Nanoscale 3D potential mapping in buried semiconductor nanostructures using sideband Kelvin Force Probe Microscopy

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Scanning probe microscopy (SPM) outstanding lateral resolution and materials sensitivity are inevitably restricted to the sample surface by the very nature of proximity probe, precluding SPM from studying buried layers and interfaces - the key elements for the performance of modern microelectronics and optoelectronic devices and nanomaterials [1]. Currently, there are no suitable solutions to study 3D structures via SPM as existing techniques are either change the object (eg. Ga-ions focused ion beam), or are limited to crystalline cleavable materials as in cross-sectional STM.

Here we report for the first time the approach that allows direct nanoscale resolution local electric potential distribution mapping via frequency modulation Kelvin probe force microscopy (FM-KPFM) in several micrometres thick 3D stack of vertical cavity surface emitting lasers (VCSEL). To achieve this, we deployed the new Beam Exit cross-section Polishing (BEXP) that uses non-reactive Ar-ions to create perfect cross-sections of the sample. In BEXP the beam is directed at the edge of the sample to exit from the sample surface, creating an open angle 3-5 degrees near-atomically flat section adjacent to the intact sample surface, preserving intact electronic and crystalline properties of the buried 3D structures and perfectly suited to the SPM study [2].

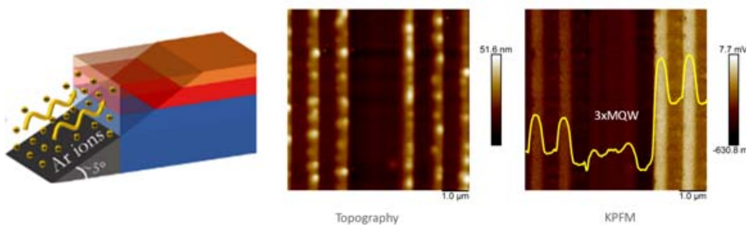

Fig 1: Left – principle of SPM-compatible near-atomically flat sectioning of sample. Right – topography and FM-KPFM image of VCSEL structure showing differential doping in the DBR layers and charge distribution in the active triple QW zone.

We then mapped the surface potential via conductive grounded diamond probe (Nanosensors CDT-FMR, 105 kHz, 6.2 Nm^{-1}) in the light tapping mode (5% amplitude offset) with 1 kHz 2V p-p AC voltage applied to the sample. The sideband detection of the deflection signal and tapping frequency reference was acquired via the custom access module and Bruker Multimode w/ Nanoscope IV controller. The sideband detection was performed via lock-in amplifier (HF2LI-MF-AM-PLL-PID Zurich instruments). The VCSEL structure revealed differential doping in multilayer Distributed Bragg Reflection (DBR), and charge accumulation in the active triple quantum wells (QWs) area of VCSEL.

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