One-step in-situ quantum dots via molecular beam epitaxy


Photonic Materials and Devices Laboratory, Department of Materials Science and Engineering, University of Southern California, Los Angeles, California 90089-0241, USA

The fabrication and characterization of structures with their electronic states confined in three dimensions (i.e. quantum dots) is an area of active research. The maskless one-step in-situ approach that exploits growth kinetics to create suitable size templates upon which nanostructures can be realized via growth alone offers potential advantages [1] over ex-situ approaches.

Photolithography followed by wet chemical etching of the (111)B face of GaAs yields truncated triangular pyramidal mesas with a (111)B top and three (100) side facets [2]. If, exploiting the 3-fold symmetry of the (111) surface, growth kinetics could be controlled such that interfacet migration occurs predominantly from the side facets to the mesa top, then the areal dimensions of the layers on the mesa top would decrease, ultimately resulting in an effectively zero area layer, i.e. mesa pinch-off. This affords the possibility of realizing quantum dots via a purely in-situ growth process.

We have identified growth conditions [1,3] for which a shrinking mesa profile during GaAs/AlGaAs MBE has been realized. Fig. 1 is a (200) dark field (011) azimuth transmission electron microscope (TEM) image of a typical mesa on which a 13 period nominal 10 ML Al_{0.3}Ga_{0.7}As/40 ML GaAs multilayer structure has been grown via MBE. Starting from a 0.6 μm as-patterned mesa top, the lateral size of successive layers growing on the mesa top is seen to decrease. A new facet identified to be of the {211} type has emerged during growth and is contiguous with the (111)B mesa top. Shrinkage of the (111)B layers is due to a net migration of atoms from the {211} facet to the (111)B mesa top. This inter-facet migration also ensures that the {211} layers are thinner than the (111)B mesa top layers. The (111)B GaAs layers are thus surrounded from all lateral directions by the thinner and thus higher band gap GaAs quantum wells growing on the {211} side facets. This difference in band gap provides the lateral electronic confinement. Vertical confinement is provided by the AlGaAs layers. The continuous shrinkage of the mesa top layers results in the mesa pinching off at the 8th period (indicated by a black arrow). This GaAs well at the top of this in-situ created pyramid has a base dimension of about 500 Å, height of 130 Å and its top vanishes into an apex. The well has its...
physical dimensions within that required for a quantum box. This is the first realization of three-dimensionally confined structures via growth on nonplanar patterned substrates.

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References