Cross-sectional Nanoscale Resolution Mapping of Potential and Current Distribution in 3D Structure of Vertical Cavity Surface Emitting Laser iii-v Nanostructures

Marta Mucientes [UK][1], Leonardo Forcieri [UK][1], Samuel Jarvis [UK][1], Iain Eddie [UK][2], Wyn Meredith [UK][3], Mohsin Haji [UK][4], Peter Smowton [UK][5], Oleg Kolosov[Lancaster,UK][1]

Physics Department, Lancaster University[1], 3CST Global Ltd[2], Compound Semiconductor Centre[3], National Physics Laboratory[4], School of Physics and Astronomy, Cardiff Universit[5]

Vertical cavity surface emitting lasers (VCSELs) hold a major promise in the telecommunication and data interfacing due to their efficient manufacturing pathways and prospects of seamless integration with microelectronics components. VCSEL structures include multilayer Distributed Bragg Reflection (DBR) surrounding an active cavity that typically have multiple quantum wells (QWs) and in some devices quantum dots (QDs) layers [2]. The properties, morphology and quality of multiple buried layers and interfaces are crucial for the development of novel devices, improving device performance and optimization of production processes. Unfortunately, accessing these layers to explore these generally three-dimensional (3D) structures is often a laborious (e.g. via cross-sectional transmission or scanning electron microscopies, EMs) task. Significantly, the sample preparation can also change properties of the material and the device studied (e.g. Ga ion implantation during FIB milling) and usually allows to see only a very limited part of the wafer. Furthermore, the EM does not allow to access local physical properties of the device – such as local electric potential, current density and heat generation, all being extremely crucial to the device performance.

Here we report for the first time the direct observation of local electric potential and conductance in the bulk of VCSEL stack by using combination of the Ar-ion beam exit cross-section polishing (BEXP™) that creates an oblique section with sub-nm surface roughness through the VCSEL structure [2] combined with the material sensitive scanning probe microscopy (SPM). We used three different SPM measurement modes – nanomechanical local elastic moduli mapping via Ultrasonic Force Microscopy (UFM), surface potential mapping via Kelvin Probe Force Microscopy (KPFM) [3] and mapping of injected current (local conductivity) via Scanning Spreading Resistance Microscopy (SSRM). These allowed to observe the resulting geometry of the device, including active cavity MQW, and to obtain profiles of differential doping of the DBR stack, profile of electric potential in the active cavity, and spatial variation of current injection in the individual QW in MQW area.

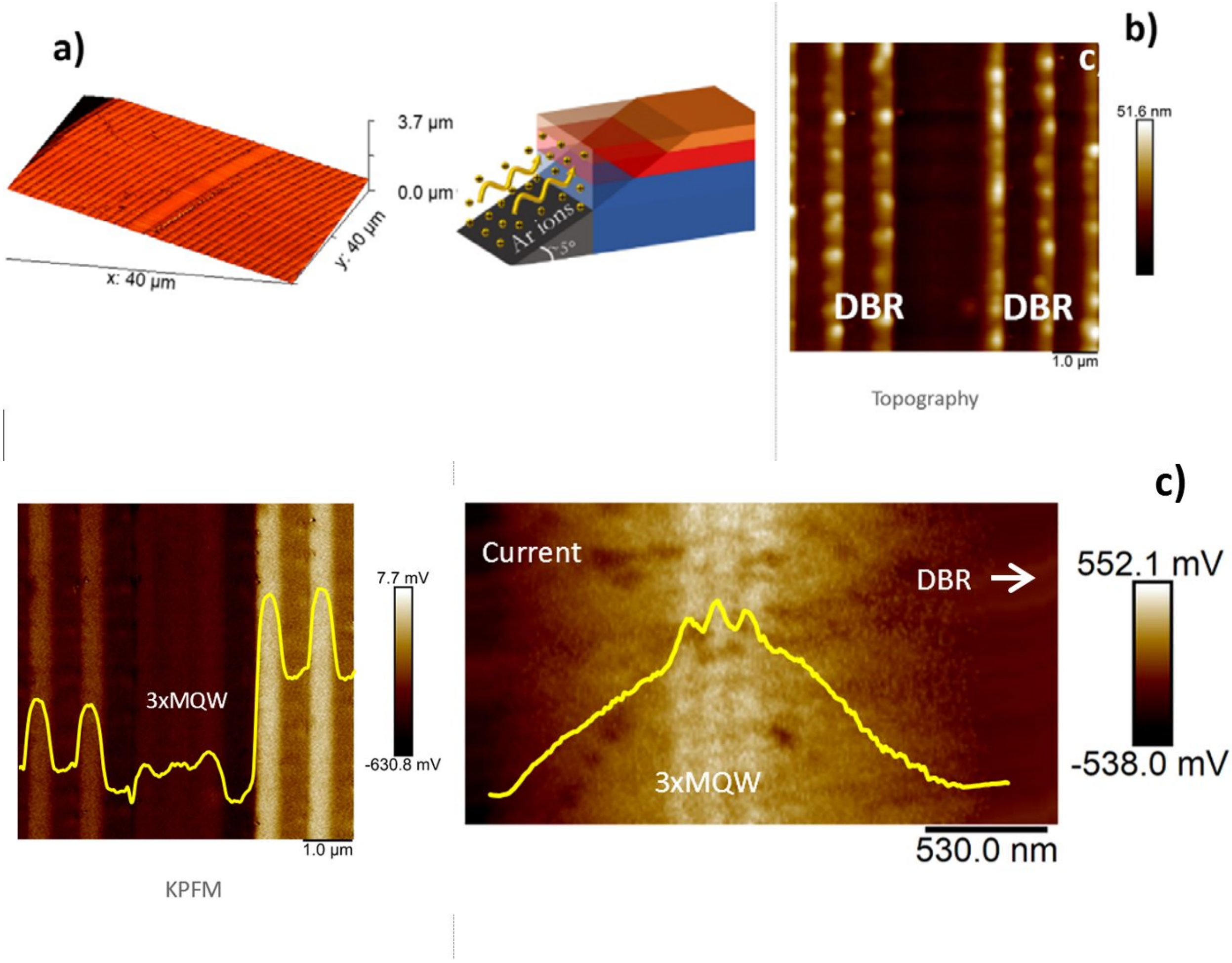

Fig. 1 a) BEXP™ nano-cross-sectioning with 3D rendering of the VCSEL structure – darker colour corresponds to lower elastic moduli, **b)** topography and KPFM measured contact potential of the iii-v DBR triple quantum well (MQW), **c)** a SSRM map of local electrical conductance showing clearly showing individual layers of QW. (**Note**: due to oblique cut, the scale bar in the cut direction (horizontal in the images) should be multiplied by approximately 0.105 coefficient, eg. 530 nm scale bar corresponds to 55 nm in layer thickness).

In conclusion, this approach opens unique novel possibility to directly explore the physical phenomena of operation of VCSELs and other iii-v devices, helping to advance the manufacturing of these these devices, as well as opening insight into the fundamental electronic and atomistic phenomena in these complex nanostructured materials [4].

*o.kolosov@lancaster.ac.uk www.nano-science.com