Size dependent luminescence of single nanowires: a cathodoluminescence study

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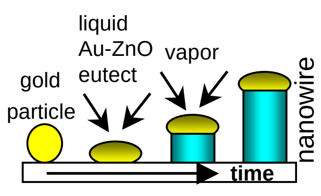
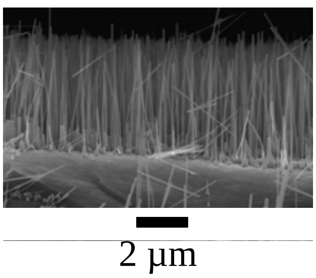
Semiconductor nanowires as one-dimensional structures and building blocks for nano-devices have received increasing attention in recent years. The progress in growth has led to the first succesful demonstration of devices based on nanoscale semiconductors. A bottleneck in the application of nanowires as light emitting elements might be the strong non-radiative recombination at surface defects due to the large surface to volume ratio. We investigate the luminescence of single ZnO nanowires with different diameters excited with an electron beam (SEM). The strong dependence of the cathodoluminescence with the wire diameter reveals the importance of non-radiative surface recombination.

Semiconductor nanowires

ZnO nanowires grown on a Sapphire substrate by the vapour-Liquid Solid growth mechanism.

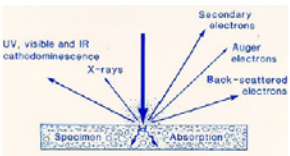


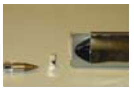


After growth some wires were removed from the substrate and deposited onto a piece of a Si wafer for cathodoluminescence measurements.

Cathodoluminescence (CL)

In a cathodoluminescence experiment the luminescence excited by an electron beam on a material is measured.



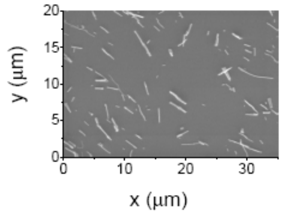


Parabolic mirror and waveguide used in our CL setup

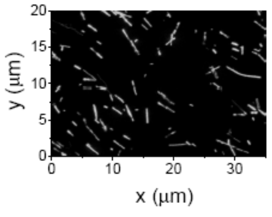
We use the e-beam of a high resolution scanning electron microscope to excite the cathodoluminescence with a spatial resolution of a few nanometers.

ZnO nanowire CL

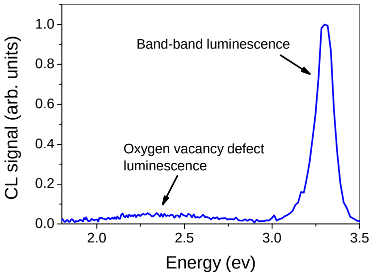
SEM image



CL image (3.3 ev)

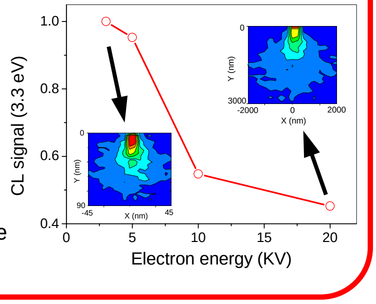


Typical CL spectrum of a ZnO nanowire



Strong luminescence at 3.3 ev (375 nm) due to band to band recombination. Weak luminescence at 2.4 ev (510 nm) due to defect (oxygen vacancy) luminescence.

CL signal at 3.3 ev of a nanowire (diameter D = 90 nm) for different e-beam energies



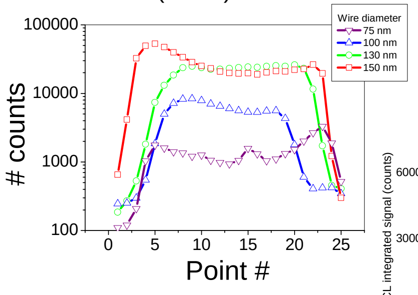
Decrease of the cathodoluminescence as the energy of the electron beam is increased due to:

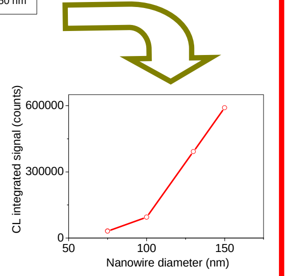
1) Larger penetration of the electrons (see inset). They do not see the nanowire.

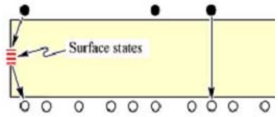
2) Possible damage of the nanowire

Size dependent CL

CL line scans (3.3 ev) of different wires



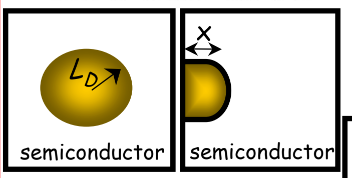




Carrier recombination rate:

$$\Gamma_{total} = \Gamma_r + \Gamma_{nr} + \Gamma_{nrs}$$

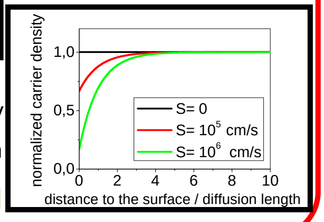
radiative | Non-radiative bulk | Non-radiative surface



L_D = Diffusion length
S = Surface recombination velocity

When $x < L_D$ surface recombination becomes relevant.
For nanowires $L_D >> D$

Steady state carrier density for different values of S



Conclusion

Cathodoluminescence is a powerful tool to investigate the luminescence of nanostructures. The size dependent CL may be attributed to non-radiative surface recombination.

We acknowledge fruitful discussions with D. Vanmaekelbergh, S. Rühle and E. Bakkers.