TEM and SEM-CL studies of β-SiC nanowires

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INTRODUCTION

The combination of the distinctive physical and chemical properties of SiC and unique advantages of nanowires (NWs) opens promising near-future perspectives for the design and fabrication of nano-scale devices. The main interests are addressed to <u>nano-electronic devices</u> (e.g. nano field-effect transistors) and <u>nano-electromechanical systems</u> able to operate even in harsh environments, and to <u>nano-sensors</u> exploiting the SiC NWs as biocompatible nanoprobes for biological systems.

GROWTH PROCESS

A) core/shell β-SiC/SiO_2 NWs are grown by a CVD process on n-type Si (001) substrates, using carbon monoxide as the carbon source and nickel nitrate as the catalyst.

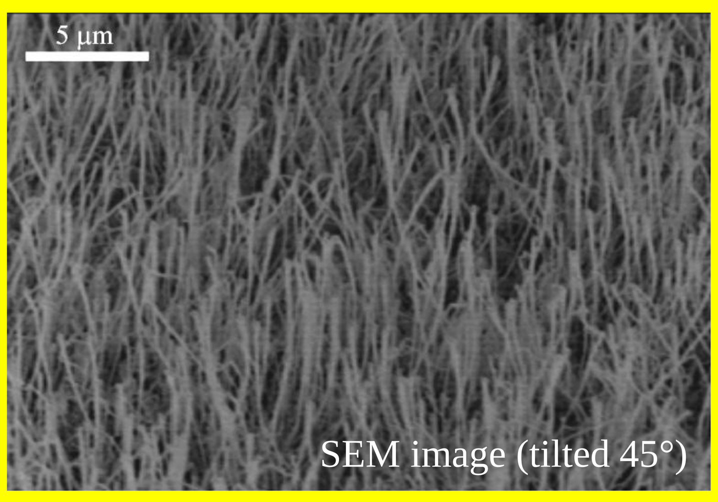
β-SiC (without shell) NWs are obtained with two different methods:

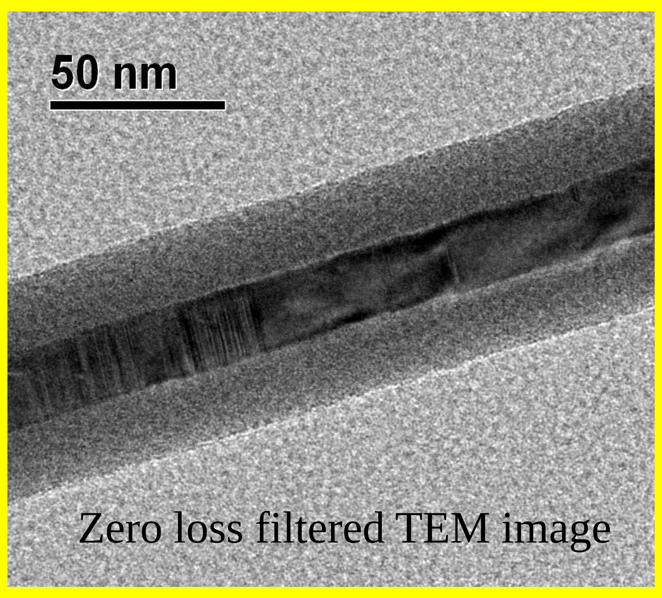
B) using VPE technique in a home-made reactor with propane and silane precursor and Ni as catalyst, on Si (100) and (111) substrates.

C) by a chemical reaction using carbon tetrachloride (CCl_4) as a precursor and Ni as catalyst.

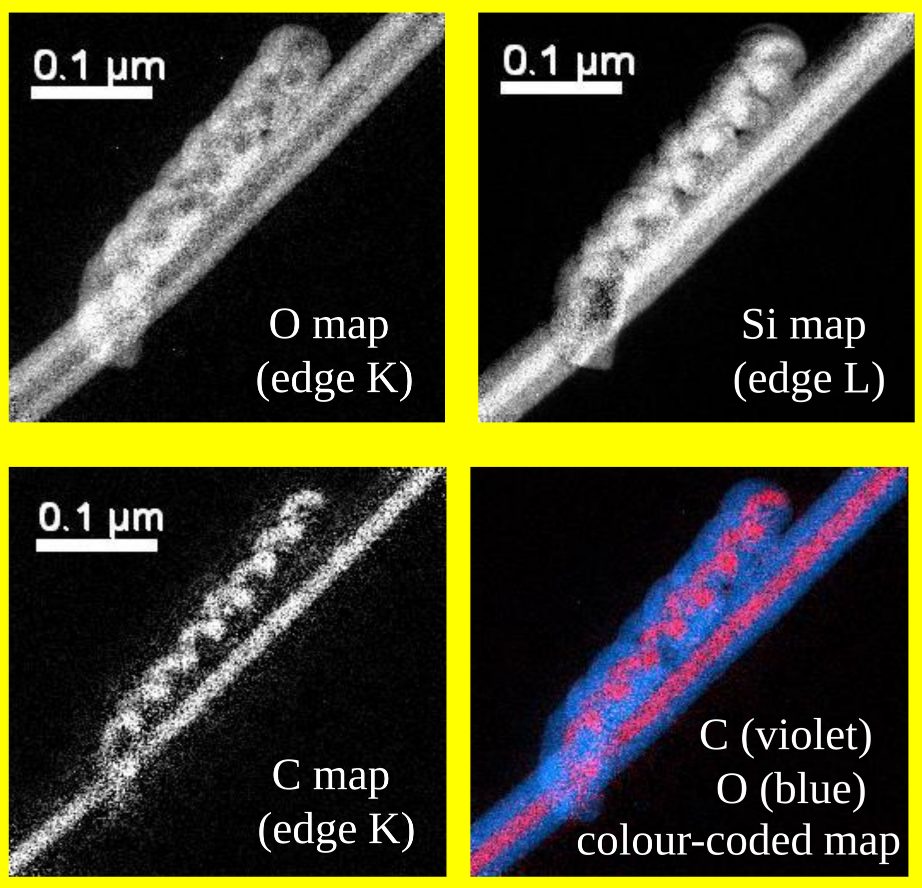
A) Core / shell 3C-SiC/SiO_2 NWs **

The NWs have a core-shell structure, with a β-SiC crystalline core (≤50 nm) coated by an amorphous SiO_2 shell. The core has a 3C structure with some stacking faults and rotational twins mainly on (111) planes perpendicular to the growth axis, as common in β-SiC.

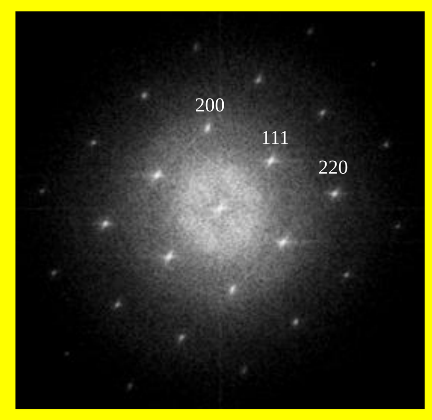


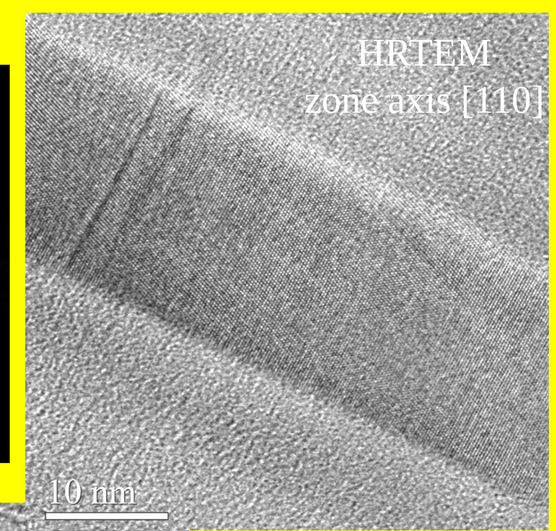


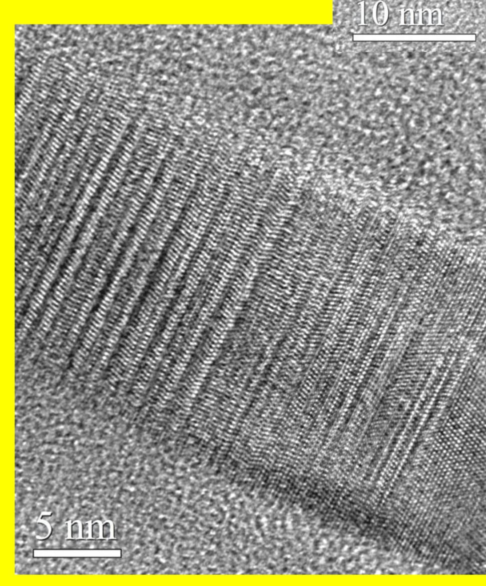
elemental mapping highlights the C and O complementary distributions



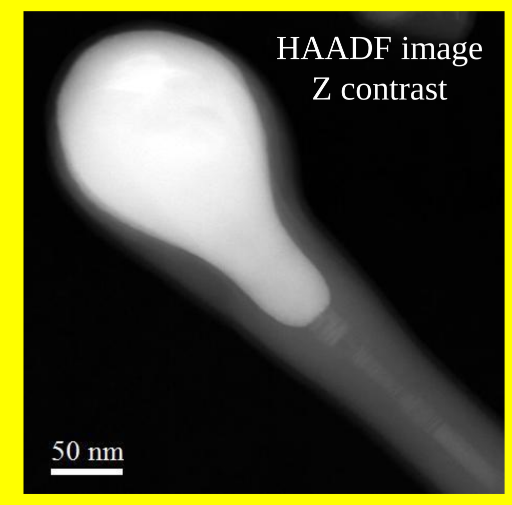
energy-filtering by in-column Ω filter
JEM 2200FS JEOL microscope at 200 kV

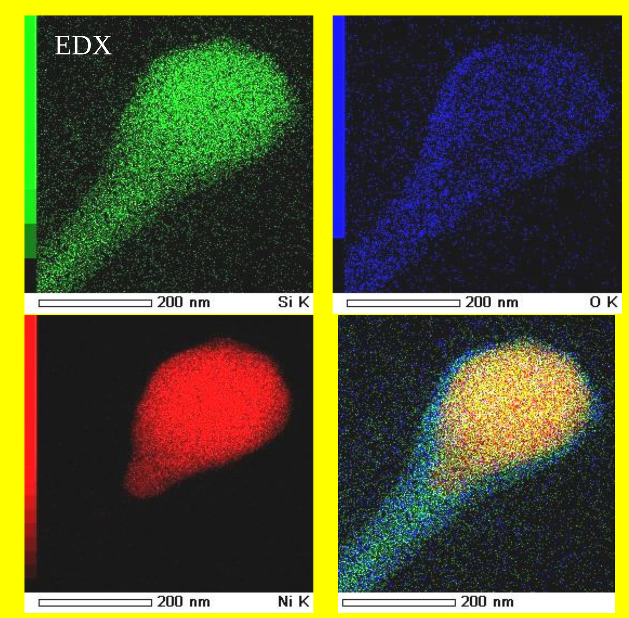






The SFs can originate very local segments of different polytypes (e.g. 2H, 4H, 6H)

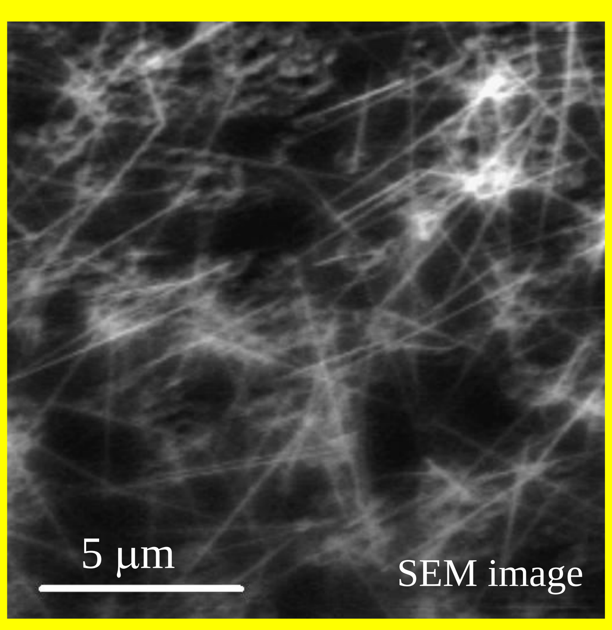


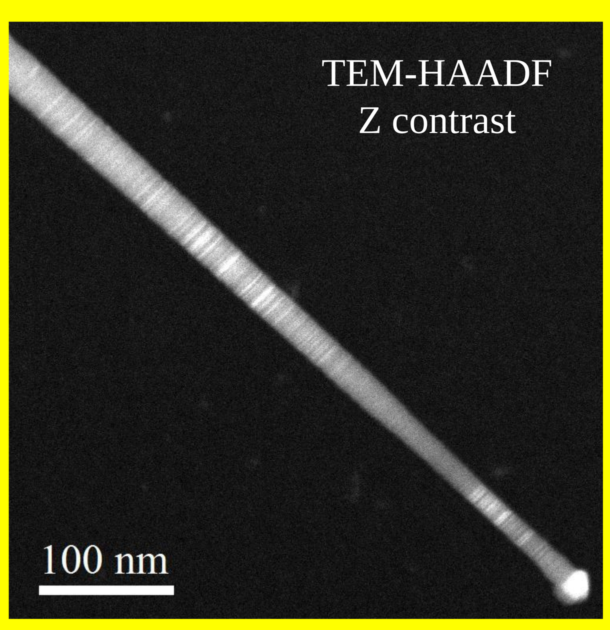


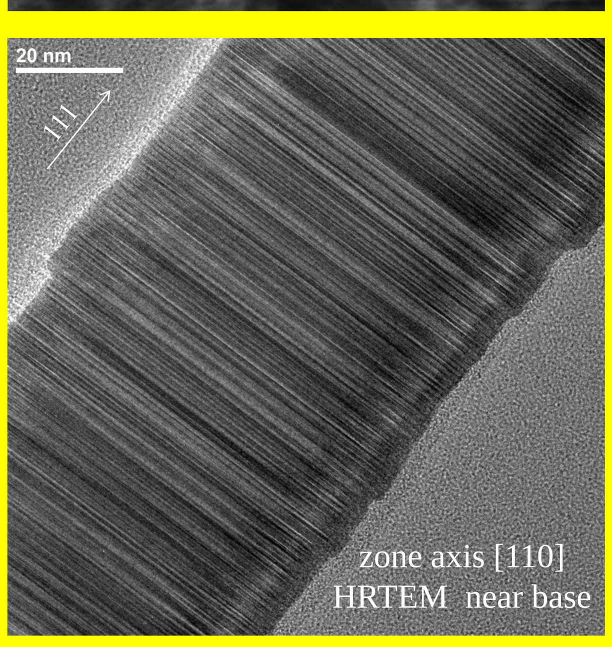
Ni at the tip of the NWs
VLS growth mechanism

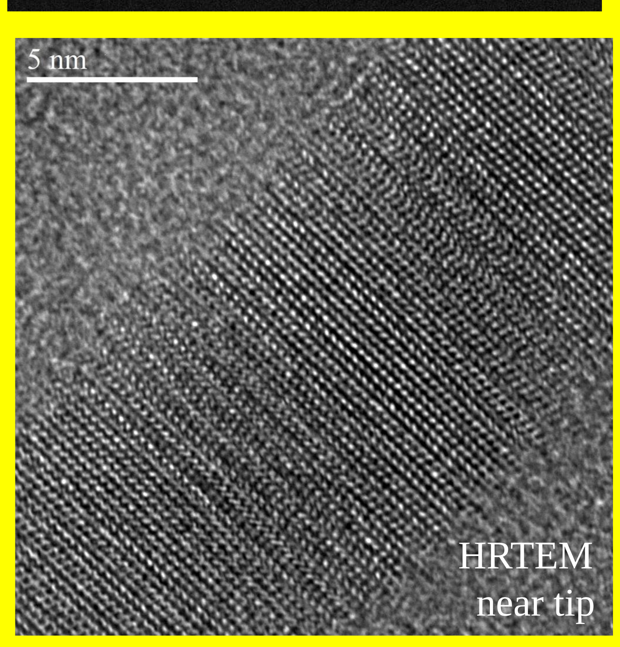
B) 3C-SiC NWs grown by VPE

Tapered NWs are obtained: size decreases from 80 nm (base) to 10 nm (tip).



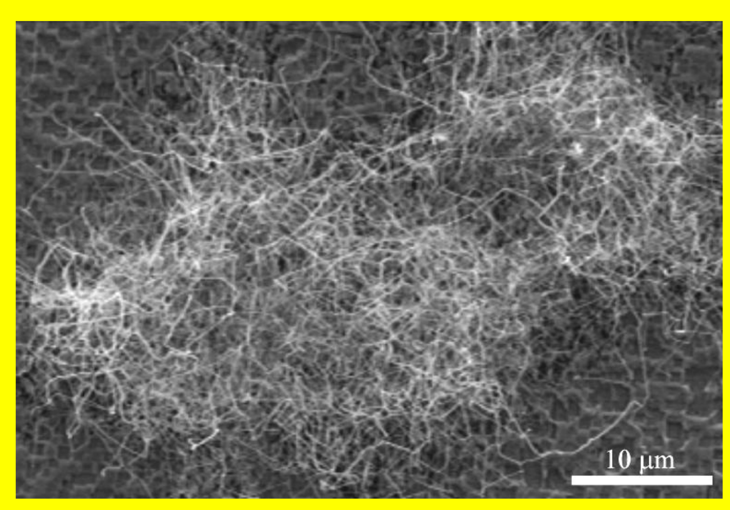


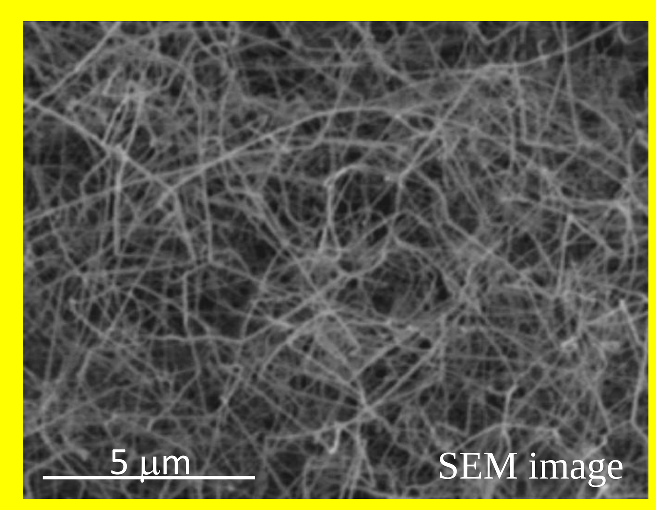




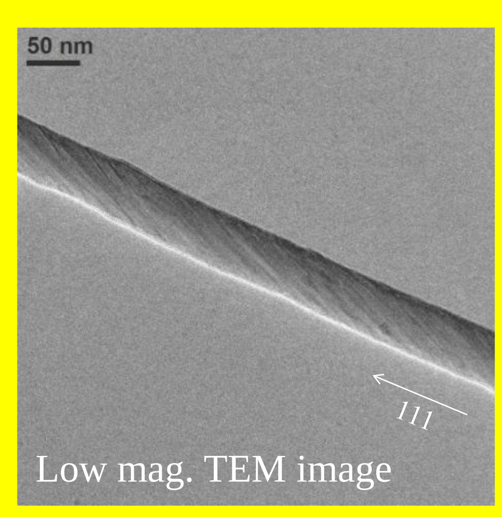
C) 3C-SiC NWs grown with CCl_4 single precursor ***

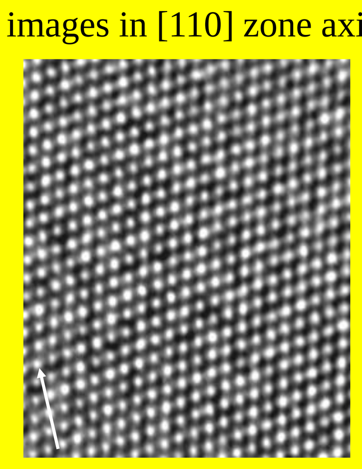
Long NWs with diameters < 80 nm are obtained, arranged into dense networks randomly oriented on the Si surface.
Some craters are opened in the substrate due to the etching action of chlorine.

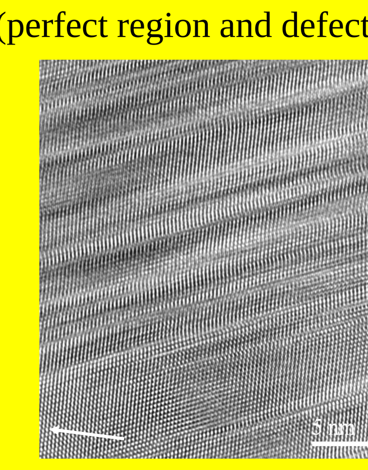


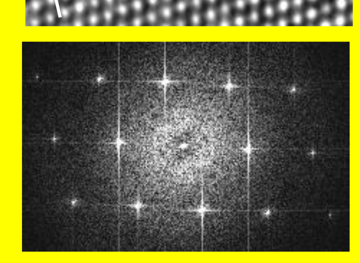


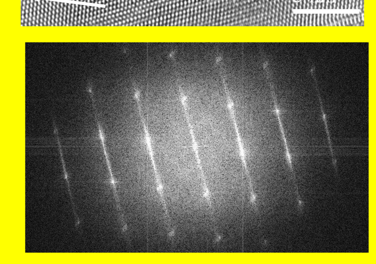
HRTEM images in [110] zone axis (perfect region and defective region)





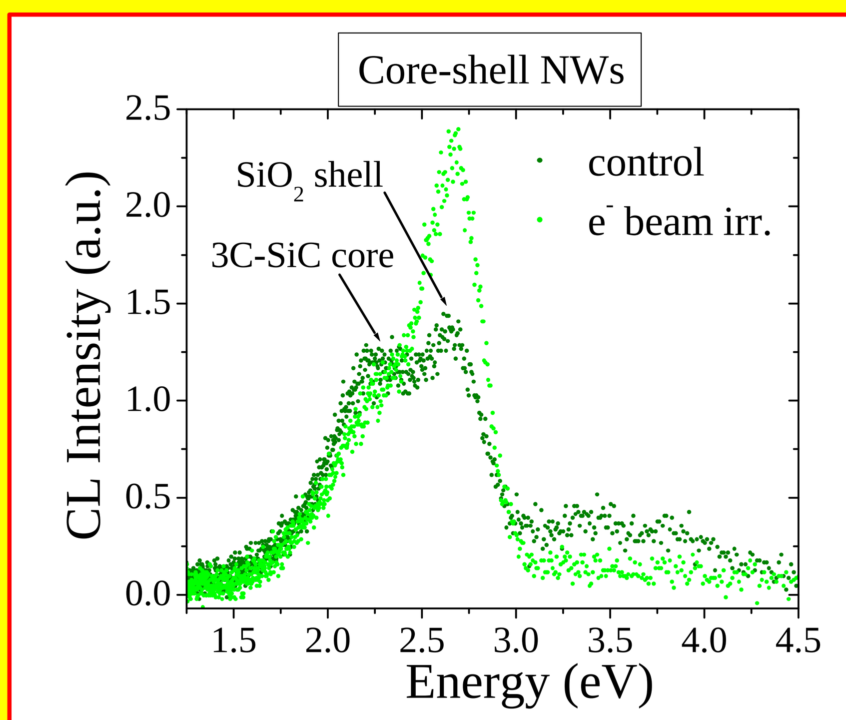


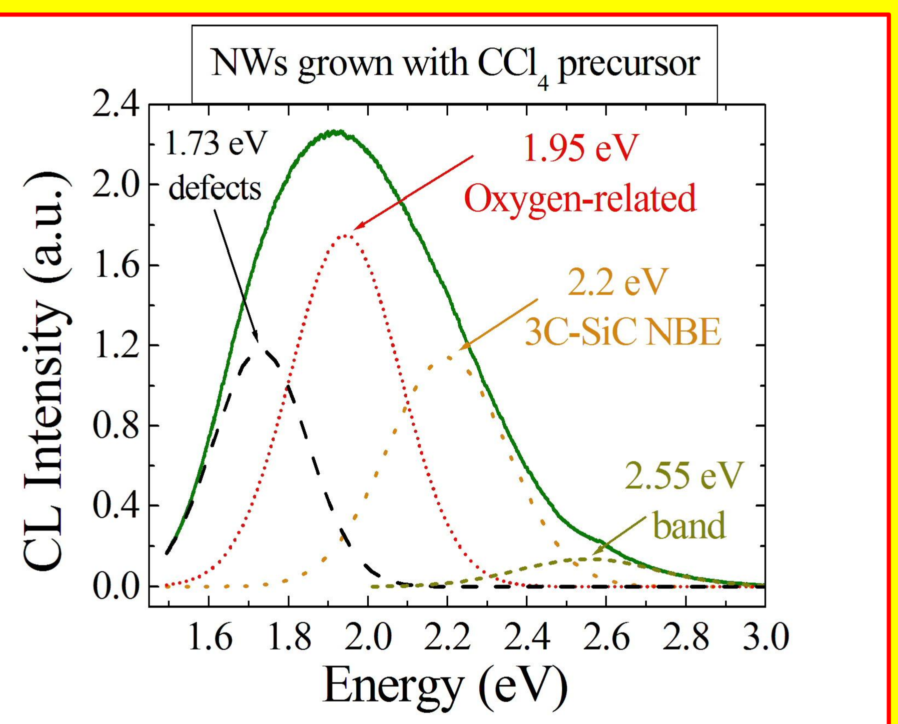




Fast Fourier Transforms

Optical properties: CATHODOLUMINESCENCE @ RT





In VPE-grown NWs the CL emission is too weak to be analysed.
Compared to the core/shell NWs, this suggests that the shell acts as carrier injecting barrier and passivation layer, and plays a beneficial role to enhance the luminescence of the SiC core.

3C-SiC near-band-edge (NBE) transition is detected @ 2.2-2.3 eV.

Core/shell NWs show an additional blue emission @2.7 eV. It increases and becomes dominant under electron beam irradiation (15 keV, 2 nA, 3600 sec). Experiments performed after etching treatments confirm the attribution of this blue luminescence to oxygen deficiency centers in the amorphous SiO_2 shell.

In NWs grown using CCl_4 the spectrum is dominated by a red emission @ 1.95 eV, ascribed to O_C defects unintentionally incorporated in the open-tube growth.
The other bands below and above the SiC energy gap are ascribed to deep levels in 3C-SiC with an activation energy of about 0.5 eV (emission @ 1.73 eV) and to surface states as dangling bonds or surface/interfacial groups (emission @ 2.55 eV).

CONCLUSIONS

β-SiC and β-SiC/SiO_2 core-shell NWs have been grown on Si substrates by:
A) CVD growth using CO as the carbon source,
B) VPE growth with silane and propane precursors,
C) synthesis by chemical reaction with CCl_4 single precursor.
The lattice structure and the elemental composition of the wires have been assessed by TEM. CL spectroscopy has been performed, finding a luminescence enhancement in core-shell structures due to a beneficial role of the SiO_2 shell layer. In NWs grown using CCl_4 precursor, an anomalous red luminescence centered at about 2 eV has been detected and ascribed to point defects related to an unintentional oxygen incorporation.

** G. Attolini, F. Rossi, M. Bosi, B.E. Watts, and G. Salviati, J. Non-Cryst. Solids. 354, 5227 (2008) ; F. Fabbri, A. Cavallini, G. Attolini, F. Rossi, G. Salviati, B. Dierre, N. Fukata, and T. Sekiguchi, Mater. Sci. Semicond. Process. (2008) (doi:10.1016/j.mssp.2008.10.004)
*** G.Attolini, F. Rossi, F. Fabbri, M. Bosi, B. E. Watts, and G. Salviati, Mater. Lett. (2009) (doi:10.1016/j.matlet.2009.09.012)