# Nanostructured ZnO for solar cell applications

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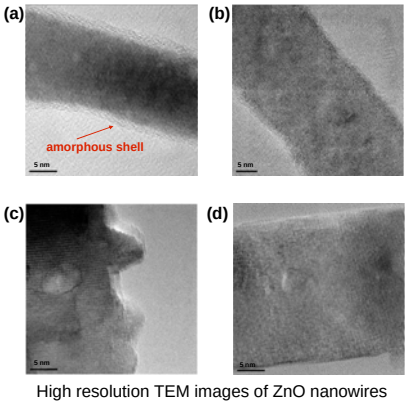
## Introduction

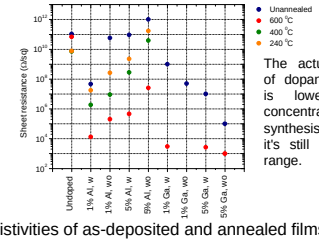
- Zinc oxide is a wide band gap semiconductor (3.37 eV) that achieves relatively high conductivities when doped, allowing it to be used as a transparent electrode in solar cells.
- Solution-grown and solution-processable single-crystalline doped ZnO nanowires pose the opportunity to take advantage of the favorable electrical properties of this material in a low-cost way that is compatible with a wider range of substrates.
- A secondary benefit is the scattering of light into the device plane, enhancing absorption in the active layer.

## Previous results

We have been able to synthesize single-crystalline nanowires, with good dopant incorporation, and moderate to high conductivities.

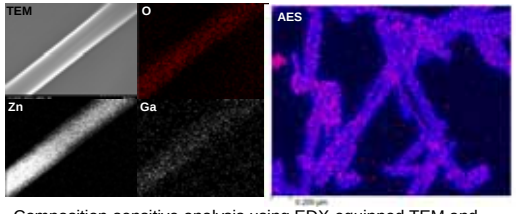



High resolution TEM images of ZnO nanowires with different synthesis parameters: (a) 1% Al-doped without surfactant , (b) 1% Al-doped with surfactant, (c) 5% Ga-doped without surfactant, and (d) 5% Ga-doped with surfactant




The actual percentage of dopant incorporation is lower than the concentration in the synthesis chamber, but it's still in the percent range.

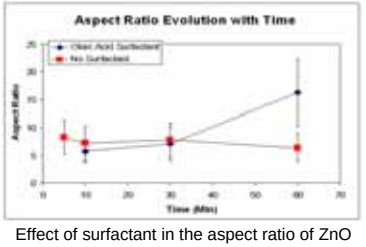
Resistivities of as-deposited and annealed films of undoped, Al-doped, and Ga-doped ZnO nanowires.




Composition-sensitive analysis using EDX-equipped TEM and Auger electron spectroscopy (AES).

## Growth mechanism

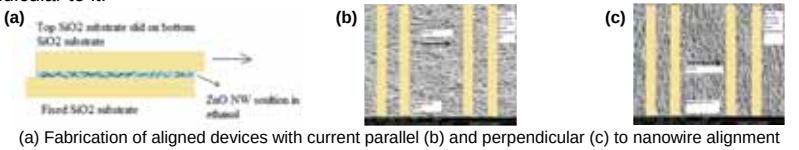
The effect of oleic acid in the growth of the nanowires was analyzed systematically, confirming the hypothesis that oleic acid promotes a one-dimensional geometry.
This is explained by the preferential adsorption of the surfactant on the sidewalls of the wires.
Nanowires grew in length over time, but oleic acid limits growth in the radial direction, increasing the aspect ratio.




Effect of surfactant in the aspect ratio of ZnO nanowires.

## Effect of alignment on film conductivity

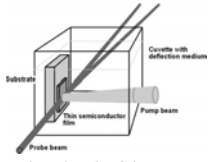
Nanowires were aligned on substrates by shearing wet films or using a flow channel for deposition from solution. Electrical characterization of these devices showed a difference in sheet resistance of ~4X. Resistance when the current flows parallel to the alignment direction is lower than when it flows perpendicular to it.




(a) Fabrication of aligned devices with current parallel (b) and perpendicular (c) to nanowire alignment

## Photothermal deflection spectroscopy

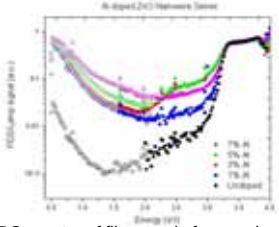
Photothermal deflection spectroscopy (PDS) analyzes the deflection of a laser beam when it grazes a film of a certain material which is heated by absorption of light at a given wavelength (mirage effect). The more the film absorbs, the more heat it dissipates, and the laser's deflection is larger.
PDS allows us to probe the low-absorption region that lies between the IR (free carrier absorption) and UV (band edge).
Another advantage of this technique is that it allows us to measure absorption of scattering films.




Illustrative sketch of the PDS setup.

Our results point out that:
- Doping increases sub-bandgap absorption.
- There are substantial differences in the absorption in the IR, due to the increase in free charge carriers.

There is a shoulder in the sub-band gap region of some spectra of doped nanowires, which could be due to the creation of defect states by dopant insertion.



PDS spectra of films made from undoped and Al-doped ZnO nanowires.

## Future work

We are currently working on:
- Determining the optimum dopant concentration through systematic doping experiments.
- Temperature-dependent measurements of the resistivity should show the activation energies of the dopants in the material, as well as possible trap distributions.
- Analyzing the infrared absorption of the films in order to measure their charge carrier concentration.
- Studying the light-diffusing properties of these and other ZnO nanostructures.

## Acknowledgements

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