials but broadened. The peak area ratio D/G determines the disorder in the materials and increases in the following order Graphite>Vulcan>GC/S2.

	Peak Area D	Peak Area G	D/G
Graphit	15649	82798	0.19
GC	12040	5313	2.27
Vulcan	2738	2201	1.24
S2	35204	15473	2.28

## Results

### Morphology and Pore Size Distribution

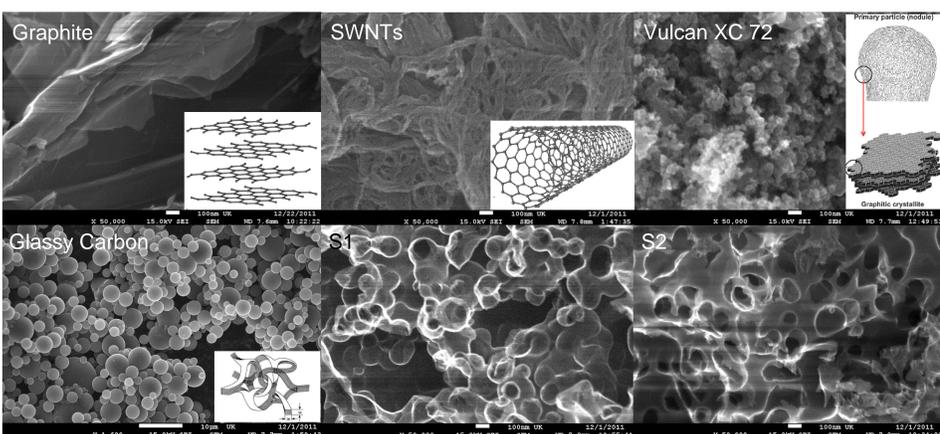


Figure 2. Scanning electron microscopy images showing the different morphologies of the samples. The white images sketch the basic structure of different carbon modifications.

[<http://www.als-japan.com/1037.htm>, <http://www.ec.gc.ca/ese-ees/>]

## Conclusion

The activity seems to be influenced by the pore size distribution of the materials and/or the size of graphitic domains in the sample. Vulcan has larger pores compared to the S2 sample and shows a lower degree of disorder.