PhD Position: Off-axis electron holography of optoelectronic materials under light excitation

General information

- Supervisors: Sophie MEURET (sophie.meuret@cemes.fr) and Christophe GATEL (christophe.gatel@cemes.fr)
- URL official offer : https://bit.ly/3bNIfNU
- Workplace: TOULOUSE
- Type of Contract: PhD
- Contract Period: 36 months
- Expected date of employment: 1 October 2020 but flexible
- Proportion of work: Full time
- Remuneration: 2135€ brut/month
- Desired level of education: Master

Missions / PhD topic

The successful candidate will join the I3EM (“*In situ, Interferometry and Instrumentation for Electron Microscopy*”) team at CEMES-CNRS and will study the modifications of electric and magnetic fields by light absorption in nanostructured semiconductor materials using *in situ* electron holography.

In such nanostructures, the absorbed photons create charge carriers which induce changes in the local internal fields. For example in III-V heterostructures used for light emitting diodes (LEDs)[1], the internal electric field resulting from the quantum stark effect is screened by light absorption. In CuInGaNSe solar cells (CIGS)[2], light induces built-in electric field across the p-n junction[3]. These effects have been extensively studied on a **macroscopic** or **mesoscopic** scale. However, the behavior of a nanostructured material under light excitation is **ruled by variation of their structural properties**, such as defect density[4], strain[5], chemical inhomogeneity[6], low dimensionality (confinement) or interfaces[7]. Therefore, studying the effect of light at the atomic scale is fundamental to understand, characterize and optimize their optical response. **Imaging light absorption at the atomic scale, will deeply increase our knowledge of optically active nanostructures.**

Due to their picometer wavelength, **fast electron imaging is not limited by diffraction** and can be used to observe atomic structures**.** Different methods based on electron excitation are used to study optically active nanostructures. For example, **cathodoluminescence (CL) spectroscopy monitors the optical response of these materials at the nanometer scale** [8]–[10]. It was used to study the role of defects[11] and polarity[12] in III-V nanowire luminescence, as well as the effect of grain boundaries for carrier diffusion in CIGS materials[13]. However, CL spectroscopy is as of yet unable to give a quantitative measurement of fundamental optical properties, such as quantum efficiency, non-linear carrier dynamics and absorption spectrum in a spatially resolved fashion. All these properties have been extensively studied with photoluminescence (PL) spectroscopy but above the diffraction limit.

Off-axis electron holography is a powerful interferometric method in transmission electron microscopy used to quantitatively map the electric and magnetic fields of nano-objects[14] **with a**

nanometer spatial resolution. Some first studies have been performed on III-V nanowires[7] and solar cells[15], but **until now it was not used to study the effect of optical excitation at the atomic scale**.

The PdH student will aim at determining **the link between atomic structure and light absorption efficiency at the nanoscale** which is one of key parameters for many semiconductor nanostructures. He/she will **study the light absorption at the nanoscale, combining under light excitation electron holography imaging and luminescence spectroscopy** (CL and PL). He/she will thus participate to the development of a light injection system on the sample into an electron microscope designed for electron holography before studying two types of materials will be investigated, InGaN/GaN nanowires and CIGS solar cells. Each representing a class of materials that will greatly benefit from the imaging of light absorption at the nanoscale. Indeed, **III-V nanowires are known for their strong internal electric field 2 MV/cm** (i.e. 100 mV per atomic layer)[16] and the sensitivity of this field to carrier[17]. In the case of light excitation of **none-contacted solar cells, the local open-circuit voltage can be derived from the accumulation of excited carriers** [18], [19].

Activities

The PhD candidate will be involved in every steps of this project:

- Cathodoluminescence and Electron Holography studies (experiment and analysis)
- Setting-up Electron Holography experiment under light injection (experimental development)
- Electron Holography imaging under light injection (experiment and analysis)
- Modelling the response of light absorption at the nanoscale (theory and simulation)

This PhD contains all of these different steps, each will allow the candidate to gain skills and obtain results.

Skills

We are particularly looking for a candidate with good knowledge in condensed matter physics and optics. Experience in transmission electron microscopy techniques is of course welcome and knowledge in programming (Python/C++) is a definite plus.
The successful candidate should have good team spirit and dedicated work ethic.

Supervision

Sophie Meuret : sophie.meuret@cemes.fr
Christophe Gatel : christophe.gatel@cemes.fr
They are both part of the I3EM team in CEMES. Christophe Gatel is a specialist of electron holography imaging while Sophie Meuret is a specialist of cathodoluminescence spectroscopy. Both will supervise this thesis to support the candidate with all expertise needed for the success of this project.

Work context

The PhD thesis will be funded by the ANR research project ECHOMELO and will be based at CEMES. The CEMES is a CNRS laboratory based in Toulouse for fundamental research in materials science, solid state physics and molecular chemistry. CEMES is an internationally renowned laboratory in transmission electron microscopy (TEM), especially hardware and software developments around TEM. Among its 7 transmission electron microscopes, the laboratory has one state-of the art TEM for electron holography and *in situ* experiments, but also a unique ultra-fast time-resolved TEM. The lab is equipped with all the technical support needed for sample preparation, mechanical and electronic engineering.

Additional information

CNRS is an equal opportunities employer.

Reference

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