Study of nanolaser optical and structural properties at the nanometer scale

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Background incl. aims
Since their first demonstration by Huang et al in 2001[1], semiconductor nanolasers have attracted a lot of interest especially for their application in optoelectronic devices. They have the advantages to be cost-effective, easy to fabricate and of a micron size. Since 2001, various semiconductors and geometries demonstrated lasing properties, for example ZnO[1] or GaN [2] nanowires act as nanolasers.

Lasing could be induced by optical pumping, usually it is characterized by a drastic reduction of the emission spectrum width, increase of the light coherence evidenced by interferences of laser diffracted light. The most significant lasing properties of nanolasers are the value of the lasing threshold, the emission wavelength (see Figure 1) and the reduction of the carrier lifetime. Moreover, nanolasers emission wavelength above the lasing threshold are linked to the laser cavity's resonance modes, which in our case is the nanowire itself. Thus, the shape of the nanowire and the laser characteristics are closely related. Due the nanoscale variation, electron microscopy is a suitable technique to examine its nanoscopic characteristics. Therefore, it is essential to link the lasing properties with the nanolaser shape and the local luminescence.

Methods
We particularly focused on the use of cathodoluminescence in a scanning electron microscope (SEM) and a scanning transmission electron microscope (STEM) to characterize the optical properties of GaN nanowires. In both microscopes, the focalised electron beam locally creates charge carriers in the semiconductor, in a pear of interaction of either hundreds of nanometers (SEM) or tens of nanometers (STEM). We studied the luminescence due to carriers recombination. Using a spectrometer, we can obtain a spectrally resolved map of the sample emission. In time-resolved electron microscopy, we are able to measure the charge carrier lifetime thank to the decay curve of the luminescence after an electron pulse (30 ps in SEM and 300 fs in STEM). . In this project we measure the lasing threshold and the cavity mode of single nanolasers and correlate the results to their nanoscale geometry and optical properties using cathodoluminescence and time-resolved cathodoluminescence measured both in STEM and SEM.

Results
We investigated the lasing properties using micro-photoluminescence UV[4] of several nanolasers and observed strong heterogeneity in the lasing mode and lasing threshold. As expected, we found that the side-pumped nanolaser had a lower energy threshold than the vertically pumped ones[5], and we observe strong variation with the nanolaser radius. We observe the same nanolaser in cathodoluminescence and obtain spectrally and spatially resolved intensity maps, that show strong intensity and spectral variation along the nanowire. Moreover, time-resolved cathodoluminescence showed that the CL decay time varies from 90 ps to 130 ps when the nanolaser radius varies from 200nm to 500nm.
Conclusion
Finally, one of the main actual challenge on the nanolaser is to link the nano-laser shape to the lasing luminescence. In this project, we combine electron microscopy to study the cavity

properties with both photoluminescence and cathodoluminescence, permitting to study respectively the macroscopic and microscopic luminescence properties.

Graphic:

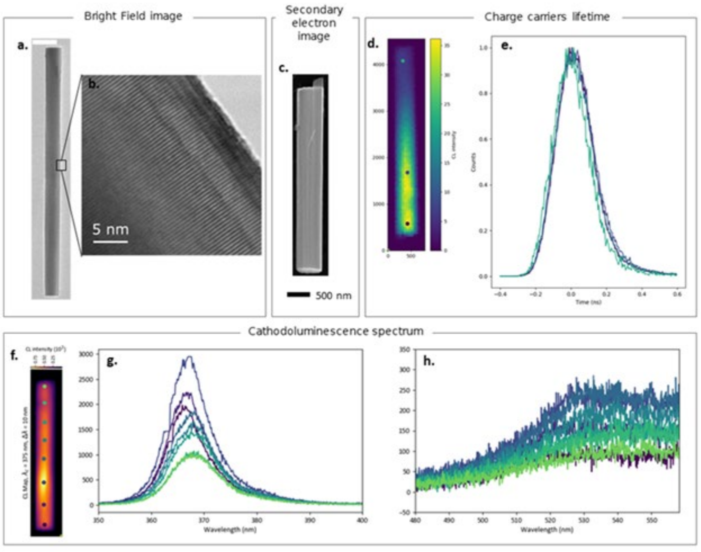

Figure 1: a.b. TEM bright field image of a nanolaser c. SEM Secondary electron image of the nanolaser studied in cathodoluminescence in d-h d. Nanolaser intensity map extracted from the time resolved cathodoluminescence dataset e. Time-resolved cathodoluminescence decay trace at different points of the nanolaser (shown in d) f. Cathodoluminescence intensity map of the nanolaser at 368nm with a bandwidth of 10nm g,h. Cathodoluminescence spectra at different positions on the nanolaser (shown in f)

Keywords:

Nanolasers, Time-resolved_Cathodoluminescence, Photoluminescence, Cathodoluminescence, III-N_Semiconductors

Reference:

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