In-situ electron-beam lithography of deterministic nanophotonic structures using low temperature cathodoluminescence spectroscopy

M. Gschrey, F. Gericke, R. Schmidt, A. Schüssler, J.-H. Schulze, T. Heindel, S. Rodt, A. Strittmatter, and S. Reitzenstein

Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

Single semiconductor quantum dots (QDs) integrated within microcavity structures are a promising tool for the development of non-classical light sources for optical quantum technology. For maximum performance of such quantum devices, the coupling between a target QD and the optical mode of the microcavity needs to be precisely controlled, both spatially *and* spectrally. To achieve spatial alignment, the growth of site-controlled QDs has received great attention. However, these QDs still suffer from a reduced optical quality if compared to standard self-organized QDs. Moreover, for a fully deterministic device it will be vital to ensure spectral alignment which can be achieved by in-situ lithography techniques.

In this work, we report on a novel, fully-deterministic nanophotonic device technology using high-resolution electron-beam in-situ lithography. Our approach combines low-temperature cathodo-luminescence (CL) spectroscopy with high-resolution electron-beam writing of nanostructures and is demonstrated by patterning single-QD mesa structures.

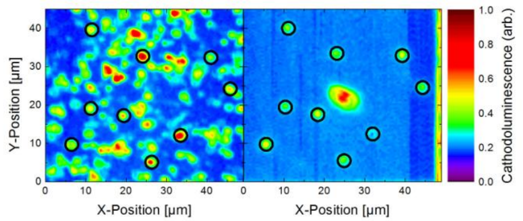

Fig. 1: CL-intensity maps before (a) and after (b) fabrication of single-QD mesa structures. Black circles in (a) mark the selected QDs that are integrated into the sub-µm mesa structures.

The in-situ lithography process starts by spin-coating a planar GaAs sample containing InGaAs QDs in the active layer with the standard electron beam resist PMMA. Subsequently, the sample is mapped by CL to select target QDs and to determine precisely their position and their emission wavelength. A respective CL intensity map is depicted in Fig. 1a). It shows CL emission from a number of QDs, nine of which are selected (indicated by black circles) for in-situ lithography. The CL-selection step is performed at low electron-beam dose to avoid an over-exposure of the resist. Next, we define sub-µm sized mesa structures on the resist which are precisely aligned to the selected QDs. The structures are written at a higher electron dose to locally invert the resist. In this configuration the exposed resist acts as an etch mask which allows us to realize sub-µm photonic structures with nm-accuracy.

To verify the positioning process of deterministically patterned single-QD mesas, another CL-mapping was performed. The associated CL intensity-map is shown in Fig. 1b) and nicely demonstrates that all mesa-structures are at the pre-selected positions, and that 90% of them are optically active. The optical properties are studied in more detail via micro-photoluminescence measurements at low temperature. We observe resolution-limited single-QD emission linewidths of 17 µeV, verifying the high optical quality of our nanophotonic structures. Single-photon emission is verified by second-order correlation measurements on single emission lines, resulting in $g^{(2)}(0) = 0.02$.

Monday
Tuesday
Wednesday
Thursday
Friday