Novel concept for all-in-situ quantum device epitaxy with III/V and II/VI semiconductors

Alexander Pawlis
Nils von den Driesch, Yurii Kutovyi, Christine Falter, Lars Maier, Benjamin Bennemann

Peter Grünberg Institute PGI-9 & PGI-10, Forschungszentrum Jülich GmbH, Jülich, Germany

a.pawlis@fz-juelich.de

Abstract

The classic III/V and II/VI semiconductors, as grown by molecular beam epitaxy (MBE) offer enormous potential for application in modern quantum devices, ranging from single-photon emitters over spin-qubits to efficient and sensitive photodetectors. For all these devices excellent crystallographic properties, high oscillator strength of direct optical transitions and the availability of sophisticated nanofabrication methods are inevitable. However, stabilization and controlled manipulation of the quantum states in such devices is still challenging due to surface and interface effects, which are mainly a consequence of a complex and especially ex-situ performed multi-step device fabrication. In order to overcome such limits and to harvest the real potential of performance, unconventional approaches for the MBE growth and all-in-situ nanofabrication are necessary.
Reshaping the MBE growth of III/V and II/VI semiconductors for quantum technology I present our novel shadow-wall concept based on the all-in-situ device processing during MBE [1]. Furthermore, I demonstrate the successful implementation of two key device examples, a GaAs photodetector and a ZnSe quantum well single-photon source, both processed using our shadow-wall epitaxy approach. The electrical characterization of first prototype photodiodes with and without illumination reveals excellent diode characteristics as well as notably high sensitivity and quantum efficiency, especially when operated at cryogenic temperatures. Optical characterization of the single-photon sources reveal transitions with high signal-to-noise ratios and quantum efficiencies. Moreover, pure single-photon emission is confirmed by photon correlation measurements under above-band-gap-excitation.
These results demonstrate that MBE growth with our shadow-wall epitaxy not only makes any post-growth (ex-situ) fabrication steps for devices obsolete but also paves the way to sustainable and energy-efficient processing technology for quantum devices of the future.

References

[1] N. von den Driesch, Y. Kutovyi, F. Khamphasithivong, A. Zass, L.R. Schreiber, A. Pawlis, ACS Appl. Electron. Mater., 6 (2024) 6246ff

Figures

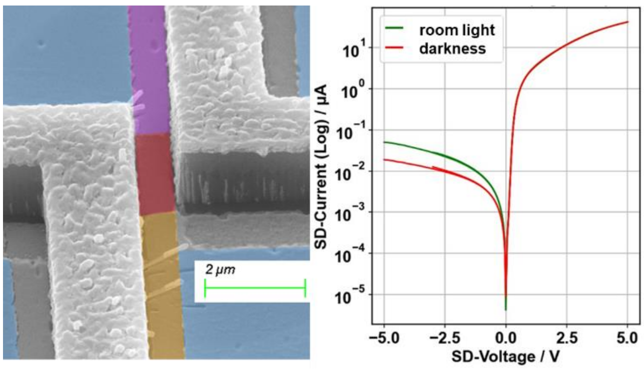

Figure 1: Left: Side-view scanning electron microscope image of a lateral p-i-n-photodetector with color-coded device regions Right: Current voltage trace at room temperature of a typical device without (red) and with indirect illumination (green).