INTRODUCTION

One of the goals of the quantum photonics NCCR is to analyze in great detail the quantum properties of light and its interaction with matter. In particular, this requires access to the properties of matter with the best achievable precision. The nanolocal probes program aims at the design of new experimental tools to enable the measurement of various properties of nanoparticles with unprecedented time and spatial resolution.

PROJECT OBJECTIVES

Picosecond Time-Resolved Cathodoluminescence

Picosecond and femtosecond spectroscopy allows the detailed study of carrier dynamics in nanostructured materials. In such experiments, a laser pulse normally excites several nanostructures at once. However, spectroscopic information may also be acquired using pulses from an electron beam in a modern electron microscope, exploiting a phenomenon called cathodoluminescence. This approach offers several advantages. The multimode imaging capabilities of the electron microscope enable the correlation of optical properties (via cathodoluminescence) with surface morphology (secondary electron mode) at the nanometre scale.

The broad energy range of the electrons can excite wide-bandgap materials, such as diamond- or gallium-nitride-based structures that are not easily excited by conventional optical means. But perhaps most intriguingly, the small beam can probe a single selected nanostructure. In this project we developed an original time-resolved cathodoluminescence (TRC) set-up to probe carrier dynamics within a single nanostructure with a time resolution of 10 picoseconds and a spatial resolution of 50 nanometres.

We have replaced the classical hairpin tungsten electron gun of a JEOL 6360 scanning electron microscope with a 20-nm-thick gold photocathode deposited on a quartz plate. By illuminating the photocathode (in transmission mode) by a ultraviolet mode-locked laser (266 nm, 200 fs, 80.7 MHz of repetition rate, spot size radius of 3 μm), we generate a pulsed electron beam, bright enough to allow secondary electron images to be recorded, thus allowing us to identify the nanostructures under study. A streak camera mounted behind a monochromator (spectral resolution better than 200 μeV) is used as a time-resolved detector (in photon-counting mode).
liquid-nitrogen cryostat is used to cool the sample down to 90 K.

study of pyramidal quantum dots

This new experimental set-up has been tested on pyramidal quantum dots. These two micron-high nano objects fabricated at EPFL by a team of Prof. Eli Kapon, contain several different nanostructures, making them ideal objects for tests. When the electron beam impacts the pyramids, the electrons diffuse towards the closest nanostructure. From there, the diffusion continues until the point of lowest energy is reached – the quantum dots at the tip of the pyramid. The time trace corresponding to each of these nanostructures reveal just how critical that 10 picosecond time resolution is.

Streak image. Typical time traces corresponding to the different nanostructures of the pyramid, when excited in the middle of one of the faces of this pyramid. The different curves are labelled accordingly to the related structure. The five different nanostructures display very different time behaviours that are signatures of the complex transport mechanisms within the pyramid.

study of nitride nanostructures

While continuing to improve the experimental set-up, we are using our unique experimental tool to investigate some fundamental questions still open in the field of nitrides based nanostructures, focusing on the following topics:

- Studies of the optical and transport properties of quantum wells based on nitrides and their alloys (ternaries).
- Study of In$_x$Ga$_{1-x}$N quantum wells ($0.1 \leq x \leq 0.25$) in the InGaN/GaN system grown on different substrates [AlPO$_3$ and GaN (Samsung, Lumilog)]
- Study of GaN quantum wells in the GaN/AlGaN system grown on different substrates [AlPO$_3$ and GaN (Samsung, Lumilog)]
- Study of the optical and transport properties of nanostructures embedded in a single pyramid in the systems (AlGaN/GaN), (InGaN/GaN) and (InGaAs/GaAs).

APPLICATION PERSPECTIVES

The impact of this research program should be very large as nitrides raise very particular and difficult problems. For example, the InGaN/GaN system is commercially used, with the success which we know, to realize LED and lasers even though the basic physics which allow the very efficient radiative recombination processes hardly begins to be understood. This is one only of the many unresolved difficulties in understanding the properties of GaN based structures. Even if indisputable progress was realized over the last years, the respective roles played by the stacking faults, the dislocations, the strain, the chemical fluctuations in composition or the internal defect analysis in GaN grown on an ELO substrate (Epitaxial Lateral Overgrowth).

Luminescence decay curves indicate the existence of non-radiative channels: the defects.

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