Fabrication and Characterization of Slab Microcavities

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There is considerable interest in fabricating high-Q nanocavities having very small volumes for delivering single photons on demand and for attaining strong coupling and entanglement between a single quantum dot (QD) transition and a single mode of a cavity [1]. Such devices play important roles in quantum information science and quantum cryptography.

Molecular beam epitaxy (MBE) is used to grow a buffer, sacrificial layer, and slab with or without quantum dots in its center. Two types of MBE structures have been grown. On a GaAs substrate, the buffer is 600 nm of GaAs, the sacrificial layer is 1000-1500 nm of $Al_{0.7}Ga_{0.3}As$, and the slab is about 300 nm of GaAs. The sample without QDs is called UdayWG4, and the ones with QDs are dubbed QD24, QD28, and QD29. On an InP substrate, the buffer/sacrificial layer is 1000 nm of $Al_{0.48}In_{0.52}As$, and the slab is about 280 nm of $Ga_{0.32}Al_{0.15}In_{0.53}As$ with 6 nm $Ga_{0.47}In_{0.53}As$ above and below; the sample name is HSG7. A QD sample HSG4 was also grown on InP with a 500-nm buffer of $Al_{0.48}In_{0.52}As$ and 3.5 monolayers of InAs for the QD layer. The samples are characterized before fabrication as follows: the top surface roughness by atomic force microscopy (AFM), the layer thicknesses and interface roughness between the sacrificial layer and slab by transmission electron microscopy (TEM), the QD transition energies by low-temperature photoluminescence, and QD cross sections by TEM (HSG4).

The fabrication is done by e-beam lithography followed by an etch process to generate patterns of holes to form the nanocavities. Chemically assisted ion beam etching (CAIBE) is used in the case of GaAs slabs, whereas inductively coupled plasma-reactive ion etching (ICP-RIE) is employed for GaAlInAs based slabs. Then the sacrificial layer is etched away by a (chemical) wet etch to obtain edge-supported suspended slabs. The fabricated cavities are then studied by scanning electron microscopy (SEM), and the cavity Qs are determined by photoluminescence if the slab contains QDs.

Examples will be given of both good and bad MBE growth and fabrication. AFM is a quick way to determine if the top surface is flat, but there are cases (QD24 and QD28) where the top of the slab is reasonably flat but the bottom (the interface between the sacrificial layer and the slab) is not, as revealed by TEM. In this case the surface smoothens as the slab is grown. There are other samples where both the top and bottom of the slab are smooth (UdayWG4), while HSG7 and QD29 have not yet been examined by TEM. Similarly, the photonic crystal hole diameters and wall verticality are sensitive to the resist and e-beam exposure and stability, as will be illustrated.

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References

[1] G. Khitrova, H. M. Gibbs, M. Kira, S. W. Koch, and A. Scherer, “Vacuum Rabi splitting in semiconductors”, Nature Physics **2**, 81 (2006).