Optical Microcavities with Pyramidal Shape

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Recently, GaAs pyramids standing on top of distributed Bragg reflectors (DBRs) have been studied as candidates for high-quality ($Q$) and low mode-volume optical cavities [1, 2]. Their fabrication through a wet-chemical etching process allows an easy geometrical tuning of pyramid size and facet angles. $Q$ factors reaching 700 have been observed by micro-photoluminescence measurements [2]. While these previously investigated pyramid structures rely on total internal reflection at the facets and a DBR at the base plane, two novel designs of pyramidal structures are suggested in this contribution in order to enhance light confinement. On the one hand, freestanding reversed pyramids have been realized as shown in Fig. 1a. In such structures, light confinement is based exclusively on total internal reflection. Calculations based on finite-element methods suggest potentially very high $Q$ factors for such geometries, especially for pyramids with an octagonal base (feasible with the same method). On the other hand, truncated pyramids standing on top of a DBR have been metallized or overgrown with another DBR as proposed in Ref. [2]. In contrast to freestanding pyramids the latter approach implies that both vertical as well as lateral light confinement are achieved by DBRs (see cross-section in Fig. 1c).

During the wet-chemical etching process the developing geometry of the pyramids is controlled by two steps: First, the size of the quadratic etching mask of electron-beam resist is designed with respect to etching rate and time. Afterwards, a certain ratio of the etchant (phosphoric acid) and the oxidizing agent (hydrogen peroxide) for the solution is chosen which determines the ratio and absolute value of the etching rates for GaAs and the AlAs sacrificial layer between the upper and lower GaAs pyramids (see Fig. 1a). In this way pyramid slopes between 20° and 60° can be obtained in a controlled manner.

To realize truncated pyramids for DBR overgrowth or metallization, two additional etching steps are needed. Based on a similar structure as shown in Fig. 1a the upper pyramid is cut off by a selective removal of the AlAs sacrificial layer. After this lift-off a smooth surface of the truncated pyramid and its surrounding—particularly important for overgrowth—is achieved by a GaAs selective etching step with a citric acid solution until an AlAs stop layer is reached.

The initial layer structures are grown by molecular-beam epitaxy. Self-assembled InAs quantum dot layers are embedded into the GaAs layers of the subsequent pyramids to use them as internal light source emitting in the spectral range between 900 nm and 1000 nm for micro-photoluminescence ($\mu$-PL) measurements. Optical modes are identified by analyzing the thermal behavior of the observed peaks in the spectra [1]. The reversed pyramids show $Q$ factors up to ~3000 without any further geometrical optimization (Fig. 1b).

Furthermore, placing the quantum dot layer near the pyramid tip can easily reduce the number of embedded quantum dots, which would be a benefit for applications like single photon emitters. We also realized freely suspended bridges between reversed pyramids which could be used for electrical contacting of previously doped pyramidal structures or for an optical coupling between them.

References