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Report on Proposal MA-3062

"The in-plane and out-of-plane strain variations within a (10-10) ZnO/ZnMgO heterostructure at a micrometer scale"

Allocated beamtime: 7-12/12/2016

Proposal Summary (as stated in the initial proposal):

The objective of this study is the measurement of the in-plane and out-of-plane strain variations within a (10-10) ZnO/ZnMgO heterostructure at a micrometer scale. The heterostructures, which are grown by molecular beam epitaxy (MBE) and employed as Bragg reflectors in strongly-coupled optical microcavities, constitute the state-of-the-art in terms of crystalline quality, comparable to that of the initial ZnO substrate. However, when stacking a large number of layers and due to the anisotropic strain relaxation, cracks appear in the structure perpendicular to the unique c axis of the wurtzite structure. These cracks restrict the maximum number of stacked layers and, therefore, the maximum photonic lifetime inside the cavity. In order to understand their occurrence a deep insight into the strain distribution (i.e. spatially resolved) around the defects is necessary. This knowledge should enable us to set up growth approaches that will mitigate or even completely remove the defects and, therefore, enable polariton devices with improved performances.

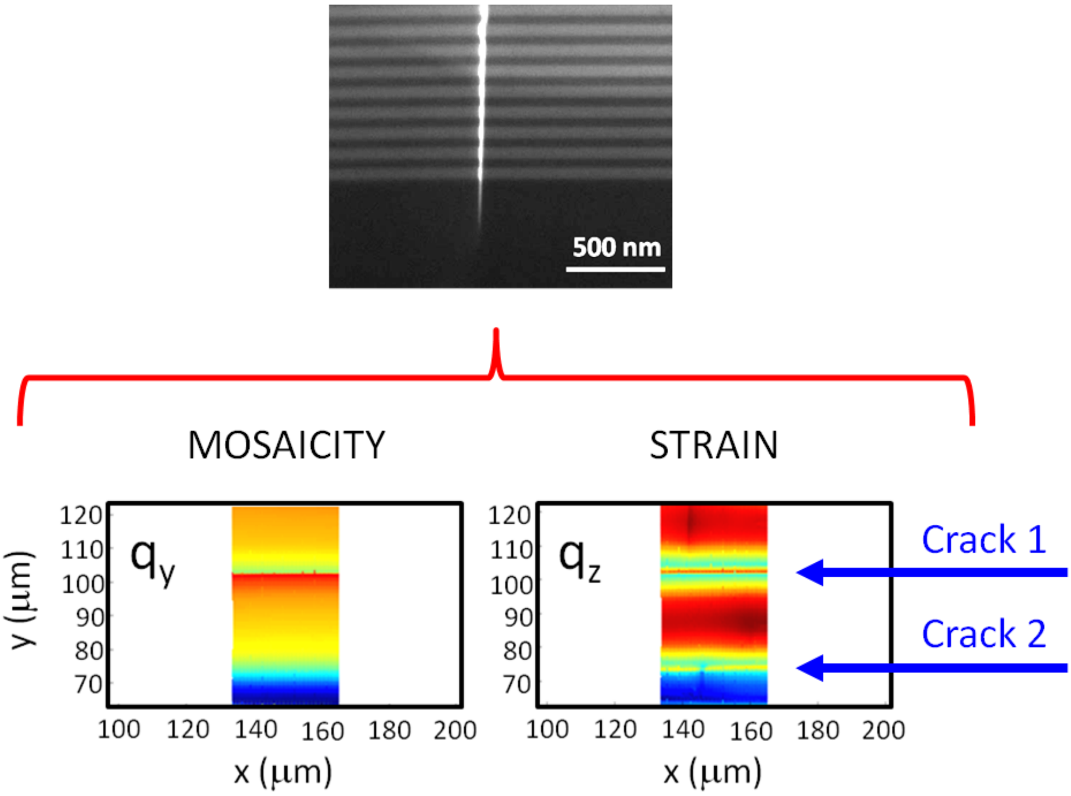
Results:

Two samples consisting of nonpolar (10-10) heterostructures grown on ZnO substrates and displaying cracks were characterized. For both samples one symmetric (20-20) and two asymmetric (22-40)&(11-22) reflections were monitored as a function of the beam position with respect to the cracks. From these measurements it has been possible to obtain, as expected, the spatially-resolved lattice parameters (i.e. the strain) of the layers as a function of the distance to the cracks. As seen from the q_z map in the figure below, the strain state of the layer is symmetric with respect to crack 1, indicating that the strain relaxation is governed by the presence of the free surface enabled by the formation of the crack. From the spatially-resolved measurements, it is possible now to assess the spatial scale at which this relaxation takes place (typically in the order of 5-10 μm). While this information was mainly what we were aiming for, it turns out that the possibility of monitoring in 3D the reciprocal lattice points associated to the previous reflections has provided an even more interesting information that we did not envisaged. Indeed, the evolution of the position of the reciprocal lattice point parallel to the sample surface has enabled us to deconvolute the effects of strain relaxation, which can be accessed through q_z, from those associated to tilt and twist (i.e. mosaicity). In this sense, while the q_z map is spatially symmetric with respect to the crack (crack 1), the q_y map is antisymmetric, which can be understood as the crack formation "bends" each side of the layer in opposite directions.

These first analyses have been so rich that they have prompted us to present them already in a forthcoming conference, just five months after the measurements:

"Compound Semiconductor Week 2017
http://www.csw2017.org/
May 14-18, 2017 Berlin, Germany

Encouraged by the success of the measurements just described, whose richness was understood already during the measurements themselves, we attempted to get the same information in cross-section, in order to monitor strain and mosaicity not only as a function of the distance to the cracks but also as a function of the distance to the layer/substrate interface. Unfortunately, the orientation of the sample for cross-section measurements is much more challenging and the acquired data do not allow to exploit them so clearly as those obtained in plain view and described in the previous paragraph.



Overall, the observations we have carried out open enormous possibilities in the characterization of heteroepitaxial systems where strain gradients coexist with mosaicity. In particular, the field of selective-area growth, used for example in technologically-relevant materials as GaN, will benefit from the possibility of obtaining spatially-resolved 3D monitoring of reciprocal lattice points.