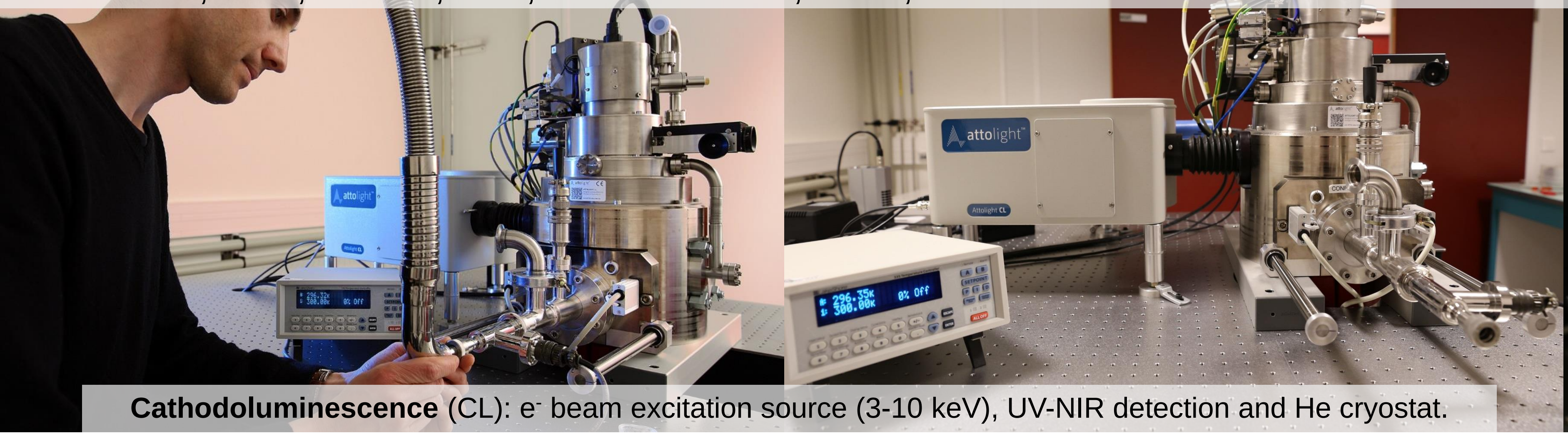
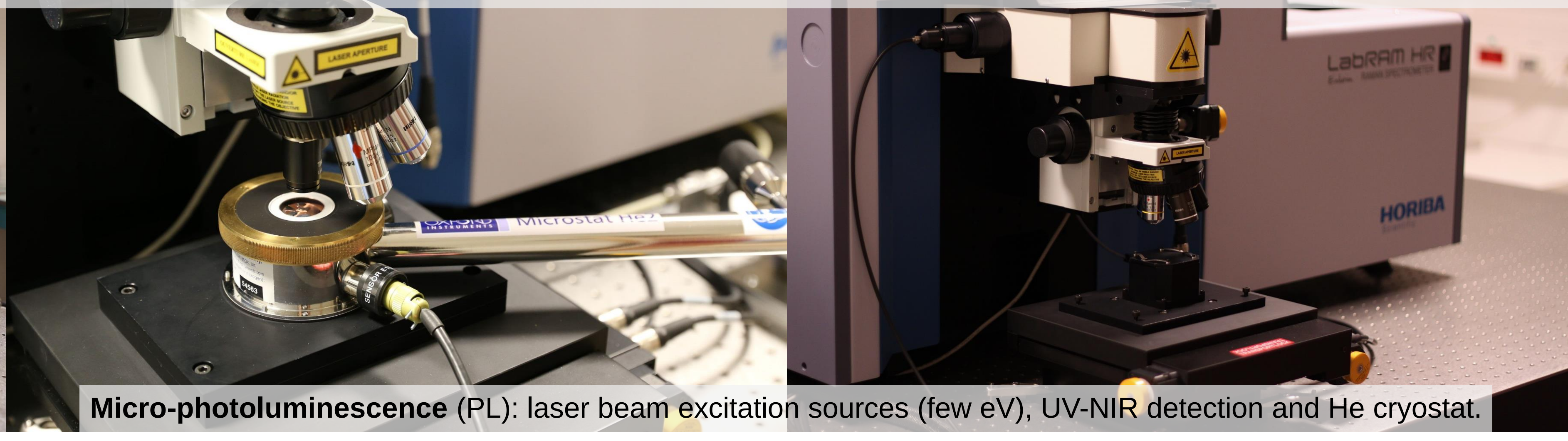
CONTRIBUTION OF LUMINESCENCE TECHNIQUES FOR THE CHARACTERIZATION OF MATERIALS AND DEVICES AT THE NANOSCALE

C. Licitra[1], N. Rochat[1], N. Gambacorti[1], S. David[2], G. R. Muthinti[3], F. Olivier[1], A. Faujour[4] and A. Chabli[4]
[1]CEA, LETI, [2]CNRS, LTM, [3]IBM Research, [4]CEA, LITEN


Cathodoluminescence (CL): e$^-$ beam excitation source (3-10 keV), UV-NIR detection and He cryostat.


Micro-photoluminescence (PL): laser beam excitation sources (few eV), UV-NIR detection and He cryostat.

Context Luminescence of semiconductors has been widely used for the study of their fundamental properties such as their optical properties, electronic processes, and crystalline quality including defects identification. Since the semiconductor industry faces major challenges to continue increasing performance and functionality of their devices, new materials are currently introduced in research clean-rooms and fabs. Whereas luminescence techniques have not been particularly popular in fabs due to the poor luminescence of silicon at room temperature, they could gain a higher interest for the characterization of alternative materials and devices. In this poster we present different applications where the characterization of luminescence is improving our knowledge on the material and device processing. This work was performed using two luminescence systems described above: cathodoluminescence (integrated tool from Attolight) and micro-photoluminescence (Horiba LabRAM HR).

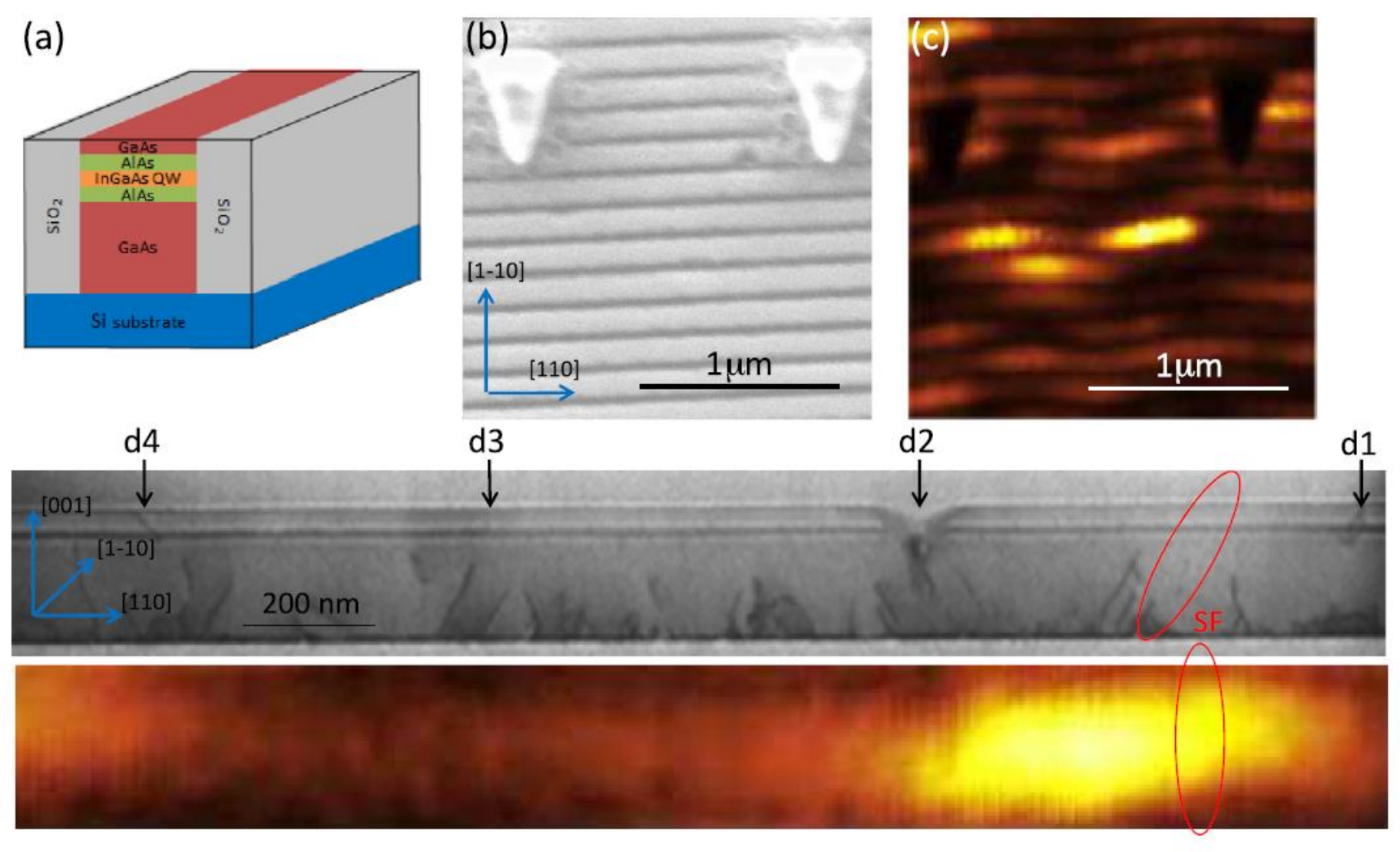
III-V monolithic integration on silicon

III-V semiconductors are used to improve device performances but direct epitaxy of III-V materials on silicon leads to defects.

CL and STEM are coupled to characterize InGaAs/GaAs quantum wells fins (QWF) formed by ART on Si:

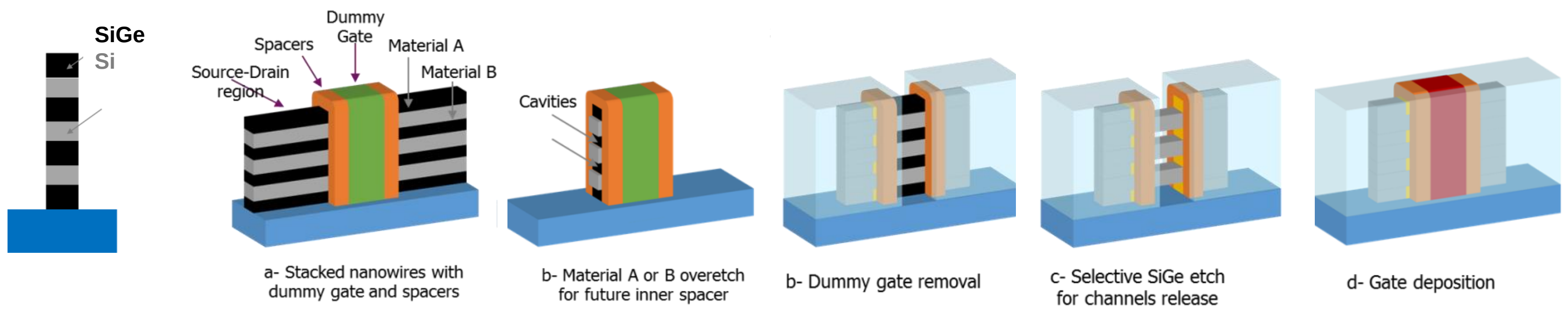
- Pt marks are formed to spatially correlate the measurements
- Low temperature top-down CL reveals the luminescent areas
- TEM lamella is prepared using an FIB
- Cross-sectional STEM reveals the structural defects
- Strain measurements are performed using precession electron diffraction

The luminescence intensity and peak position have been found to vary between the defects indicating that it depends not only on the crystal quality but also on the strain distribution induced by both the threading dislocations and the dislocations trapped on the SiO_2 sidewalls.



(a) Schematic drawing of the III-V QWF grown on silicon through SiO_2 trenches (Aspect Ration Trapping ART).
(b) Top-view SEM image of III-V QWF. Large light gray and narrow dark gray lines correspond to III-V materials and SiO_2 walls, respectively. Two triangular platinum marks are seen on the top of the SEM image.
(c) Corresponding panchromatic cathodoluminescence (T=10K) mapping showing high spatial variations of optical emission intensity. The two platinum marks appear in dark. The QWF appear wavy due to a drift during electronic beam scanning.
(d) Cross section STEM image of an extracted QWF. Lamella crystallographic orientations correspond to [001] and [110] directions. Structural defects affecting QW are marked with 4 arrows.
(e) Top-view CL intensity of the same QWF. Both CL and STEM images are spatially correlated.

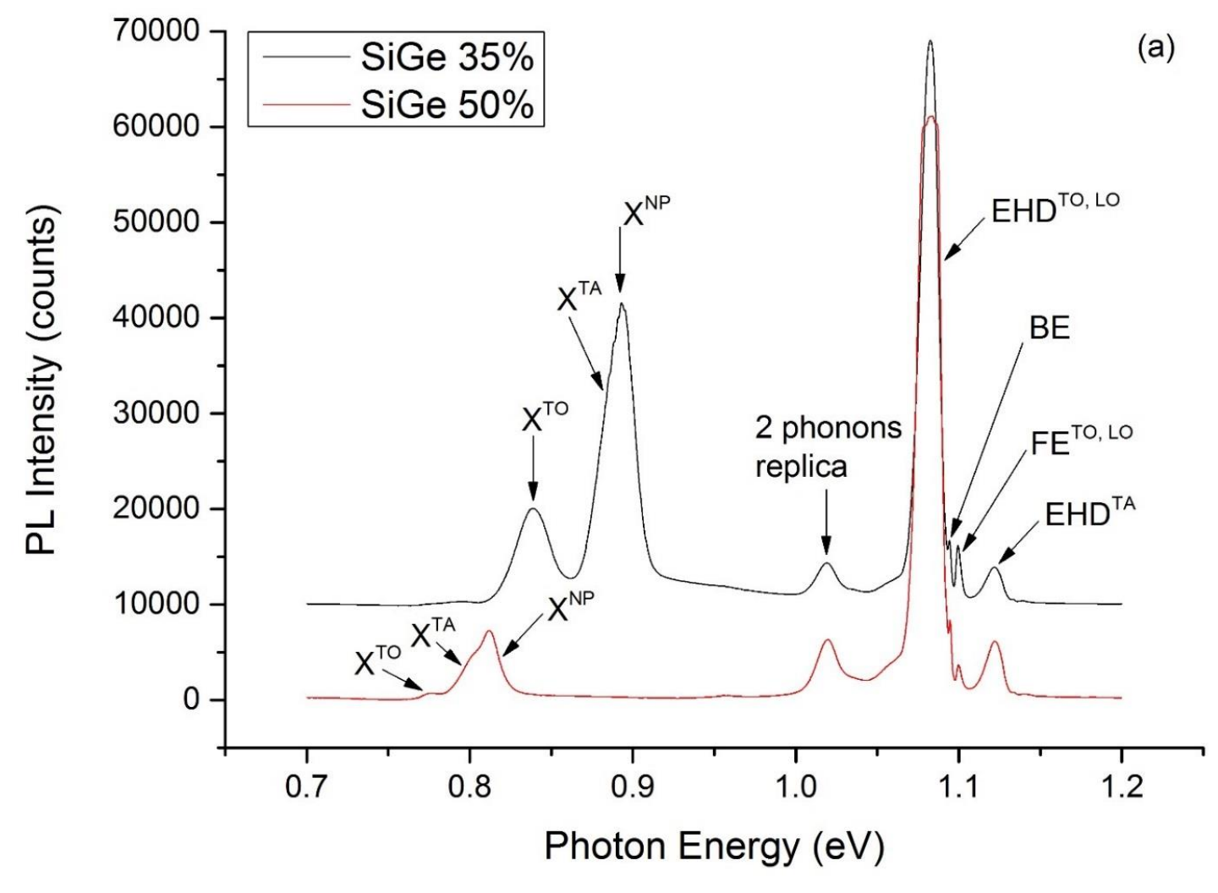
Gate-all-around CMOS devices



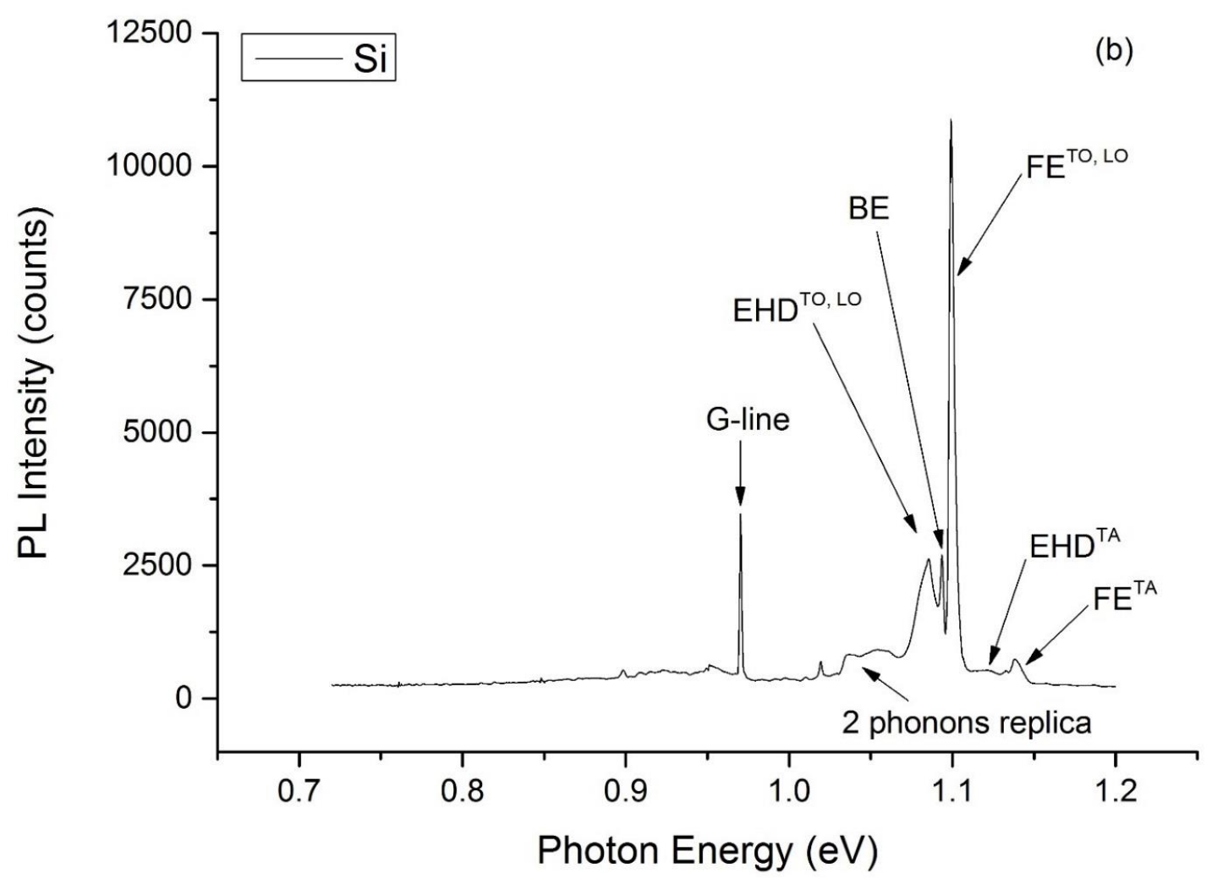
Gate-all-around devices are promising candidates to replace planar and FinFETs CMOS structures. Nanowires are formed using alternate layers of Si/SiGe and by selectively removing the SiGe.

PL is used to monitor the properties of Si/SiGe materials:

- SiGe exciton (and phonon replicas) peak position varies as a function of concentration and strain allowing possible strain or Ge diffusion monitoring.
- The silicon signature consists of excitons (free and bound exciton FE and BE), possible electron hole droplet (EHD) and sometimes defect lines can be observed after reactive ion etching (here the G-line at 0.97 eV).



(a) PL spectra at 5K of Si/SiGe multilayers with 2 different germanium content.



(b) Observation of the radiation-induced G-line after silicon etching (PL at 15K).

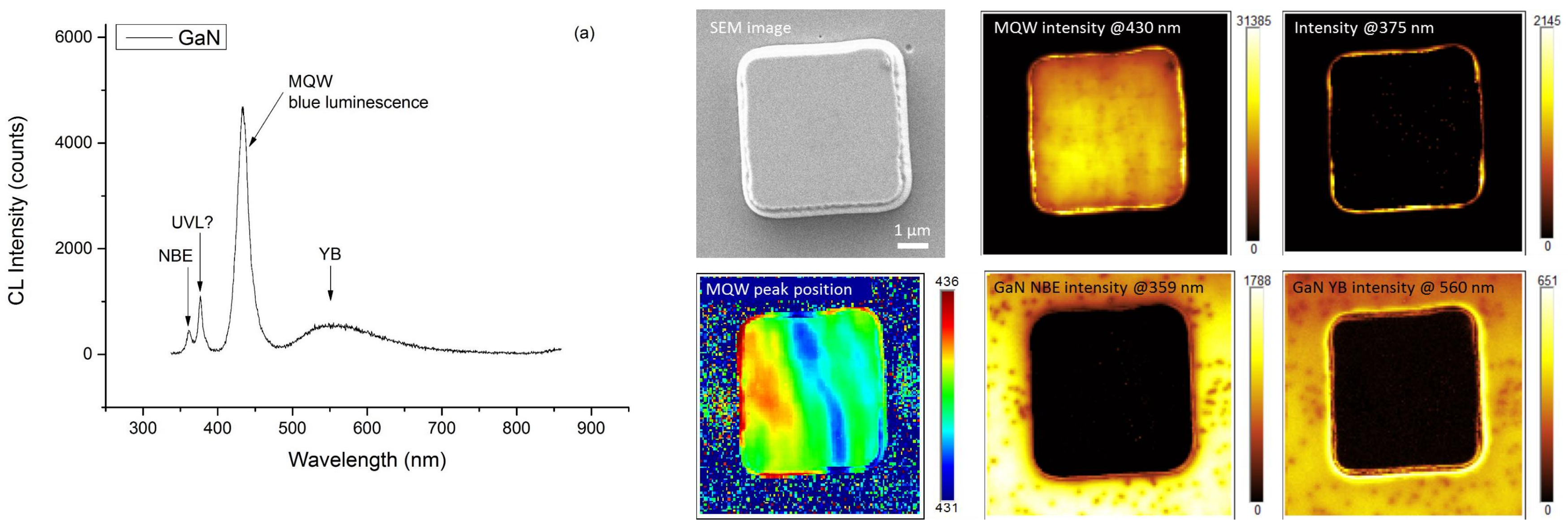
GaN-based emissive microdisplays

High-brightness microdisplays such as GaN LED arrays are needed to fulfill the growth of wearable devices. They are formed on sapphire and hybridized on silicon CMOS active matrix.

CL is used to monitor the emission properties at the pixel level:

- Multi Quantum Well (MQW) InGaN/GaN structures are optimized for blue or green emission.
- After patterning the structure, the cathodoluminescence spectra reveal different contributions.
- Each contribution can be mapped to show the emission zones.

The maps show the GaN epitaxial layer and its dislocations (Near Band Edge: NBE), the MQW emission and homogeneity (peak position), and the defects (Yellow Band: YB). We also observe a signal from the edges of the structure which may be associated with the etching process.



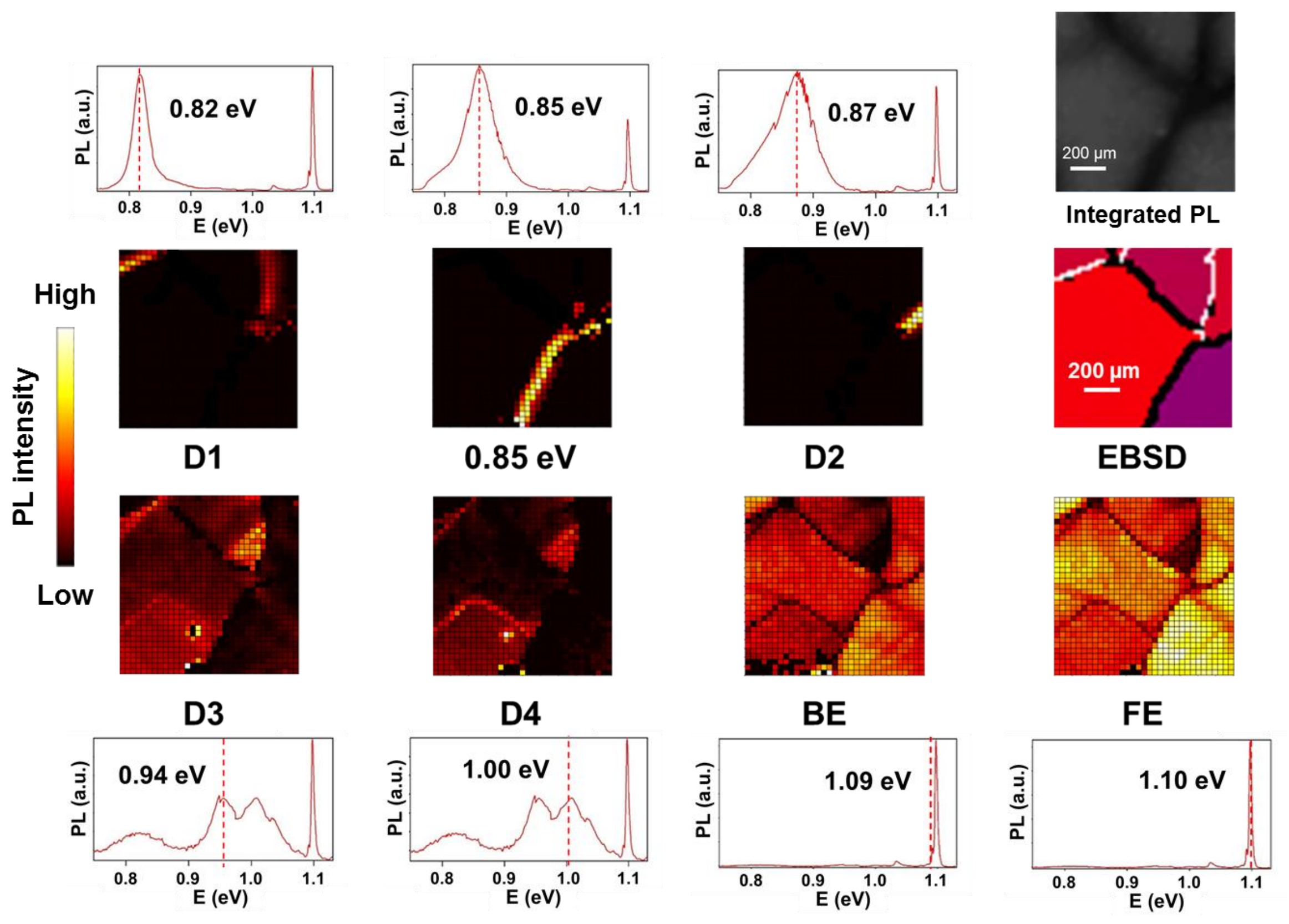
(a) Room temperature cathodoluminescence spectra showing all the emission lines. (b) SEM image of a single pixel. (c) Spectral maps of the different luminescence contributions.

Silicon engineering for PV applications

Monolike silicon is a promising material for Si-based solar cells but the local presence of sub-grain boundaries (SGBs) that may act as minority-carriers killers is the main performance-limiting factor.

PL and EBSD are coupled to characterize these defects:

- Free and bound exciton (FE an BE), defect lines (D1, D2, D3, D4) and a new 0.85 eV line are detected on the PL spectra.
- The maps show a clear correlation between the µPL intensity distribution and the position of the SGBs determined by EBSD.
- D1 and D2 lines are active on different SGBs, depending on the level of the related disorientation.
- The D3 and D4 lines show the same distribution with some extra features not related with the SGB positions.



µPL intensity maps near SGBs in “monolike” silicon showing the distribution of the well-known D-lines, the new line at 0.85 eV, the BE emission and the FE emission, on the same sample area at liquid helium temperature.

Integrated PL map at room temperature and EBSD map are given on the same sample area.
EBSD: white lines for low angle (<2 deg) disorientation, black lines for high angle (>2 deg) disorientation.